MASTER THESIS REPORT

Analysis of the Design-Acquire Paradox inherent in the Reuse of Structural Steel Elements using an Ambidextrous Management Approach

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OCTOBER 2022

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Delft University of Technology

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In partial fulfilment of the requirements for the degree of
Master of Science in Construction Management and Engineering
*at the **Delft University of Technology***

In collaboration with **WSP in The Netherlands**

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October 2022

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Acknowledgement

This thesis has marked the end of my journey as a Master's student in Construction Management and Engineering at TU Delft. Two years of my life at TU Delft have been full of learning and enriching experiences that guided me through the path of becoming a professional. I am grateful to everyone for their persistent support which highly eased this process.

First of all, I want to express my profound thanks to my graduation committee for their unwavering support during the whole thesis process. I appreciate Prof. Dr. PW Chan chairing the graduating committee and endorsing the standard of my research. Despite your hectic schedule, I sincerely appreciate the time you took to offer critical criticism. Your mentoring has been quite insightful without which I would have missed out on certain fundamental facets of the research. The comprehensive and prompt feedback by the first supervisor, Dr. John L. Heintz is what kept me driven towards justifying my research findings. It's worth emphasizing how you inspired me to overcome the challenges I faced. It has kept me driven and helped me improve the quality of my work. I appreciate how you helped me narrow down my research topic and improve on my weaknesses. Thank you, Dr. Johan Ninan, for your words of guidance at every milestone and for taking the time for feedback. It has helped me move forward in the right direction throughout my thesis. I'm highly indebted to WSP in The Netherlands, for giving me the opportunity to conduct my research at the company and the percipient experience of working as well as spending time with the team. I would like to express my special gratitude to my company supervisor, Thomas Musson, for being an exceptional mentor. I thoroughly enjoyed working with you. My thesis has benefitted greatly from your vast knowledge of multidisciplinary projects and industrial expertise. You have been the steadfast rock of my thesis and I much appreciate your ideas as I work to make it more comprehensive and impactful for the industry. Moreover, the ease with which I could approach you for guidance and support throughout this journey is highly commendable.

I would be remiss in not mentioning my family. Words cannot express my gratitude to my family for their invaluable motivation and support. I owe my success to my family without whom this endeavour would not have been possible. I would like to thank all my friends and acquaintances who were part of my journey over the past two years for encouraging me and being there for me. I thank my CME friends (Adhil, Aditya, Asit, Barsha, Karan, Mehna, Rahul and Vikas) for their presence and support from the very first day of my master's journey till date. I extend my special gratitude to Neeraj and Adila for constantly checking on me and for the impromptu weekend and weekday plans. I am forever grateful for my friends back in India, Abhi, Anand, Greeshma and Ashwini have always managed to keep in touch with me and take off the feeling that I am away from home. I am also glad to have Prema a text away as a constant support system and motivator for the past years.

I thank all my well-wishers, interview participants and other WSP colleagues for helping me further in the research journey. I sincerely hope that my findings and accomplishments from this research will be beneficial to scholars and professionals in this field.

Zachariah Kiran Varghese
Delft, October 2022

Executive Summary

Over the past few decades, the corporate landscape has undergone a significant transformation, and we now live in a connected society where change can be fast-paced, constant and unpredictable. Companies have been compelled to adjust their organisational procedures to deal with such situations. Therefore, accepting and embracing change as a constant, unpredictable feature of the working environment is vital to surviving. However, these changes are often ambiguous and can only be dealt with by promoting flexibility, adaptability and agility. The advent and increasing prominence of circularity and sustainability are key components of this change in the business environment.

Even though the construction industry is typically identified as conservative and resistant to change, there is a rising desire and ambition to comply and adhere to changing requirements and sustainability targets. The desire and ambition to comply with and uphold evolving criteria and sustainability goals are growing, despite the construction industry's typically conservative and change-resistance. One of the key elements in achieving the same goal is resource efficiency and waste minimization. It can be accomplished via a variety of techniques, with the reuse of materials being one of the most significant. By doing so, waste may be diverted from landfills or other processes that consume a lot of resources and energy, which creates unprecedented opportunities for a new lifecycle.

Steel is one of the fundamental components of construction. In addition to being a sturdy, long-lasting, versatile, and recyclable material, steel also thrives as a lightweight, flexible, adaptable, and reusable structural frame system. However, the paucity of raw materials, energy- and resource-intensive production procedures, growing steel costs, negative environmental effects, and carbon emissions make the manufacture and use of virgin steel an unrealistic choice. To address these issues, the option of reusing structural steel components in buildings is progressively gaining support in recent years.

Nevertheless, the reuse of steel is confronted with several barriers that hinder the potential to incorporate them into buildings. These barriers are multidimensional and multifaceted. The project team is faced with a number of uncertainties and conflicting demands. Among them, a combination of barriers like the lack of traceability, a lack of material availability, a lack of an integrated supply chain where a mismatch in supply and demand is identified, and a lack of desire and demand to reuse steel makes it difficult for them to adopt reuse of steel. These uncertainties and challenges force the project team to deal with a contradictory tension: "*whether is it feasible to first locate existing reclaimed/demountable materials available for reuse from the market and then design around them [Material Driven Design] or design first with the intention of sourcing/ identifying the required materials later during the procurement phase [Form-Focused Design]*" This contradiction in the decision making process to choose between a Material Driven Design (MDD) and Form-Focused Design is termed as Design-Acquire Paradox.

The characteristics of the underlying challenges in reusing structural steel elements concerning the design-acquire paradox are that, if we acquire the reclaimed/demountable materials first and then design around them, the architects will be constrained to developing a design that fits the acquired materials. Then the risk is that not all the materials can be used in the design, incurring additional storage-related issues, unnecessary acquisition and/or wastage of materials, restriction of architect's design freedom, and difficulty in achieving the client's functional requirements. In contrast, if we intend to design first and then purchase materials, it is improbable that we would be able to find the appropriate steel components that satisfy the design specifications on the market due to the lack of traceability of recovered reusable materials or a well-developed database that could function as the material bank.

The primary aim of this research is to improve the potential of employing the reuse of recovered structural steel elements in buildings by mitigating the design-acquire paradox. This research focuses on mitigating the dilemma faced by the project team by providing them with more flexibility and adaptability in the decision-making process and providing architects with design freedom by embracing the market potential. Integrating an ambidextrous management approach is recognized as a workable solution to improve flexibility and adaptation and to handle paradoxical tension where it is challenging to trade-off between many potential options.

Without necessarily choosing between different alternatives, ambidexterity focuses on balancing both ends of paradoxical poles and simultaneously accepting both possibilities. The construction industry, in particular, is known for being conservative and reluctant to change. Therefore, it places more of an emphasis on the exploitation of existing knowledge and possibilities and less on the exploration of new information and potential prospects.

It is crucial to take into account the fundamentals of ambidexterity to address the design-acquire paradox since they are in line with the industry's requirement to balance its exploration and exploitation initiatives. It is also critical to concurrently embrace a material-driven design and a form-focused design approach. However, currently, the industry is focused on choosing either of the two options by making a trade-off based on the project and market scenario. As a result, the research will broaden its scope to include a significant part in the growth for resolving the paradoxical tension by tackling the challenges through the guiding principles of the ambidextrous management approach. In consideration of the research's objective, the main research question is:

“Can an ambidextrous management approach aid in resolving the design-acquire paradox inherent in the reuse of the structural steel elements in buildings?”

The research is designed as qualitative. The data collection and analysis of the current market condition and industrial practices adopted were the keys to identifying and interpreting the barriers to reusing steel and the magnitude of the design-acquire paradox. Semi-structured exploratory interviews were conducted to get a comprehensive understanding of the current business practices and market characteristics. Additionally, a case-study analysis was carried out using the Dutch project Biopartner 5, which is the first and most likely the only project (known) to effectively combine extensive reuse of steel components. The case study was primarily concerned with finding the practical strategies employed in the project that reused structural steel as well as the solutions used to address the design-acquire paradox inherent in steel reuse.

The ambidextrous management approach's guiding principles are included in every stage of the process, and more focused attention is placed on balancing exploration and exploitation activities. This results in the creation of an Ambidextrous Process Tool.

The tool is designed to accomplish a number of outcomes that were determined by the examination of the design-acquire paradox, which is expected to alleviate the difficulties that are involved. The process tool considers a balanced approach between Material Driven Design and Form-Focused Design, investigation and exploitation at each level of the process, integration and differentiation of potential opportunities through converging and diverging throughout the process. Developing ambidexterity helps architects be more adaptable so they can respond to changing market situations and improve the traceability of available materials.

The Ambidextrous Process Tool intends to raise the chances for the project team to consider steel reuse as an opportunity, in contrast to the current methodologies used in projects involving the reuse of structural steel elements, which are heavily dependent on external variables. Currently, the construction industry places a high priority on the realistic implementation of steel reuse and how to address the highlighted difficulties. However, the industry tends to accept the existing barriers as a nature of the industry and supply chain, and choose to wait until circumstances become better. The Ambidextrous

Process Tool not only strives to resolve the design-acquire paradoxical tension but also improves industry discussions by taking into account the feasibility of reusing steel and so raising the demand and discourse in the supply chain.

The Ambidextrous Process Tool also aims to mitigate the challenges the project team encounters by giving them more latitude in the decision-making process. Currently, the construction industry holds forth its focus on the exploitation of available opportunities and technologies and limits its focus on the exploration of opportunities and technologies in the market. Accordingly, the desire to investigate steel reuse as an option is only taken into consideration to be attempted if a donor building is discovered to be available. However, the tool encourages a balanced approach and widens the exploration of opportunities.

A preliminary design that takes into account the desire and willingness to reuse structural steel elements is developed by architects as the tool's initial step. The design is developed based on the client's functional needs, and the structural engineers engage with the architects to define the steel specification and quantification. The market is then thoroughly explored to determine the materials that are available by extending the scope of the investigation to further options. To stay current with the market, the discovered opportunities are also regularly represented in the preliminary design. An inventory is created based on the recognized available resources.

A reuse target is established to create an internal demand by comparing the inventory with a combination of the updated preliminary design. Furthermore, by optimising the employment of reuse to accomplish the reuse target, a detailed design is created in collaboration with structural designers. The project team review the detailed design and confirms whether the reuse target is attained. Given the time between the design and execution phase, there are still possibilities for the exploration of available materials from the market even after the detailed design is developed. Indeed, the exploration is extended to match the market delivery with the detailed design and no major changes are made to the detailed design in this stage. If the material meets the tolerance limit, it is included in the design, increasing the likelihood that more secondary steel will be used in the final product.

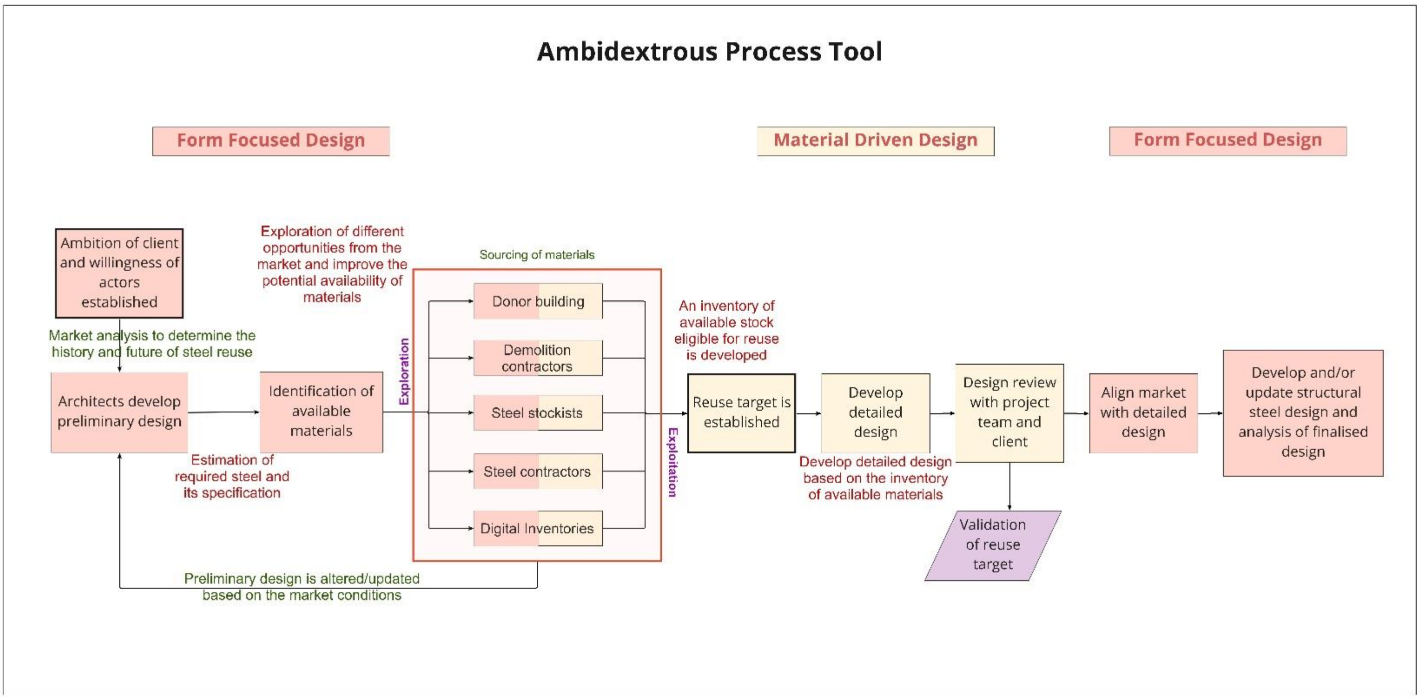

Figure 1: Ambidextrous Process Tool

The Ambidextrous Process Tool is validated to determine the reliability and potential to mitigate the challenges associated with the design-acquire paradox. The roles of an architect, client/developer, structural designer, and demolition contractor were all played by different participants during the validation workshop. The process tool has been updated using the input that was received during the session. The outcome of validation has demonstrated strong applicability in projects to reduce the tension between design and acquisition. Through the use of the tool on projects, more data can be collected and can be refined further to develop a comprehensive tool. The process tool's prompting the project players to expand their attention to investigating the market and prospects at each step rather than limiting the conversation and the opportunity for material reuse by waiting until the market is stable is one of its central tenets. Additionally, it diverts the project team's passive mindset to wait until an integrated platform is created and/or until the traceability of multiple donor buildings with readily accessible materials or stock members is improved in the market before considering steel reuse as business potential.

Research Limitations

There are several limitations to this research study. The major research limitation is addressed in this section.

1. The primary limitation of this research lies in the scope of the study. The research is solely focused on addressing the design-acquire paradoxical tension, that is whether to design first and then look for available materials or should we acquire materials first and design with these materials.

2. The tool predominantly aims to mitigate the challenges associated with the design-acquire paradox. However, adopting the process tool does not guarantee achieving a specific percentage of reuse in the buildings.

Further research

1. At each stage of the project, as depicted in the process tool, further research can be conducted on identifying the required legal and project deliverables. This could help the project team in determining the critical information required and the whole ambition and proposition to reuse structural steel elements fit into the wider regulation and canvas of the current market scenario.

2. To gain a comprehensive understanding of the current scenario, a comparative study with different projects can provide better results on the commonalities and differentiating factors among different projects in different scenarios. This could help in the better grounding of the interpretations and implications made in the development of the process tool.

3. Further research should be conducted on identifying a feasible collaboration technique to address the decision-making process, financial incentives and risk management.

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Chapter 01: Research Introduction

1.1 Introduction

Today, no industry or company is safe from disruption, however, many organisations are not well prepared to adapt quickly enough to survive the accelerating change requirements. Construction companies are no exception. They have been pushed to adjust their organisational procedures as a result of technological advancements and societal changes recently due to changing economic conditions, societal reasons, growth in business and competitors' actions. External market factors, combined with fragmented and complex industry dynamics and an overall aversion to risk, has made change both difficult and slow. The COVID-19 crisis looks set to dramatically accelerate the ecosystem's disruption that started well before the crisis. In such times, it is more important than ever for actors to find a guiding star for what the next normal will look like in the aftermath and make bold, strategic decisions to emerge as a winner.

The construction industry was already starting to experience an unprecedented rate of disruption before the COVID-19 pandemic. In the coming years, fundamental change is likely to be catalysed by changes in market characteristics, such as scarcity of skilled labour, persistent cost pressure from infrastructure and affordable housing, stricter regulations on work-site sustainability and safety, and evolving sophistication and needs of customers and owners. Especially, in these recent years, the need for a transition toward sustainability and circularity in the industry is growing in importance.

The fundamental goal of businesses is to survive. They must change their perspective and transform quickly and at a scale to become adaptable today to survive tomorrow. Indeed, the construction industry is sometimes characterised as conservative and resistant to change. Owing to their project-based structure, it is more challenging to coordinate reform measures. However, recently, there has been an increased emphasis towards the circular economy notion, notably at the EU level, with a roadmap devised to facilitate a transition to a resource-efficient, low-carbon European economy (Chavannes et al., 2021). To achieve the same there is an increasing belief and understanding that innovation in creating businesses and working methods can deliver improved growth through better market positioning (Szentes, 2016).

Considering the Dutch construction industry, they devised a specific action plan on how to transition the economy into a sustainable and completely circular by 2050, the government-wide programme for a Circular Dutch Economy by 2050 was established in 2016. The programme explained how to make sure that products, services, and raw materials are used more wisely and effectively. The timeline of the development of the circular economy in the Netherlands is depicted in Figure 2. Following the initiative, companies and the government signed the Dutch Raw Material Agreement in 2017 to guarantee the viability of the Dutch economy's transition to renewable resources. The Circular Economy Implementation Programme was unveiled in 2019 and includes five transition agendas, together with accompanying initiatives and actions, to promote the same between 2019 and 2023. In 2020 and 2021, the programme was further revised. The Dutch government wants to accomplish its ambitious initial objective of using 50% fewer primary resources by 2030 (minerals, metals, and fossil fuels). By 2050, the goal is to have a waste-free economy that relies mostly on sustainable and renewable resources and reuses both products and raw materials (Ministerie van Infrastructuur en Waterstaat, 2021b; Többen & Opdenakker, 2022; *Circular Economy Implementation Programme 2019–2023, 2019;* Versnellingshuis Nederland circulair, 2021; *A Circular Economy in the Netherlands by 2050*, 2016).

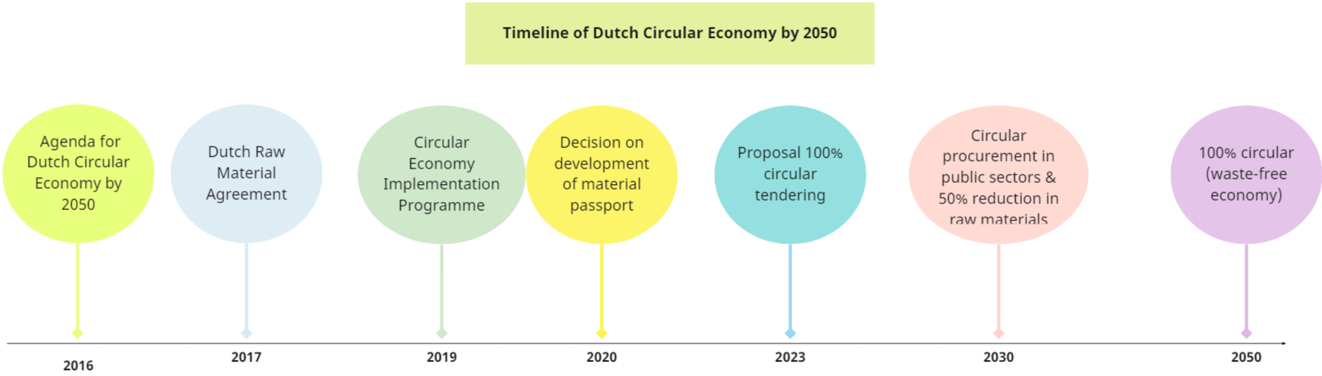

Figure 2: Dutch Circular Economy Ambition 2050 Timeline

Out of the sheer desire and ambition to implement a circular economy in the construction sector, numerous strategies such as material substitution for more sustainable materials, recycling of demolished waste, and/or reuse of recovered building components have been created. Although recycling can divert debris away from landfills, the processes involved are energy and resource-intensive, imposing a significant strain on the environment in terms of greenhouse gases (GHG) and other types of emissions (Rakhshan et al., 2020). In terms of sustainability and the Circular Economy Scheme, the potential benefit that could be accomplished by reusing recovered building materials greatly outweigh that of recycling demolition waste (Icibaci, 2019; Bianchini et al., 2019). Moreover, reuse has the potential to save and delay purchasing and disposal costs, respectively (Icibaci, 2019). However, it is also identified that the reuse of construction and demolition (C&D) waste is limited in the Netherlands (Icibaci, 2019). The construction of Biopartner 5, a laboratory building in the Leiden Bioscience Park, has managed to incorporate large-scale reuse of structural steel elements, proving the feasibility of the transition with its success (*Biopartner 5 gebouw finalist landelijke Circular Awards 2021 (categorie Public)*, 2021). However, the adoption of reused elements in new buildings has several challenges that must be addressed in terms of design and procurement.

To prevent or reduce waste during the whole lifetime of new buildings, innovative design methodologies such as design for deconstruction (DfD) and design for manufacturing and assembly (DfMA) have been established in recent times. However, most of the existing buildings are not designed based on the above techniques, which results in the generation of a considerable amount of waste during refurbishment or the demolition phase (Rakhshan et al., 2020). Therefore, to facilitate the reuse of materials now, a different approach and strategy should be followed. As the existing scenario or market conditions, regulations and design of the building are not favourable enough for a smooth adoption of the reuse of reclaimed materials (Icibaci, 2019).

The major barriers that hinder the transition to reuse structural steel elements are cost, availability/storage, lack of sufficient client demand, traceability, and supply chain gaps/lack of integration (Densley Tingley et al., 2017). Due to the accumulation of these challenges, the project team faces contradictory and conflicting demands. The contradictory tension which is in the design phase of the project is "whether is it feasible to first locate existing reclaimed/demountable materials available for reuse from the market and then design around them or design first with the intention of sourcing/ identifying the required materials later during the procurement phase?" This contradiction in the design phase is paradoxical in nature and is called the design-acquire paradox, which is explored through this research study. The significance of analysing the paradoxical tension is that it allows us to investigate the possibilities for optimising the reuse of materials and improve the potential to reuse steel by mitigating the paradoxical tension.

In the current situation, the project team should have the choice and capability to choose between design and acquisition simultaneously or even practice them concurrently depending on the project conditions. The lack of this possibility or facing a lock-in situation owing to the existing barriers to implementing reuse is something that hinders the successful realization of projects. Over the years, an ambidextrous management approach has been identified as a solution for organisations aiming to achieve competencies in dealing with contradictory paradoxical tensions (Ogrean, 2016). Moreover, the ambidextrous method employs the notion to combine the benefits and possibilities associated with flexibility while minimising the obstacles associated with developing an appropriate trade-off in decision-making (Shams et al., 2020; Szentes, 2016; Andriopoulos & Lewis, 2009). Thus, this research study aims to improve the potential of reusing structural steel elements by addressing the research question: *"Can an ambidextrous management approach help in resolving the design-acquire paradox inherent in reusing structural elements in buildings?"*

To address the existing barriers, an Ambidextrous Process Tool is developed to optimise the reuse of structural steel elements by simultaneously incorporating the practices adopted when the design or acquisition of materials is done first. The tool takes into consideration the existing market conditions, the practices adopted in the reuse of structural steel elements and the principles of ambidexterity to mitigate the challenges associated with the reuse of structural steel which is specifically the design-acquire paradoxical tension.

1.2 Definitions

In the report, the following terms and definitions have been used:

Table 1: Definitions of terminologies used in the report

Terminology	Definition
Circular Economy	It is a resilient system that dissociates economic activity and the consumption of limited resources by reducing waste and pollution, reviving nature and circulating products and materials at their highest values (*Circular Economy Introduction*, n.d.).
Deconstruction or Demolition	Deconstruction is the process of dismantling buildings or components for reuse, whereas demolition is the dismantling of building components with less effort to retrieve them for reuse (Coelho et al., 2020).
Design for Disassembly (DfD)	The process of decision-making in the design stage on how to dismantle the components and possibly reuse them (Coelho et al., 2020).
Direct Reuse	Components that are recovered from a structure are used again as materials for another structure without remanufacturing.
Donor Building	The building from which materials are reclaimed for reusing them into a new building.
Indirect Reuse	Components that are recovered from a structure are used again as materials for another structure after remanufacturing.

Material Driven Design (MDD)	design or form is not prioritised over materials, and they are not merely introduced or identified to fit into a defined shape but truly defined as the basis for design (Bak-Andersen, 2018).
Form-Focused Design (FFD)	Design is developed first and then available materials are identified or located to incorporate them into the design (Bak-Andersen, 2018).
Structural (steel) components	The load-bearing part of a steel structure provides mechanical as well as fire resistance and stability (Coelho et al., 2020).
Reclaimed or recovered steel	The steel components carefully deconstructed from an existing structure.
Reuse	Old components used with less reprocessing, either for their original function or by repurposing (Coelho et al., 2020).
Virgin Steel	The steel produced from new raw materials.

1.3 Circular economy in the built environment

The concept of a circular economy has arisen in response to the negative impacts of our traditional linear economy, which is based on the principle of 'take, make, and dispose'. The circular economy is regularly alluded to as a promising concept that has the potential to make a substantial contribution to global sustainable development. According to studies and assessments, the global construction sector has a plethora of options for implementing a circular economy (Scheuer, 2019).

According to Dutch Green Building Council (2018), circularity is not simply a matter of resource efficiency but requires a systemically different approach to our economy. Waste should be eliminated and the value of resources needs to be optimised for both people and the environment (Dutch Green Building Council et al., 2018). This trait can be achieved by keeping resources in use for as long as possible and thus extracting maximum value while in use. At the end of the service life, the products and materials need to be recovered and reused, repurposed, or recycled for further use (Steel Construction Institute, n.d.). Hence, circularity is thus related to reusing and recycling to reduce or prevent the use of virgin resources and the need for resources (Ellen McArthur Foundation, 2017). Therefore, such an efficient way of using resources is much needed in the current scenario when the global demand for raw materials is increasing drastically (Pressures on the Global Raw Material Market, 2022).

As Figure 3 shows below, in the linear economy, the construction industry currently follows the general practice to find the materials/ resources, build them into structures/products and later, dispose of the waste. In this approach, waste generation is the major factor that hinders the shift to a circular economy. This calls for a revisit to our approach to the supply of goods, its utilisation and end life. Addressing this waste generation can be useful in multiple ways, such as reduction of the cost of disposal, environmental impact, and increased competitive advantage. A circular economy is carried out by addressing waste and pollution, ensuring effective utilisation of materials, and restoring natural systems *(What Is a Circular Economy? | NetRegs | Environmental Guidance for Your Business in Northern Ireland & Scotland, n.d.)*.

Figure 3: Linear vs Circular Economy (Unterfrauner et al., 2017)

A shift to the circular economy invites us to follow the hierarchy depicted in Figure 4. A circular economy calls first for waste reduction which has the highest impact. Avoiding unnecessary wastage and using fewer goods would reduce the pressure on the environment. When the building components are at the end of their life, primary importance is given to exploring the possibility of reusing the materials. Recycling will be considered only if reuse is not achievable. The end goal of the Dutch Circular Economy Agenda by 2050 is to achieve a 100% circular economy or a waste-free economy. This top-down approach as shown in Figure 4 gives an overall idea of how should we deal with waste to achieve a circular economy.

Figure 4: Waste Management Hierarchy (Doel, 2014)

Over the last several decades, the construction industry has seen a paradigm shift with the adoption of a circular economy model that aims to keep materials in a closed loop to retain their greatest value, resulting in a higher potential to minimise waste creation and resource extraction (Benachio et al., 2020). According to the Ellen MacArthur Foundation, the circular economy (CE) is defined as: "The circular economy is an economic and industrial system that is restorative and regenerative by design, and which aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles." (Schut et al., 2015). One of the most well-known illustrations of circular economy ideas was made by the Ellen McArthur Foundation. The left-hand (green) half of the graphic represents biological cycles such as timber, while the right-hand (blue) half represents technical materials used in building, such as concrete, metals, plastics, and so on

(Steel Construction Institute, n.d.). See Figure 5 below depicting the continuous flow of materials in a circular economy:

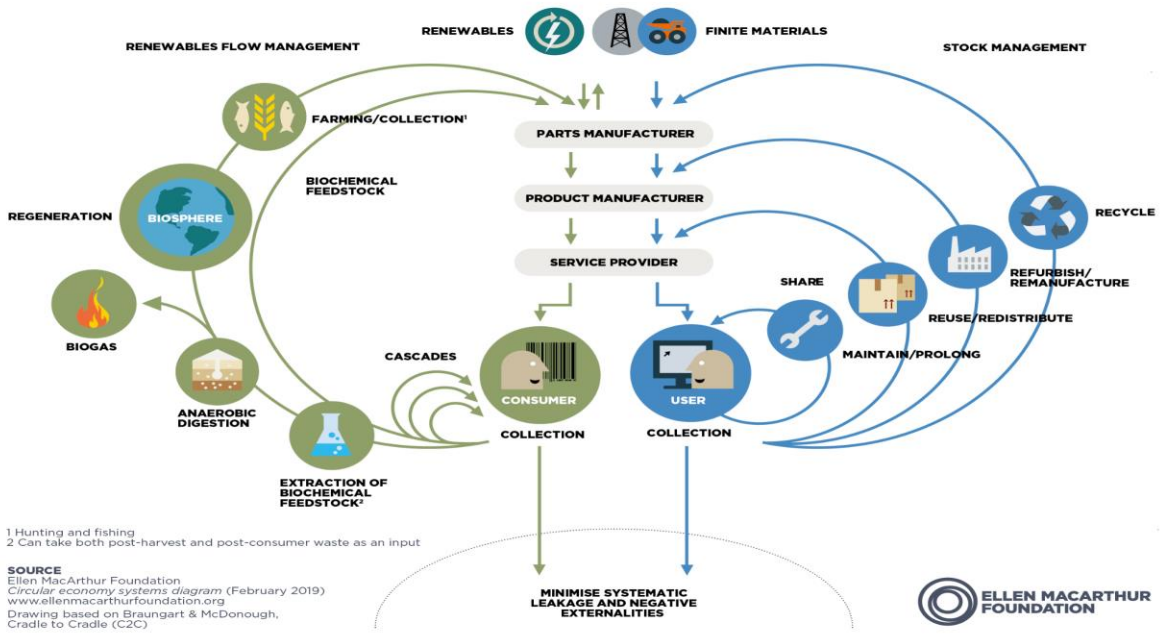

Figure 5: Ellen McArthur Circular Economy Butterfly Model (Kanters, 2020)

There are two major elements to ponder in the illustration of Figure 5 (Kanters, 2020):

- Wherever feasible, leakage out of the circular system to energy recovery or landfill should be prevented.
- The smaller the diameter of the concentric rings, the more effective the procedure.

The transition to a circular economy is underpinned mainly by three principles (The Crown State et al., 2019; Ellen McArthur Foundation, 2017) :

- Design out waste and pollution: Reveals and designs out negative impacts of economic activities that affect the health and natural system.
- Keeping products and materials in use*:* designing for durability, reuse, remanufacturing, and recycling to keep products, components, and materials circulating in the economy.
- Regenerating natural systems: avoids the use of non-renewable resources and preserves or enhances renewable ones.

The construction industry is the most resource-intensive sector in the world, and for the industry to become more "circular", existing building materials and product loops must be revised, and product life cycles must be improved. It is critical to shift gears and consider how to make the most effective use of resources possible by utilizing fewer raw materials and less energy, as well as repurposing materials whenever feasible (Ministerie van Buitenlandse Zaken, 2021). To follow the Ellen MacArthur Foundation's fundamental principles, we must prioritize our waste management strategies and aim for the best possible reuse value at the lowest possible environmental cost (Hossain et al., 2020).

The objective of transitioning towards a more circular economy in the construction industry is to maintain, reuse, refurbish, and/or recycle resources and materials consumed along the value chain. (Afshari, A.R.; Górecki, J.,2019). Scarcity is seldom the primary motivation for implementing circular economy ideas in the construction industry. The magnitude of waste flows, which generated worries about the huge environmental effects of building materials, spurred the forerunners in their efforts to implement a circular economy in the recent past (Schut et al., 2015).

The construction business, in contrast to other industries, has a lot of opportunity for a circular economy since value chains are often localized. To tackle climate change, the construction and infrastructure industries are undergoing a major transition. (Transition Agenda Circulair Economy, 2018). The construction sector offers several prospects for the circular economy, however, little study has focused on how the circular economy may be implemented in the built environment (Joensuu et al., 2020). The construction sector is one of the world's major users of energy and raw materials and has a significant impact on the environment (Schober, 2021). In the Netherlands, the sector accounts for half of all resource use (Scheuer, 2019). This is having a detrimental effect on the environment, especially in the EU, where building accounts for roughly a third of all trash and more than 40% of CO_2 emissions (Schober, 2021).

Our infrastructure and buildings are made up of a lot of – often heavy – components like steel, stone, and concrete. The extraction, processing, and transportation of these commodities have a substantial environmental impact. We must guarantee that resources in the building chain are utilized and reused as much as possible and that more organic-based materials are employed to preserve a clean and safe living environment for future generations. (Transition Agenda Circulair Economy, 2018). The challenge is complex, but it does present an opportunity. The construction business can grow swiftly and produce tangible benefits in a short period. A variety of new products and services are in demand, each with its own set of economic incentives. New knowledge innovations are being started by architects, designers, engineers, service providers, knowledge institutes, clients, contractors, manufacturers, and a slew of other stakeholders (Transition Agenda Circulair Economy, 2018).

End-of-life building materials should be reused, and their components and elements should be disassembled to function as material banks for new structures in Circular Economy models, keeping the components and materials in a closed loop (Hopkinson et al., 2019). Cost savings can be achieved through smart reuse (Transition Agenda Circulair Economy, 2018). However, this concept still requires the development of knowledge and tools to gain wider adoption in the industry, particularly in the construction industry, where innovation takes longer to implement because buildings are typically one-of-a-kind projects with a large supply chain, adding to the complexity (Benachio et al., 2020). Structural steel elements are one of the few structural construction components that can be dismantled and reprocessed reasonably easily. Steel elements can be cut from existing constructions, trimmed to a specific length, and refabricated even without special jointing procedures that allow for easy disassembly (SCI-The Steel Construction Institute, 2019). The used steel may be processed and even repurposed in another structure after going through various steps (Fujita & Masuda, 2014). Thus showcasing a good profile and reuse potential.

1.3.3 Embodied carbon
In the building industry, embodied carbon refers to the greenhouse gas emissions footprint arising from the manufacturing, transportation, installation, maintenance, and disposal of building materials. This accounts for more than 11% of all total emissions from human activities on the planet. In contrast, operational carbon refers to greenhouse gas emissions due to building energy consumption (Himes, 2020).

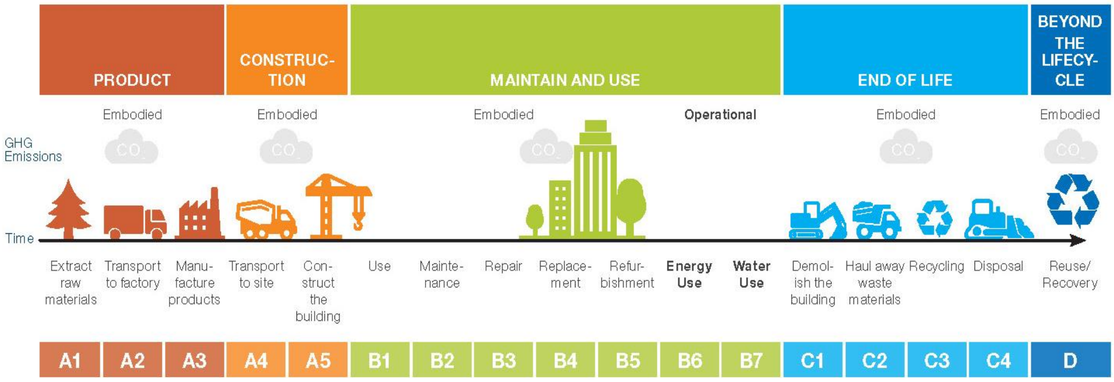

Figure 6: Life cycle stages (Embodied Carbon, 2022)

The majority of a building's total embodied carbon is released upfront in the product stage at the beginning of a building's life as depicted in Figure 6. Unlike operational carbon, there is no chance to decrease embodied carbon with alterations in efficiency after the building is constructed (Naditz, 2016; Himes, 2020). There is an urgent need to address embodied carbon to meet short-term and long-term climate targets. This will prompt several countries to levy taxes on CO2 emissions from buildings, hold building owners liable for emissions, and hold them accountable for finding solutions to reduce embodied CO2 (Embodied Carbon: What It Is and How to Tackle It | RPS, n.d.; Himes, 2020).

1.3.4 Paris Agreement

Paris Proof is a term that the Dutch Green Building Council (DGBC) introduced as a common sustainable goal for urban buildings to achieve the Paris climate accords (Paris Proof - Dutch Green Building Council, 2020). The aim of the Paris Agreement was introduced with the realisation that an increased reduction of CO2 emissions is needed to adhere to the agreement and climate change. It calls for transparency and accountability in energy use and CO2 emissions in buildings. The primary focus was to restrict the rising temperature globally. It was discovered that the built environment could play a significant role in adhering to the agreement. The energy consumption in buildings accounts for 37% globally and construction and demolition are responsible for 12 million tonnes of CO2 emissions a year which is 6.4% of total Dutch CO2 emissions (Dutch Green Building Council, 2020). Until recently, there has been little focus on the embodied carbon associated with buildings. However, the growing demand to mitigate climate change and limit CO2 emissions is forcing several countries to take stricter measures (Edge, 2020). To achieve the trait of a building being Paris-proof, buildings will have to be redesigned to use no more than two-thirds of current energy consumption and reduction of carbon emissions by 40% (Paris Proof - Dutch Green Building Council, 2020).

1.3.5 Carbon taxes

One of the largest financial tools to combat climate change is a carbon tax. A carbon tax is imposed by a government to put a direct price on greenhouse gas emissions (per tonne) produced by companies or industries (Center for Climate and Energy Solutions, 2021; Koch, 2021). It works as an economic incentive for polluters to lower emissions or switch to more efficient processes or cleaner fuels (What Is Carbon Tax and Will It Help to Limit Emissions?, 2022). The European Union has one of the best examples of a cap-and-trade system, called the EU Emissions Trading System (ETS). Importers of emissions-intensive goods have to pay a charge based on what producers would have had to pay under EU carbon emission regulations (Lai, 2022). Currently, 28 countries are imposing taxes on CO2 emissions, and several other countries have planned to join this list (world-economic-forum, 2022). As of September 2021, the price of carbon per tonne in the EU programme is at 62.45 euros and continues to rise. It is estimated that the ETS covers 45% of the EU's greenhouse gas emissions, and 30 countries are participating (Lai, 2022). Recently, in 2022, Denmark increased the tax on CO2 emissions to 159 euros per tonne (Reuters, 2022; world-economic-forum, 2022).

The building sector accounts for 21% of CO_2 emissions. Therefore, the industry needs to move away from using carbon intense materials and switch over to using materials with low embodied carbon emissions. However, these carbon-intensive materials are often used because they are cheaper than alternative materials. Thus, to achieve this goal, there needs to be a reversal in the cost of low CO_2 materials vs conventional high CO_2 materials. The simplest method to achieve this is a carbon tax on the manufacturing of building materials (Green Building Materials and Carbon Taxes on the Building Sector: Reducing Emissions from the Built Environment – Debating Science, 2018). Steelmaking is highly emission-intensive and the nearly 2 billion tonnes of steel produced every year generate around 8% of global CO_2 emissions (Klassen, 2022). Considering these facts, the use of virgin steel in building construction becomes an even less feasible option, both environmentally as well as economically.

Circularity in the built environment requires adaptation and practice, which is difficult to accomplish. Design-thinking strategies and efficient environmentally friendly procedures should be taken into account as additional measures to improve the practicality of achieving circularity. However, due to the current market conditions, achieving or moving toward a circular economy places pressure on the industry and the actors involved.

1.4 Perceived challenges in achieving circularity

A circular economy has developed as a way of achieving sustainability. However, there are certain barriers identified in the literature that hinder the adoption of a circular economy in the built environment. *The attitudinal challenge* is when there is an industry's resistance to change from the traditional methods of construction and a lack of client demand to take extra efforts to incorporate circular economy practices. This also stems from the attitude towards the quality of reused materials. There is a lack of awareness and/or willingness to engage with the circular economy principles (Kirchherr et al., 2017). This is greatly influenced due to a clear absence of awareness about the approaches and benefits of reuse (Charef et al., 2021).

The financial barrier is another major challenge, as the circular business model isn't compatible with the current linear model that doesn't take into account the environment as well as social damage as expenses. Investors should be willing to adopt the circular model, but appropriate awareness of every level of the plan is necessary. However, there is a shortfall in the required data for this implementation (Conci, 2019). Furthermore, there is a lack of clear depiction of the economic viability of circular economy business models which limits the motivation of the clients to adopt such practices in their projects (Kirchherr et al., 2017).

The presence of *structural barriers* is due to the lack of industry awareness and responsibility in terms of sustainability. The implementation is also dependent on the awareness of the government and the officials about the issue, and the convulsions of the rules and regulations will hinder the business of the circular economy (Ritzén & Sandström, 2017; Tura et al., 2019).

With the emerging efforts to generate awareness around the circular economy and its benefits, the reuse of materials is gaining visibility, thereby increasing the chance of increased demand for reused steel in particular. However, there are *operational barriers* as demand and supply are not equal due to an underdeveloped supply chain. This can be conquered only when the demand for reused steel and the market conditions are stable for demolition contractors to reclaim and deconstruct the steel (Densley Tingley et al., 2017).

When it comes to *technological barriers*, there is a lack of procedures to guarantee that the materials will comply with the functionality, tools for the designers that will enable efficient deconstruction, and techniques for reusing reclaimed materials (Charef et al., 2021). There is a lack of proven technologies to implement a circular economy (Kirchherr et al., 2017).

The regulations and system of administration are vague in terms of the implementation of a circular economy. They are too difficult to understand and apply. This *legislative barrier* and bureaucracy, in turn, make the whole process slower, more expensive, and perplexing. This disinterest from the government could be owing to the emphasis on operational emissions and a lack of awareness around the reuse of materials as a feasible strategy to reduce emissions. The government could take some initiatives in association with the industry, focusing on improving the sustainability of construction. The availability of steel for reuse could be increased by mandating all buildings to have a pre-demolition audit to ensure that the materials can be salvaged (Densley Tingley et al., 2017; Kirchherr et al., 2017).

The Environmental Cost Indicator (ECI) unites relevant environmental impacts into a single score of environmental costs. Recently, results from LCAs are being used increasingly in public procurement tenders, especially in the Dutch construction sector. In such tenders, the Environmental Cost Indicator (ECI) is used as an important criterion to determine the winning bid (Hillege, 2021). However, it is identified that there is no clear separation in the accountability of the usage of primary and secondary materials. Even though the environmental impact of both materials is different, there isn't any reward for the building owner for using the secondary materials. Thus the legislation requires an amendment to promote and improve the potential of reuse. (Interviews 3 and 4).

A concise depiction of challenges associated with the adoption of a circular economy in the built environment is shown in Table 2 below.

Table 2: Perceived challenges for the adoption of circular economy

Perceived Challenges of Circular Economy					
Attitudinal	**Financial**	**Structural**	**Operational**	**Technological**	**Legislative**
Lack of client demand	Incompatible with the current model	Lack of industry awareness	Lack of integrated supply chain	Product design	Lack of regulations and legislation
Resistance to change from traditional methods	Non-consideration of indirect damages	High dependence on government and officials	Mismatch in supply and demand	Lack of procedures	Vague administration system
Acceptance of reclaimed materials	Investor's resistance to circular business models	Unclear responsibility distribution	Unstable market condition	Limited integration into manufacturing processes	Limited amendment in LCA
Absence of awareness	Lack of quantitative data	Lack of proper information exchange	Fear of an immature market	Fear of increased complexity	Lack of protocols and incentives

Risk aversion	Lack of due incentives or rewards		Lack of infrastructure	No performance guarantee	

To achieve a circular economy in a built environment, the main strategies are to reduce, reuse, and recycle. Among these, reuse is identified as a key principle in the waste management hierarchy as it has a higher impact when compared to recycling (Zhang et al., 2022). It improves material efficiency across all economic sectors and represents the second-best choice after waste prevention to decrease resource consumption and carbon emissions, and divert demolition waste from landfills (DGB, 2019). The reuse of construction materials and products has great potential to reduce the environmental footprint of a building. However, the way buildings are designed and constructed rarely considers closed-loop materials systems, and the implementation of reuse in building projects is associated with many hurdles. Concerning a less energy-intensive approach, embodied CO2, issues related to transportation, environmental repercussions of burning and melting the steel, and so on, reuse is more effective (Chen et al., 2022; World Steel Association, 2022). Moreover, among other materials, the reuse of steel is considered a more practical option. When it comes to characteristics such as durability, volatility, and lifespan, structural steel elements have a much better reusability profile, considering their ability to retain strength and span length (Brown et al., 2019).

The major focus of the research study is the reuse of recovered/ reclaimed structural steel elements. Several studies have been conducted on the reuse of structural steel elements and the research is mainly centred on identifying and acknowledging the challenges associated with reusing structural steel elements. However, limited publications dealt with proposing a practical solution or mitigation measures that can resolve the identified challenges. Therefore, to address this issue, this research the major challenges the project team faces during the design phase of projects which aims to incorporate the reuse of structural steel elements.

1.5 Problem Statement

The section outlines the recognised research problems that are impeding the large-scale adoption of the reuse of recovered structural steel elements as well as the paradoxical tension associated with it. The reuse of structural steel elements has several barriers to its implementation. The industry faces obstacles with a lack of a well-versed database of suppliers or recovered material availability, a lack of a clear demonstration of client demand, a lack of technical knowledge and expertise for the construction industry, and limited government intervention with legislation and regulations (Densley Tingley et al., 2017). As a result of these obstacles, the organisation must overcome several transitional barriers. The tensions are often multi-level and multi-faceted, affecting actors ranging from the CEO to the front-line employee. Moreover, these tensions include cognitive and emotional reactions and thus their enhanced salience is crucial for understanding businesses experiencing considerable transition (Carmine et al., 2021).

The design of buildings as well as the procurement of recovered materials for reuse plays an important part in embracing circular aims in reuse projects (Kanters, 2020). Studies agree that design professionals have the most critical role in addressing circularity challenges within the building industry. Especially considering their strong influence on the specification of the final product in the design phase (Iacovidou & Purnell, 2016; Iacovidou et al., 2017; Tingley & Allwood, 2014). However, organisations within the construction industry have been faced with the heightened need to navigate the paradoxical tension between design and procurement in the reuse of recovered structural steel elements. This is certainly true, especially in the construction industry, where the transition towards a circular economy is highly designer-focused.

When investigating the reuse of materials, a contradictory tension in the design phase of the project is identified, that is *"whether it is feasible to first identify existing reclaimed materials or demountable materials available for reuse on the market and then design around them or design with the intention of sourcing the materials later during the procurement phase?"*

If they acquire the reclaimed/demountable materials first and then design around them, the designers will be constrained to developing a design that fits the acquired materials. Then the risk is that not all the materials can be used in the design, incurring storage-related issues, unnecessary acquisition and/or wastage of materials, restriction of architect's design freedom, and difficulty in achieving the client's functionality requirements. In contrast, if they design first and then plan to source and purchase existing, it is not guaranteed that they will be able to locate the right steel elements that meet the requirements of the developed design from the market, due to the lack of traceability of recovered reusable materials or a well-developed database that could serve as the material bank.

It is identified that there are several publications dealing with the importance of the reuse of materials or even publications identifying several barriers to reusing materials. However, there is only limited literature addressing how to overcome the barriers and successfully implement the reuse of materials, specifically structural steel elements in buildings. This limited focus on the implementation strategy for reusing structural steel elements often hinders its potential for a successful realisation. Furthermore, the research elucidates on identifying and analysing the optimal method to overcome the above-mentioned paradoxical tension of choosing whether to design or acquire first. Moreover, the possibility of adopting a management approach that could simultaneously discover both options or synergize them is also being evaluated.

The concept of circularity necessitates the exploration of various alternatives and possibilities to achieve the desired objectives (Ministerie van Infrastructuur en Waterstaat, 2021a). Making a trade-off between both the option of design or acquire first and streamlining the exploration of opportunities into one of these options may not aid the project team in coping with the challenges associated with transitioning from recycling to reusing elements. This approach could stifle the enthusiasm to achieve circularity goals. To overcome such a contradictory design-acquire paradox, the project team must be able to make objective judgements based on the available opportunities and existing market conditions. However, in reality, they are often forced to live in hindsight because they have limited knowledge or understanding of the risks due to the limiting factors of retrospect and decision-making. This can limit the project team from identifying and exploring different possibilities associated with the reuse of structural steel elements or the potential benefits that can be gained from reuse over recycling.

The application and possibility of large-scale structural steel reuse to achieve high-impact circularity goals have not been widely explored yet. Most of the research study concluded with the identification of the barriers to reusing structural steel elements. In the practice of incorporating large-scale reuse of structural elements, the project team has to undergo a variety of decision-making processes along with the client in the challenging scenario to deal with the contradictory paradoxical tension. In such a scenario, considering the risks and opportunities associated with different available options, they are forced to make a trade-off. However, little has been explored about the possibilities and challenges associated with the implementation of the large-scale reuse of recovered structural steel elements. Nevertheless, limited organizational management measures and approaches have been developed or explored to overcome these barriers. To achieve this management trait, an organisation should be able to explore and exploit different possible solutions simultaneously, such as flexibility in the chronological order of design and procurement of buildings. This capability is recognised as ambidexterity. The feasibility of practising an ambidextrous management approach and the impact it could have on better incorporation of reuse of recovered materials owing to the identified challenges are yet to be explored and defined. The dilemma of balancing contradicting tension is considered one of the toughest managerial challenges in sustaining a firm's competitive advantage (Cao & Jiang, 2022). However, ambidexterity is considered a trait to achieve incremental and radical innovation outcomes (Cao & Jiang, 2022). Thus through this research, a process tool is developed incorporating the principles of ambidexterity to balance the contradictory tension of the design-acquire paradox. Furthermore, whether can the ambidextrous management approach can mitigate the design-acquire paradox is studied through this research.

1.6 Research Relevance

It has been identified that the process of re-use belongs more towards the inner circles of circular economy schemes, which means that it has a greater impact on achieving circularity when compared to other processes like recycling (Icibaci, 2019). However, only nearly 6% of overall steel is reused in the construction sector, the remaining 93% is recycled, and the remaining 1% is wasted (Caruana, 2019). This indicates the potential and needs for re-use in the Dutch construction sector, owing to the limited reuse of construction and demolition waste. Moreover, considering the resources and energy requirements for recycling effectively produces less impact on achieving circularity (Icibaci, 2019). To achieve high-impact circularity goals, some scholars have concentrated on the significance of reusing materials and products as well as the significance of changing the industry's focus from recycling to reuse. They also outline the principal advantages and opportunities that the sector may take advantage of to promote a stronger circular economy. Meanwhile, several other academics also focus their attention on figuring out the barriers to material reuse. Despite these factors, the fact that there is currently little to no study being done on how to appropriately incorporate reuse for its successful realisation.

Considering the current scenario or market conditions, the availability of raw materials is very limited and the prices of virgin steel are drastically increasing. Thus the construction industry needs to look into the possibilities of reusing the available or recovered steel. However, due to several challenges especially due to the premature supply chain and underdeveloped infrastructure to support this transition, the reuse potential of steel is hindered.

Additionally, because the design-acquire tension is paradoxical and contradictory in nature, it causes the project team to run into conflicting demands. Project teams can benefit from this research's capacity to assist them in finding a balance between conflicting demands and fostering decision-making flexibility during the design phase. Thereby, exploitation of the advantages of both options is done This might be achieved by contrasting the various alternatives using an ambidextrous strategy. Ambidexterity could be able to aid in the exploration and utilisation of diverse choices as well as increase the client and project team's motivation for the transition towards circularity.

1.7 Research Objective

The study is designed as qualitative research with the primary aim of improving the potential for employing the reuse of recovered structural steel elements in buildings through an Ambidextrous Process Tool. There are various barriers to overcome or mitigate to realise this project's distinctiveness. Lack of traceability, market availability of reused materials, lack of an integrated supply chain, and logistical challenges are just a few of the barriers. These factors create a conflict for designers and procurement teams: should they develop the design first and then locate materials from the market, or should they locate materials from the market first and then design around them? Due to the aforementioned impediments, it is complex for the project team to decide whether to design first and then acquire or should first locate available materials and then design around them. This complexity often results in the team abandoning the ambition of reuse in favour of more traditional approaches. This research focuses on mitigating this dilemma faced by the project team by providing them with more flexibility and certainty in the decision-making process. As a result of this research, a process tool that can look for possibilities to investigate and utilise different options simultaneously is considered. The ambidextrous management approach could provide a methodology to synergize both possibilities while avoiding the strain of having to choose between them. The method can employ a combination of approaches to a strategy to improve the reuse of recovered structural steel elements, either simultaneously or sequentially.

1.8 Research Questions

The research strives to answer the main research question:

"Can an ambidextrous management approach aid in resolving the design-acquire paradox inherent in the reuse of the structural steel elements in buildings?"

For answering the main research question, the following sub-questions have been framed:

Problem Diagnosis

1. What are the managerial constraints and practical barriers to reusing structural steel elements?
2. What is the design-acquire paradoxical tension in reusing reclaimed structural steel elements?
3. What are the current industrial practises adopted in successful projects to mitigate the challenges associated with the reuse of structural steel in the design and procurement phase?

Solution Design

4. How would an ambidextrous management approach serve to improve the potential of reusing reclaimed structural steel and to what degree will ambidexterity aid in managing the design-acquire paradox?

Solution Validation

5. How well could the ambidextrous management approach mitigate the design-acquire paradoxical tension to improve the potential of reusing structural steel elements?"

The sub-questions are ultimately aimed to answer the main research question and fulfil the research objective. As mentioned above, the research aims to develop a process tool which is practically applicable to the project team, therefore, the research problem and objective is oriented accordingly to make successful intervention to the existing and adopted practices in the industry. The process tool aims to facilitate a structured approach the project team could follow to enhance the flexibility in the process adopted and to further the exploration of potential opportunities available in the market.

1.9 Domain and scope of the research

The study's major areas of interest include the circular economy in the built environment and the use of recovered/reclaimed structural steel elements in the building. Utilizing recovered structural steel pieces will enable the building industry to move toward a circular economy, but this will need intensive coordination between the project's many stakeholders. Additionally, the crucial role that designers must play in promoting the reuse of materials in structures has been stressed in several publications. However, several barriers prevent the reuse of structural steel. When considering these barriers that limit the ability to reuse structural steel elements owing to the existing market constraints, the project team are forced to cope with opposing pressures that are paradoxical in nature. The research study analyses the nature of this paradoxical tension that arises in the design phase of similar projects, whether to design first and then source the required materials or locate the available materials first and then design around them. The prospect of using an ambidextrous management approach to help the project team maintain the goal of reusing structural steel elements is investigated through this research to lessen the negative impacts it has on the project. It has been identified that the existing barriers in the current industry setting and supply chain conditions limit the motivation of the client as well as the project team to explore the opportunity of reusing structural steel elements. In certain conditions, the client and project team initially would develop the ambition to reuse materials, in this case, reusing structural steel elements. However, over the process, the involved parties may later drop their ambition and shift towards using virgin material. This is due to various barriers identified through literature review and semi-structured interviews, which will be explained further in the report. Despite the barriers, the output of this research aims to develop a process tool to demonstrate to the client and project team the process of how to preserve the ambition of reusing structural steel elements and to enable flexibility in the process of reusing structural steel elements. However, it should be acknowledged that the process tool does not guarantee that following the same will ensure the project team achieve a specific percentage of reuse in their projects.

Chapter 2: Research Methodology

This section focuses on the methodologies that are deployed in deriving concepts and solutions. The research is intended to be carried out through qualitative analysis of data and information. This section is to provide an overview of the research processes and expected outcomes from each phase. The research is mainly divided into three phases: problem diagnosis, solution design, and solution validation.

The research was developed through different approaches, including a literature review of circularity in the built environment, the reuse of recovered structural steel elements, paradoxical tensions and an ambidextrous management approach. Since there was a limitation in relevant research documents, several explorative interviews with industry experts having ample experience working in similar sectors were selected to participate. Later a case-study-based analysis was conducted to gain insights into different real-life scenarios and to understand the background of the project where the ambition of reuse projects was successfully implemented. To further expand the understanding of the project and gather more insights regarding the perspective of the actors, a set of case-study-based interviews was conducted. Based on the findings and results from the analysis, an Ambidextrous Process Tool is developed to assist the project team and particularly architects with the flexibility and adaptability to develop the design owing to the current market conditions. Following this, a validation workshop was conducted to assess the applicability and relevance of the developed process for its implementation and to determine whether the tool can mitigate the design-acquire paradoxical tension.

2.1 Methodological Approach

With a strong base on the theoretical background and literature review of the concepts that are needed to take the study forward, this chapter deals with the chosen research methodology to arrive at the outcome. The research strives to investigate the main research question: “Can an ambidextrous management approach aid in resolving the design-acquire paradox inherent in the reuse of the structural steel elements in buildings?” To facilitate the study, the approach adopted is qualitative research methods. The research involves collecting and analysing non-numerical data to understand conceptual details from literature and the opinions and experiences of industry experts with backgrounds in similar sectors as that of the research domain. Even though there are several publications addressing circularity in the Built Environment and sustainability-related aspects, based on the findings from exploring Scopus and other research publication databases like Elsevier (ScienceDirect) and Springer, it was identified that limited publications are addressing the possibilities of reusing structural steel elements. Nevertheless, even in the literature, there is no specific mention of specific practical measures or industrial practices adopted in successful projects to overcome the challenges identified associated with reusing steel. Most of the scholars extended their focus toward identifying the benefits and/or barriers associated with reusing structural steel elements. Nevertheless, how to facilitate the implementation of this trait in the industry is underexplored. With this research, the focus is extended to mitigating this gap by developing a process tool that could assist the project team to preserve the ambition of reusing structural steel elements despite the existing barriers and ensure enough flexibility to explore different opportunities available in the market incorporating the principles of ambidexterity.

The existence of several barriers and impeding factors in the realisation of structural steel elements owing to the current market conditions and scenarios develop a paradoxical tension on the project team in the decision-making process. To analyse the background of this paradoxical tension, a literature review and an empirical study were conducted to understand the circular economy in the built environment and how circularity can be achieved by implementing the reuse of structural steel elements.

Therefore, several exploratory interview participants were selected by purposive sampling, who, by investigation, were found to have sufficient background knowledge or experience working in similar sectors associated with circularity in the built environment and/or reuse of structural steel elements. The interviews were conducted as semi-structured and the questions or prompted discussions were planned based on initial literature and empirical study findings. In addition, information that seemed missing or outdated was prompted by the participants to gather further understanding.

To further extend the understanding and analyse the critical factors involved in successful projects, a case study was selected. This approach helps in the exploration of phenomena within the particular context of reusing structural steel elements. The project has successfully implemented this trait and is also considered the first "Paris-proof" building in the Netherlands. This helped with identifying and analysing the possibilities and limitations in the successful realisation of the project in the existing industrial condition. The data regarding the project was collected from various sources of desk research, and published interview transcripts of various actors involved in the project. Furthermore, due to the limited availability of open-source primary data, a further collection of information was through case-study-based interviews to address specific questions and gather insights from prompted discussions. This approach undertook the exploration through a variety of lenses to reveal multiple facets of the project. The lack of more identifiable successful projects that implemented large-scale reuse of structural steel elements in projects limited the analysis to only one project. Furthermore, even though several projects would have been unsuccessful in incorporating the reuse of steel or projects that might have shifted their ambition from reuse, the data collection or traceability of such failed projects was not possible.

With these gathered insights, a further literature review has been conducted on the ambidextrous management approach and its feasibility in dealing with paradoxical tensions. The underlying principles of ambidexterity are studied and possible approaches were correlated from a paradox's point of view. The current industrial practice of reusing structural steel elements is mapped down, and it is already acknowledged by industry professionals that they exert limited exploration of available opportunities. In this case, the ambidextrous management approach is used to intervene in the current practices and propose a process tool which balances exploration and exploitation. By integrating the practices adopted on both sides of the paradox and incorporating the principles of ambidexterity a process tool is developed to simultaneously explore and exploit both options which can mitigate the identified challenges that strengthen the design-acquire paradoxical tension.

Further, the Ambidextrous Process Tool is validated by industry professionals playing the roles of developer/client, architect, structural designers and demolition contractors during an organised validation workshop which considered an imaginary project aimed to construct an office building in the outskirts of Amsterdam trying to access and incorporate the reuse of structural steel elements. Except for the demolition contractor, all the other participants of the workshop are holding the same position by profession. The process tool focused on an output-oriented approach, where the expected outputs aimed to mitigate the challenges that lead to the design-acquire paradoxical tension.

2.1.1 Phase 1: Problem Diagnosis

The initial phase of the research is focused on understanding and developing a theoretical background on concepts like the circular economy in the built environment and the reuse of structural steel elements. The collection of information is through a literature review and exploratory interviews to understand the Dutch market conditions. In the literature study, the background of circularity in the built environment and its importance in the construction industry are identified. Moreover, the impact of reusing structural steel elements on achieving a circular economy in the construction industry as well as the barriers to reusing structural steel elements are also analysed. In the exploratory interviews, the perspectives of the professionals involved in the reuse of steel projects are assessed to identify their perspective on whether they should develop the design first and then look for available materials for reuse, or should they first locate available materials for reuse and then design around them.

To mitigate the research gap, it is vital to seek input from professionals who are actively involved in the process. Given the niche stage of the construction industry's transition to a circular economy and the industry's limited adoption of the reuse of recovered materials, the interviews provide the data required for a better understanding and offer a broader perspective on the current situation. Understanding the context and analysing both sides of the plausible paradox may lead to a deeper understanding of the criticalities involved, as well as the managerial methods used, which serve as the conceptual process tool for this research. Furthermore, because of the paucity of research studies, the paradoxical tensions that are seen, particularly in the construction sector, are underexplored. Thus, this investigative methodology by gathering inputs from the interview participants allows for a better interpretation of the insights gathered from the literature and gains a better understanding of the issues faced by the industry in the large-scale reuse of structural steel elements.

Information on management constraints and practical challenges encountered during active and large-scale reuse of recovered structural steel components is primarily obtained through a case study and semi-structured interviews based on the selected project. The case study project is selected based on the reuse of structural steel elements and whether the objective was achieved or not. The selected case study is one of the most successfully executed projects in the Netherlands that realised the large-scale reuse of structural steel elements. Following the case study analysis, the actors involved in the projects are selected for interviews to gather more insights into the practical and managerial constraints faced during the implementation of the reuse of structural steel elements. The approaches adopted during the projects to mitigate the identified barriers are also analysed to ground the better formulation of the solution. Moreover, this could provide insights into whether the ambitions were defined in the initial stages or at a later stage of the project and analyse whether there were any deviations from the initial project plan. The collaboration of various actors involved in the projects and the kind of competencies they put on the table to implement reuse projects are crucial to understanding the critical elements that led to the successful realisation of the project.

In addition, a case study analysis is conducted to serve the understanding of different scenarios in which the initial ambition of implementing circularity and reusing structural steel elements develops. These shifts are mainly identified due to several perceived challenges associated with incorporating the reuse of structural steel elements. Despite the several challenges identified or the existing barriers, the industry provides a clear understanding of the adopted strategies in successful projects.

2.1.2 Phase 2: Solution Design

Based on the data gathered from the investigation of the circular economy in the Dutch construction industry, and the current practices, limitations and drivers and opportunities identified in the implementation of the reuse of structural steel elements, a process tool is developed. From the literature study and following the exploratory interviews of several industry experts, it was identified that the ambition and enthusiasm of the client and the project team are the initial steps towards achieving circularity and implementing the reuse of steel in buildings. Often, the ambition to achieve circularity in buildings by incorporating recovered steel elements in the building is due to the barriers in the construction industry and supply chain. One of the main impeding factors is the attitudinal barriers of the client and the project actors as they approach such projects with a traditional mindset and planning methods. In such a situation, the project team stumble during the decision-making process, especially with the contradictory tension of whether to first design or source materials for the project. This is because either of the options exhibits several barriers.

In this phase, the research aims to develop a process tool, which could assist the project team to mitigate the challenges and take forward the ambition of the client further towards realisation. The process tool is grounded to mitigate the identified challenges to reusing structural steel elements that constitute the emergence and existence of reuse of structural steel elements. Therefore a set of expected outputs are established which could potentially mitigate the paradoxical tension. Following this, the principles of ambidexterity which focus on balancing both sides of a paradoxical tension by simultaneously exploring and exploiting are adopted to tackle the challenging factors. The process tool mainly focuses on its application during the initiation phase of the project during the designing and sourcing of materials. The process tool also aims to include the options of either designing or sourcing the materials first based on assessing the existing conditions in the project condition to improve the potential of reusing structural steel. The tool can enable and enhance the flexibility and adaptability of the project actors and architects to explore and exploit the current knowledge and opportunities associated with the reuse of structural steel elements owing to the current market conditions. However, this process tool does not guarantee that steel reuse can be made possible or a specific percentage of reuse can be achieved.

Phase 3: Solution Validation

The final phase of the study is to validate the approach and define the findings in such a manner that they can analyse the applicability, efficiency, and reliability of the process tool to tackle the defined design-acquire tension. The developed Ambidextrous Process Tool is applied to an imaginary project to test the applicability of the tool in mitigating the design-acquire paradoxical tension which is prevalent in the existing market conditions. The validation is conducted through a workshop where industry professionals will be invited to play the roles of critical actors involved in reuse projects such as clients/developers, architects, structural designers, demolition contractors and the author acting as project manager. The process tool is presented to the participants of the workshop and the conversation is mainly driven by a step-by-step approach which aims to achieve certain predefined expected outputs which are aimed to overcome the challenges associated with the design-acquire paradoxical tension. The process tool is presented with its application to an imaginary case where the theme is the construction of an office building on the outskirts of Amsterdam and the project is not a high-rise building. The feedback received from the participants regarding improving the representation of the process stages and the addition or omission of process steps are fed into the developed process tool and is used to finalise the tool.

2.2 Methods of data collection

In the initial phase of the research, the collection of data was mainly through desk research, focusing on literature reviews and empirical data collection methods. During this phase, several publications which dealt with the implications and applicability of achieving circularity in the built environment were explored. Further exploration was conducted to deepen the understanding and explore the feasibility of reusing structural steel elements to achieve circularity. However, during this phase, it was identified that limited publication or realisation of a research gap in the domain was witnessed. Several protocols and guidelines about the implementation of reusing structural steel elements, especially those published in the UK market, were studied and analysed. Nevertheless, the collection of documents and publications did not give a complete picture of the current scenario in the industry. This lack of information led to the decision to conduct exploratory interviews with industry experts involved in the reuse of structural steel elements. The selection of participants was based on an investigation of the participants' backgrounds either through academic or industrial publications, industry experience, or sustainability experts with experience in regulations or material reuse.

The data collected for the analysis of successful projects were assessed through the selection and analysis of a case study. The selection of the case study was initially identified through desk research and preliminary data collection to understand the characteristics of the project. Based on the initial data assessment and background of the project, different actors involved in the project were identified and tracked based on their roles. The different actors involved in the project were contacted directly for their willingness and commitment to participate in a case study-based interview for further collection of detailed information.

2.3 Interviews and Validation Workshop

The interviews were conducted mainly in two phases: exploratory interviews to analyse the current market conditions and industrial practises; case-study interviews to understand the critical factors and engagement of different stakeholders involved in successful projects, and a validation workshop to determine the feasibility of the process tool on its applicability to achieve the expected output which could mitigate the design-acquire paradoxical tension.

The research study had ten interviews, of which six are exploratory and 4 were case-study-based. All the interviews were semi-structured discussions. Initially, the interviews were planned and conducted in person. However, due to unforeseen health conditions, most of the interviews were shifted to virtual mode and MS Teams was used to organise the meeting. All the interviews were recorded, and notes were taken and transcribed during the interviews, which were summarised further for analysis. The summary of the interview responses was sent to the interview participants within 7 working days and was requested to revert with any corrections within 7 days after receipt of the document. If no intimation is received within the due period of the next 7 days, permission to use the responses unamended in the research is granted by all the interview participants by default as notified through the informed consent form. Of the ten interviews, nine interviews lasted approximately 60 minutes, and one of the exploratory interviews lasted for 30 minutes.

Chapter 3: Reuse of (recovered) structural steel elements

3.1 Introduction

In construction, reuse is the process of utilizing an object or material that has been recovered from a structure, either for its original purpose or for a similar purpose without much change in its physical form (worldsteel, 2022). It is defined as the subsequent use of an object after its first line. The objects may be repurposed, but their original form will be retained with only minor alterations. (Densley Tingley et al., 2017). The salvaged components are retained as undamaged as possible during this process. It is considered that the most efficient type of material recovery is reusing components or complete buildings, which is also known as waste prevention or high-level recycling. Especially when compared to alternative recycling solutions, it provides significant environmental and economic benefits, but it frequently demands a greater initial investment (Coelho et al., 2020). In this way, reuse contrasts with recycling, which includes transforming an element back into a raw material by mechanical or chemical processes.

Circular economy principles have lately been advanced, notably at the EU level, with a roadmap devised to facilitate a transition to a resource-efficient, low-carbon European economy (DGB, 2019). However, the construction industry consumes a considerable amount of raw materials and produces a lot of construction and demolition waste. They are under increasing pressure to be more resource efficient, waste-free, and have fewer embodied carbon consequences (DGB, 2019). Material reuse is one possible technique for increasing the built environment's material efficiency (2019, Icibaci). The objective of today's environmental regulations is to minimize waste streams through material recycling and reuse, as well as prolong the life of components and buildings. As a result, the built environment can act as a material bank, storing embodied energy and carbon in building materials, manufactured components, and structures. Their focused separation and recovery during demolition may divert more than 70% of materials from landfill, and it can also help achieve circular economy goals if the materials, components, and structures are reused in new buildings (Coelho et al., 2020).

Steel has excellent circular economy attributes, both as a material that is strong, durable, versatile, and recyclable, and as a lightweight, flexible, adaptable, and reusable structural frame system (DGB, 2019). Steel is especially well suited to being easily recovered from demolition projects and used in new construction (Gorgolewski et al., 2008). When compared to recycling, structural steel reuse has more significant environmental benefits. It can be reused or repurposed in many ways, with or without remanufacturing because of its durability (Dimitropoulos et al., 2021). This includes reusing them over time and with minimum reprocessing throughout several building projects. Steel, in particular, lends itself to this strategy since it can be quickly inspected for deflections, distortions, and corrosion, as well as determine whether it is suitable for reuse before demolition (Densley Tingley et al., 2017). It is also acknowledged that a reuse level of between 20 and 40% would reduce the environmental footprint of the steel used in the building by 18 to 36%. This markedly improves the already strong position of steel when it comes to making life-cycle-based decisions about material choices for new buildings (worldsteel, 2022a).

3.2 Current potential of steel reuse

Steel has high recycling potential. When produced in an electric arc furnace (EAF) using recycled scrap (secondary steel production), it offers approx. 50% energy savings and 75% carbon savings over primary production from iron ore in a basic oxygen furnace (BOF)2. Nevertheless, to achieve even greater carbon reduction, reprocessing should be limited only to products that cannot be reused directly (e.g., reinforcing steel recovered after demolition) (Drewniok, 2021). If done properly, reusing steel from old buildings into new ones may significantly reduce carbon emissions by avoiding energy-intensive procedures involved in recycling, primarily by avoiding having to remelt the steel, or in the production of virgin steel. (ARUP, n.d.). The current virgin steel production process, dominated by the use of blast furnaces, has an average carbon intensity of 1780–1830 kg CO_2e/ tonne steel due to energy input and by-product gases (Dunant et al., 2017; European Commission, 2016c; Worldsteel Association, 2017b). However, recycling steel can bring down the carbon intensity of steel to 330 kg CO_2e/ tonne and the reuse of steel can abate the carbon intensity to 60 kg CO_2e / tonne (ReLondon, 2022).

The reuse of steel is not limited to its original application; repurposing dates back to ancient times. It is expected that rates of reuse will increase as eco-design, design for reuse and recycling, and resource efficiency become more commonplace (Dimitropoulos et al., 2021). Reusing reclaimed structural steel is not a new idea; in fact, the practice was more prevalent in the past but has declined over the last few decades. There are several reasons for this, the most significant of which include (new) development programme constraints and tougher health and safety requirements with demolition activities, in particular, working at height. Reuse is technically viable, as demonstrated by isolated projects and in certain niche markets, but there are barriers to mainstream reuse (Steel Construction Institute, n.d.). The decision to reuse steel may be made early in a project if the building is to be reused on-site, or at a later stage, during tendering for steelwork, if the building is to be relocated for reuse (Densley Tingley et al., 2017). The primary focus of this research study is looking at improving the potential of component and element reuse(large-scale) as a relocated reuse. The relevant section addressed in this research is component system reuse at the relocated project site is shaded (blue) in Table 3 below.

Table 3: Categorized types of steel reuse (Densley Tingley et al., 2017)

	In-situ Reuse	**Relocated Reuse**
Building Reuse	Reuse of a significant portion of a building, for instance: the entire structural frame, facade or envelope, in-situ	Deconstruction, and reassembly on a new site of a building frame/envelope
Component system reuse	Reuse of a small part of a building in-situ, e.g. foundations	Reuse of system of components, e.g. steel truss
Element Reuse	Deconstruction and reuse of elements in a new configuration	Reuse of individual elements, e.g steel section(s), on different sites

However, steel reuse, on the other hand, is not frequent because of the fewer incentives and barriers in the supply chain that impede its successful adoption. Several impediments to the reuse of recovered structural steel elements have been found (Densley Tingley et al., 2017). There is a lack of client demand, a lack of integrated supply chain, difficulty storing recovered materials, inertia in the construction industry to adapt to the reuse of structural steel elements, a lack of information about existing structures for demolition or available materials for reuse, and limited jointing techniques that can be used (Densley Tingley et al., 2017). The perception of a lack of availability of steel available for reuse is also due to a lack of communication between the demolition contractor and the team involved in the new design. It was identified that often the demolition contractor is appointed just before work begins, even if the building has lain empty for several months before demolition. This makes it difficult to conduct a pre-demolition audit to identify elements for reuse, and as a result, the default is to send the steel for recycling (Drewniok, 2021).

3.3 The process of reclaiming structural steel

The process of reclaiming or recovering the elements from an existing structure is a very critical process that determines the potential of reusing the elements. It is important to make sure that the reclamation of steel is meticulously done to ensure that recovered steel can serve the function of the element (SCI-The Steel Construction Institute, 2019). In Figure 7, the process of reclaiming steelwork to reuse in another structure is broken down into several stages (Interview 8):

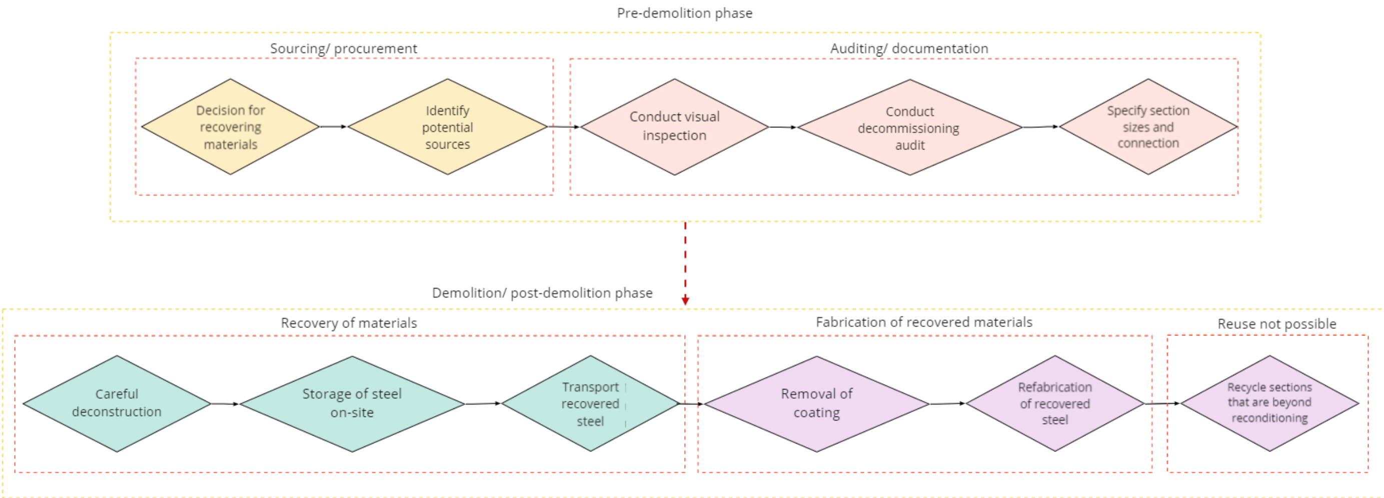

Figure 7: Process of reclaiming steel (author)

1. Decision on using the salvaged steel: At the end of the life of a building, usually the building owner decides to demolish or dismantle the building. Being the building owner, they are the owners of the building materials as well. This reflects the fact that it is the responsibility of the building owner to dispose of the materials. The building owner usually approaches the demolition contractor for the same. The client might also incur the need for salvaged or reclaimed materials if the project team in general develops the ambition and enthusiasm to realise building with donor materials.

2. Identify potential sources and sites for salvage and demolition: When a building is offered for reclamation, it is considered depending on whether the source material is acceptable, the structure is dismantlable, and the cost of demolition. This decision is made in the early stages of the design process, allowing more time to identify sources of steel.

3. Conduct a visual inspection and identify the characteristics of the sections: When the donor building is identified for salvaging or reclamation, a preliminary visual inspection is conducted on the existing materials to identify its reuse capability, material characteristics and condition or exposure of the materials in the donor building.

4. Conduct a pre-deconstruction audit and documentation: Generally, the demolition contractor conducts a decommissioning audit to record the available materials and the quality and quantity

of these materials. They include material characteristics and could often include a digital twin based on the identified materials. This database could be used by the client, designers or engineers to determine the reusability and compatibility of these materials in the new construction.

5. Specify various section sizes and design connection details: The connections used in various buildings are different from one to one. This has a great impact on deciding the type of demolition process and how the recovered materials can be reused. The designers of the new buildings greatly depend on the different sizes of the sections and the connections used in the elements. These are critical for the designers in developing and modelling the new buildings. This specification is generally collected with a combination of demolition contractors and structural designers.

6. Demolition contractors store the steel until required on site: The recovered materials are generally safely stored on the demolition site for a considerable duration of time. However, if the demand for these recovered materials does not match the recovery process, the demolition contractors are forced to store them in salvage yards either in their portfolio or lease out the storage space.

7. Transport the recovered steel to the project site: The transportation of the recovered steel could be either from the demolition site or from the salvage yards to the new building site. Generally, this transportation is done by the demolition contractors, or at times, it should be done by the steel contractors, depending on the project settings and contractors. However, during this process of transportation, which includes loading and unloading and stacking while transporting, the elements could undergo deformations.

8. Remove all coatings containing toxic substances: The existing steel might contain several toxic substances that could be harmful to the labourers involved, or even during the cutting or salvaging process. Furthermore, the steel elements might contain substances that make them inappropriate to be used in interiors. The steel could be checked for the presence of chrome 6 in the existing paint needs to be removed before reusing it. Furthermore, the steel should be inspected to whether the elements have a galvanised coating. In such a situation, fire cutting is not suitable. Therefore, the coating should be removed if there is a presence of the same to enable the cutting of steel to adjust the elements according to the new design.

9. Carry out refabrication, sandblasting, and painting of the salvaged steel: After adjusting the specifications of the recovered steel elements and making them eligible to be further used in the design, it requires further repairs and refabrications. Based on the functionality the steel might need to undergo painting-related works and compulsory fire-cutting to enable safety.

10. Recycle the sections that are beyond reconditioning: During the demolition or recovery phase, the elements might undergo several deformations during recovery, storage, or transportation. This can be due to dents or twisting of the elements, which makes the recovered elements not more suitable for reuse in the new building. Furthermore, by cutting the materials to comply with the new design, there could be a waste of materials. In this process, unsuitable elements and waste sections are taken for the recycling process.

3.4 Drivers and Opportunities for Structural Steel Reuse

Strong and dimensionally stable elements are fastened together to form structural steel sections, which in turn form structural assemblies that can often be dismantled. Hence, structural steel can be reused instead of recycling as it will result in more environmental savings. Emphasising the escalating pressure on the construction industry to move towards a resource-efficient and low-carbon economy, circular economy concepts are being highly promoted and wherein the reuse of structural steel will play a vital role in this transition. The environmental effects of utilizing new steel sections, which contain around 60% recycled material, are nevertheless 25 times greater than those of employing similar amounts of recovered steel sections. Reusing reclaimed structural steel can reduce environmental consequences by 96%, according to research. It is mainly because building component reuse (BCR), as opposed to recycling, requires a lot less treatment and reprocessing (Rakhshan et al., 2020).

As mentioned above, carbon taxes are being introduced in several sections of the supply chain and production units. This will soon be incorporated into the built environment where building owners will be entitled to pay taxes for the embodied CO2 of the materials used in the structure. The replacement of virgin materials with recovered materials to reuse them in the structure could significantly reduce the embodied CO2. Considering the characteristics of the steel section with excellent potential for reuse offers great opportunities for deviating from the use of virgin materials with high carbon intensity. This makes the preposition of reuse of structural steel more environmentally and economically feasible.

Structural steel has the potential to deliver truly circular, dismantlable, and reusable buildings. However, new legislation, business models, and technical advancements are required to realise these opportunities and make the process easier. The positive approach from the local authorities and national governments actively involved in the preparation of developing protocols and guidelines for steel reuse is a major supporting factor (Interview 9). In terms of multi-storey buildings, structural steel reuse provides opportunities for substantial standardization of structural grids, improved span, standardization and adjustments of connections for smooth deconstruction, and the development and testing of new, dismantlable flooring and connection systems. (SCI - The Steel Construction Institute & BCSA - British Constructional Steelwork Association, n.d.).

Reusing recovered structural steel, as opposed to the common practice of recycling by remelting scrap, offers significant environmental benefits and potential cost savings (DGB, 2019). Reuse can lead to cost savings, compared to the use of new structural steel, especially considering the current scenario when the prices of virgin steel elements are exponentially increasing and is identified that there is a hike of over 250% in price during the period of 2020-2022. Even though new steel and scrap steel prices fluctuate, data shows that the long-term price difference between structural steel and scrap steel is significant (Coelho et al., 2020). Currently, the price of new steel varies between 1050-1150 euros/T and the scrap steel price varies between 350-450 euros/T. The price difference of approximately 700 euros/T shows that there is a clear marginal price difference (Interview 8). This marginal difference in the cost could overcome the additional expenses associated with reusing structural steel if the associated process is optimised and controlled. Although deconstruction, testing, storage, re-fabrication, and other expenditures (in comparison to recycling) may be incurred, structural steel reuse can result in cost savings (DGB, 2019). The major drivers and opportunities that enable and motivate the need for transitioning toward reusing structural steel elements are shown in Figure 8 below:

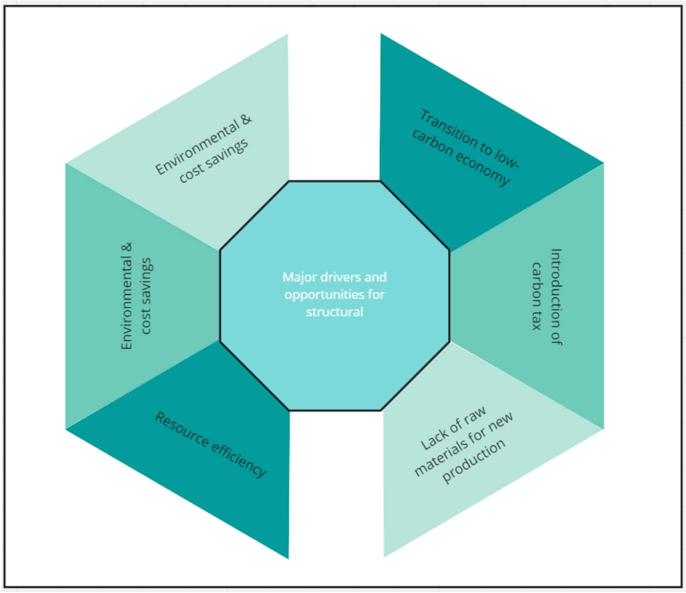

Figure 8: Major drivers of transitioning to reuse of steel

Eliminating testing costs while increasing on-site fabrication, and reducing transport and stocking costs are critical factors for the economic feasibility of structural steel reuse (Cullen et al., 2016). Furthermore, it is evident from several stakeholders that the demand for steel construction is increasing. Contrastingly, the production of steel is not meeting the demand of the market. This could be because of the lack of raw materials for production. This trend shows that the price of new steel is likely to increase further owing to existing and forecasted market conditions (Interview 8). It is also identified that governments across different countries are planning to implement carbon taxes on the manufacturing process and embodied carbon associated with each product. This relates greatly to steel production as well, with extensive embodied carbon (Interview 8). According to prior information in the study, 1.85 tons of carbon dioxide were emitted on average for every ton of steel produced in 2018 (Hoffmann et al., 2021). Governments from several nations are currently seeking to impose taxes on this carbon emission and hold steel manufacturers and building owners accountable for the same. This emphasizes even more how crucial it is to make a transition toward steel reuse.

3.5 Barriers to reusing structural steel

While implementing a circular economy is of significant importance in achieving sustainability, quite a few risks are also associated with the same. Considering the possibility of reusing structural steel elements, owing to the current market conditions and scenarios, achieving this trait is hindered by several factors at different levels. The identified risks are multifaceted and multidimensional in nature. This section identifies the major impeding factors that act as a barrier to the realization of the reuse of structural steel elements and an illustration of the same is shown in Table 4 below.

Table 4: Barriers to reusing structural steel elements

Technical	**Logistical**	**Liability**	**Financial**
Lack of innovative solutions and robust products	Lack of local facilities for reclamation	Recovered steel not accepted by fabricators	Limited demand creates a lack of commercial drivers

Lack of standardised components	Mismatch in supply and demand	The demolition contractor ends up selling steel as scrap	Long-distance transportation can incur huge additional costs
Unavailability of technical solutions for reprocessing reclaimed sections	Extended time for deconstruction and storage	Permit for demolition	Specialised labour requirements
Ensuring and certifying the performance of reused/ recovered components	Extended supply chain compared to new steel	Lack of support from regulations and protocols	Additional safety considerations
Implementation requires new tools	Lack of definite measures to include demolition contractors in the early stages of the process	Quality assurance of reused products	Extended time in the construction process
Lack of sufficient knowledge about product properties	Transportation of heavy steel sections		Cataloguing of steel
Loss of information in the process			Testing and certification
Challenges in processing reclaimed sections in automated fabrication lines			Contingencies in pricing based on the condition of the steel
The practicality of economic deconstruction			Financial feasibility of reusing high dependency on the demolition process
Safety issues			

3.5.1 Technical barriers

Innovative technical solutions are required to achieve circularity in the best way possible. Currently, it's a mixture of traditional methods and changing technology, which could cause challenges in the future. A lack of standardized components and procedures for reuse remains one of the main technical barriers. There is unavailability of adequate technical solutions for the processing of reclaimed sections and ensuring and certifying the performance of reused components (Cullen et al., 2016). This is significant as clients are reluctant to use reclaimed steel that has not been tested and verified owing to the perception of inferior quality of reclaimed steel. Reuse requires robust products that weren't subjected to severe damage, as lighter products will not make it out of the deconstruction process (Densley Tingley et al., 2017). The current testing and certification demand the reclaimed or recovered steel to meet the quality standards for new steel. There are no specific regulations that can be used for reclaimed steel to assess its reusability (Interview 4). Moreover, currently, the industry lacks a programme that promotes the reusability of materials. The implementation of reuse requires providing enough room for additional design, accountability of deconstruction time and cost, additional procurement and testing and certification of reclaimed products (Interview 5).

The innovative technologies required for the implementation also require new skills to use the tools that enable reuse. However, the absence of sufficient knowledge about product properties and previous usage history poses a hindrance to the future potential of reuse (Interview 9). Difficulties in adapting to the innovations also need to be addressed in the long run (Rizos & Bryhn, 2022). Furthermore, it is often seen that the buildings that are available for deconstruction have mostly been in use for the past 25 to 50 years and had no aid of advanced digital data storage facilities like BIM. This often hinders the lack of information about the existing building (Interview 1; Interview 3; Interview 4). Over the past years, an increase in the automation of production lines for steel fabrication is witnessed. The production is set up to match the specifications of the new steel, and replacing them with the reclaimed steel sections makes it far less efficient (PROGRESS; Interview 5).

Furthermore, until recently, the extensive application of BIM was not applied by all actors during the entire process of development, which often resulted in a loss of information during the process of design to execution or maintenance. For instance, the architects will be providing a set of design information to the contractor or the developer. However, later during the execution phase, several changes could have been implemented into the developed design to cope with the deviations incurred on-site. These changes are not promptly reflected or documented back to the original design that the architects have developed. This further limits the traceability of what's actually inside the buildings, as often there is a mismatch between what was actually in the design and what has been realised on site (Rizos & Bryhn, 2022; Interview 1).

3.5.2 Logistical barriers

The lack of local facilities for reclamation causes a great difference between the location of the reclaimed items' stock and the market. There isn't an assured availability of supply and sufficient demand for reclaimed steel. It has been identified that the mismatch between supply and demand is one of the major hindering factors. The main reason is due to the extended time taken for the deconstruction and storage. At times, the demolished products from a donor building will need storage space as they might not be needed by a new building then. This will incur additional expenses as well (Knoth et al., 2022). To avoid this issue of dealing with storage space, most of the time, even after the use of buildings becomes obsolete, the materials are not recovered until demand arises. In other cases, if the building materials are recovered, they might go to the steel stockist, and after that, often the traceability of materials is very limited (Interview 4). The whole supply chain of new steel is comparatively shorter than that of reclaimed steel. The major addition is the involvement of demolition contractors in the reuse supply chain. However, even knowing these facts, definite measures to include demolition contractors from the initiation phase are found lacking. This existing practice doesn't act in favour of realising the reuse of steel (Interview 5).

The availability of recovered materials at a nearby location is critical to the commercial success and economic feasibility of realizing the project successfully. Considering the heavy structural steel sections, transportation of these structures over long distances and loading and unloading of them makes them a less economically and environmentally viable option (Knoth et al., 2022; PROGRESS; Interview 3, 4). Furthermore, over long transportation, the recovered steel sections can undergo deformations like dents or twists. These deformations either demand additional repair measures on-site or in some conditions, the deformations can be beyond repair. In such cases, the steel section becomes obsolete to be reused and should be recycled after investing additional expenses for careful recovery, storage and transportation (Interview 8).

The health and safety of workers for manual demolition is a matter of high concern. Hence, there are mechanical demolition techniques. Even so, the risks in terms of health and safety can be reduced only if ample information about the building's design and composition is available. However, such information is often unavailable. Demolition programmes are often very short because the careful packing of the items is difficult (Interview 8; Interview 9).

3.5.3 Cost

The demolition contractors sell scrap steel for recycling based on the scrap price. Under specific economic and technical conditions, deconstruction and refabrication can be profitable. There is a client perception that reclaimed steel is inferior to new steel and would be cheaper. The profitability is also dependent on the prices of scrap steel and new steel, as well as the companies that take up the demolition and reconditioning of steel (Interview 4). However, there is a lack of demand for this reused steel, hence, commercial drivers for reuse as well. The mismatch of supply and demand and logistical concerns of moving heavy materials long distances can also bring further expenses. Therefore, the availability of materials within the proximity of the project site is a critical factor in the successful and economically feasible realisation of the project (Interview 8). The willingness to use reclaimed steel calls for testing and certification to verify the performance and guarantee properties of steel, for which the costs will be added to the cost of the product (Interview 9). There can be additional costs associated with using reclaimed steel, such as deconstructing, storing, and cataloguing the reconditioned steel, and so on (Interview 3, Interview 4; Interview 8). The additional time required for completing the project can also incur more expenses. With the technical challenges of deconstruction and reconditioning, the cost savings will likely decrease (PROGRESS). Furthermore, all the actors involved in the process have to deal with additional requirements for competencies, uncertainties and risks. This involves the additional requirement for budget allocation in the project (Interview 9).

3.5.4 Liability

The additional costs that incur in terms of storage space, logistical requirements, innovative technologies and so on, the difficulties in tracing the steel, uncertainty in the availability of steel and so on are certain factors because which the clients are reluctant. These barriers are significant for demolition contractors, stockists, and fabricators. Instances, where the fabricator could not accept the steel procured from the yards, are plausible. Fabricators will have to use more of their production capacity for steel reuse projects than for traditional projects, and the business model of stockists does not allow for long-term storage of the steel (Dunant et al., 2017). Even though, the deconstruction of steel can benefit demolition contractors. It is likely to have less demand for reused steel, and they will have to sell the steel as scrap only. Furthermore, after the materials are recovered, it is the liability of the demolition contractor to make value out of them (Interview 8). The whole process from design to construction has a flow, and the other members of the supply chain might not be trustworthy enough to face new challenges. Liabilities and insurance also need to be addressed appropriately (Dunant et al., 2017).

Considering the programmes and regulations existing in the country, they are not inclusive of reusing materials. Today, most building construction is assessed by Life Cycle Assessment and the Environmental Cost Indicator is one of the major factors that is taken into account. In this assessment, the use of primary and secondary materials is taken into account as both have similar impacts on the environment. However, as we all know, secondary materials have a far less environmental impact when compared to primary materials. Since this consideration is not reflected in the regulation, the project team often loses the motivation to make extra efforts to incorporate the reuse of steel (Interview 3; Interview 5). Furthermore, testing and certification are important criteria to assess the reusability of materials. Currently, the guidelines developed to test the quality of new materials also apply to the testing and certification of secondary materials. This often hinders the reusability of steel (Interview 4). As there is a lack of definite protocol, guidelines or tools, often the structural designers might have to undergo a strenuous process of convincing the local authorities to approve the building design developed to incorporate the reuse of steel. Also, the attitude and assessment methods of local authorities differ based on municipalities (Interview 9).

Chapter 4: Design-Acquire Paradox

4.1 Introduction

Over the past few years, sustainability has quickly moved up on the building agenda. Natural resources are under a great deal of stress due to the world's need for raw materials and the ever-growing economies and demographics (*We're Gobbling Up the Earth's Resources At An Unsustainable Rate*, 2019). One of the major concerns that our society must address to protect the well-being of future generations is the consumption of non-renewable resources and the production of waste (RIBA, 2021). Waste, particularly generated during construction, has a significant effect (RIBA, 2021). The underlying principles of the circular economy state that all waste should be viewed as resources (Resource Efficiency and Waste, 2019). Over time, waste has transformed to be seen as a lost resource and lost revenue. Processes that give value to waste materials have a positive impact on the environment and the economy as well (Gorgolewski et al., 2008). The competitive advantage gained via effective resource usage is projected to produce growing strategic benefits in the current global economic environment. However, the way we plan and build our structures results in the production of enormous amounts of debris and the use of resources whose extraction causes significant environmental damage (RIBA, 2021). So, how can we design structures so that closed-loop material systems reduce waste production and maximise the utilization of raw materials? (Gorgolewski et al., 2008).

Designers are essential in ensuring that projects have positive effects on the environment, society, and economy. Recent research by WRAP (Waste & Resources Action Programme) in their publication titled "Designing out Waste: A design team guide for buildings", has identified the important contribution that designers can make in reducing waste through effective and efficient design (RIBA, 2021). Designing with the intention of using resources from structures that are nearing the end of their service life is also quite important. The fact that a building's materials may still function after its life is frequently acknowledged and explicitly indicated (RIBA, 2021). The need to address the problem is growing as a result of factors like rising prices for new steel, a shortage of raw materials for manufacturing, a comprehensive review of the environmental effects of using virgin steel, and wastage of existing resources (Interview 1, Interview 3, Interview 4, Interview 5).

As discussed earlier, the concerns around the applicability of how to implement the reuse of structural steel elements develop a contradictory tension which is paradoxical in nature. In the current scenario, circularity is considered important and has several ways of achieving the same. In this research, the reuse of structural steel elements is identified as one such possibility. To improve the potential of reusing steel, flexibility in the design helps to accommodate more available reclaimed steel sizes. Also, the use of more commonly available steel sections in the design helps to increase the probability of finding the materials on the market (Gorgolewski et al., 2008). Often, it is identified that long spans can be a problem as there is limited availability of reclaimed steel of this type (Interview 7). A detailed explanation of a set of design principles that can improve the potential for reusing structural steel elements is provided in Appendix C. Over years with different cycles of reusing, materials could undergo extensive deformations with deconstruction and execution and can have high variability in span specifications due to several fabrication cycles. This will eventually lead the material to be recycled to meet the design requirements and to divert them from waste streams.

Often, people, in general, tend to prefer having as many choices as possible and see the choices as a luxury that facilitates their decision-making process (Paradox of Choice, 2020). In a similar context, actors who wanted to pursue the ambition to reuse structural steel are offered different options whether to design first and then locate materials from the market that fits the design or vice-versa. However, an American psychologist Barry Schwartz, states that having too many options may often lead to a negative outcome. The major underlying impact is Choice Paralysis, where actors end up not making any choices because they get paralysed by the variety of options and can't even make a decision (Paradox of Choice, 2020). In this case, both the identified option, design first or source materials first has their underlying challenges that need to be addressed and make it difficult for the actors involved to make a decision.

Furthermore, in a similar situation, it is often seen that there is a degradation in satisfaction of the people involved having an abundance of choices makes it much easier for them to blame themselves for not making the right decision. That is especially when encountering challenges or when things don't proceed as planned after choosing either of the options. Often, the actors involved regret the choices made and live in hindsight (Paradox of Choice, 2020). The paradoxical tension of choosing between a design or a material-driven design is defined and addressed through this research, which is called the design-acquire paradox. A short explanation of the context of what is a paradox and how the characteristics of this tension relate to the current scenario revolving around the reusing of structural steel elements are discussed below.

4.2 Paradoxical tension – Review of Literature

The section addresses the nature of paradoxical tension and why is it important to understand the contradiction and uncertainties underlying the concept. The paradoxical tension is studied through a literature review to understand the concept and further the paradoxical tension concerning reusing structural steel elements is established.

Contradictory tensions can take many forms, including dilemma, trade-off, dialectic, duality, and paradox, and might "have overlapping aspects, producing a degree of analytical ambiguity and uncertainty (Love et al., 2021). Tensions are cognitively and socially constructed as paradoxical when actors polarize elements, ignoring or masking their interdependence, which is often seen in the design and procurement of reused elements for buildings (Lewis & Smith, 2014; Schad et al., 2016). This often exists in the design-acquire paradox. When the actors involved, i.e., architects, structural designers, project managers, suppliers, and the procurement team, conceive design and procurement as two phases without exploring and exploiting their interdependence. This results in the previously mentioned paradoxical tensions.

Proponents see tensions as pervasive and persistent forces that both challenge and inspire long-term success. Acceptance and involvement allow actors to survive and grow in the face of conflicts (Lewis & Smith, 2014). Paradoxical thinking entails a comprehensive and dynamic both/and perspective that explores synergistic solutions for coping with persisting conflicts (Szentes, 2016). The conflict is when the design does not fit with the available materials from the market and acquired materials are not compatible with the developed design. Juxtaposing contingencies or conflicting demands helps in embracing the potential of both options simultaneously without necessary making a trade-off between them (Lewis & Smith, 2014). For companies in different industries, it makes sense, on the one hand, to exploit existing knowledge and technologies to perform efficiently today but, on the other hand, to also simultaneously explore new knowledge and technologies to adapt to future demands and conditions (O'Reilly & Tushman, 2013).

Paradoxes are contradictory and interrelated elements that persist over time (Lewis, 2000; Smith and Lewis, 2011). By definition, paradoxical tensions are stressful encounters often resulting from frustration, uncertainty and inconsistencies that individuals face while dealing with contradictions

(Smith and Berg, 1987; Vince and Broussine, 1996; Lewis, 2000; Smith and Lewis, 2011). However, Lewis & Smith (2014) clearly emphasize that utilizing a paradox lens would highlight the significance of a comprehensive understanding of organizational conflicts. Today's complicated business models necessitate managers that can address challenges at several levels of the company at the same time. Overall, adopting a paradoxical viewpoint to major building projects seems to be a promising method for developing systemic insights.

4.2.1 Design Processes

Several studies have showcased and substantiated the importance of the design phase in the success of a project. There is a quandary in the relationship between form (design) and material in the design process of improving the potential for reusing structural steel elements and thereby achieving circularity (Bak-Andersen, 2018). The majority of important publications have focused on how to aid designers in selecting appropriate materials within the constraints and/or needs of the form and manufacturing process. Scholars have recently become interested in a newly established study topic that examines materials' active roles in influencing our experiences with things (Karana et al., 2015). Considering the incorporation of the reuse of recovered structural steel elements, this can be realised in two different ways: Form Focused Design (FFD) and Material Driven Design (MDD).

Form-Focused Design (FFD) process

The traditional form-focused design process causes a lack of knowledge regarding materials and, as a result, creates a knowledge barrier between the designer and the product—a barrier that acts not only against the implementation of opportunities for incorporating advanced materials and recovered materials (Bak-Andersen, 2018). The Form Focused Design is the traditional process of developing construction projects. In this process, the design is developed first and then available materials are identified or located to incorporate them into the design. A lack of understanding of available materials effectively creates a knowledge barrier between the designer and the structure to be developed, impeding the sustainability of the product (Bak-Andersen, 2018). This ends up being the major obstacle to the large-scale incorporation of reclaimed steel elements, as the formulated design limits the flexibility in incorporating the materials. In this process, the development of a flexible design is critical to maximising the possibility of fitting in available reclaimed sections.

Material-Driven Design (MDD) process

Most researchers describe a design process in which material plays a fundamental role from the beginning of the design process as material-based or material-driven. The process in which design or form is not prioritised over materials, and they are not merely introduced or identified to fit into a defined shape but truly defined as the basis for design (Bak-Andersen, 2018). This new type of design process is emerging in which the material is present from the outset and can be seen as the driver of the process. This material-driven design process breaks down the aforementioned knowledge barrier and has shown potential for being a design process that enables design for sustainability. It has been identified that the specifics of the MDD are compatible with the ambitions of a circular economy (Bak-Andersen, 2018). However, adopting a material-driven design limits the freedom of the architects and constraints are introduced making it complex for them to meet the functionality requirements of the client. Furthermore, the sourcing of materials is not guided by a design, making it uncertain for the project to identify the required materials and their specifications.

The main difference between a material-driven design process and most conventional design processes is that the designer plays an important role in designing, developing, or manipulating the material that is being utilized for the design from the outset, instead of merely selecting a material to fit the form once the design process has been finalized (Bak-Andersen, 2018). When the material is not present in dialogue with design and function from the beginning of the process, it can be complex for the designer to make appropriate decisions—not just regarding sustainability. Leaving the material to the end of the process, or even in the hands of others, provokes a knowledge barrier between the designer and the end product. This design process is identified by most designers as a more feasible option. Here, all the available materials are identified right from the start, and the design is developed around these materials. This process could greatly mitigate the uncertainty of whether the right elements will be available to meet the specifications of the developed design.

However, certain challenges need to be addressed while implementing the reuse of structural steel elements. The hassles of sourcing and tracing the steel are followed by the absence of logistical facilities for salvage, unsecured health and safety conditions of the workers and cost barriers in terms of additional costs of deconstruction along with disparities in demand and supply. Technical barriers dominate when it comes to the lack of standardized procedures for reuse and certifying the quality/performance of the reclaimed materials and the lack of skilled labourers for utilizing the full potential of technological advancements. These barriers incur additional expenses and directly affect the demolition contractors, stockists and fabricators creating a further barrier of liability.

This challenging scenario exerts pressure on the project team. Emphasizing the current scenario, the research study extends its focus toward a contradictory tension the project team faces: "Whether it is feasible to first identify existing reclaimed materials/demountable materials available for reuse on the market and then design around them or design with the intention of sourcing the materials later during the procurement phase?" If reclaimed materials are acquired first and then the design is made around them, the designers will be constrained to develop a design that fits the acquired materials, which indeed limits the design freedom and flexibility of the designers. Here, the risk is that not all the acquired materials can be used in the design, incurring storage-related issues, unnecessary acquisition and/or wastage of materials. In contrast, if the design or programme is prioritised and then the materials are purchased, it is no guarantee the project team will be able to locate the right steel elements that meet the requirements of the developed design from the market. Currently, in the industry, there is a lack of an integrated supply chain, which further makes the possibility of locating and sourcing materials that match the developed design difficult to achieve.

As discussed earlier, the concerns around the applicability of how to implement the reuse of structural steel elements develop a contradictory tension which is paradoxical in nature. This paradoxical tension defined and addressed through this research is called the design-acquire paradox. From the literature reviews, it was identified that limited research was done on the practical adoption of the reuse of structural steel elements in buildings and most of the publications from the limited research, focused on barriers associated with reusing steel. Thus, to identify the industrial practises adopted in response to the underlying challenges associated with the implementation of the reuse of steel in buildings, exploratory interviews were conducted with industry professionals. A short explanation of the context of what is a paradox and how the characteristics of this tension relate to the current scenario revolving around the reusing of structural steel elements are discussed below based on exploratory interviews.

4.2.2 Exploratory Interviews

Over time the preposition for adopting steel reuse is changing. Initially, we explored its possibilities to promote circularity and later to meet the ambitions of limiting carbon emissions. Nevertheless, today, as virgin steel prices are exponentially increasing and there is a serious lack of availability of raw materials for the production of new steel, actors are considering the option of steel reuse for cost reasons as well. However, the existence of the paradoxical tension of design-acquire is an underlying factor that limits the potential of reusing structural steel elements in buildings.

The exploratory interviews were conducted for identifying the underlying reasons that are contributing to the development of the design-acquire paradoxical tension. The conversation with industry experts focused on investigating the challenges faced by actors in the project teams due to several industry conditions and a lack of traction in adopting a similar practice of reusing structural steel elements in buildings. The contributing issues that create the paradoxical tension are discussed below:

Primarily, there is a lack of traceability of materials available for reuse in the market. This is due to the fragmented database of available materials. Several companies in the industry are gaining interest in exploring the potential opportunities and possibilities of reusing structural steel elements. They are keen and focused on developing an internal database with available materials identified from the buildings within their portfolio and other sources. The information stored in the database is preserved and protected for internal use. This is due to the reluctance of companies in sharing their internal data on a business opportunity and concerns associated with their intellectual property. Different companies are competing to develop their databases and are not willing to share the information with other companies unless they have a larger database. Furthermore, because no specific protocols or underlying guidelines are supporting the reuse of structural steel elements in buildings, there could be a mismatch in the type of information stored in the database. These factors result in diminishing the traceability of available materials from the market, limiting the potential to reuse structural steel elements.

Lack of information: Over recent years the construction industry is undergoing a paradigm shift in the adoption of several digital tools like BIM or Revit. They have extensive capabilities for integrating enormous amounts of information and data about a building. However, looking into the past, the construction sector being the last industry to adopt any technological advancements due to its conservative nature, most of the drawings and information were handwritten or stored in hard copy format. Over years, this resulted in a loss of data and information regarding the structures and materials. Often, the buildings available for demolition (donor buildings) are 25-50 years old and hardly have any archival data available for reference to determine the characteristics of the building and the materials used. This often acts as a barrier limiting the potential to reuse materials from a building and makes the traceability-related issue further worsen. Furthermore, there are several secondary challenges associated with the lack of information:

- The lack of availability of archival data on the design of the existing building, quality test reports of material, and actual specifications and composition of the building further make the preposition and ambition to reuse structural steel difficult to achieve. This results in a loss of information completely or a loss of details over the process of design to execution phase or a mismatch in the information available. This demands extended requirements such as conducting an extensive decommissioning audit, and testing of all steel elements used in the building to determine whether the available materials in the building are reusable and meet the design requirements. The availability of archival data providing information about material quality data during the time of delivery or installation helps in determining the change in characteristics the material has undergone over the period of its life span. This helps the structural engineers determine the feasibility of reusing the materials by comparing them with the current data. This further extends the impulse of the paradoxical tension creating a dilemma for the project team whether the identified building without archival data aligns with design requirements or whether the identified or available building material is capable enough to serve the design to meet the functionality.

Information getting lost: It was also acknowledged from the exploratory interviews that several actors are involved in the construction process. Often information gets lost when transferred from one party to another or during the prolonged phases of construction. This information might be vital in determining the reusability of the identified steel elements. Before the advent of digital tools, architects provide a design and designers often provide the specification of the elements and composition of the building. This information is transferred to the contractors, wherein during the execution phase, the provided specification like span length or connection details could undergo several changes. The actual specification on-site is often not reflected in the original design or data. Thus when you identify these materials available in a building for deconstruction or reuse, the actual specification on-site could be different from what is represented in the design. This resulted in further diminishing the possibilities of adopting a Form Focused Design (FFD) as cataloguing existing information might not be a reliable source and makes it difficult for the designers to derive specific conclusions with the available materials in a building.

Lack of programme: In the Netherlands, we have a lack of programmes that facilitate or promote the reuse of steel. At the end of life, a building becomes suddenly available for deconstruction or demolition. Thus materials become available for their next phase through reuse, and recycling or end up being waste. In such case, to make the reuse a feasible option, there should be a similar project to be executed which requires similar materials to be incorporated into the new structure. This makes it difficult for the project team and actors involved to plan the recovery of materials from the end-of-life of a building for reuse and for the actors involved in the construction of new buildings to incorporate the available recovered steel. Further, the possibility of identifying a similar project or the materials getting available at a particular time is not traceable in the industry unless direct matchmaking or through specific digital inventory companies, if the product owner of the donor building chooses to list or advertise the same with them. Furthermore, municipalities or local authorities can play an important role in creating traction in improving the potential for reuse. Thus, due to this lack of specific protocol, guideline or integrated programme to facilitate reuse, it is highly unlikely to rely on the possibilities of adopting a Form-Focused Design and expect the materials to be available and traceable at the time of execution of the new project.

- Supply and demand: The lack of a programme is further aggravated by the mismatch in supply and demand. The materials could be available for reuse soon or later, say after 2-3 years. It could also be under the condition that the recovery of the material or deconstruction should be done at the earliest. But the matched project might take 1-2 years along the process of design to execution to put the materials to use. Thus the option available for the project team is to acquire the building and store the recovered material at a warehouse or storage site until the project requires these materials. This could incur additional storage-related expenses and makes the whole business case financially not viable for the client, which limits the enthusiasm and willingness of the client to explore the opportunity. Further, the time available to determine the quality of available material from the donor building through extensive testing is limited. This can have an impact on the entire project due to the unnecessary acquisition of materials or materials that might not meet the design to comply with the functional requirements of the client and design specification. Thus making the whole proposition of adopting the Material Driven Design complex and uncertain to achieve.

Involvement of relevant stakeholders right from the start of the project: The designers should be involved in the project from the initial business development phase of the project. They will be able to identify the feasibility of incorporating recovered materials based on the functionality requirements of the building. Addition of a new role/stakeholder, sourcing manager (locating the materials, assessing the feasibility or reusability, source materials from different sources like donor buildings, steel stockists of different formats, and digital inventory companies) and municipalities (identification of buildings which seek permissions for demolition permit or buildings at the end of their life cycle) can help in developing a holistic network of stakeholders to facilitate and improve the potential of reusing structural steel elements by enhancing the traceability. Furthermore, demolition contractors are not yet involved or engaged with the whole sustainability-carbon debate. Considering normal steel construction and steel reuse construction, the latter has an extended supply chain and demolition contractors are one of the key actors in the supply chain. However, they have not yet been involved in the whole initiation or design phase.

4.3 Interviewees perspective of MDD and FFD

The section identifies the interviewee's perspective on the contradiction between whether to design first and then locate and source materials from the market, which is the Form Focused Design (FFD) or first source the materials and then design around these materials, which is the Material Driven Design (MDD). The section focuses on the same through the lens of the contradictory perspective or paradoxical tension they face when making a trade-off between the options.

It is acknowledged that the easiest way is form-focused design, which is to design a building from scratch and compare it with the database of available materials and then promote a one-on-one replacement of virgin materials. However, considering the current scenario, there is no guarantee that it is possible to identify the required elements from the market with the specification defined in the design. This approach also helps the project team to stay with the traditional design process and can facilitate an effective design.

- However, in this approach, often the database is limited to internal usage and the exploitation of further opportunities in the market to improve the reuse of structural steel elements is not accounted for since the market is not explored. Also, if the approach of MDD is adopted by finalising the design first and then sourcing the materials, limits the flexibility in adopting the available materials or even incurs additional expenses and time when altering the finalised design to incorporate the identified materials.

Considering the current industry scenario, it is also seen that the Material Driven Design is more feasible to achieve the trait of reuse of recovered materials. This is due to the lack of availability of materials, traceability-related issues in the market and even the lack of an integrated supply chain that limits the dependency and assurance to finding the materials from the market. Thus identifying a set of materials and having a reference to a defined set of a catalogue of materials can help the designers to improve the potential to achieve the trait of reusing structural steel elements.

- Even though several advantages are identified for Material Driven Design (MDD) they are not devoid of several complications and setbacks to achieving the success of the project. When the designers have to deal with a bundle of elements available for reuse in the new structure or even when you have a lot of identified materials with different specifications and connections, it is difficult for the designers to make logic out of these steel sections with different steel profiles. It is also acknowledged that this design process could be more challenging and can restrict the design freedom of the architects, making it arduous to comply with the client’s design and functionality requirements. Currently, the industry is advancing through the development of tools and software with the aid of artificial intelligence that can make logic out of the available database to fit them or develop a design based on these stock materials. The architects feed preliminary design with grid sizes into the tool and it identifies matching materials from the database with a catalogue of materials linked to them that meets the design.

4.4 Challenges associated with the dilemma of FFD vs MDD

As acknowledged by several interviewees, both options have their challenges and setbacks. Therefore, when making a trade-off between either/or of them, which further limit the potential to reuse structural steel elements.

- Due to challenges associated with making a trade-off between both options, it is often seen that there are several uncertainties and black holes in the whole process of incorporating the reuse of structural steel elements. This results in a lack of confidence in the client and other project actors to further explore and exploit the opportunities available in the market. This conflicting demand often has a serious impact on diminishing or affecting the willingness of the client. It is acknowledged by different actors involved in the reuse of structural steel elements that, it is the ambition of the project team and the willingness of the client that would overcome the early discounting of the opportunities associated with the implementation of the reuse of structural steel elements. However, this contradicting tension and lack of clarity and uncertainty in determining the feasible option hinders the whole process of exploring and exploiting the potential opportunities of steel reuse.

- The challenging situation of paradoxical tension slows down the motivation of the project team for exploring the possibilities of the reuse of structural steel elements, thus the demand is not widely created in the market and industry. Based on the underlying principles of the supply chain, unless extensive demand is created, the supply might not gain its full potential and integrate sufficiently for providing critical services. This lack of an integrated and stable supply chain further add to the challenges of meeting the supply and demand, that is aligning the construction of new building and deconstruction of donor building at the same time frame to limit the storage-related issues.

- Due to the lack of a defined programme approved by local authorities or government, further challenges in decision-making to determine when is the best time to invest in testing the reusability of the materials identified. Furthermore, the client and project are conflicted with the ambiguity of whether is it feasible to have the additional investment in inspecting and testing several available buildings.

4.5 Relationship between paradoxical poles

The literature identifies the root causes of a paradox, its underlying tensions and how these are reinforced by actors' defensive reactions when they try to deal with the paradox. Considering the case, whether to design first or locate and source materials first, actors try to make a trade-off in the decision-making process. This tension exists as duality which has different methods of implementation approaches in practice. Consistent with the pursuit of synthesis as a way to deal with paradox, these tensions are addressed within these organisations through concepts and practices that combine these polarities. At the core of paradox theory lies the acceptance of dualities of coexisting tensions, where no compromise or singular choice between them has to be made. The effective management of these tensions is therefore based on finding creative ways to engage both poles; capitalising on the inherent pluralism within the duality. This process of managing paradox by shifting rigid dualities into more workable entities has often been referred to in the literature as synthesis or transcendence (Papachroni et al., 2014).

Focusing on the relationship between the poles of dualities proposes three alternative ways of dealing with organisational paradoxes: formal logic, dialectics and trialectics. Considering dialectics views, paradoxes are considered dualities, whose oppositional poles are in a dynamic or interrelated relationship, with a both/and approach where the paradox is ultimately resolved through the transformation of the tensions into a new synthesis. Instead of trying to eliminate or solve the paradoxical tensions, the literature proposes keeping the paradoxes open and examining the relationship between their constituent poles. This relationship emerges through everyday practice, is context-specific, and can lead to a synthesis in cases where the opposite poles are mutually reinforcing. It is acknowledged and argued in the literature that exploring competition without simultaneously considering cooperation offers an incomplete view of competition, as competitors do not always act on the same level of competitiveness and at times they can work together toward a common goal. In a similar vein, the concept of duality assumes both contradictory and complementary relationships between the poles of a paradox. One such approach that extends its focus toward dealing with paradoxical tension without making a trade-off between different options is the ambidexterity or ambidextrous management approach. The approach focuses on exploring and exploiting both plausible sides of a paradox simultaneously. Further explanation on how ambidexterity can mitigate the tensions associated with the design-acquire paradox and how it can be implemented in developing a process flowchart to aid the project team to deal with the paradox is discussed below.

Chapter 5: Case Study - Biopartner 5

The chapter explains and analyses the selected case study to gather a better understanding of the industrial practices adopted in projects which successfully incorporated the reuse of structural steel elements, identify the critical (success) factors and recognise how the project team tackled the existing design-acquire paradoxical tension.

5.1 Introduction

The Netherlands Institute of Building Biology and Ecology (NIBE) established a CO2 budget for building products in the Netherlands for the nation to abide by the Paris Climate Agreement on behalf of the Dutch Green Building Council (*Dutch Green Building Council*, 2021). Biopartner 5 is one of just a few finished structures in the Netherlands whose embodied carbon is below the budget's current upper limit (Bouwen met een CO2 budget zou de maatstaf moeten worden, 2021).

Biopartner is a successful incubator organization based at the Leiden Bio Science Park (LBSP). The building offers flexible office spaces and laboratories to start-ups in the life and health sciences (Busschots, 2022). The development of the project is closely related to the construction of its fifth building, which will serve as a gathering place for the new areas of the Oegstgeest campus. As a result, Biopartner 5 is a key factor in the development of the campus and aims to set the stage for the long-term growth of the surrounding area (*BioPartner Center 5 - De Vries en Verburg*, n.d.).

A 7,000 square meter tiered laboratory building called Biopartner 5 blends high-tech and unsophisticated features (Dutch Design Daily, 2021). The project's relevance in this research is based on how existing, redundant structures were demolished so that salvageable components might be "donated" to future construction projects and employed in those projects. The structural engineers of the project (IMd Raadgevende Ingenieurs) established the notion of the "donor skeleton," which has since matured and found use in project practice. Additionally, Biopartner 5 catalyzes the area's long-term circular utilization as well as a stimulant. The main load-bearing structure of the new building was constructed using components of the neighbouring Gorlaeus laboratory's steel structure (Bouwakkoord Staal, 2022).

Figure 9: Reused structural steel elements in Biopartner 5 (author)

The character and background of the previous construction are therefore carried through to the current one. The "new" steel structure is also designed and constructed in a way that will allow for its future deconstruction and possible reuse. Because of its unique scale and method of construction, Biopartner 5 is a potential illustration of extensive reuse in buildings and a paradigm for creating Paris Proof buildings (Bouwakkoord Staal, 2022).

General Project Information

Biopartner 5 is the first energy-neutral laboratory building in the Netherlands. The university's Gorlaeus high-rise building, a 10-story steel structure that was dismantled after 50 years of service, served as the source of steel for the main construction. To use the steel as a donor skeleton for the new building, it was dismantled, transported 750 meters, treated onsite, and then reconstructed. Biopartner 5 is an example of the potential for large-scale reuse in construction because of its distinctive scale and working method (Lissenberg, 2020).

With 90 to 95 per cent of the steel used in the new building recovered from the donor structure, the building made it possible for significant steel reuse. The donor building was meticulously dismantled and was barely 750 meters distant from the new building's placement. The new structure is claimed to have used a total of 165,000 kg of reclaimed steel (*BuildingLife Case: Biopartner 5 - Dutch Green Building Council*, 2021; Redactie Bouwwereld, 2020). The new building's design was also created with the idea of utilizing it again, creating a doubly circular building. The new building is the first building in the Netherlands that complies with the Paris Climate Agreement and has decreased CO_2 emissions by 40%. The Paris Climate Agreement will become the paradigm for buildings, requiring the realization of structures with CO_2 budgets (Redactie Bouwwereld, 2020).

Project Details

- Location: Verlengde Wassenaarseweg, Oegstgeest
- Size: 6,200 m2 GFA
- Completion: February 2021
- Construction start: December 2019
- Design start: December 2018
- Assignment: Biopartner Center Leiden
- Architecture: Popma ter Steege Architecten
- Construction & Structural design: IMd Consulting Engineers
- Advice on installation technology, building physics and sustainability: Deerns
- Advice on construction costs: IGG bouweconomie
- Project management: Stone 22
- Landscape design: Lodewijk Baljon Landscape architects
- Main execution: De Vries en Verburg
- Dismantling work: Beelen Next
- Steel construction: Vic Obdam Staalbouw

5.2 Major drivers

The main drivers or business cases for the project were space and facilities. The space is the office spaces and lab spaces, and the facilities are those users of the building requirements. There were 3 principles reasons for developing the Biopartner 5 project. The first is that the Biopartner needs the space to fulfil their needs and help the start-ups to flourish. The second reason is being one of the major drivers is to create movement, development and to create activity in the area. The third reason is the personal ambition to make something monumental and provide an identity to the Bioscience park and the Oegstgeest area (Interview 2).

Paris Proof

The PTSA architects used the design process as an opportunity to explore the meaning of circularity in modern construction methods. According to market research, rational thinking and design principles were used to look at how the environmental impact could be minimized for each building component.

These ideas included leaving out what can be left out, using secondary materials when possible or available, and using biobased materials when possible. Afterwards, NIBE calculated that in this way the CO2 emissions of the building were reduced to such an extent that the building can be called Paris Proof (STUDiO iBiZZ, n.d.).

Figure 10: Construction of Biopartner 5 (retrieved from Popma ter Steege Architecten, 2021)

Double circular

Biopartner 5's connections were created using the little amount of welding feasible, preserving the goal of creating a demountable structure. Korthagen (IMd): “This not only creates an unexpected cycle for the Gorlaeus high rise but also prepares for the following cycle. The lab building can also be taken apart and rebuilt again. So doubly circular!” (Redactie Bouwwereld, 2020).

Complete CO2 impact calculated

The complete CO2 impact of materials and energy consumption has been calculated by the sustainability agency NIBE. It turns out that the total CO2 impact is 248 kg CO2/m2 (Dutch Green Building Council, 2021).

Limit environmental burden

The best, most practical option for reducing the environmental impact of construction was carefully considered for each building component. This construction technique produced a structure with CO2 emissions that are 40% lower than the typical current building practice. The declared sustainability aim led to an excellent environmental performance in addition to a lot of engagement from other partners who viewed the project as a chance to build their circular ambitions (Dutch Green Building Council, 2021).

Budget

The budget of the project was estimated based on a traditional project with all new steel and all new materials. The initial budget allocated for the project was roughly around 19.5 million euros. The balance or split-up of the project cost components changed because the project has shifted its ambition toward reusing building components. Therefore, the cost of materials was lower than estimated when compared to traditional projects. However, the drawings had to undergo changes and mostly had to be redone. Redoing the design costed extra money and incurred more time as well. It was notified that the marginal cost difference between the steel prices of new and scrap steel made the project more economically feasible and viable to achieve (Interview 2).

5.3 Strategies Adopted

The section addresses the circular and design strategies adopted in the project.

5.3.1 Circular Strategy

The designed trajectory was an exploration of the potential importance of circularity in existing building techniques for the project's architects. This search yielded a commercial, 7,000-square-meter laboratory building with large-scale use of radical construction materials. The design process aimed to look at how each building element's environmental effect may be reduced based on market data, common sense, and, above all, design concepts (Bekkering et al., n.d.).

During the design phase, a plan was presented to scout for and acquire possibly reusable materials. At the time, it was not anticipated that this aim would lead to the acquisition of the whole primary supporting structure, which was composed of recoverable steel. Following that, The Netherlands Institute of Building Biology and Ecology (NIBE) assessed that the building's CO2 emissions were lowered to below the new DGBC Paris-Proof standard (Bekkering et al., n.d.).

5.3.2 Design Strategy

The selected design strategy in this project is to use the recovered existing stock materials as a catalogue for the design of the new building. The available materials were able to be recovered from the identified Gorlaeus building. The limitation of designing around the identified available steel elements gave the freedom to reflect on ways to best apply materials and, conversely, on identifying what is required to achieve the best possible building.

Figure 11: Gorlaeus building – Donor building (author)

Designing with available materials

Korthagen (IMd):” I foresee that in the future we will no longer talk about new construction versus reuse. But about construction where you reuse as much as possible. And that is most achievable when materials are harvested nearby. Go locally and see what is possible. What's in the area? And adjust your design process accordingly, by designing based on the available materials.” (Redactie Bouwwereld, 2020).

Donor skeleton

The excellent environmental performance is largely attributable to the project team's reuse of structural steel elements demolished from a neighbouring university building. The fifty-year-old hot-dip galvanized steel has been used to construct a new, demountable main supporting structure as seen in Figure 11. The majority of the recovered materials were transported and fabricated on-site at the new-building location (750 meters away from the donor building). A fire-resistant coating has been applied to the steel to keep it exposed (Bekkering et al., n.d.).

5.4 Interviewee's perspective

Several project actors involved in the Biopartner 5 project have been interviewed to gather data and understand the practical approach adopted to mitigate the challenges identified through literature review and exploratory interviews.

Client's perspectives and ambition

The client's primary goal was to create an energy-neutral structure. The major drivers of the project were functionality and space for the users, and the client approached the architects to develop the design based on their business case. The designers created both preliminary and detailed designs following the objectives. At that point, the architects learned that a 50-year-old, 10-storied structure was being torn down close to the project site. They saw this as an opportunity to reuse steel in the new structure. The client has been informed of this and has consented to move forward, acknowledging that the finalised design would need to undergo several significant adjustments (Interview 2).

Figure 12: Reuse of different materials in the building (author)

Preliminary scope

"Reuse has a tremendously positive influence on the environmental impact of construction. As an architect, we like to work with meaningful materials. So, in theory, it fits together nicely. However, the practice of serious reuse in construction is still in its infancy. The trick is, therefore, to find demolition projects yourself, see the opportunities and come up with solutions for reuse. It seemed logical to start searching as close as possible to the construction site. Yet we had almost finished the final design when we discovered our donor skeleton." (Josse Popma, PTSA) (Lissenberg, 2020)

5.5 Lessons learned from the project

Based on the input from the project actors, several lessons learned were derived. The project was evaluated based on the design and construction phase (Terwel et al., 2021; Interviews):

- Extended consideration should be given to determine what components of the new building could be constructed from pre-existing components and what components require the use of new materials should be carefully considered.

- Reuse should not be restricted to only elements but, if practical, should also include components. Because T-frames were reused in Biopartner 5, fewer steps were required to establish connections. However, relocating these connected components was more difficult.

- A testing methodology must be developed to identify attributes and usability after it is determined that donor elements can be implemented. To be able to calculate the permissible stresses, it is crucial to choose the appropriate number of samples. To help with this choice, the existing structure may need to be recalculated. Determining the composition and conservation of the current steel is also necessary. Galvanizing steel, for instance, lessens the likelihood of welding and the need for fireproof paint. It is also necessary to know if Chrome 6 paint is applied.

- If the origin of the steel is unknown, execution of the donor material into the design may be challenging.

- Dismantling an old structure to reuse its elements or components differs greatly from demolishing it. Between engineers and demolition contractors, communication and instruction regarding potential and requirements are crucial.

- Defining the permissible deviations and identifying the tools available to deal with variations in size and shape. Additionally, since not all constituents meet the criteria, a surplus of donor material is required.

- All building partners must be dedicated for the project to succeed. Numerous difficulties were encountered throughout the design and construction that frequently required more time to resolve than in conventional projects. This necessitates strong cooperation and dedication from the different parties involved during design, dismantling, and construction.

5.6 Project Process

The project progress of the Biopartner 5 construction was organised in different stages with extended collaboration with different actors and overlap of progress with the demolition of a donor building called Gorlaeus.

Considering the construction of Biopartner 5, the client had an initial ambition of developing an energy-neutral building using virgin materials. The client approached the architects and other relevant actors required for the project. They developed the business case and project development plan accordingly. The architects developed the initial and detailed design for the building according to the client's demands and the required functionality of the building. It is then, soon after the development of the detailed design, the architects found the Gorlaeus building was preparing for demolition of the structure. The donor building was located within the proximity of the construction site. The architects approached the client and notified this opportunity regarding the possibility of reusing structural steel elements in the building. The client was positive about exploring this possibility and approached the project leader and demolition contractor of the demolition project.

Meanwhile, the Gorlaeus building was in the phase of asbestos removal for almost a year. The demolition contractor was further added to the project team and had extensive collaboration regarding the demolition process and construction of the building. During this stage, the visual inspection and preliminary testing of the materials were conducted. The materials were found viable for reuse in the building. The structural design was developed during this stage. The structural designers communicated the protocol and guidelines to the demolition contractor regarding the meticulous recovery of materials with the ambition of reusing them. The demolition contractors adopted several deconstruction methods with a focus on minimised deformation of the steel elements making it possible for reuse with limited repairs. After the recovery, the materials were stored carefully on-site and were further transported to the new building construction site which was only 750m away from the demolition site.

After the materials are transported to the project site, the removal of coating and required repairs to correct any kind of deformations were conducted by the steel contractor according to the structural design. The recovered and repaired structural steel elements were erected on the new building to construct the Biopartner 5 building. The building was able to replace almost 90% of the total elements in the building with the recovered structural steel elements. An illustration of the project's progress is depicted in Figure 13 below:

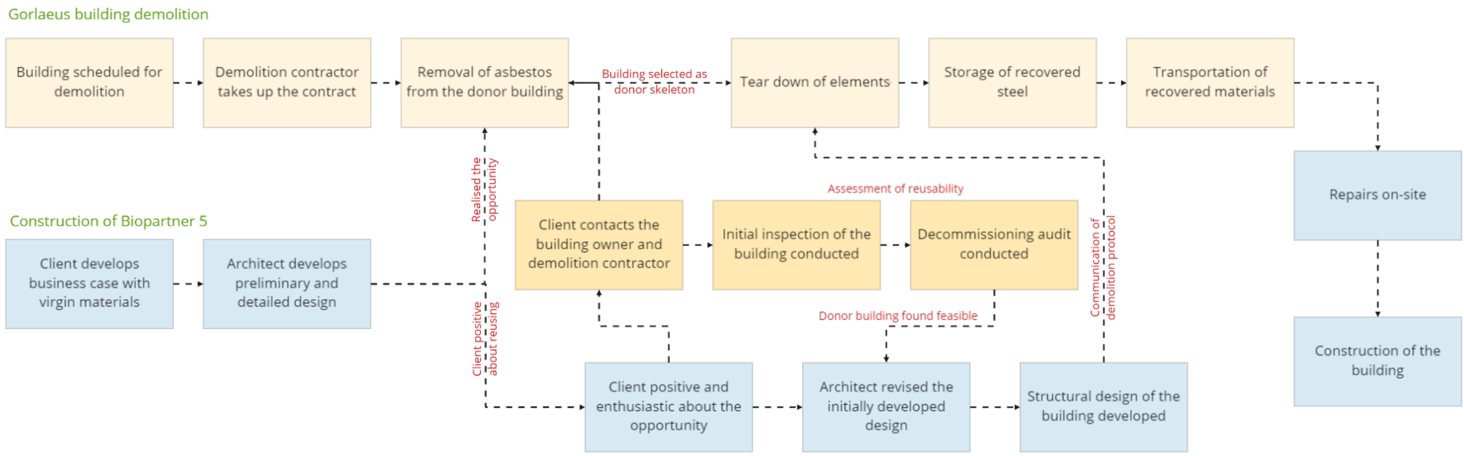

Figure 13: Project progress of Biopartner 5 construction and Gorlaeus building demolition (author)

5.7 Discussions and Findings

Reusing structural steel components was initially not a goal of the project, and the design was created to employ virgin materials. Despite the detailed design being developed, the architects found a donor building close to the construction site. The architects had to make significant design revisions to include the identified elements from the donor building since they lacked ambition throughout the planning process. This resulted in incurring additional time and cost associated with altering the developed design due to extended testing requirements.

Considering the project, several fortunate factors in favour of the project were critical to the successful implementation of the project, especially the availability of the materials at the right time within the proximity of the construction site and the willingness of the client and project actors involved. However, the project initially has not taken into account the other possibilities and opportunities available in the market including steel stockists, demolition contractors, digital inventory companies and donor building. Due to a lack of ambition in the initiation phases of the project and the opportunities to reuse structural steel were merely introduced into the project and design when a donor building was identified in proximity. The project did not take into account any of the businesses established to facilitate the reuse of building components such as Copper 8 or New Horizon. This is a departure from what many people consider a standard practice while establishing the ambition to reuse structural steel elements.

Furthermore, during the initiation phase, there was very limited inclusion and collaboration between the relevant actors including demolition contractors, architects, designers and project managers. This resulted in several challenges in the initiation phase. For instance, there were no protocols the demolition contractors could follow and there were limited communication between designers and demolition contractor as well. Due to this, in the initial stages of the demolition process, the extraction resulted in deformations on materials while cutting and stacking the steel elements. Thus it could be concluded that extensive collaboration and definition of developing a protocol for the demolition contractor should be established according to the design requirements for effective and efficient recovery of materials.

The method and the project team must be flexible enough to handle the unknowns associated with the extraction, acquisition, and use of secondary materials. Among other things, actual quality, quantity, and executed specifications are not always as planned and documented. The designers must be committed throughout the process and might need to be involved in updating the design until the final stages of implementation, and the development team must be able to fix challenges (Bekkering et al., n.d.). Furthermore, the logistics entailed in the reuse initiatives are a well-known bottleneck. Materials that are easily accessible may not be useful, and materials that are wanted may not always be accessible at the appropriate time. Reusing construction materials as a building block or as a source of new goods is essential to achieving this aim. (Bekkering et al., n.d.).

The project planning had to undergo several challenges and drastic shifts in ambition. However, several critical factors led to the successful implementation of the project. The critical success factors are as follows:

Ambition and enthusiasm

The major contribution of the project team toward the success of the project is their strong ambition and enthusiasm. The client initially had the ambition of a fully energy-neutral building and later, despite the several changes the project had to incur to incorporate the reuse of structural steel elements, the opportunity was further exploited. The several actors involved in the project, like the demolition contractor, designers, project management team, and contractors, all shared an extensive enthusiasm to steer the project.

Availability of the materials

The availability of the materials was realised right on time, as the project team acknowledged. Even though the detailed design was developed for the initially planned building, soon after locating the availability of materials, the design was altered accordingly. By locating the materials, the designers were able to design based on the identified materials, which enhanced the maximum reusability of materials.

The proximity of available materials

It has been identified from several works of literature that the transportation of materials over a longer distance is the main barrier to achieving the reuse of structural steel elements. The donor skeleton building was located in a nearby location, just around 750m away from the site on which the new building is being realised. This drastically reduced the cost of transportation challenges and costs associated with the long-distance transportation of heavy materials. This helped the project save most of the costs associated with them and reduce the CO_2 associated with transportation.

Engagement of a demolition contractor

In the reuse project, unlike traditional projects, the demolition contractor plays an important role in the project team. Often, in most projects, the demolition contractor is not involved from the start of the project. In this project, the demolition contractor was involved during the design phase itself. This helped the project team to get a better understanding of the demolition process and ensure the undisrupted supply of materials from the demolition site.

Collaboration between actors

The project team was mostly involved from the early stages of the project and was selected during the initial project business case of developing energy-neutral. This helped the sharing of information and developments in the identification of the opportunity and decision-making process about incorporating the reuse of structural steel elements to be communicated to the whole project team. The assessment of the uncertainties and competencies required by the contractors who take up the work was determined during this collaboration process. The tendering of the steel contractors was thereby meticulously and effectively carried out.

Storage space

In most of the projects which incorporate the reuse of recovered structural steel elements, the availability of space to store the recovered materials is identified as a challenge. The project had ample space to store the materials after recovery from the donor building. The materials were initially recovered and stored at the demolition site and then they were transported to the new site for further adjustments to precisely fit the design.

Characteristics of the steel identified

The identified steel from the building had several properties that were positive to be reused in the new structure. After initial inspection and testing, it was identified that the steel didn't contain chrome 6 in the paint. This was the beneficiary for reprocessing the steel to meet the design requirements. Furthermore, the standard span of steel identified in the donor building mostly matched the design developed for the new building. This characteristic of the steel enabled minimal adjustments on-site to fit the design.

Demolition ahead of Execution

As mentioned earlier, the opportunity to reuse or the availability of a building eligible for demolition was identified later in the initial process of the project. The demolition project was undergoing the removal of asbestos from the structure. It was during the final stages of the asbestos removal process, that the designers approached the demolition contractor. Parallelly while the design was altered, the demolition was progressing according to o the instructions of the project team. This helped the demolition company to be well ahead of the execution of the project.

Visual Testing and Inspection

The reusability of the steel from the donor building was initially assessed through visual inspection and preliminary Non-Destructive Testing (NDT) methods. The judgements made from initial testing were used to further proceed with the decision to design accordingly to fit the steel from the donor skeleton into the design. Subsequently the detailed test results confirmed the same and affirmed the steel could be eligible for further reuse This prompted the designers to think further to design for further deconstruction and reuse.

Minimal stocking of steel

As the availability of the steel from the donor building and the time frame of the execution in the new structure were mostly matching, this could overcome the barrier of stocking the steel for a longer duration. Therefore, the recovered materials, without many stockings were repaired on-site and used in the new structure.

Careful dismantling

The steel was recovered from the building by separating the components from the concrete. It was done with the aid of the saw-cutting method. During this process, there were deformations happening to the steel elements. Soon, specific instructions were given to the demolition contractors and careful recovery protocols were adopted. Furthermore, while stacking the steel on-site, initially the steel elements were dropped from the site. This caused several dents in the material which also had to undergo repair. It was identified from (Interview 6) that developing better communication and guidelines given to demolition contractors enabled meticulous recovery of materials, which eventually saved lots of repairing time and cost.

Meticulous storage and transportation

The storage and transportation of steel elements are important factors that determine the reusability of the recovered materials. The storage of materials should be safely protected from the exposed environment and stacking of the materials. It is often seen that steel elements can undergo several deformations during the storage and transportation of the materials. If the materials face extensive deformations, the recovered materials lose their feasibility to be reusable in the new structure, as they may become beyond repair. Therefore, the limited repairs the steel elements must undergo before reuse determine the successful and feasible reuse. Clear communication and following several protocols and guidelines provided by structural designers and steel contractors helped demolition contractors achieve the same.

Chapter 6: Ambidextrous Management Approach

6.1 Introduction

Consider the situation where you had to do work using both hands; sometimes the left, sometimes the right and other times both of them simultaneously. What if everyone in an organisation or a project faces the same challenge? Being able to use both hands adroitly is known as ambidexterity. This phenomenon was applied to companies facing tensions who had to deal with contradicting business models and is applied in the organisation's top management (Antonio Nieto-Rodriguez, 2014). However, it was seen from literature reviews that limited research and application of the same approach were done in the construction industry. The approach can be adopted in strategic management practices, operational management and innovation management. In 1976, the first application of the ambidextrous management approach from the operation point of view was done on the contradicting tension of flexibility versus efficiency (Antonio Nieto-Rodriguez, 2014).

Du & Chen (2018) state that organisations confront dual demands of exploration and exploitation, particularly in today's competitive market environment by a trend of volatility, uncertainty, complexity and ambiguity (VUCA). It is a fundamental axiom that organisational forms must match their environment to survive and prosper. As business contexts become increasingly complex and pose paradoxical demands to maintain effective exchange conditions with their environments, organizational structures must become agile and flexible (Andersen et al., 2021). With the global environment becoming more dynamic, firms are faced with discontinuity and rapid changes caused by technological development, disruptive innovations, intense global competition, alterations in governmental regulations and shifts in industry structure which makes the organisations and project teams address bedevilling challenges (Du & Chen, 2018). This was further piqued in the construction industry with the introduction of sustainability and circularity along with the client's desires in achieving business goals and profit generation alongside. From a strategic perspective, achieving long-term success requires that firms possess not only the operational capabilities and competencies to compete in existing markets (O'Reilly & Tushman, 2008). Whereas, ambidexterity has been proposed as an effective way by which the ability to recombine and reconfigure assets and organisational structures can be enhanced to understand and adapt to changing technological and market conditions (O'Reilly & Tushman, 2011).

Ambidexterity urges project members to be able to accurately sense changes in their competitive environment, including potential shifts in technology, competition, customers, market conditions and regulations. Following up, they must be able to act on these opportunities and threats; to be able to seize them by reconfiguring both tangible and intangible assets to meet new challenges. As a dynamic capability, ambidexterity embodies a complex set of routines including decentralization, differentiation, targeted integration, and the ability of senior leadership to orchestrate the complex trade-offs that the simultaneous pursuit of exploration and exploitation requires. It is also acknowledged that a common vision and values are necessary to promote a common identity across explore and exploit units. It is also given due importance to enhance the presence of separately aligned approaches for the explore and exploit units coupled with targeted integration to ensure that common resources are leveraged across units (O'Reilly & Tushman, 2011).

6.2 Exploration and Exploitation

Splitting and integrating the way organisations develop is a key characteristic of practising ambidexterity (Klonek et al., 2020). The ambidextrous approach matches entrepreneurship by extending innovation from a demand-side perspective, where the core of product/market exploration/exploitation activities could be expanded into customer value creation (Andersen et al., 2021). It enhances the ability to seize opportunities through the orchestration and integration of existing assets to overcome inertia and path dependency (O'Reilly & Tushman, 2011). Ambidexterity is a balance between explorations and exploitations (Antonio Nieto-Rodriguez, 2014). As it exists in two divergent dimensions, both dimensions are explained by O'Reilly & Tushman (2008):

- Exploitation is in terms of refinement, efficiency, and stability, that is intended to respond to current environmental conditions by involving the use of explicit knowledge bases.
- Exploration is in terms of search, risk-taking, experimentation, flexibility, and innovation, that is intended to respond to possible environmental conditions by involving the use of tacit knowledge bases.

The approach can be defined as simultaneous actions undertaken by organisations to address two heterogeneous situations simultaneously, to explore and exploit the possible opportunities (Du & Chen, 2018). O'Reilly & Tushman (2008) state that ambidexterity involves the capability to both exploit existing knowledge, assets, and customers/markets for short-term profits and explore new knowledge, technologies, and customers/markets to enhance long-term development. Even though Szentes & Eriksson (2016) suggest that the actors in the construction industry are aware that both long-term innovation (exploration) and short-term efficiency (exploitation) are of crucial importance for innovativeness, they face difficulties with achieving both exploitation and exploration practices. The complexity in achievability is due to the project's discontinuous nature, decentralization, time pressure, and short-term focus (Eriksson & Szentes, 2016; Dekker, 2020). However, today the heightened importance to achieve this trait is at its peak due to fast-changing market conditions. Thus, the construction industry can no longer extend its adaptive approach to changing requirements (Innovation in Construction Projects, 2022).

Ambidexterity takes account of the relevant conditions of market volatility and uncertainty as it helps companies manage strategic agility by being both aligned to the existing environment and adaptive to possible turbulence in the industry setting. Organizations have had to adjust to unprecedented complexity and ambiguity as a result of the pandemic's disruptions to the global economy and conventional modes of operation (Olawale, 2022). Organisations can be identified as a specific set of individual actors coming together to deal with specific changes. Projects help organisations achieve these goals and objectives. This is certainly not the time to revert to the old practices when businesses waste their resources on endeavours brought on by inadequate managerial oversight (Olawale, 2022). Projects that are successful and well-designed aid organizations in avoiding subpar performance and establishing the proper culture and behaviours. Thus it can be acknowledged that efficient extension of organisation practices can yield better results to meet the organisational objectives. Therefore, even though ambidexterity has generally been identified as an organisational management approach can be applied to a project setting. As mentioned earlier, looking back to history, the application of ambidexterity can be traced to operational practices.

Failure to manage the above-mentioned tensions can result in a success trap- that is too much exploitation at the expense of exploration, which is adopting the safest option of staying with the exploitation of virgin steel elements in construction. Contrastingly, too much exploration at the expense of exploitation, which is looking for opportunities to reuse steel, however not exploiting the opportunities available in the market due to lack of ambition and willingness of the actors involved can result in a failure trap. Extending one's focus on either of the two is fatal to the success of the project and the organisation's growth (Du & Chen, 2018). This approach encourages managers to embrace or live with paradoxes and find a means of accepting them simultaneously. The approach could assist the project team to integrate the cognitive pattern or the decision-making approach of top management into the project level (Andersen et al., 2021). Considering the challenges in managing ambidexterity, studies have suggested that organizational ambidexterity is associated with longer survival, better financial performance and improved learning and innovation. Thus, although ambidexterity is a difficult managerial challenge when executed in the appropriate strategic contexts, these complex designs are associated with sustained competitive advantages (Du & Chen, 2018).

6.3 Exploration vs Exploitation in the reuse of structural steel elements

The construction industry is one of the world's oldest industries and they are regarded as conservative, due to their obtuse approach to adapting and changing (Why the Construction Industry Should Embrace Digitisation, 2021; Hart, 2022). This is mainly due to the liabilities associated with the practice of designing and constructing structures that are complex in nature and the actors involved in such projects need to be extremely cautious about making new decisions. Over years, we have witnessed several changes or technological advancements introduced into the industry. However, it takes a while to get all the associated practices like materials, testing and quality, design and so on to get standardised (Alizadeh, 2018).

Even today, most of the practices adopted in the construction industry are conventional. However, recently it was realised that the construction business cannot sustain the way it proceeds due to extensive environmental impact and due prominence given to sustainability and circularity (Call for Action: Seizing the Decarbonization Opportunity in Construction, 2022). Also, considering the lack of raw materials for the production of virgin materials for conventional processes is diminished and becoming not a feasible option (Tyan, 2022). Thus, as discussed earlier, the possibilities of reusing structural steel elements in construction are explored further through this research. However, to achieve this trait, the involved parties and organisation must be more adaptable and flexible in the streamlined process. As mentioned above, being conservative in nature, most of the practices adopted in the industry follow a standardised procedure and adopt the safest option with minimal risk (Alizadeh, 2018). Being said that, the market conditions and associated requirements to adhere to the changing regulations are capricious. Thus the focus of the industry was mostly on the exploitation of the possible opportunities available in the market. However, today the market conditions demand exploration to enable flexibility from the grass-root level to be adaptable to these changing needs.

In terms of structural steel reuse, as discussed earlier, there are several hindering factors like lack of availability of materials, traceability-related issues and lack of integrated supply chain leading to the paradoxical tension (Densley Tingley et al., 2017). It was acknowledged from several exploratory interviews that lack of traceability is the major challenge the project team faces in the attempts to reuse structural steel elements. However, currently, options adopted for tracing the available materials are stringent and no due importance is given to exploration activities. Often the project team settles on exploring the availability of materials from a donor building in the proximity or materials available in the database of a digital inventory company, which limits the possibilities to achieve the potential of reusing structural steel elements.

The design-acquire paradoxical tension aligns more towards the operational and process side of a project. Ambidexterity from a process perspective is the discovery, evaluation, and exploitation of opportunities (Bouzdine-Chameeva et al., 2013). The literature review recognises that ambidexterity requires some mechanisms of balancing or separation to reconcile the tensions between performing exploration and exploitation activities. While the firms have the potential to pursue exploration and exploitation concurrently by allocating these activities to different business units. It is acknowledged that exploitation often leads to early success, reinforcing exploitation but crowding out the risk-taking and broad search needed for exploration. Similarly, an exploration often leads to failure associated with new ideas, as it pushes aside attention to reliability and efficiency to failure associated with new ideas. Providing flexibility in actions and practices is a prime factor in developing an ambidextrous management approach in operations (Klonek et al., 2020).

To understand the comprehensive nature of ambidexterity and its applicability to a process to facilitate the exploration and exploitation simultaneously or indeed balancing both the poles, the design-acquire paradox of reusing structural steel elements is further studied based on a comprehensive model of Andriopoulos & Lewis (2009), which adopt the integration and differentiation tactics to help manage the interwoven uncertainties.

The underlying basis of the existence of the paradox is that they exist interrelated yet contradictory in nature. Thus, managing a paradox does not imply resolution or eliminating the paradox. It is also acknowledged that effective management leverages paradox in a creative way that captures both the paradoxical poles. In Table 5 below, the integration and differentiation approach is adopted to manage the paradox. Integration efforts stress the interdependence between seeming opposites and enable coordination, which encourages actors to find means of linking contradictions, thereby leveraging their synergies. However, in contrast, differentiation focuses efforts on the exploitative or exploratory qualities of the paradox, where it focuses on splitting the paradox to encourage actors to focus on each pole to accentuate its distinct value (Andriopoulos & Lewis, 2009). The shortlisted uncertainties that trigger the design-acquire paradox are the ambition to reuse structural steel elements, the availability of materials in the market and the reusability of the available or recovered materials. A wider picture of the same uncertainties is depicted in Table 5 below, where the first-order concepts explain the associated criticalities that need to be addressed which are linked to the second-order themes and further connect them to the aggregate dimensions.

Table 5: Underlying uncertainties within the design-acquire paradox

<table>
<tr><th>First order concepts</th><th>Second order themes</th><th>Aggregate dimensions</th></tr>
<tr><td>- Ensure achieving the key requirements of clients
- Focus on the key functionality of the building and budget</td><td>Willingness</td><td rowspan="2">Ambition</td></tr>
<tr><td>- Involve and encourage key actors early in the process
- Clearly defining and allocating key roles and responsibilities to actors</td><td>Competency</td></tr>
</table>

- Coordinate sourcing of materials from different sources - Develop flexible preliminary design to maintain the functionality requirements and probing investigation	Explore	Material availability
- Prob technological advancement in platforms and tools - Extend knowledge base and long-term collaboration	Exploit	
- Meticulous deconstruction of materials improves the applicability - Proximity and specification of materials impact the feasibility of the reuse of steel	External factors	Reusability
- Enthusiasm and flexibility of the client and actors involved - Business case and functionality requirements of the client	Internal factors	

In Table 6 below, the corresponding management approach to deal with the identified underlying uncertainties within the design-acquire paradox is stated. As mentioned earlier, the ambidextrous management approach is the balance between different poles of a paradox. Based on the identified challenges, a simultaneous process of balancing between integration and differentiation of practices is adopted.

Table 6: Corresponding management approach against the identified uncertainties

First order concepts	Second order themes	Aggregate dimensions	Corresponding paradox
Develop the business case by collaborating with key actors	Cultivate the enthusiasm of clients and actors	Integration	Ambition
Explore the commercial potential of reusing steel Exploit the competencies of actors and market conditions	Diversify project drivers	Differentiation	

Leverage synergies between designing and sourcing and adapt to emerging possibilities	Practice flexibility and adaptability	Integration	Material Availability
Begin by FFD to direct the sourcing activity adhering to functionality requirements Switch to MDD to alter the preliminary design based on available materials	Iterate design and sourcing procedure	Differentiation	
Analyse available archival data, test the quality of available materials, condition and specification of identified materials	Extensive feasibility check	Integration	Reusability
Segregate the locations in which recovered materials are not feasible Define the tolerance limit and material characteristics	Segregate critical points in the design and critical factors of material specification	Differentiation	

6.4 Development of Ambidextrous Process Tool

The process tool is developed by analysing the existing industrial practices adopted in reuse projects and by intervening in the conventional processes by following the principles of ambidexterity. The process tool can be used by anyone in the project team (parties involved in defining the need for the project) as a guiding tool that can support them in the process of reusing structural steel elements in the buildings. The tool is developed in such a way the project team could follow the processes in the tool to achieve specific expected outputs that can mitigate the design-acquire paradox. For successful implementation of the process tool to facilitate the reuse of structural steel elements, project actors should have specific competencies. Therefore, the expected key roles and responsibilities of the actors involved in such projects are also developed. The insights gathered from exploratory and case study-based interviews are used to ground the development of the process tool, defining the roles and responsibilities of the actors involved and the principles of the ambidextrous management approach. The development of the process tool is driven by the critical factors identified, integrated with the balancing simultaneous exploration and exploitation. These differentiating elements for the successful implementation of reusing structural steel elements are defined below in Table 7:

Table 7: Critical factors for successful realisation of reuse of structural steel projects

SL. No.	Critical factors	Description
1	Ambition and Enthusiasm	• The ambition to reuse structural steel elements should be defined at the initiation phase of the project. • During the development of the business case, the initial potential and feasibility of incorporating the reuse of steel should be established. • The actors involved in the project should have the enthusiasm to investigate the possibilities and develop the competencies required for the realisation of reuse.
2	Availability of materials	• Availability of materials that meet the specification. • Material availability should match the project execution timeline and delivery methods.
3	The proximity of available materials	• It is important to assess the proximity of the available materials which is critical to determining the financial feasibility (fuel prices are rising). • Also provides the option to ease down the process of transporting the materials on-site within a short time frame.
4	Engagement of demolition contractor	• Engagement of demolition contractor right from the initiation phase and during the development of the business case. • The decommissioning audit is conducted to determine the condition of the materials available in the building. • Assist the project team in locating and sourcing materials
5	Collaboration between actors	• Extensive collaboration between demolition contractors, architects and designers is important in determining the reusability of an available building. • Engagement of demolition contractors and structural designers to determine the protocols for the demolition and to monitor the quality of the recovered materials. • Structural engineers guide the contractors during the demolition process to minimise the deformation of the recovered materials as well as suggest best practices for the storage and transportation of materials.
6	Storage space	• The availability of sufficient storage at the demolition site or construction site is an advantage. • Storage warehouses can be rented and it is not financially feasible to store the recovered materials for more than a year.

		• The availability of storage space within the proximity of the construction and demolition site is also important.
7	Characteristics of the steel identified	• The identified steel should comply with the steel profiles and standards defined in the preliminary design and meet the functionality of the building. • The connection used in the elements is also important to be assessed (welding in the elements should be further tested to determine its quality).
8	Demolition ahead of the execution	• The demolition process has to undergo several initial preparation stages like removal of asbestos, decommissioning audit and cataloguing of the available materials. • It is important to plan the demolition process in such a way that the materials could be recovered before execution and minimal storage is required.
9	Visual Inspection and testing	• The preliminary visual inspection after identifying a potential donor building determines the reusability of the materials available. This helps in the determination of whether to conduct the decommissioning audit and material testing • If archival data is available, extensive testing requirements could be limited and help in a safer assumption that similar elements in the building exhibit similar quality.
10	Careful deconstruction	• A careful deconstruction process should be carried out to limit the deformations during the recovery of materials • Extensive deformations on elements can make them not feasible for reuse • Extraction or harvesting of the materials should comply with the span lengths in the design specifications
11	Meticulous storage and transportation	• It is determined that there is a high chance of deformations during the stacking of the elements during storage and transportation, which should be limited. • The extracted materials should be stored in a closed area without being exposed to changing environmental conditions

6.4.1 Insights gathered from different research methodologies

Literature review

During the review of the literature, it was identified that several publications and findings dealt with the concepts of circular economy and circularity in the built environment. In addition, some publications addressed the benefits and challenges of reusing structural steel elements in buildings. However, there was limited research being conducted on the identification of practical approaches to overcome the challenges identified or reference to the practical implementation of the reuse of structural steel elements in real-life case scenarios. Thus, gathering a holistic understanding of the current scenario and depicting a grounded conceptual knowledge was difficult. Therefore to gain a better understanding of the conventional approaches adopted in the industry in similar projects, several industry professionals were interviewed. From these interviews, the perspective and approaches of the industry professionals are defined which was further used to identify the feasibility of implementing particular steps in the process tool.

Case-study Interview

Biopartner 5 of Leiden Bioscience Park was identified and analysed as a case-study project which successfully incorporated large-scale reuse of structural steel elements in the Netherlands. The typical approaches adopted in the steel reuse project were analysed and it was identified that conventionally the projects extended the focus of identification of secondary materials only to available donor buildings. Considering the Biopartner 5 project, initially, the project team didn’t have the ambition to reuse steel or incorporate secondary materials into the building. However, later during the detailed design phase, the opportunity of incorporating secondary materials from a donor building was identified. This showcases the flexibility the project team adopted in the exploration and exploitation of available opportunities even in a later stage of the project.

Initially, the project proceeded with a Form-focused design where the preliminary design was developed and following which the detailed design was developed. Later when the opportunity of available materials from the Gorlaeus building (donor skeleton) was identified, the architects took a transition to a more Material Driven Design, with due consideration given to preserving the key functional requirements of the client. Nevertheless, several favourable factors supported the successful adoption of the reuse of steel in the project. For instance, the identification of a donor building in the proximity of the construction site that matched the floor-to-floor height specifications of the new structure. Even though the project was in the phase of development of the detailed design, the project team explored the available possibilities and opportunities to reuse secondary materials. Following this, when the opportunity was identified, exploitation of the same was performed by altering the developed design and redesigning the structure to maximise the potential to incorporate the reuse of steel. This can be linked to the ambidextrous management approach of incorporating the practices of exploration and exploitation and balancing or embracing different options simultaneously. Thus, it can be deduced that the principles of ambidexterity were matched with the adopted practises.

However, it should be acknowledged that there has been limited exploration of available opportunities in the market and exploitation was merely introduced when the opportunity was identified. Furthermore, the practice of ambidexterity was not really in the initial phases of the project, which resulted in the delayed and limited exploration of available opportunities. Which indeed resulted in delays in the finalisation of the design and incurred additional costs. Therefore, it is identified that a clear depiction of a feasible approach is required for the project teams to have a clear notion of how to approach the practice of reusing structural steel elements.

6.4.2 Ambidextrous Process Tool

Background Information

The Ambidextrous Process Tool is developed as a mitigation measure to the identified challenges of reusing structural steel elements gathered from the review of the literature and exploratory interviews that constitute the emergence of the design-acquire paradox.

As mentioned earlier, the ambition of the client and the willingness of project actors are important to identify and include the reuse of structural steel elements as an opportunity in a project, which is often lacking. Furthermore, there is a lack of traceability and a lack of materials available to reuse. These major barriers are often identified to have a crucial impact on the initial phases of the project. The process tool considered these barriers to reusing structural steel elements identified during the conceptual study phase and the factors that signify the existence of design-acquire paradoxical tension. Thus, the focus of the process tool is to mitigate these challenges to overcome the design-acquire paradoxical tension.

When analysing the current industrial practices adopted, it was identified that the projects are more focused on the exploitation of the market and extend the limited focus on the exploration of potential opportunities. However, to mitigate the paradoxical tension, balancing between exploration and exploitation is vital. Thus, the process tool focuses mainly on the front-end cycle, i.e. the design phase of the project where the paradoxical tension of whether to adopt a Material Driven Design or a Form-Focused Design is prevalent.

The case study analysis included desk research and case-study-based interviews. Mostly the projects and actors bound themselves to identify the availability of a donor building within the proximity of the building. Moreover, they restricted investing time and focus to identify materials from other possible sources, which often limited the possibility of improving the potential of reusing structural steel elements.

A flowchart showcasing the adopted industrial practices in the reuse project is portrayed to understand and illustrate the current industrial scenario. The developed flowchart is intended to investigate and interpret the underlying bottlenecks associated with existing processes and provide a resort based on an ambidextrous management approach. It was identified that the project actors indeed limited extending their focus on the exploration of different opportunities for sourcing materials from the market.

It was identified that the adopted approach matches the underlying principles of ambidexterity that is exploration and exploitation. However, this was practised only when the opportunity was identified and the approach was merely introduced into the detailed design development phase. This approach cannot be identified as a uniform resort to current market conditions or industrial scenarios in a nominal way, as the Biopartner 5 project had several favourable conditions that were critical to the success of the project. Therefore, analysing the current market and industrial conditions and existing procedures adopted in the industry, an intervention into the existing industrial practices with the principles of an ambidextrous management approach is performed.

The Ambidextrous Process Tool involves different layers to its development and understanding of the adopted approach. The section addresses the basic assumption made in the process of developing the tool and explanation of the approaches adopted in illustrating the Ambidextrous Process Tool.

Assumptions

In the development of the process tool, there are several assumptions made:

- The client already has the ambition to develop a sustainable building
- In the process of identification of potential opportunities to achieve circularity, the reuse of materials is identified as a feasible solution
- In a project setting, the architects lead the conversation concerning defining the design objectives by abiding by the client's functionality requirements
- Different projects have different objectives and characteristics like size, budget, collaboration and external factors. Therefore, it might not be equally feasible to follow the process tool.

Characteristics of the Ambidextrous Process Tool

Considering these identified characteristics, the Ambidextrous Process Tool encourages the project team to conduct an initial market study. The architects are acquainted with sourcing managers regarding the existing market conditions and potential availability of materials. The sourcing manager gathers an understanding of the history of reusing recovered steel elements, current sources from which materials could be available and the expected or forecasted availability of secondary steel in the market. These insights are provided to the architects involved in developing a preliminary design for the structure. They are identified as the key actors who will lead the discussions around defining the high-level design to meet the functional requirements of the client.

Prior to proceeding to the detailed design, the process tool advocates conducting an exploration of available opportunities in the market based on the preliminary design by diverging the exploratory views of the project team into a different direction for the identification and sourcing of materials. Based on the preliminary design, the sourcing manager predominantly and other actors explore the availability of secondary materials from different sources like donor buildings, materials from steel stockists, demolition contractors and steel contractors, and digital inventory companies in their database.

Intermittently the developed preliminary design is updated to fit in the maximum identified materials and to adhere to the client's functionality requirements. It is identified that during these initial stages of the process tool, the process and actors are more driven by the design or form-focused approach and later slightly make a gradual transition to material driven when the preliminary design is altered based on the identified materials. The results from the exploration phase are used to develop an inventory of identified available materials.

The preliminary design and the developed inventory are compared and analysed carefully to maximise the incorporation of identified secondary materials into the design. The detailed design is developed by incorporating the identified secondary materials into the preliminary design and by developing a more concrete specification. This showcases the exploitation of the opportunities identified during the exploration phase.

Further, assuming the execution of the project might generally take almost a year after the detailed design is developed opens the room for further exploration. In this phase, the market is aimed to be aligned with the detailed design and therefore, the detailed design is not altered further. However, if more materials become available and if they meet the design requirements and tolerance limits, they can be incorporated into the design. This indicates a further shift towards a more Form-Focused Design.

The approach of developing the Ambidextrous Process Tool depicts that it is developed by considering the balance between exploration and exploitation, Form-Focused Design and Material Driven Design, and Integration and Differentiation in the process of converging and diverging when required.

6.5 Ambidexterity in Process Tool

The process tool is developed following and incorporating the underlying principles of the ambidextrous management approach and considers the balancing of conflicting and contradictory demands like Material driven and Form-focused design, exploration and exploitation, and integration and differentiation.

6.5.1 The balance between Material Driven Design (MDD) and Form-Focused Design (FFD)

As discussed earlier in the research, the emergence and existence of the design-acquire paradox are due to the contradictory tension and pressure the project team faces to make a trade-off between the identified options of Material driven and Form focused design. However, in the process tool, the initial processes are mostly driven by the form-focused design during the preliminary design and later sightly takes a simultaneous approach of going back and forth by exploring the materials based on the preliminary design and also altering the design based on the availability of materials in the design. Further in the process, a transition is witnessed when the inventory of available materials is developed and is used to develop the detailed design based on the preliminary design. Thus, it could be deduced that the process tool gives indispensable consideration to the ambidextrous management approach to simultaneously balance both options.

6.5.2 The balance between exploration and exploitation

The process tool initiates with the establishment of the ambition of the client and the willingness of the actors to incorporate the reuse of structural steel elements. During this phase, a market analysis is conducted by the sourcing manager to determine the market feasibility and understand the market conditions. This encourages the project teams to focus on the exploration of available opportunities and knowledge and not merely exploit the available knowledge and opportunities. Further, the sourcing manager will be guiding and making them acquainted with a peripheral view of the existing market current conditions and the potential of reusing structural steel elements. This helps the architects to exploit the acquainted information and intellectual knowledge to develop a preliminary design that meets the standards and client's requirements.

6.5.3 The balance between integration and differentiation

The initial phase starts with market analysis and feasibility study. The results of the same are integrated with the architect's expertise to develop the preliminary design. Further, as the project furthers, during the exploration of available materials from the market, the sourcing options are differentiated and diversified into different opportunities. Later, over the process, when the materials and their availability in the market are traced and determined, they are integrated into an inventory of materials converging back to a streamlined process with the tool.

Analysing these key characteristics of the process tool establishes how well the tool is aligned with the principles of the ambidextrous management approach. Moreover, the tool is developed with an output-oriented methodology where the barriers identified in reusing structural steel elements and those which stimulate the paradoxical tension are aimed to be mitigated by creating favourable conditions that reduce the complexity for the project actors.

6.6 Expected Outputs within the process tool to mitigate the design-acquire paradox

In the process flowchart to assist the project team through the process of reusing structural steel elements, the initial process involved in developing the preliminary design. This primary step could help the project team steer locating the materials based on the requirements and the preliminary design providing basic information regarding the material. The expected output at the end of the process is to estimate the quantity of steel required and its specification. In this phase, a more flexible requirement of materials with a wider tolerance limit is specified to further explore the market with a more specific agenda.

One of the major challenging factors that lead to the existence of the design-acquire paradox and hinder the successful realisation of the reuse of structural steel elements is the limited traceability and availability of materials in the market. Thus, to extend the possibilities of locating and sourcing the materials, more focus on the exploration of available opportunities in the existing market is emphasised. The expected output of this phase in the process tool is the exploration of different opportunities from the market and improve the potential availability of materials.

Furthermore, following up on the exploration of available materials can aid in improving the possibilities of meeting the expected output of developing an inventory of available stock eligible for reuse. The exploration of available materials and development of an inventory of available materials is steered through different sources like donor buildings, demolition contractors, steel stockists, steel contractors and digital inventories. The possibilities of locating and sourcing materials are further extended and explored during this phase.

Later based on the expected output at the end of this phase, the developed inventory of available materials is used to steer the development of the detailed design. It is acknowledged that it is still possible that the project team fails to locate any available materials eligible for reuse in the project timeline. In a similar scenario, the detailed design is developed with the option of using virgin material. However, it cannot be underlined that materials eligible for reuse or available materials will not come up in the market during the detailed design phase or soon after that. Therefore, the architects and structural engineers could extend their consideration for this possibility and develop a more flexible design to incorporate reused materials in non-critical points in the design without extensive alterations.

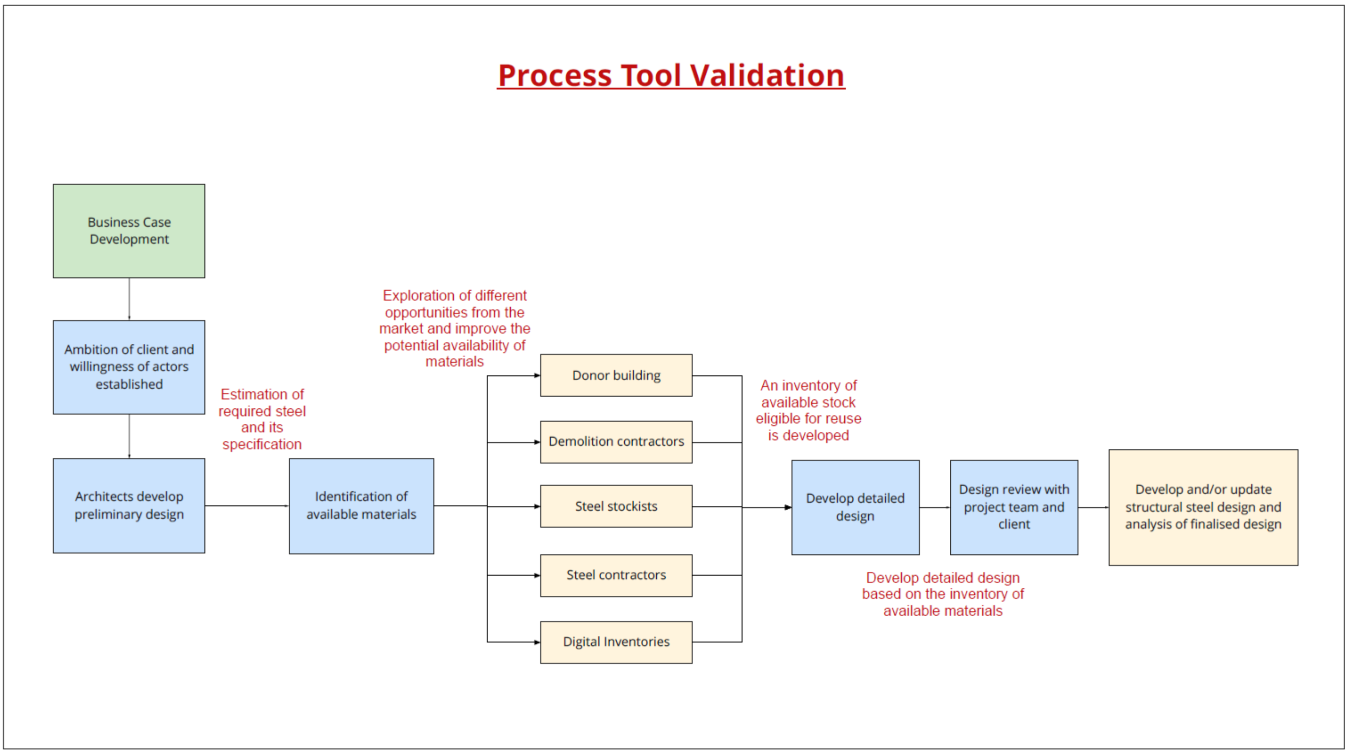

Figure 14: Preliminary results-Process Tool

6.7 Key roles and responsibilities

The facilitation and incorporation of the reuse of structural steel elements in buildings demand extensive involvement of a set of actors who could play specific roles with particular competencies. Primarily, it is important to have an extended collaboration among actors from the initial phase of the project. As mentioned in Appendix C, to adhere to meeting the critical factors which are vital for the successful implementation of the reuse of structural steel elements, the involved actors should be able to showcase certain competencies and take up the responsibilities to facilitate the same. The critical competencies and responsibilities are depicted in Table 8 below:

Table 8: Key roles and responsibilities of critical actors involved in steel reuse projects

SL. No.	Role	Responsibilities
1	Client	• Develop and own the business case for the new building • Define the functional requirements of the building • Develop/approve the ambition to reuse steel in buildings
2	Project Manager	• Elaborate on the business case for the project along with the client and other project stakeholders • Estimate the schedule and budget for the project in collaboration with cost consultants • Analyse the feasibility and earned value of the project
3	Architects	• Develop design based on clients' ambitions, requirements, and functionality. • Prepare the preliminary design with the ambition of reuse of steel following design principles • Coordinate a detailed design based on a catalogue of available recovered materials • Involvement in the project initiation and design phase • Extensive collaboration between clients, structural designers, contractors and demolition contractor
4	Demolition Contractors	• Assess the feasibility of de-constructability of the donor building • Selection of deconstruction methods according to the arrangements and form of connections in the donor buildings and specifications in the design • Conduct decommissioning audit if archival data is not available • Responsible for the safe recovery and storage of materials
5	Sourcing Manager	• Locating and tracing the available materials from the market • Analyses and directs the cost and expenditures associated with the procurement • Analyses the feasibility and reusability of structures at their end-of-life • Develop relationships and long terms partnerships with product owners of buildings

6	Structural designers/engineers	• Develop the structural design • Conduct a structural analysis of the design and determine the critical points in a design • Analysis of the conditions, quality, and reusability of the identified materials • Monitor and establish protocols for the demolition contractors
7	Steel contractors and Fabricators	• Comply with the steel design and make necessary adjustments to the recovered materials to meet the design specifications • Erection of the recovered steel elements into the structure • Removal of coating from the elements
8	Product Owner	• Responsible for the safe and feasible disposal of materials used in a building at the end-of-life • Collaborate with (demolition) contractors and/or consultants for effective disposal of materials either by advertising the availability for recovery and reuse or recycling
9	Steel stockists	• Supplier of materials from the stocks available with them • Support in locating and sourcing materials available for reuse
10	Digital Inventory companies	• Database of available materials or materials that could be available shortly from buildings nearing their end of life. • Extend the traceability of the materials • Sharing information with the design team for them to develop a detailed design around the available stock materials
11	Local Authorities	• Responsible for checking the quality standards and whether the building complies with the safety regulations

Chapter 7: Solution Validation

The chapter focuses on validating the developed process tool. The goal of the validation process is to determine the applicability of the developed process tool in a project to minimise discounting the possibility of reusing structural steel elements due to the barriers identified from literature reviews and interviews which hinder the potential for reusing structural steel elements. The chapter aims to answer the sub-question: "*How well could the ambidextrous management approach mitigate the design-acquire paradoxical tension to improve the potential of reusing structural steel elements?*"

Aim: Determine the trustworthiness of the interpretations and conclusions made and the applicability of the process tool in a real-life scenario.

7.1 Validation Procedure

As mentioned, to determine the feasibility and applicability of the developed process tool, participants are selected to take part in a workshop wherein, an imaginary project condition is created for reference.

Project Details:

Location: Outskirts of Amsterdam

Business case: Construction of an office building with an ambition to use recovered structural steel elements.

Project Conditions:

- The building is not a high-rise
- The building does not demand specific requirements for specialised design components
- The client does not have any prior experience in working with the reuse of structural steel elements in their projects

7.2 Validation Strategy

The validation of the qualitative research is conducted by a workshop. It is often seen that the ambition or exploration of the possibilities of reusing structural steel elements is discounted early in the process due to the identified barriers mentioned early in the report. Even though in the literature, several challenges of incorporating the reuse of structural steel elements were acknowledged, it was identified that there was a lack of specific guidelines or protocols for the project team to implement the same in practice. Until now, paradoxical tension existed in the industry during the process of applying the reuse of structural steel, however, it was just considered a natural phenomenon. During the research, the cause of the existence of the paradoxical tension is defined and it was identified that something could be done to mitigate the challenge. Furthermore, it was identified that limited focus was extended toward defining the involvement of key actors, and what are the expected competencies and responsibilities that are required to successfully facilitate the implementation of the reuse of structural steel elements.

The final product which is the process tool is presented to a tailor-made team, participating in the session by playing different roles of Client, Architect, Structural engineer and Demolition contractor. The author played the role of a project manager who aims to integrate the idea of reusing structural steel elements into the project. The process tool intends to delay and if possible, avoid the discounting of the ambition by providing them with a structured process flowchart the project team can follow to mitigate the design-acquire paradoxical tension.

Initially, during the workshop, a briefing on the identified challenges associated with reusing structural steel elements which results in the design-acquire paradox is communicated to the participants in the workshop. Following this, the adopted approach of ambidextrous management to mitigate the challenges is also explained to the participants. The process tool is designed in a resulted-oriented approach, wherein, each phase aims to achieve expected outputs which could improve the potential of reusing structural steel elements by mitigating the design-acquire paradoxical tension.

The expected outputs are derived based on the identified barriers that lead to the existence of design-acquire paradoxical tension. These barriers exist due to the niche stage of the reuse of materials and the associated market conditions. Therefore, to mitigate these barriers and to assist the project team to further in the process of reusing The expected outputs are as follows:

- Estimation of required steel and its specification
- Exploration of different opportunities from the market and improve the potential availability of materials
- An inventory of available stock eligible for reuse is developed
- Develop detailed design based on the inventory of available materials

The actors were taken through each stage of the process from the initial steps with the test case conditions or project conditions mentioned above. The participants are provided with clear differentiation by adopting the ambidextrous management approach when compared to the Material-Driven Design and Form-Focused Design. Integrating the ambidextrous management approach of exploration and exploitation in each stage is prompted by the participants During the validation process, after each phase, it is assumed that the expected output of the previous phase is achieved. The perspective and feedback of the workshop participants are collected to identify the feasibility of applying the process tool and how well following the process meets the expected outputs. The viewpoints of the actors are collected to determine whether the developed process tool which incorporated the principles of ambidexterity can mitigate the design-acquire paradoxical tension.

7.3 Feedback from experts

Four industry experts were invited to participate in the validation workshop. After briefing the problem and defining the paradoxical tension, open-ended questions and leading the participants through the process tool to determine whether following the tool meets the expected outputs to mitigate the design-acquire paradoxical tension is understood. The major feedback received for making the process tool stronger is as follows:

1. Exploration of market and opportunities: It is interesting to see the process tool extending the focus on exploring the market and opportunities in each stage and not limiting the discussion and potential to reuse materials by waiting until the market is stable, an integrated platform is developed and/or until the traceability of several donor buildings with available materials is enhanced in the market.

2. A balance between options: The process tool diverges and converges to explore and exploit different options and opportunities as the situations or scenarios change based on the current market conditions, which encourages a balanced to keep the project furthering.

3. Process tool addresses design-acquire paradox: It was also acknowledged that they identify the challenges associated with a form-focused or material-driven design and also compared the existing practices to determine the contributions of the process tool to find that the tool could mitigate the paradoxical tension by following a balanced approach to initiating each step with exploration and exploiting the opportunities identified through exploration. However, to make the process tool stronger, a description of the (legal) requirements or deliverables at each stage, involvement of actors throughout the process stages and definition of best collaboration techniques including the liability and defining who will be in the best position for decision making.

4. Business case: The business case is a strong terminology and includes formal documentation of all the strict targets set by clients. Nevertheless, the interpretation of the business case is different for different actors based on the requirements. Therefore the incorporation of the reuse of steel should not be driven by the business case development when the market conditions are volatile and uncertain.

5. Ambition and Demand: It is acknowledged by the participants that there should be a clear distinction between ambition (desire) and demand to reuse structural steel elements. When the process is driven by ambition and/or desire, it opens up opportunities to explore and provides much flexibility to achieve the wishes. However, when the demand, say from the regulations or during the initial conversation is established, the need for setting a reuse target from the initial phase is necessary and makes it a strict preposition to achieve a certain level of reuse of steel in the project. Therefore, it should be clearly defined at the start whether the opportunity to reuse steel is explored because of ambition and desire or demand.

6. Feedback loop: A feedback loop should be incorporated into the process tool in the exploration phase of material sourcing. After the preliminary design is developed, the exploration of materials from the market is researched and based on the findings from the market, a timely update of the preliminary design should be carried out. This helps in further aligning the preliminary design based on the market conditions and material availability to improve the potential of reusing steel.

7. Establish reuse target: In the process tool, after an inventory of available stock eligible to reuse is developed, a reuse target is established based on the preliminary design and the developed inventory of materials. The target can then be aimed to be achieved through the development of a detailed design helping to achieve a balance between desire and demand to reuse steel as well.

8. Further research: As further research or making the process tool stronger, it would be important to address the involvement and collaboration of actors and also who will be responsible for sourcing the available materials in the market. It was explained that extensive collaboration and involvement of actors are important to facilitate the ambition and initiate the process of reusing steel. However, who will make the final design regarding whether it is feasible to reuse steel or not is yet to be determined and whether the payments to the actors for the involvement in the discussion phase can cost additional money for the client and further make the whole preposition of reuse of steel more commercially riskier to attempt.

7.4 Updated Process Tool

The developed process tool has been depicted and explained earlier in the report in Figure 14. However, based on the input received from the validation workshop and to make the representation clear, the process tool has been updated with more specifics. The generic step of business case development has been omitted as it could very subjective and the different actors in a project can perceive it differently.

Furthermore, it was acknowledged that there is limited demand from the government as well as actors to reuse steel in particular. Therefore, since the ambition to reuse is established based on desire, this desire may not be well transferred across different actors involved for an increased span throughout the project. Thus establishing an internal demand to reuse or achieve a certain level of reuse can foster the potential to reuse steel as much as possible. That being the case, after the inventory of available materials is developed, a reuse target is inveterately based on the preliminary design and the developed inventory of available materials. Following this, the detailed design is aimed at achieving this reuse target. Furthermore, validating whether the reuse target is achieved is given an explicit mention in the process tool to make it more clear for the users.

In addition, it was also suggested that even after the detailed design is developed, the project might start only after a year or so. Therefore, the exploration of available materials to reuse can still be continued by aligning the market with the detailed design without further altering the finalised detailed design. This could potentially improve the possibility of identifying more secondary materials that could fit the design. With all the feasible feedback received from the participants of the validation workshop, the process tool is updated accordingly which is depicted in Figure 15.

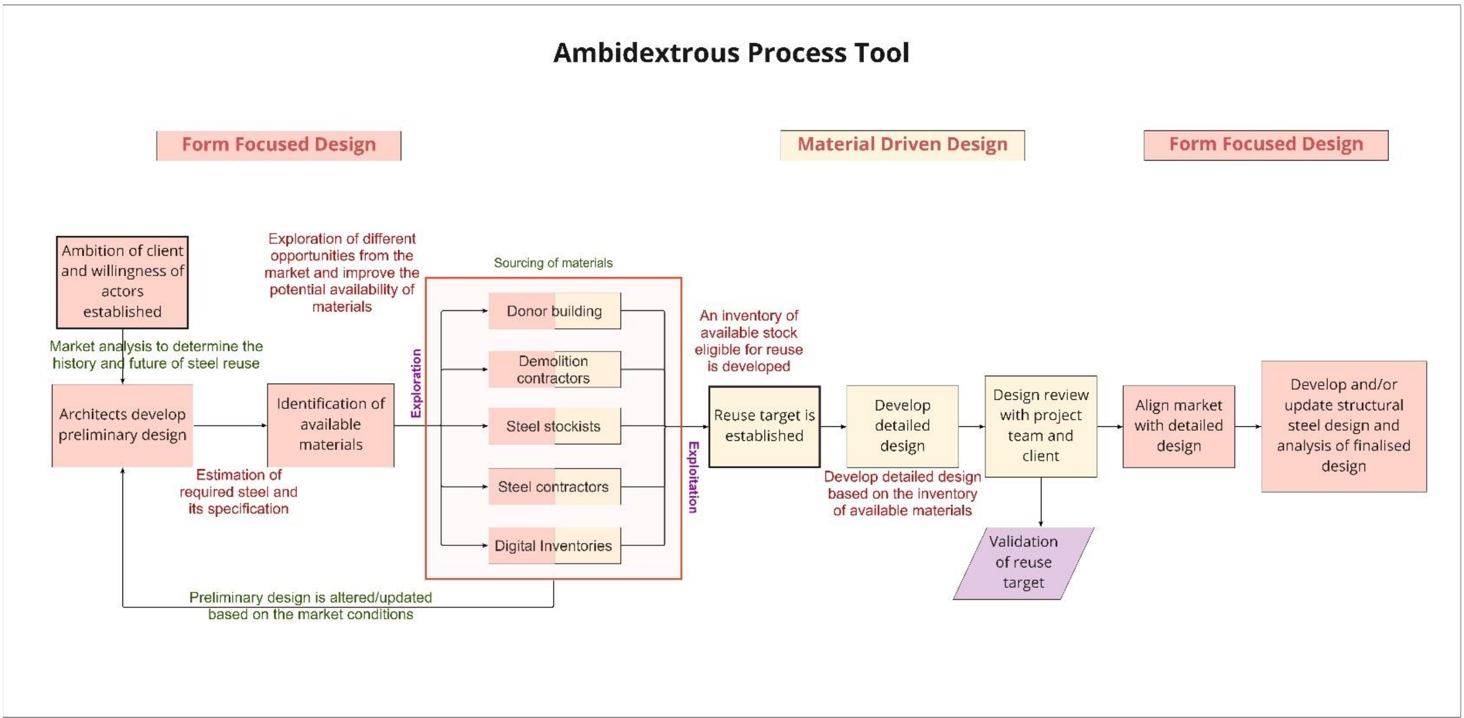

Figure 15: Ambidextrous Process Tool-Final Version

7.5 Conclusion

The existing methods adopted in the industry to reuse structural steel elements are rationalised in two ways: Material Driven Design and Form-Focused Design. However, both of these options do not resolve the uncertainties or contradictory tension the project team faces whether to design first and then source materials or vice-versa. It was also acknowledged that both options had underlying challenges which limit the potential to reuse structural steel elements. The participants of the workshop reviewed the process of following a Material Driven Design and Form-Focused Design in association with the existing market conditions and industry scenario. However, the participants acknowledge the limitations to the practical application of either of these possibilities for the successful incorporation of the reuse of structural steel elements. It was recognised and affirmed by the participants of the workshop that the process tool by providing enough room for the architect to practice flexibility can mitigate the challenges associated with the design-acquire paradox. During each phase, the expected output is revalidated whether following the steps in the process tool can guide the project team, i.e., the client, demolition contractor, architect and structural designers to achieve the desired results.

Chapter 8: Conclusion and Recommendations

The chapter discusses the key findings and implications of the research by answering the research questions. In addition to that, the chapter explains the limitations of the study, future research possibilities and generic recommendations.

8.1 Discussions

According to the studies, the reuse of steel is a crucial instrument for accomplishing sustainability ambitions and goals. The design teams and the client require assistance to be able to optimize steel reuse in projects due to a lack of guidelines, protocols, existing industrial constraints, and reference projects. Additionally, in the upcoming years, such ambitions and goals will be considerably stronger and governed by law. Thus, there is no room for further postponing the transition, and steel reuse need to be encouraged throughout the sector.

The fundamental goal of the study, which is structured as qualitative research, is to enhance the likelihood that recovered structural steel components would be used again in structures. However, it was found via a review of the literature, in-depth interviews, and case-study research that several barriers prevent the reuse of structural steel components. Nevertheless, among these several obstacles, the lack of traceability of available materials, the scarcity of available materials, the mismatch between supply and demand, and the loss of information add to the difficulties a project team has when making decisions.

Due to the aforementioned barriers, it is complex for the project team to decide: *"whether it is feasible to first identify existing reclaimed materials or demountable materials available for reuse on the market and then design around them or design with the intention of sourcing the materials later during the procurement phase?"* The project team frequently encounters this conflicting tension when they try to choose the feasible option or deliberate how to balance the two possibilities. As mentioned earlier, the conflicting demand cannot be resolved by selecting just a material-driven design or a form-focused design due to the current market constraints and low demand for the reuse of structural steel parts. A paradoxical tension known as the "design-acquire paradox" emerges as a result of the alternatives' conflicting characters and difficulty in deciding which to trade-off.

The research was initiated by conducting a literature review on the underlying terminologies associated with reusing structural steel elements such as circularity, drivers and challenges associated with reusing structural steel elements. Nevertheless, it was identified that there was limited research on mitigating the challenges associated with the reuse of steel and often it was considered a natural phenomenon in the industry due to the existing market conditions. Furthermore, it was identified that there was no research extended toward the emerging design-acquire paradoxical tension and limited focus was given to different paradoxical tensions existing in the construction industry.

Following the limitation in gathering a comprehensive understanding of the reuse of structural steel elements, exploratory interviews were conducted with industry professionals to identify the industrial practices adopted. During the interviews, the concrete establishment of the reasons that contribute to the emergence of the design-acquire paradox is further studied from the experiences of the professionals involved in the projects who desired to incorporate the reuse of structural steel elements. However, it was identified that the perspective of involved actors and professionals was more of accepting the limiting factors and often taking the stance of waiting till the current market scenario changes. Thus, it should be acknowledged that there was often a lack of ambition to reuse structural steel elements and limited endeavour to resolve or deal with the challenges.

To gather a further understanding of the design-acquire paradoxical tension and industrial practices adopted, a case-study project was selected to further study the implementation of incorporating the reuse of steel in projects. However, it was identified there was no specific ambition, desire or demand established initially in the project to reuse structural steel elements. Later during the project, a donor building was identified as an opportunity to recover materials to reuse them. However, it should be acknowledged that the successful incorporation and implementation of recovered structural steel depended on several favourable conditions and this catalysed the project team to consider the possibility and opportunity to reuse recovered structural steel elements.

Additionally, the desire to explore steel reuse as a possibility is only considered to be attempted to include in the project if a donor building is found to be available. As a result, the developed detailed design usually undergoes modifications, which adds time and cost to the design process. The process tool is therefore relevant because it gives architects the freedom to navigate the current market circumstances and enhance the potential for structural steel element reuse. According to the case study investigation, the Netherlands only had one project that effectively used secondary structural steel elements on a large scale. However, the project had the subsistence of several favourable conditions and therefore, no concrete and uniform conclusions could be derived from the selected project.

The combination of literature review, exploratory interviews and case-study analysis was used to draw the key challenges and derive particular outcomes that could mitigate the paradoxical tension. As mentioned earlier, the ambidextrous management approach is identified as a feasible option to deal with contradictory paradoxical tension. Further, the process of recovery of secondary structural steel elements and incorporation of the same materials into buildings has been studied. A process flowchart was developed depicting the same. Following this, the principles of the ambidextrous management approach balances exploration and exploitation, integration and differentiation, and divergence and convergence have been incorporated into the process tool. The process tool focused on providing ample opportunities for the architect to switch between different options and not necessarily make a trade-off between Material Driven Design and Form-Focused Design.

Currently, the industry and professionals are primarily driven by the possibilities associated with either a Material Driven Design or Form-Focused Design, which indeed is confronted with paradoxical tension. Moreover, in most cases, industry professionals are willing to explore the possibilities of reusing steel only if a donor building is identified. This approach is triggered by the existing barriers to the reuse of structural steel elements. Therefore, to improve the acceptability of this opportunity associated with the reuse of materials, an Ambidextrous Process Tool is developed incorporating the principles of the ambidextrous management approach of simultaneously extending the focus on exploration and exploitation.

In addition, the process tool considers the critical factors involved in the reuse of structural steel elements. This aimed to enable and enhance the project team especially architects to practice increased flexibility and adaptability during the process of developing the design. As mentioned earlier, based on the research study and analysis, it was identified that the emergence and existence of the design-acquire paradoxical tension are predominantly to the existing market conditions and limited demand to reuse structural steel elements. Therefore, the tool focused on achieving a set of expected outputs that could mitigate the identified challenges limiting the adoption and incorporation of reusing structural steel elements.

The research centred on reducing this challenge the project team encounters by giving them more latitude in the decision-making process. As a result of this research, a management approach that may seek opportunities to examine and employ several solutions simultaneously is taken into consideration. As a result, it was determined that an ambidextrous management strategy was a feasible method for dealing with paradoxical tensions. The ambidextrous management strategy offers a technique for combining both options (Form-Focused Design and Material Driven Design) without feeling pressure to pick one over the other.

Ambidextrous Management can employ a combination of approaches, either concurrently or sequentially, to optimize the reuse of recovered structural steel elements. Combining the exploitation of existing information and technology with the exploration of new knowledge and possibilities allows for the simultaneous balance of several feasible solutions. These include diversifying the focus into various opportunities or departing from a simplified approach. Exploitation, on the other hand, focuses on combining the identified potential prospects in the market and converging them into a precise approach to maximize it. Thus main research question was developed as "Can an ambidextrous management approach aid in resolving the design-acquire paradox inherent in the reuse of the structural steel elements in buildings?"

It was identified that the construction industry holds forth its focus on the exploitation of available opportunities and technologies and limits its focus on the exploration of opportunities and technologies in the market. Moreover, as the reuse of structural steel elements hasn't gained much visibility and traction in the industry, so far, there is limited research happening in academia and implementation in the projects. This resulted in limited guidelines, protocols or reference projects, which the enthusiasts of structural steel reuse could rely upon.

Therefore, with the aid of this study, a process tool was developed that enables the project teams to operate ambidextrously to optimise reuse. The process tool serves as the initiating factor in the development and promotion of steel reuse. The tool is meant to be utilized right away throughout the project. The project manager, sponsor, architects, structural designers, and demolition contractors are among the essential players who are most equipped to use it in the early stages of the project. The tool's applicability to projects has been demonstrated through validation, and by using it on projects, additional information may be gathered and the tool can be improved.

The business community is aware that they must adapt and that laws will eventually be used to enforce them. Furthermore, it is obvious that the government is enforcing carbon prices, and it will only give permits to structures that can show they have successfully reduced their carbon emissions. In addition, considering public tenders, it has been customary to move away from MEAT (Most Economically Advantageous Tenders) in favour of project proposals that can demonstrate a sizable decrease in material consumption and a decrease in carbon emissions to acquire a superior proposition for winning bids.

Moreover, the ambidextrous management approach is generally used to resolve organisational tensions. However, it can be acknowledged that the project team is no different from an organization in that it is attempting to execute change via the integration of departments and disciplines. Due to this, ambidextrous tools and methods can act to support those teams' efforts to innovate and promote steel reuse. The process tool makes use of the advantages of ambidextrous techniques to enable the project team's players to investigate, manage, and maximise the reuse of secondary steel. Even though this is just the outset of the application of ambidextrous approaches for reusing steel, the research lays a solid foundation for further study, investigation, and validation of this useful approach.

8.2 Answering the Research Questions

The section focuses on answering the main research question: *"Can an ambidextrous management approach help in resolving the design-acquire paradox inherent in re-using structural steel in buildings."* The main research question is an assemblage of the five sub-research questions and thus answering the sub-questions will conjointly answer the main research question.

SRQ 1. What are the managerial constraints and practical barriers to reusing structural steel elements?

The reuse of structural steel components in buildings is now hampered by several barriers. The majority of the barriers are related to the current market circumstances. It is possible to categorize the identified barriers into a technical, logistical, liability, and financial categories since they are diverse and multidimensional in nature. Table 9 gives a comprehensive breakdown of the components connected to each barrier. The combination of these obstacles makes it difficult to undertake the reuse of structural steel elements successfully. The main barriers are recognized as the limited availability of materials, a lack of knowledge about the available materials, a lack of traceability of the materials, a mismatch between supply and demand, a lack of a program that supports implementation, and additional expenses related to the recovery and reuse of structural steel elements.

Table 9: Barriers to reusing structural steel elements

Technical	**Logistical**	**Liability**	**Financial**
Lack of innovative solutions and robust products	Lack of local facilities for reclamation	Recovered steel not accepted by fabricators	Limited demand creates a lack of commercial drivers
Lack of standardised components	Mismatch in supply and demand	The demolition contractor ends up selling steel as scrap	Long-distance transportation can incur huge additional costs
Unavailability of technical solutions for reprocessing reclaimed sections	Extended time for deconstruction and storage	Permit for demolition	Specialised labour requirements
Ensuring and certifying the performance of reused/ recovered components	Extended supply chain compared to new steel	Lack of support from regulations and protocols	Additional safety considerations
Implementation requires new tools	Lack of definite measures to include demolition contractors in the early stages of the process	Quality assurance of reused products	Extended time in the construction process
Lack of sufficient knowledge about product properties	Transportation of heavy steel sections		Cataloguing of steel
Loss of information in the process			Testing and certification
Challenges in processing reclaimed sections in automated fabrication lines			Contingencies in pricing based on the condition of the steel

The practicality of economic deconstruction			Financial feasibility of reusing high dependency on the demolition process
Safety issues			

SRQ 2. What is the design-acquire paradoxical tension in reusing reclaimed structural steel elements?

In literature, paradoxes are identified as contradictory and interrelated elements that persist over time (Lewis, 2000; Smith and Lewis, 2011). By definition, paradoxical tensions are stressful encounters often resulting from frustration, uncertainty and inconsistencies that individuals face while dealing with contradictions (Smith and Berg, 1987; Vince and Broussine, 1996; Lewis, 2000; Smith and Lewis, 2011). The paradoxical tension the project team faces is whether should they design first and then look for materials available in the market (Form-Focused Design- FFD) or should they first source materials with the intention of designing the structure based on them (Material Driven Design- MDD). Both options act contradictory in nature and it is difficult for the project team to make a trade-off between them. This uncertainty in choosing between a material-driven design or a form-focused design is defined as a design-acquire paradox.

The design-acquire paradox exists in reusing structural steel elements due to the current market conditions and the criticalities involved in the process. Both sides of the paradoxical poles, that is form focused and material-driven design has their barriers that limit the potential for successful reuse of structural steel elements. When adopting a form-focused design, the architects encounter limited knowledge of materials that will become available or will be incorporated into the design. This tempts the architects to over-design causing waste of materials or developing designs that cannot incorporate most of the available materials since there is also a lack of understanding regarding the availability of materials. It also limits the flexibility in incorporating available materials as the design hasn't considered the available materials.

In contrast, when adopting a material-driven design, the approach limits the freedom of architects in developing the design. The architects are constrained to develop designs around the available or sourced materials. Adopting this approach can often make it complex for architects to incorporate dual demands of incorporating available materials and achieving the functional requirements of the client. Furthermore, there is no reference for the actor involved to source materials based on requirements or specifications, which can limit effective communication to stakeholders with available material.

Therefore, considering both the possible approaches of form-focused design and material-driven design, the shortcomings put the involved actors in a difficult situation to make a trade-off between the options and decide which could be beneficial for the successful implementation of the reuse of structural steel elements.

SRQ 3. What are the current industrial practices adopted in successful projects to mitigate the challenges associated with the reuse of structural steel in the design and procurement phase?

It was identified that there weren't many projects which successfully implemented the reuse of structural steel elements. The project of Leiden Bioscience Park, which is BioPartner 5 is a selected case study in this research study to understand the industrial practices adopted. Based on the analysis of the case-study, a process flowchart is developed to depict the existing industrial practices adopted in the implementation of recovered structural steel elements. However, due to limitations with not being able to communicate with the architects of the project and limited possibilities of comparing the implications and decisions made in the project. Therefore, it cannot be concluded that the identified critical industrial practices can assist in successfully implementing the reuse of structural steel elements. Furthermore, it needs to be acknowledged that the project had assistance with several favourable conditions. Therefore, the insights gathered further the project and approaches adopted in the projects cannot be uniformly considered as a consistent solution to achieve large-scale reuse of structural steel elements or resolve the design-acquire paradox. It was identified from interviews that there are no specific or standardised industrial practices adopted in successful projects. However, the success factors identified from the case study of Biopartner 5 are as follows:

- Ambition and enthusiasm
- Availability of the materials
- The proximity of available materials
- Engagement of a demolition contractor
- Collaboration between actors
- Storage space
- Characteristics of the steel identified
- Demolition ahead of Execution
- Visual Testing and Inspection
- Minimal stocking of steel
- Careful dismantling
- Meticulous storage and transportation

SRQ 4. How would an ambidextrous management approach serve to improve the potential of reusing reclaimed structural steel and to what degree will ambidexterity aid in managing the design-acquire paradox?

Organisations confront dual demands of exploration and exploitation, particularly in today's competitive market environment by a trend of volatility, uncertainty, complexity and ambiguity (VUCA) (Du & Chen, 2018). The underlying basis for the existence of the paradox is that they exist interrelated yet contradictory in nature. Thus managing a paradox does not imply resolution or eliminating the paradox. It is also acknowledged that effective management leverages paradox in a creative way that captures both the paradoxical poles. When analysing the current industrial practices adopted, it could be identified that the projects are more focused on the exploitation of the market and extend the limited focus on the exploration of potential opportunities. However, to mitigate a paradoxical tension, balancing between exploration and exploitation is vital. It is acknowledged by different industry experts and pieces of literature that there is a lack of traceability and a lack of available materials to reuse. From case study and case study-based interviews, it was identified that the project actors indeed limited extending their focus on the exploration of different opportunities for sourcing materials from the market. Mostly the projects and actors focused on identifying a donor building within the proximity of the building and restricted investing time and focus to identifying materials from other possible sources, which often limited the possibility of improving the potential of reusing structural steel elements.

Considering the design-acquire paradox as witnessed in the research study indicates the difficulties with making a trade-off between the options of material-driven design and form-focused design. It is identified from the kinds of literature that the ambidextrous management approach is an effective method to deal with dualities or contradicting demands. Fundamentally, ambidexterity focuses on balancing both the plausible sides of the paradox without making a trade-off between different options. It is acknowledged that the construction industry is conservative in nature and focuses more on the exploitation of possible opportunities at the expense of exploring potential opportunities. To address both the plausible sides of the paradox that is design and acquisitions, ambidextrous management focuses on exploring and exploiting the available knowledge and potential opportunities simultaneously. In this research, the research problem is identified from literature reviews and exploratory interviews which are further analysed through a case study. Based on the insights gained from these research methodologies, the adopted practices in the case study are identified and analysed, where the extensive focus was given to exploitation and exploration was conducted without preliminary ambitions which impacted the project process. Therefore, the research aimed to develop a process tool which could assist the project team to delay the early discounting of the ambition to reuse structural steel elements. The tool is developed with its focus extended toward balancing the exploration and exploitation of knowledge and opportunities. Ambidexterity encourages project actors to look into the exploration of different sources of available materials. The major factors that hinder the successful implementation of the reuse of structural steel elements are identified as lack of traceability, lack of availability of relevant information regarding materials and limits to the design freedom of architects. These factors are taken into consideration while developing the tool and providing enough room and a structured approach to looking into the possibilities of FFD and MDD.

SRQ 5. "*How well could the ambidextrous management approach mitigate the design-acquire paradoxical tension to improve the potential of reusing structural steel elements?"*

It is identified that the ambidextrous management approach is an effective way to deal with contradicting and conflicting demands which are prevalent in the design-acquire paradoxical tension. It needs to be also taken into consideration that making a trade-off between contradicting and conflicting demand is difficult. However, as identified, ambidexterity encourages an approach which can explore and exploit both options simultaneously. In the design-acquire paradox, it is the architects and the design team which confront the contradiction in choosing between a Material driven or Form-focused design. The principles of ambidexterity help in enhancing the flexibility and adaptability of the design team to cope with the existing market conditions having limited traction. Ambidexterity encourages a balance between the exploration of new knowledge and opportunities and the exploitation of current knowledge and opportunities, however, in the construction industry limited focus is extended towards the exploration of new knowledge and opportunities. With the process tool, several expected outputs are aimed to achieve which could potentially resolve the major barriers that constitute the design-acquire paradoxical tension. With the validation workshop, it has been affirmed that the process tool has helped the project team achieve the expected output by following the same. The identified constraints are predominantly due to the lack of traceability of available materials which restricts the flexibility of architects, limiting the potential for reusing structural steel elements.

The process tool with the incorporation of ambidexterity principles aims to deal with the challenge constituting the paradoxical tension. The contradiction between choosing a material or form focus design is addressed in the process tool by balancing both approaches initially and slowly making transitions as each step of the process demands. Furthermore, the traceability-related challenges are predominantly due to a limited focus on exploration activities and they are addressed through a systematic exploration of market opportunities before the preliminary design extends even after the detailed design is developed in different tones. In addition, the process considers the balance between integration and differentiation of activities to exploit the opportunities identified through exploration by integrating process stages and collaboration, and differentiate activities during exploration to maximise the reach.

8.3 Research limitations

The primary limitation of this research lies in the scope of the study. The research is solely focused on addressing the design-acquire paradoxical tension, that is whether to design first and then look for available materials or should we acquire materials first and design with these materials. However, there are several other challenges as well which hinder the potential of reusing structural steel elements in buildings, which is not addressed through this research study.

The second limitation is the adopted research methodology. The research study looked at only one case study as an example for analysis due to the limited number of projects that successfully implemented the large-scale reuse of structural steel elements. Moreover, there was limited traceability of projects which failed to implement the reuse of steel elements after having an initial ambition. Therefore, insights or critical factors that led to the failure of such projects are also not addressed. The challenges faced and limitations the project team faced in the selected case study is used to ground the research problem and develop the process tool and define the key roles and responsibilities of the actors. Therefore, a limited comparison of elements or criticalities between different projects is possible. Furthermore, despite architects being one of the most critical actors in the project, an understanding of their perspective on the design-acquire paradox based on the case-study project was not collected.

The solution focuses on solving the paradoxical tension by using an ambidextrous management approach. Wherein, balancing the practice of exploration and exploitation is focused and advised. Since, until now limited research and implementation of an ambidextrous management approach have been carried out in the construction industry, prerequisites for enabling the right balance or ratio of extending the focus on exploration and exploitation in each phase of the process are not addressed through this research. Therefore, being identified as a conservative industry, the acceptance of the ambidextrous approach is not looked at from a practical point of view regarding its application and acceptability by applying it to an actual or pilot project.

Stakeholder involvement is crucial throughout the whole process from the initiation phase. As a result, the project team's size matters. Therefore, the developer will perceive there is a higher cost involved when there are more actors involved. The client could be resistant to the approach if the developer can save a certain amount of money through the reuse of steel but these savings are then used to cover extra costs such as increased collaboration and actor engagement, higher complexity as a result of more actors being engaged, and even then ultimately using secondary materials in their product. The process tool does not address this risk.

The Ambidextrous Process Tool is developed to address and minimise the difficulties brought on by the design-acquire paradox in the reuse of structural steel components. Despite overcoming the difficulties brought on by the paradoxical tension, adhering to the process tool does not ensure that the project team will be able to achieve a specific reuse percentage.

In contrast to a real project context, where more actors are engaged, the designed process tool's validity is tested on a hypothetical instance with only four chosen participants. Therefore, the practical feasibility and applicability are only investigated to a limited extent because the implementation of the process tool is not validated through a real-life case or project. Additionally, none of the participants in the validation workshop has any past engagement with the reuse of structural steel projects.

8.4 Further research

Reusing structural steel is considered a feasible method that could significantly lower carbon emissions in the process. However, the quantification of the amount of carbon emissions reduction resulting from the replacement of virgin materials with recovered materials is yet to be acknowledged and accounted for, providing a comprehensive picture of the relevance of reusing structural steel components in both this research and in real-world applications. The desire and willingness of the client and project actors to investigate and take advantage of the prospects may also be enriched and enhanced by demonstrating the advantages of carbon reduction and the financial potential of adopting reuse.

It was discovered through the exploratory and case-study-based interviews that the industry experts had the knowledge and technology necessary to reuse structural steel components. However, it was frequently stated that actors found it challenging to execute without a clear set of guidelines to follow to meet specific requirements. To determine the necessary legal and project deliverables, more research can be done at each step of the project, as demonstrated in the process tool. The project team can utilize this to determine the critical pieces of information required and how the objective and goal to reuse structural steel components fit into the larger framework of the market's current regulatory environment. As a result, this information may be further integrated into the current process tool to create a larger cross-section that could direct the project team in adhering to the guidelines and project specifications influencing the reuse of structural steel elements.

Due to a lack of information about other projects, the current research's research methodology only employed one case study. To gain a comprehensive understanding of the practical approaches adopted in the industry, a comparative study with different projects can provide more accurate information on the commonalities and differentiating factors among different projects in different settings. This could facilitate a stronger foundation for the interpretations and implications made throughout the process tool's development.

As mentioned earlier, the projects require increased attention to extensive collaboration and involvement of actors. However, it should be acknowledged that the projects should practice an optimised approach to complete the project within budget and time. Additionally, depending on the size of the project, appropriate collaboration techniques should be adopted. The decision-making process, financial incentives, and risk management should thus be addressed in an additional study on developing a feasible collaboration technique.

Furthermore, as circularity and reduction of carbon emissions have gained great prominence in the industry, life cycle assessment is an important factor in determining how well the projects manage to meet expectations. One of the major factors in the Life cycle assessment is the Environmental Cost Indicator (ECI). This can have a high impact on guiding the companies right from gaining a competitive advantage over winning bids in public procurements to guiding them in the selection of materials. However, currently, the primary and secondary materials are not considered separately in determining the environmental impact calculations, which limits the incentives and subsidies they might be eligible for their initiative in implementing circularity. However, it is expected and acknowledged by industry professionals that government agencies are working on altering the protocols and guidelines to promote the use of secondary materials. Further research can be conducted to assess and determine the best practices that can be adapted to calibrate the Environmental Cost calculations to promote high-impact measures to be adopted and to provide due recognition and incentive for adhering to the same.

8.5 Recommendations

It is identified from the review of literature and interviews that extensive collaboration is required throughout the project with all the relevant involved actors to successfully implement the reuse of structural steel elements. It is acknowledged that the lack of willingness and ambition of the client and actors negatively impacts the project. In projects which has the ambition to incorporate the reuse of structural steel elements, additional emphasis has to be extended to exploring the availability of materials from the market to identify whether they meet the design requirements. There is no clear emphasis on who is responsible for sourcing or identifying the availability of materials and often it is merely carried out by architects, structural engineers and demolition contractors if they are involved right from the initiation phase of the project. There, I would recommend the project team should consider including an additional role of a sourcing manager, who focuses on identifying materials available in the market from different sources. The sourcing manager should be responsible for exploring and shortlisting the availability of materials that meet the timeline of the project and the specifications depicted in the preliminary design.

Role of Municipalities/local authorities: They being powerful players in the process, can take the additional lead in enabling circular construction hubs that could provide warehouses for the storage of materials for further use. Moreover, additional permits and approvals are required from local authorities when a building needs to be deconstructed or demolished. Considering the current industrial practices adopted, limited involvement of municipalities/local authorities is witnessed. It is recognised that buildings at the end of life should apply for and gather permits for demolition or deconstruction. At this stage, the demolition contractor or the product owner should put in a planning application. Therefore, this makes the local authorities well-placed to develop a database containing information regarding the building, location, planned demolition or deconstruction timeline or start date and contact person. The project team with an ambition to reuse materials can contact the concerned person associated with the building which could aid the project team find a potential building with materials eligible for reuse. This could provide possibilities and potential opportunities for matchmaking, which makes it an important proposition to include them in the discussions during the initial phases of the project. Thereby mitigating the traceability-related issues that hinder the potential for reusing structural steel elements and associated design-acquire paradoxical tension. Furthermore, municipalities can encourage the collection of decommissioning audits and can publish the same in an open platform that can be accessible and enable the use of secondary materials. This can enable a better estimation of materials that becomes available shortly in the market.

Consistency in the information collected, stored and processed should be practised.

- Helps in serving the necessary information required by different stakeholders and actors because the information required by architects, contractors, structural engineers and others actors tends to be different in processing and performing their works to serve the purpose or role in the project. Furthermore, it has been identified that the design details provided by architects might get slightly altered in the due process of execution by the contractors. Often these changes in specification or connection used are not reflected in the original design developed nor updated. This results in the archival data of design stored becoming obsolete for further use and often results in extensive decommissioning audits to be conducted during the demolition process furthering the extent of paradoxical tension. Therefore, practising uniformity in the information available helps in improving the potential of reusing structural steel elements. This ample information aid in determining or assessing the feasibility of reusing available materials at an early stage of the project.

- Today the construction industry is advancing towards Construction 4.0 which helps in the digital transformation of the industry enhancing the immense possibilities in the industry. The whole ecosystem of BIM and Revit opens up the possibility of storing sufficient information on a building consisting including design, materials and even maintenance details are some among the lot. This helps the integration of several sectors of construction projects starting from design to handover and even maintenance. These advancements can help adopt further measures to be incorporated into the construction sector to ensure that the flow of information is practised throughout the project to enhance the potential for the reuse of structural steel elements by overcoming the lack of ample information.

It is identified from the pieces of literature and acknowledged by industry experts during interviews that the design of the building can have a great influence on improving the potential of reusing structural steel elements. Therefore, considering critical design principles and adopting them into the process can benefit the design process and sourcing of materials. To improve the potential of reusing steel, flexibility in the design developed helps to accommodate more available reclaimed steel sizes. Also, the use of more commonly available steel sections in the design helps to increase the probability of finding the materials on the market (Gorgolewski et al., 2008). Often, it is identified that long spans can be a problem as there is less availability of reclaimed steel of this type (Interview 7). The traditional approach of strictly following the initially developed detailed design throughout the project might not be a feasible option (Interview 7). However, sourcing the materials without an initial idea of the functionality of the building does not aid in the furthering of the project to incorporate the reuse of steel (Interview 8). Owing to several impeding factors discussed earlier, the designers and architects should take into account certain critical factors to improve the potential of reusing structural steel elements. The critical factors are listed in Appendix C.

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Interview 09. (2022, July 15). (Z.K. Varghese, Interviewer)

Interview 10. (2022, July 19). (Z.K. Varghese, Interviewer)

Appendix A: Exploratory Interviews

Exploratory Interview Protocol

Introduction and background

My name is Zachariah Kiran Varghese and I am pursuing a Master's in Construction Management and Engineering at the Faculty of Civil Engineering and Geosciences at the Delft University of Technology. I started my graduation assignment with WSP in The Netherlands and TU Delft in April 2022.

My research interest: Circularity in the built environment/ the use of recovered structural steel elements/ the paradoxical tension (design-acquire)/ the ambidextrous management approach.

My primary motivation to research in this area is the urge to be a part of the transition toward a circular industry. When investigating the reuse of materials, a contradicting factor in the decision-making process is whether is it feasible to first locate structural steel elements available for reuse from the market and then design to the available materials or design to then source the materials during the procurement phase. When analysing this contradictory nature, in reality, making a trade-off between both options is difficult.

Considering the circularity aspects, the impact of reusing recovered structural steel elements has a great impact on achieving the circularity goals. However, several barriers like lack of availability and knowledge of materials available on the market, traceability-related issues, certification and testing are some that impede the potential of implementing the reuse of materials. With this research, the major focus is to identify the several factors that are associated with the reusing of recovered structural steel elements and analyse the perspectives and approaches adopted by designers and procurement teams. The research aims to provide insights from several projects which have either successfully or unsuccessfully implemented the reuse of structural steel elements and propose an ambidextrous management approach which could help the designers and procurement team to identify the most feasible option possible for the project. This could help the better realisation of projects with an ambition to incorporate the reuse of materials and leverage the potential of reuse by mitigating the challenges associated with decision-making. Moreover, the contradictory nature of paradoxical tension wherein both options seem to be feasible, nevertheless, in practicality, it is difficult to achieve both of them. This characteristic seems interesting to be explored, especially in the domain of the reuse of materials, which could potentially have a high impact on circularity goals.

Research Objective

The study is designed as qualitative research with the primary aim of improving the potential for employing the reuse of recovered structural steel elements in buildings. There are various barriers to overcome or mitigate to realise this project's distinctiveness. Lack of traceability, market availability of reused materials, lack of an integrated supply chain, and logistical challenges are just a few of the barriers. These factors create a conflict for designers and procurement teams: should they develop the design first and then locate materials from the market, or should they locate materials on the market first and then design around them? It is complex for the project team to decide whether to design or acquire first due to the aforementioned impediments. This research has a great focus on mitigating this dilemma faced by the project team. As a result of this research, a management technique that can look for possibilities to investigate and utilize different options at the same time is considered. The ambidextrous management approach could provide a methodology to synergize both possibilities while avoiding the strain of having to choose between them. The method can employ a combination of approaches to a strategy to improve the reuse of recovered structural steel elements, either simultaneously or sequentially.

The purpose of the interview

The interviews are organized to gain insights into the background of the barriers to the large-scale reuse of recovered structural steel elements. The interview focuses on understanding the feasibility of adopting the reuse, identifying barriers associated with the reuse, and the methods of dealing with using recovered structural steel elements. The interview will also focus on the varied impacts of locating and incorporating the right materials at different stages of the development of the design.

Confidentiality

The confidentiality of the personal information shared by the interview participants is explained to them through the informed consent form before the start of each interview. To confirm the right interpretation of the responses shared by interview participants, a summary of the responses is sent to the interview participants within 7 working days. If no response is received within the next 7 working days after sending the response, the right to use the response amended is also notified through the informed consent form.

Exploratory Interview Questions

1. What are your experiences with (attempts to) reuse recovered structural steel elements in buildings?

2. What do you think about the feasibility of incorporating the reuse of recovered structural steel elements?

    a. What are the critical factors (major enablers) involved in the realisation of the projects to adopt the reuse of recovered structural steel elements?

    b. What challenges are you encountering while incorporating the ambition of reuse of recovered structural steel elements?

    c. What methods were adopted to deal with the impeding factors?

3. What are the managerial constraints to the large-scale reuse of structural steel elements?

    a. What are the practical barriers to its implementation?

4. What major differences do you witness between traditional projects and projects which incorporate the reuse of steel?

5. In your opinion, is developing a flexible design or locating the right elements from the market, the most critical in the realisation of the reuse of recovered structural steel elements?

6. What is your opinion about the chronological order in which the design and locating of the materials should be carried out for improving the reuse of recovered structural steel elements?

7. What are the current industrial practices adopted in successful projects to mitigate the identified challenges? (availability, traceability, storage issues, financial barriers, liability actors, regulations)

8. What are the identified success factors that facilitate an improvement in the reuse of structural steel?

9. Are you aware of any digital tool which can overcome the tension of meeting the supply and demand or traceability-related issues?

Conclusion

10. In your opinion, what measures should be considered to improve the utilization of the reuse of recovered structural steel elements?

11. Do you have any other comments or suggestions related to the reuse of recovered structural steel elements? Or is there something that remains undiscussed during the interview that could be important for this research?

12. Do you know of any projects in which the recovered structural steel has been used on a large scale?

13. Do you know anyone who is particularly well-informed or expert in terms of reusing recovered structural steel, preferably architects?

Exploratory Interview 1

What are your experiences with attempts to reuse recovered structural steel elements in buildings?

Initially, we looked at the potential for reusing steel and the issues associated with EPDs (Environmental Product Declarations) and environmental data. Then we worked on the development of a tool to get a quick Revit model to compare with the database of available steel elements and then presented an overview of how much can be reused considering element by element. We assessed how can we use that information to develop a tool which can quickly analyse the feasibility of reuse in the early stage of the project. This provides an idea of how much virgin steel we could save potentially by using the reuse of steel. So we developed the tool further last year to make it more user-friendly and we did two case studies with an imaginary database to look at some constraints and the completeness of the data. Which data do we need to say whether this steel element is OK to reuse or not or whether everything should be tested first?

What do you think about the feasibility of incorporating the reuse of structural steel elements at this point compared to the market, especially with the critical factors involved and considering reuse as a feasible option?

Yeah, I would say it's a feasible option but there is a lot of uncertainty also. However, looking at regulations is important and I think the regulations are now lacking a bit.

I think at the moment it's more based on experience and using proper checks which take more time, but I also see in the future then it gets relaxed and a bit more information will be there making it more feasible to apply it. Because at the moment, I think the risk is being put on the engineer or the contractor involved in the project. So we have to say something about how feasible it is.

Is it the only challenge that you notice in the current situation about the reuse of structural steel elements?

The state of the elements that you are reusing is a concern because they have been in use in a building for a couple of years or more. However, you don't have all the information about it and need to be careful about it like how true all the information is in the design because often during the design, the contractor changes stuff which isn't being updated back into drawings. Therefore, the risk is that if you use the drawings to define identified elements with the required material properties or specifications you never know about holes or connections which are usually not on drawings that are part of the attention. Also, you can fore say, we could have all the connections and user-reduced section length. I think inspecting the elements and probably testing them at the moment is a necessity. But that would take a lot more time than just looking at the catalogue and deciding we can use this section in new ones and compare how you do it now.

Is developing a material passport after the execution or the completion of the project make it easier?

Yes definitely. We have companies who do that, providing a digital inventory of available materials. Also, I think designers should be involved in deciding what information we need in the passport. But if we want to implement stuff in our design, we should be involved in that decision-making. However, it is not happening much now, the designers should be involved in the early stage of the project itself so that they could analyse the feasibility better and identify which steel elements can be reused in the buildings.

What approach could mitigate the challenging factors?

Designing and building with the knowledge that it's being reused are completely different from designing a building purely for that building‘s function. For example, using more similar elements or profiles or sections with simple connections and then being able to say that the building consists of three different sections or three different connections, could constitute the whole set of elements making it so much more reusable. I think that also helps in mitigating those measures because you have better information about, What's actually in there and how it's designed for.

In recent years, we develop 3D models, and Revit models and have a lot of information which makes it more beneficial in the future, when compared to buildings from the 80s or 90s being demolished now with very limited information (hand drawings and all). Buildings that are being modelled now have way more information and will only become more and more. Moreover, additional parameters are added to every element when compared to scenarios that existed a few years ago, which makes the structural models as complete as possible.

However, it is often seen that the contractor executes the final design developed. It is also important to check with the contractor what they put in as valuable information, because, for example, the designers develop a develop for a certain load and capacity. Even though the contractor checks them, he is not held responsible for them. He may not need most of the information in that model. He might probably need information only on length, type of connections and openings. This information may not be enough information which the designers require to design a new building as they often get lost in the process.

But getting back to that question about how you could mitigate the challenging factors, in the built environment, several parties are involved in the process, and often information gets lost when transferred from one party to the other. This information could also be the key information to identifying which element is good for reuse. Especially during the execution phase, several changes could have been made in the structure or elements. So when you identify buildings available for demolition or reuse, the actual characteristic of the element on-site could be different from what is represented in the design. Then again, you have to go to the drawings and analyse the structure, which could then become invaluable then.

Since we don’t have an integrated supply chain to locate and identify the materials, where can we identify the right materials from the market to incorporate the reuse of structural steel elements?

This should be regulated by different parties involved and firms like Madaster are actively involved in mapping out the materials out there and developing a material passport. It is possible to build up their database to exploit the potential of reusability by tracing and locating the right materials with the required properties. From the perspective of the designers, it is important to keep account of the design developed and Arup then develops a database around them. However, it may not be providing the right information to design further around this information, because several changes would have been made by the contractor or even would have made a new model during the execution phase.

However, the built models could provide an initial idea of the structure and you can find information such as a particular building is available for demolition in 2 years or so and a different building needs to be developed in 2 years or so, then we have a match. This match could potentially provide a lot of materials to reuse. After finding the match, someone could go to the site and inspect the conditions of the elements available from the building. With this information, a database or stock can be developed with identified elements that meet the requirements.

From your discussion, do you refer to portfolio mining?

Yes,

However, with portfolio mining, the identifiable materials or the capacity of the database will be very limited right? Since we don't have a globally accepted platform, the lack of traceability or availability of the right materials is identified as an impeding factor.

Yes, definitely. The procedure of designing around the identified materials makes it much easier to achieve the trait of reuse of recovered steel. Right now, the design of the buildings is developed based on available catalogues. We look at the steel profiles which are predesigned and we take them based on the required capacity. So we could develop based on a catalogue of materials of stock members, then developing a design based on slightly varying span length or capacity is also much more easily achievable. In my opinion, designing around assumptions is hard and prone to lots of changes, especially changes in length or connections to make a whole new one.

What do you mean by the catalogue?

The steel producers develop the HE section or IPE section in different classes. The bundle of these different classes of steel sections is defined as a catalogue. Software like CAD or Revit has these predefined standardised lists of steel sections that are available to be used in the design of structures.

Are we following the same catalogue for several years now? Because when we identify a building available for demolition, it might be developed 25 to 50 years ago. Were they also developed with the same catalogue of steel sections that we use now, or has it changed over the years?

Yes, I think so. They might have added some more elements, however, the existing ones are still there. The catalogue of elements in the software mostly contains only information on the cross-sections. Nevertheless, the catalogue of steel sections that need to be reused should ideally contain more information than a normal catalogue with virgin materials. It would also be important to include identifiers in the models, which could locate reusable materials that match the required level of load capacity, and then the virgin materials could be replaced by these materials.

So does that mean that following the most common cross-sections of the catalogue now and designing the structure, could potentially help identify recoverable materials as well comparatively easier?

Yes, definitely.

In your opinion, is developing a flexible design or locating the right elements from the market, the most critical in the realisation of the reuse of recovered structural steel elements?

The easiest way is to design a building from scratch and compare it with the database available. Then it makes it possible to follow the traditional design process and have an efficient design. Then you can check for the availability of reusable materials from the database and replace the virgin materials from the developed design. However, then you don't go forward or exploit the opportunity to improve the reuse of steel because the actual availability of steel from the market is not taken into account.

Something, that could be done is to identify the ranges of elements and when designing, you can stick on to a more standardised set of elements available with similar connections as well. Especially, if you identify a particular building that is available for reuse, you may identify 50 elements of the same spans and connections, and then you can think of incorporating them into the new design with the same span and connection. Thereby an adaptation of the new building design is made based on the available materials.

Thus do you indicate the process of designing around available or identified materials is more of a feasible option?

The easiest way to design is to follow the first approach of design and then look for materials from the available database of elements. However, there is no guarantee that a particular amount of steel reuse can be achieved or incorporate a certain amount of recovered steel elements into the design. In that case, the most feasible approach to achieve the potential for improving the reuse of steel is the 2^{nd} approach. However, this can be a tough design process. When you have a bundle of elements available for reuse in the new structure or even when you have a lot of identified material available for reuse, making logic out of these steel sections with different profiles is difficult. Even when we talk about tools or software that could make logic out of these available elements, the development of such a tool doesn't happen overnight. So I think, in the short term, it is not easy to achieve. However, even when we achieve that automation trait, it is always wise to make the design simple, without incorporating elements of different profiles or spans or connections, making it complicated. If flexibility in design is something to be achieved which could be also beneficial for further reuse of the steel sections in the future, the simplicity of the design is very important.

Do you have any opinion about the chronological order of this? Should the design be developed 1st and then look for materials or should we first look for the materials and then design around them?

Knowing the availability of materials first and then designing cleverly around them, which is what the tool is also focusing on now would be great to achieve or improve the reuse of stock members. I feel that is something we should look for and exploit. However, looking at the short term, the most feasible option would be to first develop your design and then compare it with the stock where you can use the materials or compare it with stock to identify which elements could be replaced. The stock can be gathered from several digital inventory companies or agencies and then compare with the developed design, then use the stock members for reuse, for example, 30-50% only. That is something achievable for now. From what I know, there is very limited control or standardisation of the procedures in the Netherlands regarding developing a database or a portal to gather the materials. It should be more centralised to achieve the second approach. For an ideal improvement of the reuse of structural steel, following the chronological order of first identifying and locating the materials from the market and then defining what can we design with them is better. We have been facing difficulty with developing the tool: we have been talking to different parties, but it is difficult to find the stock(i.e., traceability). Considering the demolition contractor, may not be willing to store their elements for so long without putting them back into use, which would impose severe storage costs and it would be easier for them to sell and send them to recycling.

What are the characteristics of the tool you are developing?

- look at the stock
- look at the steel elements
- compare with designed models: BIM or Revit model
- in output, shows the amount of reusability;
    - What materials are required to be achieved with virgin materials, direct and indirect reuse?
    - For indirect reuse, a slight variation from the requirement. Send to the manufacturing unit, to add a plate or do welding and all.
- The impact of using virgin materials is almost 9 times more when compared to the mix of using the direct and indirect reuse of elements.

If the length in our stock is 3.9 and we need four, you can say if that's acceptable or not, because, for example, you think we can add a plate and if we have a higher material class, let's say, SP255, while we need them in our design as 235, OK, we can also say it's better and stronger. So yeah, we accept it for now. OK. So those are settings that we can incorporate. A list of information that is required to be added to the database is also determined and is also added to the tool, such as profile loss, characteristics and other relevant information for the designers. Define a grid parametrically and define rules of thumb, then looks at the database to identify the stock that matches the design. Then iteratively, it goes in a loop again changing the parameters used in the grid. Later the best grid that fits the initial design and provides maximum reusability is adopted. However, the limitation is that it can result in an unsymmetrical design. When you look at the grid, the performance of each grid is analysed to adopt the best possible option. We agree that this workflow is not suitable for all the projects, as this involves changing even the column positions. This demands a discussion with the designer, architects, contractor and even the client. The same workflow can also be integrated with a database of stock timber in the tool. The tolerances of each element are defined in the script in the tool, which identifies potential replacement opportunities for the elements with the stock members. Labelling of the replacement is also made by defining whether it is a direct or indirect reuse of elements. The best thing with workflow 1 is that, since you design them already, you can confirm that the design will work.

In the second workflow, an analysis is then made to understand what impact different parameters or different designs could impose on the structure. Over here, you allow the script to change the design to achieve maximum reusability. The change in design is involved with the alteration made in the grid spacing or even adding/removing a line of beams. The parameter increases as you incorporate more and more design degrees of freedom.

This could be work-intensive as if you have to change the design, then you again have to conduct the structural analysis to obtain the permits and for workflow one, it's already done and we are not weakening the structure.

What is the major input to your database? Is it the portfolio stock or do you collect the information from other agencies?

Right now, we are just using imaginary stock and assumptions are made. Moreover, in the future, we encourage the suppliers like steel contractors to provide the data of members that are available or qualify to be reused and not all the recovered materials. Those parties are also involved in similar projects to map out stock and based on our engineering skills, a selection is made and added to the script.

Is the tool used in any of the projects?

No, An actual project design is used to compare with our imaginary stock. We analysed the potential of the tool, however, it is not yet put into practice as we just have imaginary stock. The real potential and limitations of actual stock are underexplored since we have limited hands-on experience with them. In the background, we are trying to find parties who could provide this information.

Are you buying the stock or just identifying the stock?

We are just identifying the stock and taking this opportunity to the client.

But, the same stock will be shared with other parties and by the development phase of the project, the identified stock could get unavailable anymore, right? How would you tackle this?

Yes indeed, we identify this as a risk. We hope there will be a possibility to make a reservation for the identified relevant stock. However, at the same time, if we choose to keep the stock for ourselves it doesn’t help the world and doesn’t create the demand from different parties to exploit the potential of reusing the recovered members. Also to achieve sustainability and circularity, a lot of parties are involved and it’s more like a collective approach.

Even when you say that the tool could find matches for the design developed with the stock members, would you consider the existing stock members when you initially develop the design in the initial phase of workflow 1?

The workflow how it's done now is the architect makes the design and wins the competition and the design should be informed in the beginning. But now we adapt our architectural design based on the structural design. The orientation of the design change and should match both the structural and architectural design.

In your opinion, what measures should be considered to improve the utilization the reuse of recovered structural steel elements?

- Regulations, in general, should be standardised and improved.
- The availability and traceability of stock elements should be analysed.

Is there something that remains undiscussed during the interview, which could be important for this research?

The actors who are involved in the reuse of materials should be kept well informed about the benefits of reusing materials whether directly or indirectly. Quantification of difference in embodied carbon achieved with the new process and traditional way should be analysed to conclude. This takes into account different processes involved in reusing such as transportation, man-hours, average welding requirements, addition using plates and so on. How much does the process help in saving them, could be a good addition to your research.

Summary of workflow in the tool

Workflow 1: *Developed design> tool analyse the elements specification and tolerance limit of each element and look for elements from the stock members (portfolio mining > the tool currently developed based on assumed/imaginary data> 1-on-1 replacement could be made with elements from the database> check for direct reuse or indirect reuse> assess the impact it could create when compared to the initial design (based on CO2 reduction and other factors)> certain percentage of reuse is achieved.*

Workflow 2: *The tool plays with design altering the specification or geometry of the design developed to achieve the maximum percentage of reuse of steel adapting based on the database/ catalogue of elements. Then the best possible design could incorporate maximum replacement of virgin materials with reusable materials.*

Exploratory Interview 2

What are your experiences in dealing with enabling the reuse of steel in buildings?

I haven't worked on projects specifically working on structural steel elements and their reuse of them. I've worked on more high-level projects, for example, for municipalities helping them around with strategies, what we call urban mining. So collecting secondary building products for reuse. What we have encountered mostly when working with municipalities is setting up infrastructure around reusable materials. So how to develop a secondary material building hub where you have the space to store all these building materials until they're used by a new project? Also **matching the supply and demand is relatively difficult**. As you know we often have a lot of time between the demolition or deconstruction of a building where the materials are becoming available until a new project arises, which one to use these materials? Which means you have to **store them for a very long time**. Who pays for that? Those are the barriers that I encountered mostly which have to do with every type of building product, so also structural steel suffers from this. But I also know that I haven't personally dealt with this, but that's like the testing of the building product to make sure it complies with new building regulations is a thing as well and is what holds a lot of people back from reusing this because then you have to go through the testing process again and it's just so much easier to get a new steel beam and just use that.

And of course, this design cycle that you talk about, so in my experience, the way people approach the secondary building product use is to see the design as a cycle where you start with a very preliminary design, see what materials are available, go back to your design phase and it's more materials become available, you revise your design. But there's tension there too because it takes longer and is more expensive.

So there should be an initial well-defined ambition to reuse elements, right? Only then you can, like, plan it in the initial phase itself. You will be designing for designing around the available materials. So if that ambition is known there, this cannot be made possible, right? So over the process, you also tend to find that you can't locate the materials that need to comply with the design. You either like to drop the ambition itself and then look for alternative recycled materials or even virgin materials.

What kind of strategies do you propose to the clients when you need to take over the ambition from the initial phase until the end and realize it successfully?

It's difficult. If the products you're looking for are not available in your area. In the case of steel elements, what I would say is to see if you can adjust the design to use. So primary materials, but of less impact than steel. So if it's possible. For example, to go with the steel T structure instead of a steel structure. And otherwise, yeah, it still is a requirement and if you can't get the products, then the only option is to go for primary.

How do you tackle the storage-related issues, which were one of the major barriers the demolition contractor and the contractor was facing? Who is responsible for storing the recovered steel?

It’s a difficult question, So if you need a stakeholder who wants to take on this responsibility, then there's of course a financial risk to it.

One of the things that we try to do is encourage municipalities to take on this risk and responsibility. So providing a place to store these building products and create a marketplace for them because it aligns with a lot of goals that municipalities have set for themselves in terms of CO_2 reduction or material reuse, reducing primary material consumption.

I think that is a very good stakeholder to engage to set up the infrastructure. Or otherwise, a private sector company that specializes in the deconstruction of buildings can create a market for itself and would also be a good stakeholder. But as far as I know. We don't have these on a big scale.

I know for example there's this project in Den Bosch or near Den Bosch. But they knew from the start that they wanted to have circular ambitions and reuse a lot of material for their project, and they just rented a big warehouse somewhere, 20-30 kilometres away for little money for a lot of space and they store their products themselves what they need for the projects. So then I guess, it's the contractor or the developer who is taking on the risk.

Because I know it's very important for them. Like the success of their project. So are the municipalities open to this setup of strategy that they should take the risk of like storing the materials? So the municipality of Rotterdam is working on this. I think they're not fully taking on the risk. I think they're mostly enabling a business case for a private sector company. Yeah, they are enthusiastic about it because it a lot of municipalities right now are working on their climate goals and their circular economy *goals. And this really can help them achieve those goals.*

Were you involved in collecting the information on available materials from the market that are available for reuse?

Not on the building-specific level, but a lot of things we a lot of projects we do are urban mining assessments, we call them. So we use data on how many buildings are being demolished or are slated for demolition in the coming years. And then based on that, we estimate the number of materials that will become available shortly.

We do this for municipalities or national governments to incentivize and put on the agenda, the potential value in these buildings and what the upside would be if you go for the reuse and recycling of these materials instead of demolishing and disposing of the waste like in a linear economy.

What are the sources of this information?

So how we do this is we have something we call the urban mining model. It's a collection of building profiles we have established. So for example, I live in a serial home. So for the building type serial home, we have made an average building material composition. So we know roughly per square meter of the gross floor area of a residential house how much brick is there typically in a Dutch home, how many window frames, and how many wooden doors.

All that kind of stuff we have estimated and based on the number of residential or offices or warehouses, there are being demolished in a certain region. We estimate what materials would approximately be in there based on our building profiles.

So are these applicable for residential homes and estimate the same for the commercial building session because they differ in size and functionality itself, right?

Yeah, the first is different in functionality and also material composition. But we have for all types of building in both residential and utility.

Do you think that this tool can like my solve the problems associated with the traceability and availability of materials?

So it's mostly a starting point. Creating agenda for how urgent it is to scale up the urban mining-like practice in every single country into the construction and demolition sector. But for really providing information on specific buildings and how much material become available exactly when this is not the right tool. So we make estimations of sort of more like high over to create urgency for municipalities to make a building hub or something like that.

So this tool is mostly for that, and if you want to know what materials are becoming available from a specific building? This is not very suitable.

What kind of advancements do you like seeing that are happening in the industry that can potentially improve the reuse of materials?

I do notice that more architects are becoming interested in this design cycle thinking. However, just a general awareness of circularity in the construction sector is growing and I think people are thinking about it a lot more.

Successful projects are also happening in the Netherlands and we're moving towards how they calculate the environmental impact and the legislation around that for buildings, for new construction, so there's legislation around this where you calculate like an environmental impact indicator. Environmental costs indicator per square meter of new construction and there's legislation around how much environmental impact you can have when constructing a new building. So primary steel, for example, is bad for your environmental cost indicator. So it's becoming less attractive to build with that.

First, you have to use a tool where you list out all the building products that are going to be in your final design and then you get like a calculation of your total variable environmental impact per square meter. And they're not starting to add also secondary building products to this database. Which wasn't there before, and that made it unattractive to use secondary building products because they would be counted in your environmental costs.

Calculation as primary products and for example using secondary steel then is bad for environmental costs indicator because it's being taken into account as if it's primary still. So that makes it unattractive to use it. Then you would rather use for example CLT or even a concrete structure is better. So I think that is also an improvement we're moving towards. That's going to enable reward circular design also from a legislative perspective.

If you take into account the embedded CO2 within the buildings isn't the secondary reuse of like steel more attractive?

Yes, for sure. So reusing secondary steel is from like a real-world perspective. It's much better than using primary steel or concrete or even using CLT. But it's currently in the legislation and the way it's being calculated, it's not rewarded. So that's like a limiting factor. When you construct this new building, you have to like conform to this certain maximum you can have in terms of environmental impact. And right now in your environmental impact calculation, it's not rewarded to use secondary materials. And if that changes, I think it will be a big driver for people to reuse more. So right now it's not in the regulation or the legislation, but I think it can come shortly.

In your opinion, what further measures could improve the utilization of secondary materials apart from the legislation or the Regulations?

Taxing materials is more than labour because it's generally more labour-intensive to deconstruct the building and to get the material ready for reuse than it is to create just primary material that will be an enabling factor. I think another enabling factor is in lot of power of the municipalities to take on the risk of building a secondary construction hub using the tendering capabilities your municipalities have. Also, I think subsidies would be a great initiative as well to close the gap in finance in terms of primary material and secondary material use.

Do you find a mismatch between the information that the actual project team requires and what is stored in the market right now, like in several other tools? Is there a mismatch between what is information available in those tools and what is required by the project team to like improve the potential?

So I think in terms of secondary material available there is a secondary material online marketplace. Which is, you know, it's quite good, but there's not that much on there. So I think this is just a huge mismatch, right, in general, for an architecture team that wants to design a building, it's so difficult to find out what materials are available and so I think that could be a huge improvement. And if it would, for example, be a requirement if you're going to demolish a building to have, like, a description of the materials that are in there and that you would have to communicate that to your municipality, for example, when asking for demolition permits, that would be a big, big improvement as well. So there are estimations, good estimations available of what's becoming available shortly. I think that's the biggest mismatch.

Exploratory Interview 3

What are your experiences with or attempts to like reusing recovered structural steel elements?

Not directly, anyway. I mean, as a professor, I'm not hands-on involved in these projects, but I do know of projects of course where they have tried to reuse and I recognize the problem that you sketch. Should we design with reuse or should we design 1st and then see what's available?

What do you think about the feasibility of incorporating the reuse of structural steel elements in buildings?

In general. When I compare it to projects I know of in which they worked with a design based on reuse, reusing materials that become available from the deconstruction of existing buildings or structures, for example. You know that it is possible and if you want to design with having these materials in mind already and knowing that in two years, these steel beams for example become available from a certain project and then you need to know it in time, and it requires a lot of cooperation between, for example, the demolition company, the deconstruction company as they call themselves now or and the developer, either it's being the architect and developer or the contractor or a combination of them.

Because, of course, the developer has to make it a part of a proposition towards the client. So the client also needs to be aware of, he is going to get a building that uses a lot of reused materials and some of these materials in case A, where you already know where they come from, will influence the flexibility I have around the new product. So basically how it means that at the start of the planning process that at the very beginning of the initiation phase, they already need to be some form of contact between deconstruction companies, developers and clients to be able to manage expectations.

In the same way that also counts a bit for case B, when you just say, we are going to design with reuse materials, but we don't know yet where we get them from. Still, that requires at least between the developer and the client a good understanding that this is what we're going for because again the client needs to be aware of and agree that, at least they're going to try to work with reused materials as much as possible, but in case of A when you already want to know what kind of materials there are, I think it's even more important to start even earlier and add the deconstruction company or companies to the equation then as well.

With the current market situation, it's like finding the availability or traceability of materials is also limited. How do you tackle the scenario?

Exactly. And of course, we also know that fortunately, a lot of our buildings and infrastructure works are still in use and from a circularity perspective, that's good. So actually the number of usable materials like steel beams becoming available on the market for reuse is very limited in comparison with the construction challenge we still have. So paradoxically, that makes the case more interesting where you can do much, making on almost a building-to-building basis or buildings-to-building bases.

Do we still have a platform where we have this traceability of available materials for us to design based on it?

Primitive. No, I doubt that there are some initiatives, of course, but they are all very experimental. You will have seen that in your review there in the very experimental stage and you can wonder. Yeah, of course, those platforms will be useful. But I think at this stage, given the number of materials becoming available, it's more important that there are good contacts between demolition companies and developers and contractors than there are Marktplatz and marketplaces for materials. I mean, it's nice that happened, but it's not necessary yet. So it's more about good relationships in the important network.

What are the particular challenges that you encountered when incorporating the ambition of reuse of structural steel elements right from the start of a project or the client's perspective?

It will restrict the flexibility of the design. Then it's the cost of getting them out of an old building or construction in a reusable way because not all of these buildings have been designed for clean deconstruction. The second thing, that I always hear, is the certification or acceptance, or even the compliance with building regulations. Often they have to go undergo quite some testing to make sure that they meet the standards for new construction and that's tricky. Because we say it was good enough when it was in the old building or the old bridge, but now we use it on a new bridge and suddenly it has to comply with new standards. That’s something I understand is also quite costly to do all that testing on the existing materials to see if they also comply with the current building regulations.

Do you see any particular methods that were adopted to deal with these impeding factors?

In some of the projects in the Netherlands, they did manage to put in a little extra labour and smart *thinking to get the components out in a reusable way.*

What managerial constraints would you like to identify?

I think the potential constraint could be a procurement guideline, particularly for public actors, because it requires really upfront cooperation between the demolition company, the contractor, and the client. Then it also becomes necessary that at a very early stage of the process you do the procurement.

So without a definite design, isn’t the tendering procedure also difficult?

Yes, definitely.

What are the practical barriers that you identified for these kinds of buildings?

You need specific labour, so you have to attune your procurement process to it, which is probably new to many of us. You will probably also need a different way of collecting information. If you see several projects that incorporate reuse, there was not a BIM model that was usable, so they had to make the additional effort to collect the information about what was in the building.

How was it attached? What was the quality of the elements? Was it reusable etcetera? So they had to construct a whole BIM model with extensive information attached to it of the existing building. So that's another extra effort you have to make. Which to perform these kinds of reuse things?

If you do not have that relationship between the contractor and the demolition company, but go more through marketplaces or there are also actual material brokers, small and some larger medium-sized companies, they specialize in finding these materials for you, but it's still an extra step because you have to make the effort to find the materials and assess them. So a lot of time and effort is needed. That's the practical barrier as well. Also, the regulations we've already talked about as a specific barrier.

Do you also see something about the economic considerations?

Yeah, because it's more time and it's more effort. So it becomes more expensive, and you know that we are quite competitive in what we want to pay for the building. Also, clients look at what it would cost me if I just developed it traditionally and what it will cost me now. And clients often don't have the means or willingness to pay a lot more than they would for traditional construction.

However, in several pilot projects, they have used recovered steel to assess the feasibility. Then they identify that there is this margin between the price of new steel and the price of scrap steel, which makes it more economically feasible to improve the reuse potential. Therefore, considering the rising prices for new materials, we're getting closer to the tipping point.

Also, recertification is an additional cost that is incurred in this kind of process. Bring that into new developments so that those companies are growing as well, and some of them are also developing their products.

To use marketplaces to try to be like the connecting factor in a network of clients and contractors and deconstruction companies. I think about the cleaning and the certification processes and translating that into usable data. So the data is usable for architects and construction companies. I think there's still room for improvement and, probably in essence, a lot of the technologies we need for that are already developed, but they need to be adapted for this specific purpose. And so, for example, you know, that certification process and that testing, I think there are like scanning techniques that can be used to assess the strength of the steel beam, and see if there are any damages which may inflict safety, see if it needs a paint job. If there's any, you know, corrosion, whatever. And I think if we develop that we can make that assessment process a lot more efficient, and if we're able to do that, then the cost of the reuse will increase substantially, which will then make it an even more interesting business case.

Yeah, and traceability is one thing, but there's a lot of talk about traceability, but also the assessment of the quality of the materials. If we can make that much more digital industry 4.0-based, then I think that will also be a big plus for the adoption of this approach.

Do you see any particular industrial practices that are adopted in successful projects that were critical?

We involve demolition companies when we design a building. So if we design, even if you work with reused materials, you still want to think about the next reuse. So really, that requires a different way of designing and constructing buildings if you want to make that easier in the future. The demolition companies have an assessment as well. If you construct it like this, will it be very hard for me to take it apart in the future? So you may want to change that, but also from a wider circularity perspective, often we still don't really have maintenance companies involved in the design process, and of course, maintaining a building is also good for circularity because it's slowing loops, and they will take a look at the design and say things like "if you design it like that, it's going to be very hard for me to maintain that part of the building, or I can already tell that particular parts will run down quite quickly because it's too exposed."

Do you see that the ambidextrous approach of creating flexibility in design and procurement helps to mitigate the challenges associated with the reuse of steel?

So you have to work with the sketch design and then see what the available redesign is and go for the real proposal now. So, I think that that makes sense. I'm not ready yet to say that's preferable to the other approach, like if you first know what becomes available and then make good designs based on what's coming available. I think they should coexist.

In your opinion, what measures should be considered to improve the utilization of steel elements reclaimed from buildings?

Well, in the end, it's all about, whether it's better for the environment or not. I mean, the circular approach is that they are, at a more fundamental level, a means and not an end. We want to adopt circular approaches because either we don't have the materials available anymore in the raw sense or if we dispose of our current materials, it creates a lot of waste and, through that, more environmental burdens are created.

In the Netherlands, the current way of recycling materials is still creating a lot of emissions, and so, actually, the future lacks scarcity of certain raw materials because although we do recycle a lot, it's still not a very environmentally friendly process. That makes it necessary to rethink what we use and how we use it.

Do you see some measures that could improve this utilization that could be adopted by the industry?

Well, in the Netherlands now we have the environmental cost indicator in the building sector. But then this measure relatively encompasses all the environmental effects of what we use in buildings.

One of the challenges in that measurement is that it needs to be calibrated in a way that incorporates circularity. Like if I use the reused steel beam, avoid all those emissions from the normal recycling process of that steel, and avoid all the emissions from the production of a new steel beam and the resource depletion, I still don't get awarded a lot in that system. So we need to work on those awards to create a realistic view. But in principle, we have a very good basis in the Netherlands with that system. It just needs to be refined and tuned.

Exploratory Interview 4

What are your experiences or attempts to reuse structural steel elements?

Well, I am not directly involved in the reusing of steel. However, for over 20 years or so, I have been engaged in the sustainability of steel construction. In my job, it is seen that steel reuse has historically never been of interest to steelmakers. Why would we reuse stuff rather than sell new stuff? I think until the last 5 years or so, it wasn't seriously considered with greater focus, particularly on carbon, but also the focus on circular economy. During my job, I have been involved in looking into barriers to steel reuse and supply chain integration. We're providing guidance, developing standards, and doing higher-level things to facilitate it.

What do you think about the feasibility of incorporating reuse and what are the major critical factors that are involved in the realisation of reuse in building projects?

I guess there is not enough availability that you can't design something and then try and source it. Hopefully, we'll get there and we need to do things like creating databases of new buildings.

We can facilitate that, but at the moment, you know, availability and supply are very critical factors. So you know a project of any size will just kill it commercially if you're trying to source from several projects and that it's just not commercially viable at the moment based on availability. I mean, most of the reuse case studies we're aware of are generally whole building reuse or whole structure reuse. So again, that is easier at the moment than a larger one.

wholesale reuse market. As you know, we have stockholders that sell new steel. We're a long way off from having a stockholder who's stocking a range of sections that will enable a designer to just design something and then order it. You know, we're a long way off from that yet. So the critical factors are availability, and cost, although the cost has changed dramatically. As you all know, recently we've been promoting reuse in the context of carbon and circular economies. Now people are doing it for cost reasons. It's still, as you know still price has gone so high that the equation has changed, if you like, up until recently, I would say marginally cost is beneficial as well.

Every project is specific and depends on how much testing you need to do. There have been extensive arguments in this regard. But I think that's changed more recently in favour of reuse because of the price rise for new steel. Other critical factors were sort of obvious things like length or span. We generally, even if they're bolted sections, we cut them out, so we lose a bit of section every time, so you know, you've got to be careful. You're not cutting it too short to make it unusable, limiting its reuse potential.

Until now, there have been several studies in the UK looking into the barriers or challenges to reusing steel, and I mean, they are still there. So in a way, we almost know it's technically viable or possible.

We know the supply issues, but the other challenge, at least in the UK, is that most of our big fabricators are now set up with automated production lines, and if you've got a reclaimed section that's got fittings welded on or stiffeners or endplates or it's been painted, it's much harder to put that through an automated production line. It slows everything down.

And so it's not that easy for most Stewart contractors to reuse and reclaim steel work. So there's some resistance there. And I mean, you know, it comes back to the whole supply chain. So if we think of a supply chain for new steel, it's relatively short when a steelmaker makes steel, goes to a stockist, goes to a contractor, and then goes to the site where it is erected. In a sense, the supply chain is stopped there. whereas in reusing steel, of course, we have the end of life. So the demolition contractor is involved there and they haven't been engaged at all with this Sustainability-carbon debate yet. So we do have a much longer supply chain, and the demolition contractor is probably one of the most important actors in that supply chain. And that actor hasn't engaged yet with the whole sustainability argument. So, I think supply chain integration is very important.

We also have a lack of a programme. So basically, what happens is that, at the end of the life cycle, suddenly a building becomes available. However, they still sit there until a new project is initiated and gets planning permission. Then the new project proceeds quickly and there isn't enough time to deconstruct the building or think about the option of reusing the available materials.

A buffer period in the planning process because, at least in the UK, at the moment, many new development programmes don't allow you to deconstruct. So, to integrate the supply and demand cycle, a demolition contractor should also be involved in the whole process and coordinate to find the available stock.

So, with steel prices going up significantly, scrap prices have gone up, but not as much. So the differential would certainly be greater. I mean, you could probably quickly, I think the sources are referenced there, you could probably have a quick look and make an estimate of that to today's level, but it must be higher, it must be quite a lot bigger than 300 and whatever pounds we said.

Are you aware of any particular methods that are adopted to deal with these impeding factors?

No, I don't think something is particularly being done in this regard. I am also not aware of any taxation or regulations specifically targeting this. So basically, it's the ambition and the willingness of the client that acts as a driving factor towards implementing reuse.

Do you identify any particular managerial constraints as well as any differences in the practical challenges that we face?

Yeah, we see a lot of companies who are often trying to pursue reuse, or even sustainability and low-carbon design. They start with very high aspirations. But after some time, it becomes too problematic or too costly. Other than managing supply and demand, I don't think there are any particular managerial challenges. So if you can reclaim steel and fabricate it again to identify a market, it is very little different from using new steel. It is then the same supply chain.

Considering the traceability-related issues and the fact that the information o the materials getting lost in the process is often witnessed. I was involved in working on developing a prototype of the database with used materials. I consider this a real priority. I was also focused on keeping the information on the new steel used in the buildings for future use. It is often seen that the client or the contractor develops a BIM model for the structure, and this often gets lost in 10 years or so, which again hinders the potential for improving the reuse of steel. Instead, of using the platform, they can upload it into a cloud-based database where it can sit for the future. Therefore, we have a virtual inventory of steel for the future. However, reusing the existing steel or reclaimed steel is a different and challenging process altogether.

How open were the clients to sharing the database or information about their buildings?

We didn't get any positive responses from the clients. However, some steel contractors were uploading their BIM models into the prototype in terms of beta testing. There are two fundamental challenges with that database thing. One is the intellectual property of the designer, and the other one is probably the security-related issues for the client. You know, some buildings might be sensitive and you wouldn't want to share data about how that building or the structure is configured.

In your opinion, is developing a flexible design or locating the right elements from the market, most critical to realising this reuse of steel?

I mean, again, it's a time-related thing. You need to be as flexible as possible. Considering the current scenario, we haven't seen anything like this. We initially decided we are going to reuse it, we developed a design, and then tried to source materials from the market. At the moment, we wouldn't be able to source that.

At the moment, you have to have a very flexible design or you have to know the building. We call it the donor building. You would have to know that in advance. Reusing the entire building is more like relocating the existing building. That is a whole different scenario and a different market than the mainstream model. But there is no market to make a product and expect and anticipate sourcing the required materials from the market. They tend to have a mixture anyway, so there's never going to be a new building where you're going to use 100% reclaimed sections. You're going to have to use a blend of new steel and reclaimed steel, and that gives you a bit more flexibility.

Do you see any common factor in the successfully realised reuse projects?

At quite a human level, we have to have a willing and flexible client. It is from there everything extends. The most successful reuse projects I've seen have had this as a common theme. It is also about the actors involved in the project. If you have had any one of the actors involved in the project against the ambition or don't agree to accept the risk, then you won't be able to realise the project successfully. Thus the collaboration and mindset of the whole supply chain make it whole possible.

It is also seen as a mainstream fashion that developers reuse steel within their portfolios which makes it less contractually difficult. In this case, you are not technically selling it again and certifying it

In the UK there is a whole rule of thumb, the total reuse is not up to the mark of utilisation ratio of 80%, and it is better to recycle than reuse. I have considered both options. There is a calculation considering the impacts associated with reuse and recycling. There is a tipping point. However, this is still up for debate.

What are the factors being considered to identify this tipping point?

Considering the reuse of steel in buildings, the design might need a steel section that requires 1 tonne. However, looking at the availability of the steel sections, you might end up using a 1.3-tonne reclaimed steel. Because you are slightly uncertain about the strength and other properties conditions, you often tend to overdesign them. Because during the inspection, you might have found some holes or slight corrosion. So in that case, if we choose to recycle the same steel, you can nominally design it because it seems to serve the same characteristics as new steel, as it hasn't got corroded or has no holes as we find in reclaimed steel.

What measures should be considered to improve the utilization of reuse of steel?

I guess the obvious answer to something like this is to legislate. Generally, we don't regulate or legislate on things like that in the UK. Certainly, we kind of encourage it.

The most brutal ways are some form of legislation, arguably some form of carbon taxation mainly. Then the industry might soon adapt.

But if we're looking for specific things we can do, like a bit more detailed level, we're producing the protocols, we're producing the testing regime, we're working on classification systems, we're kind of working on all those things to make the process easier, but ultimately it's going to be driven by legislation or cost. So unless there are some mechanisms put into legislation to financially penalise it or encourage it, I think it's going to be slow to change. Everyone's talking about it, but not a lot of people are doing it yet.

Exploratory Interview 5

While developing some interest in the field of circularity and we are developing a tool. It builds a database of all the available circular materials that are on the market. Now we don't have a unified database. Such we think as one database which collects all of the available material. Now we have separate small markets dotted everywhere in the country, and that does not help much with the client part or the side of the person who wants to build a circular building.

Secondly, with the database, we try to identify the material streams which could help to identify the material source. Further, we would like to link it with BIM software. We focus to make the preliminary design, checking the database and then defining the replacement of elements from the database. Or even, make necessary adjustments in the design that could improve the reusability of the building or maximise the incorporation of better steel elements. Then you can better realise how much circularity or reusability can be incorporated into the building and how much virgin materials are required.

Talk with everyone who owns their database, you know and add them all together. But then a platform will arise from that and eventually it will become something like eBay or something. This way the traceability of materials could be enhanced and even know where can we look for materials. This could provide a platform for building owners to sell materials.

So after the preliminary design, you look into your database and then you kind of have a one-on-one replacement of these elements with the available materials on the database. Is that how it works?

If you make it a parametric model is pretty easy to do.

Were the other clients or companies willing to share the data in their database with you?

Unless you have the largest database, no one will be willing to share theirs, so as long as we're not at that point, we are just another database. But we have one unique selling point and that's the coupling with BIM. Then others will be more willing to share their database because it will benefit them. But we have lowered the threshold for people to use their stuff.

Yes. So basically you're building like a digital twin.

Is that what you mean by the existing donor building? And then you compare it with the new design? Is that how it works?

I would hope that once the material becomes available, it will also be in an IFC format. Files for that with all its right dimensions, so you can easily implement it into a BIM model. If you want to have a circular economy, I think we should support such procedures.

It's not really about whether it's our database that becomes the largest or someone else's. What I care about is that there will be one database and it's not split everywhere and we will be able to couple it with BIM software which is our goal, whether it's our platform or someone else. You know, right now it's all new.

Does the building owner of the building that's going to be demolished or like at the end of their life approaches you, or do you approach several building owners like whether this building is at the end of the life cycle? How does the matching between, the building owner or the availability of a particular building or materials?

I think in practice the building owners should be also the owners of the materials and it should be their responsibility of them to dispose of them and it's also the responsibility of the building owner to approach them. We want to create a platform where that's available. You know we can just put his stuff in there and make it sort of advertisement. I want to put on the market and then whoever wants to buy can buy it.

What do you in general, think of the feasibility of incorporating the reuse of structural steel elements considering the current market situation or the scenarios?

The feasibility of reusing steel elements, I think beams and columns, you know are pretty standardized products you have. You have your profiles. We know what their properties are, their strength and everything. As long as you do not need to add any lengths to an element, then you can easily cut a piece off and that's pretty reusable and it's easy to modify. You should also be looking at the connection which is specific to different designs.

If you want to have a greater length for a steel section, is adding a plate to the existing steel an option? Does that affect the strength of the element?

Yeah, yeah. I think if you can have a steel profile with a top plate welded on top of it and then you bold other elements such as that with the same top plate on that profile and I think yeah, that's pretty doable. Yeah. So that way you can you can still make your element longer.

This way, we could improve the potential of reuse as well, right? If you find even a shorter element you can like expand it with a combination of different elements.

It is pretty complex to calculate. The stability of such a structure builds with several segments. However, with the tools and software we have, we can still calculate the analysis.

What are the challenges that you encounter while trying to incorporate the use of steel?

Especially, the issue of guaranteeing quality. You can’t tell what the strength is and if the ductility is still the same, you know it still ages. It could become more brittle.

For the platform that you're developing is it mostly like that you are accounting, for the donor buildings or do you also check with the steel stockists to identify the available materials from the market?

No, it's not only donor buildings, it's any ay place where there are materials stored you know which were taken from demolition. Wherever that is, that can be advertised on the platform. Yes. So basically wherever the steel is still in the building that is eligible for demolition, right and Not the steel that is already demolished. If the demolition date is definite, then you can share the date from which the particular elements could be made available. Then new building constructions could be planned accordingly, and then the demolished materials could be used in the new building without having to store anywhere.

How do you tackle storage-related issues?

Yeah. So predicting when materials become available is key in this part. So that depends on data from the owner. You know, if we know when the building is at the end of its life cycle and needs to be demolished or renovated or whatever, then he should make an inventory on time.

But also that's another tool. There are prediction algorithms that can be fed with data. Based on the number of stories, land value and their function, it can be predicted that you can find available buildings in an area over the next couple of years or the next 10 years. Based on this, an inventory of materials could be prepared.

Do you ask the client for the inventory of materials that are in the building or do you calculate them?

No. Well, it's there in their interest to make that inventory. So I will ask the client.

Do you act like a middleman by buying the steel from them or the building from them?

No, I'm not the one who buys it. That's someone else you know, who comes on the platform. We match the buyer and the seller.

What are the major differences that you witnessed in like a traditional project and in projects where you wanted to like reuse success elements?

The main difference of course is looking at production costs. You know you try to design it as optimal as possible to use as few kilos of steel as possible to reduce its price. That becomes less relevant when you are reusing. Because there are no production costs, that's only transportation and demolishing. But those are for totally different levels. So in ideal conditions, the new building client will be paying the building owner.

What do you think about the chronological order in which the whole design process could go further? So in both cases, if we identify the available materials first, how could the entire process works? And if he doesn't have the materials, but then we develop a flexible design, how could that process go further?

Either way, it's an iterative process. A building should define its functional use, and for that, the designers must have an initial idea of what kind of materials they want. When you define the functionality, then you kind of eliminate certain elements because it does fit the purpose.

I would say start with a generic design of your spaces. Find the materials, adjust your design and find some new materials. So I guess, either if you start with a generic design or a pile of materials, either way, it's an iterative process.

What are the success factors that you identify for the reuse of structural steel elements?

The donor material could be a critical factor, especially the availability and traceability of the materials.

Do you identify any design considerations that need to be adopted for incorporating more reuse of steel?

Yeah. Make your models parametric, because then you can easily adjust them to whatever material becomes available.

Do you think that the industry lacks the clarity of a process on how to like implement the reuse of steel?

I think it does. We have things like material passports. But that only tells you how much material is used, and maybe something about how it's manufactured or whatever, but not about its quality or guarantees. And that should be added to the material passport in my opinion.

In your opinion, what measures could improve this potential for reuse?

We talked about building digital tools or databases. We have a matchmaking tool. We have a tool for BIM, an inherent part of the process. And we have also a prediction tool. Maybe what still would be useful, is a tool to measure the quality of the available materials.

If anything has been documented right, we know what the initial quality has been and if it hasn't changed much, I think we can safely assume that for the rest it is also not changed much.

When you ask the building owner to provide the necessary data, do you have like a checklist of information that is required?

Yes.

What is the information that you asked for from the building owner?

Well, especially element dimensions and quality. Preferably in IC files that can be imported into the BIM. Original manufacturer and its life cycle. I would like to add that as well. You know, it's kind of the history of the materials and their properties over time.

Exploratory Interview 6

Explanation of the research and both sides of the contradicting paradoxical tension
To me, there are three simple BOT models without getting complicated, a traditional model where you just design something, then you buy the materials accordingly. That is where you pre-source the materials and then try and design around them. I've done a couple of projects where they've done that and, to be honest, it works very badly because the supply chain isn't used to it, and also there are commercial issues about paying for material. For some of these projects, they start the design process two years before they start the construction. When you look at how volatile steel prices have been and always are, in truth, if you look at the 20-year pattern, you can be securing material at a price today that could look very attractive or unattractive in two years. It's the same risk as when you do the other model because you don't know what the price will be in two years. However, it's different when you've asked people to part with the money upfront. They have a different attitude about it. So if they buy it today and it is expensive in two years, that's a problem. If they don't buy it today and it's expensive in two years, they seem perfectly happy.

To me, the real solution ultimately is the hybrid model where it's almost for sure you're never going to be able to build something out of all secondary steel because you're not going to find everything you need. Which, if you accept means that you design the building in the most efficient way you can. And then you allow the specification to be flexible enough to allow reused elements to be incorporated, and that's the perfect solution for the planet. The problem is that it doesn't allow architects and people to create low carbon scores for their buildings when they submit applications for planning and other quotes. So you've got two things in conflict. You've got the requirement to create a really low carbon score for a building and get credit for that and win contracts which compete directly with the best practice of acquiring the material.

In the UK, there is a whole argument that designers tend to over-design or try to fit in materials that are exceeding the requirements. When the recycling process is getting more efficient, and reuse incorporates more than what is required, employs more weight of steel in a building.

The other problem with material being acquired upfront is that the entire supply chain is unhappy about it. So your architect can find it, but your engineers are unhappy because now he's got to design according to it. The quantity surveyors are unhappy because they're probably being told what they have to use, and the cost of fixed or they've been told which supply it should go to get the product and they hate that. When it comes to the fabricator, he doesn't like being told where to buy his material or not, and at the moment the fabricators don't like reuse anyway. It's just such an unusual scenario in most business cases currently that nobody likes change or anything different. So everybody kicks against it.

What are the practices adopted in the industry to maximise steel reuse?

Steel gets used in construction is fine and it's very valid. But what's much more important is making sure that all of the material that could be reused coming out of construction doesn't get scrapped. Now, whether it ends up in a posh building or whether it ends up as a gate post doesn't matter at all, provided that the material has substituted new. The benefit is only achieved when you reuse it, not when you fail to dispose of it. So you demolish the building, and you don't get any kind of carbon score. However, if you put the reused material into the new building, going up, suddenly you're building scores look fantastic. But unless all the people doing all the demolishing start to change their mindset, nobody's building anything out of anything reused apart from like you've just said.

Currently, the supply and demand do not match in the industry. Thus most of the potential stakeholders who are best positioned to stock steel are reluctant and price fluctuations are drastic. Therefore unless they find the right demand for reusing steel, they will opt for recycling even with the recovery methods. What is your opinion on how the situation could be addressed?

Some of the stakeholders are permanently against it because you can't have a full range in inventory. After all, you can't buy it. You can't satisfy a significant proportion of the inquiries because the material doesn't suit it. That doesn't change the fact there's a very viable business among it. But it's a very different set of expectations from anybody that operates normally. It is a puzzle to a lot of people. They find it a real enigma because it doesn't make sense. I've got some pipe in the very old yard. But we never scrap it unless it's completely disintegrated because somebody will always buy it. But the idea with reused steel that you should be able to buy it today and sell it before Christmas is unrealistic. That's the market that I think has to be established because you will sell it.

To limit the recovery costs, should we identify and define at the start, during the recovery stage that a particular steel element is feasible for reuse or recycling/scrap?

Well, the problem then is that we've done a bit of work with the company in the UK where we tried to create grades of reuse. So you've got material that's because you can get it if you get a big warehouse, you can get big long lengths of steel with almost no defect at all. You can get it with a few holes in it. You can get it with lugs on, but the issue is that if I sell it to you, say if it's a 12-metre-long beam and it's got a 12-millimetre hole every meter down the web, Most applications will be accepfgure. So why would I ever repair it before the sale? But there may be an application where that's critical, either because they won't accept it cosmetically or because those holes prevent them from drilling other holes to make connections. Then those things have to be repaired. Or the beam is rejected. But there's no formula for what should be repaired or not, or what should be rejected or not. The golden rule of our reuse market is that we do not do work until we make the sale.

What do you see as a commercial potential for promoting the reuse of steel?

We have to get nicer and nicer, shiny-looking stuff causes people wouldn't buy the other stuff and it was never because it failed. It was because of people's quality systems and architects' aesthetic requirements. I'm told 95% of structural steel, isn't visible after construction. And yet it will get rejected at fabrication if it's got a rolling mark on the flange. So the law can't sell material with rolling marks on it, even though they're within specification, because the client won't accept it even though they can't see it after the building's been built. And the only way they would be able to get them to accept it is for it to be cheaper. I think it's far too much to ask to expect the general market to have steel in their buildings that's got holes or attachments on it where they didn't expect them to be any. And it cost them more money. I think you could sell it all day long for a bit less money. Most people, if you say you're going to be 1000 pounds, better off, really won't care if there are a few holes in the web or the flange of the beam. As long as the engineers said it's still strong enough. And in fact, some of them now would love it because they'll be able to say it's reused and sell the story. But the real challenge isn't to get it sold to the people who want the use it. It's to get it to the people who don't care, which is the majority and *they'll buy it for the price and it can be done.*

Is it worth investing more time and money in the recovery of materials from buildings with minimal damage to increase the reuse rate of the recovered materials?

Well, the big problem with complex demolition is the material that comes as a result of it. If it has damage, you're not allowed to use it in new structures. Because you have to meet N 1090, which is the CE marking standard for structures. And if you're taking concrete off, you almost always damage the flanges with little dents or little marks. No standard exists for those dents, so if they exist, the material is out of specification. Because there isn't an allowance for them, so, therefore, they can't exist. You try getting concrete off of the beam without having markings. Now you can get away with a small amount of damage, maybe two millimetres because of the tolerances for the new beam. But logically then, if I buy a beam with 5% of its area as holes, I shouldn't even have to think about it. Because they've got they should, when they use it potentially in case they drill too many more, but I shouldn't even have to think to repair it. Welds are easy because there's no standard, so you can't breach them. They're there isn't anything to measure, so they can't stop it. But out of the shape of the beam, after dents or damage, I can eliminate the prospect of reuse. So if you spend a lot of time and money taking concrete off, you'd better be ready for a huge reject rate when it comes to structural reuse. You can go back to my gate post scenario or possibly farm buildings, but you not putting it into anything better. Because it would be illegal.

Do the client or the architects approach you with the requirements and then you provide the availability or do you have a platform or a database that you have published as an open resource for the other parties to look into and then decide their design?

At the moment I'm trying to just have it so that my stock list is available and people can buy my stock. The issue with them designing around it is if they're designing around it today and don't tell me, it won't be there tomorrow if I sell it. And that's the other big difference between reuse and new because you just keep refilling the shelf. There's always more of it. Some things are much less critical. They just have to have the strength to perform rather than physical size. Buildings are awkward because people get excited about ceiling heights and the floor's clear span and size and things like that. But there are agricultural buildings and portal frame warehouses. They're classic examples. You have to achieve a structural strength and the material size that you achieve it with is largely irrelevant. Whereas if you're doing a building in London, it might be very, very important that there's section isn't more than 250 deep, because otherwise, people can't walk underneath it without banging their heads. And it is as daft as that.

Do you think that in the entire process you should at least have the preliminary design to communicate with the stock? Is it that they have these requirements and then go for the detailed design and then finalize the design based on the available materials?

I honestly don't know the answer. My concern is if somebody comes to me and says they've designed around our inventory, we reserve it for them. And I've been doing that for the last year or so. But more than 50% of that ends up not in the job. No, that's not viable for me. I can't have half my stocklist marked out as unsalable to not sell it. So I'm increasingly looking at either deposit type system, so at least I don't lose all my margin opportunity.

What if like the client needs steel after around a year or so, will you be charging them for the storage?

If the client buys the material, we never charge storage, we just hold it until they take it.

Then how do you deal with the fluctuation in steel prices?

That happens. I don't believe commercially you can agree to hold material for months and not sell it to anybody else to then potentially find out your client doesn't want it. It's happened to me twice and I've only done about a dozen jobs at the moment. There are two different marketplaces. There's a marketplace for me as a stockist. There is also a marketplace that's completely non-existent. Currently, we're doing a bit of it as an experiment, but it doesn't exist commercially, which is where people own the steel themselves and want it refurbished and put back into their buildings. That's the sort of business model where the storage costs and the reprocessing costs and everything become applied.

Currently, as you might have witnessed the supply is primitive. But as the whole preposition of reuse of materials is growing around achieving circularity, isn't the supply chain and demand for more reuse expected to be more stable?

The demand is great. There's no doubt about that. I genuinely think that's just going to grow. The supply side is all the problem. Two reason the supply side isn't mature is none of us know how much of it there is. So we all know how much new steel is required for new buildings in any country and it was given year more or less. We don't know how much total material would be available if all of the demolition was satisfactorily recovered. And it's going to be far less than the new production. But that doesn't mean it's not worth doing.

Do you see any particular measures that could improve the potential or the current situation?

The problem at the moment is the demand has come out of nowhere. So the reuse market in the UK, nobody was even talking about it. I've been doing this for 10 years for different reasons. That's when eight years where I was alone voice nobody cared. In the last two years, I've become an ad hoc consultant on steel reuse and sustainability in the UK construction sector. But it's all demand driven currently. But my experience of any commercial marketplace is that even if there's no evidence of demand, supply will sort itself out. It just will take some time. Now the biggest worry is it does it take too long for the demand side to lose interest.? Well, the answer is no, because if it's taking them two or three years to build the buildings that they're talking about now, that's lots of time. Getting some material to offer into the supply chain won't be all that everybody wants, but that's something the market's going to have to get its head around. The market is going to have to understand that in reuse you cannot just buy what you want, you never will be able to, never. You will always have to accept a compromise solution in terms of the requirements.

You might have noticed, the industry is encountering issues with a mismatch in the information available from documentation and what is available in the building, or even a lack of availability of archival data for reference. What is its impact on the reuse of steel and conducting decommissioning audit a feasible option?

Ultimately the stockist plays the key role because for you to sell the content of the building to another architecture engineer, you need all the exact information, the role of the stockist is like a librarian. Essentially, we saw it and we categorize it. So in fact, you can take the building down that you don't have the correct information for and it's fine for reuse, but then you have to have this intermediary personal business or time as well. So I'm not buying steel at the moment with much design information at all. But we do have a pre-demolition audit. We do know what the sizes are. We do know what the age of the material is and we think we can then test it. So by the time I sell it as a stockist. That information is now all present. But that's much more problematic in older buildings. If you want to back-to-back it from being knocked down to going straight into a new job. But people aren't doing it. To the client says we've got this asset, they send in their demolition audit team and do a full assessment. But that is adding more cost if you haven't got the original information.

How would you identify the possibilities of commercially optimising the sourcing of materials?

To me, in most cases, there should be an opportunity to save money, but that's the other problem with the building-to-building scenario. It's like building a new building, but 80% of the time is taken up by the designers and the architects. You give no time to physically build it. It's the people working at desks that take up all the time. And it's a bit like this with reuse. If you pay a consultant to design your materials, they will potentially try to demonstrate a saving. But it'll be as small as possible that they can get away with because everybody's trying to factor margin in and if they know they can get away with an increase, they will.

Do you have any other comments?

Your research is interesting and we both acknowledge the fact that at the moment the reuse is so minimal. One of the other problems is that people like you and I are interested in this and promoting it miles ahead of the normal marketplace. So at the moment, we ought to be making the normal marketplace make it as easy as possible for them and just make it start to happen. When I was much more interested academically and architecturally to look at some wonderful, complex buildings and see what can be done. But we're missing the fact that we could do thousands of tons of really boring stuff. Instead, it's all the big architects, the academics, and the big engineering practices that are all looking at this reuse thing. But all of their focus is on elaborate schemes.

Appendix B: Case-study Interviews

Case-study Interview Protocol

Introduction and background

My name is Zachariah Kiran Varghese and I am pursuing a Master's in Construction Management and Engineering at the Faculty of Civil Engineering and Geosciences at the Delft University of Technology. I started my graduation assignment with WSP in the Netherlands and TU Delft in April 2022.

My research interests are circularity in the built environment/ the use of recovered structural steel elements/ the paradoxical tension (design-acquire)/ the ambidextrous management approach.

My primary motivation for conducting research in this area is the urge to be a part of the transition toward a circular industry. When investigating the reuse of materials, a complicating factor in the decision-making process is whether it is feasible to first locate structural steel elements available for reuse from the market and then design them to the available materials or design to then source the materials during the procurement phase. When analysing this contradictory nature, in reality, making a trade-off between both options is difficult.

Considering the circularity aspects, the impact of reusing recovered structural steel elements has a great impact on achieving the circularity goals. However, several barriers like lack of availability and knowledge of materials available on the market, traceability-related issues, certification and testing are some that impede the potential of implementing the reuse of materials. With this research, the major focus is to identify the several factors that are associated with the reusing of recovered structural steel elements and analyze the perspectives and approaches adopted by designers and procurement teams. The research aims to provide insights from several projects which have either successfully or unsuccessfully implemented the reuse of structural steel elements and propose an ambidextrous management approach which could help the designers and procurement team to identify the most feasible option possible for the project. This could help the better realization of projects with an ambition to incorporate the reuse of materials and leverage the potential of reuse by mitigating the challenges associated with decision-making. Moreover, the contradictory nature of paradoxical tension wherein both options seem to be feasible; nevertheless, in practicality, it is difficult to achieve both of them. This characteristic seems interesting to be explored, especially in the domain of the reuse of materials, which could potentially have a high impact on circularity goals.

Research Objective

The study is designed as qualitative research with the primary aim of improving the potential for employing the reuse of recovered structural steel elements in buildings. There are various barriers to overcome or mitigate to realize this project's distinctiveness. Lack of traceability, market availability of reused materials, lack of an integrated supply chain, and logistical challenges are just a few of the barriers. These factors create a conflict for designers and procurement teams: should they develop the design first and then locate materials from the market, or should they locate materials from the market first and then design around them? Due to the aforementioned impediments, it is complex for the project team to decide whether to design or acquire first. This research has a great focus on mitigating this dilemma faced by the project team. As a result of this research, a management technique that can look for possibilities to investigate and utilize different options at the same time is being considered. The ambidextrous management approach could provide a methodology to synergize both possibilities while avoiding the strain of having to choose between them. The method can employ a combination of approaches to a strategy to improve the reuse of recovered structural steel elements, either simultaneously or sequentially.

The purpose of the interview

The interviews are organized to gain insights into the background of the barriers to the large-scale reuse of recovered structural steel elements. The Leiden Bioscience Park, BioPartner 5 project is a leading example of incorporating large-scale reuse of structural steel elements in buildings. The interview focuses on understanding the feasibility of adopting the reuse, identifying barriers associated with reusing and the methods of dealing with using recovered structural steel elements from the client's perspective. The case study interview also intends to focus on identifying the clients' perspective of the identified project value indicators in the early-phase of the project as well as the additional benefits received. The flexibility of the client, particularly in the design phase, is a critical factor in the successful implementation of reuse in projects, thus the background of this is also analysed.

Confidentiality

The confidentiality of the personal information shared by the interview participants is briefed to them through the informed consent form before the start of each interview. To confirm the right interpretation of the responses shared by interview participants, a summary of the responses is sent to the interview participants within 7 working days. If no response is received within the next 7 working days after sending the response, the right to use the response amended is also notified through the informed consent form.

Client

1. As a client, did you have the vision to reuse steel elements in the BP5 project?
2. What references/beliefs had driven the ambition for reusing steel?
3. What demands did you put forward to the designers and project team? Also, were you flexible with the design and structural specifications of the project?
4. How open-minded were you with the additional resource requirements (time and cost) that will be incurred due to demolition, decommissioning audit and considering the economic feasibility while reusing the steel?
5. In the literature on steel reused, additional cost incurred due to reuse is seen as a major barrier to reusing steel. However, in the BP5 project, it was seen that the project was completed on budget.
    a. Was the additional cost already taken into consideration from the beginning of the project?
6. Were there any particular decisions made in the early phase of the project critical to the successful implementation of reusing recovered steel?
7. What were the project values identified in the early phase of the project?
    a. Grants, funds, subsidies from municipalities?
    b. Other values or benefits that came later?
8. Were there any specific requirements/ documents demanded by the building insurers?
9. At which stage was the availability of the materials or the building available for demolition introduced into the project?
    a. Was the building under the ownership of Leiden University?
10. As a client, what challenges did you have to overcome that you may not have encountered in traditional projects?
11. Were there major changes adopted in the project to improve steel reuse?

Conclusion

12. Do you consider the project a success?
    a. Would you consider the option to reuse structural steel in future projects?

   b. What changes would you be bringing into the early stages of the project different from the BP5, if you would go for another project?
   c. Will you opt for the same project team/ will you make any changes to the setup of the project team by bringing in or removing any particular actors in the early phase for future projects?

Project Manager

1. As the project manager, how did you and the client develop the business case and what were the major vision and goals in the project charter?
2. What references/beliefs had driven you to the planning and execution of the project?
3. What difference do you witness between traditional projects and projects that incorporate the reuse of steel?
4. Were you involved in the project team when the client initially had the ambition of an energy-neutral building?
   a. What was your response when the client changed his ambition to reuse structural steel elements?
   b. What were the uncertainties you identified in the transition towards reusing steel?
5. Did the project demand extensive collaboration throughout the project process when compared to traditional projects?
   a. In this project, the demolition contractor is a new actor, which is not common in traditional projects. How did you engage them in the project?
6. What do you think about the feasibility of incorporating the reuse of recovered structural steel elements?
   a. What were the critical factors involved in the realization of the projects to adopt the reuse of recovered structural steel elements?
   b. What challenges were you encountering while incorporating the ambition of reuse of recovered structural steel elements?
   c. What methods were adopted to deal with the impeding factors?
7. Were there any particular decisions made in the early phase of the project that was critical to the successful implementation of reusing recovered steel?
8. What are the managerial constraints to the large-scale reuse of structural steel elements?
   a. What are the practical barriers to its implementation?
9. What control measures were adopted to mitigate the uncertainties and challenges identified in this project?
10. What measures were adopted to take into account the additional time associated with demolitions and reprocessing the recovered steel?
11. Despite the design being redone, which incurred additional costs, were there any particular control measures considered to keep the project under budget?
12. What additional resource requirements were incurred in the project because of reusing recovered structural steel elements?
13. Were there any specific requirements/ documents demanded by the building insurers?

Conclusion

14. In your opinion, what measures should be considered to improve the utilization of the reuse of recovered structural steel elements?
15. Do you consider the project a success?
    a. Would you be open to taking up a project that wanted to incorporate the reuse of structural steel in a future project?
    b. What changes would you be bringing into the early stages of the project different from the BP5, if you would go for another project?

16. Do you have any other comments or suggestions related to the reuse of recovered structural steel elements?
17. Is there something that remains undiscussed during the interview that could be important for this research?

Demolition contractor

1. Could you explain your experiences with involvement in the reuse of recovered structural steel processes?
2. Could you explain the demolition process of the Gorlaeus building and how the recovered steel was reused in the new building?
3. Did you conduct a decommissioning audit before the decommissioning process?
    a. What kind of information do you store or collect?
    b. What is the kind of information do different actors like structural engineers or designers required about the recovered materials?
    c. How did you manage to maintain the traceability of the materials?

4. Which stages of the project were you involved in? (decommissioning audit, demolition, transportation, repurposing)
5. Which all procedures or processes were conducted by Beelen next and what further processing was done on-site by steel contractors before installation?
6. Was there enough documentation reflecting on the quality of the existing materials reflecting on their historical usage and what kind of testing was adopted to assess the same?
7. What is the commercial feasibility or benefit for you as the demolition contractor when facilitating the reuse of recovered materials compared to traditional demolishing and scraping or recycling?
8. Were there any changes made to the demolition process when BP5/PTSA approached Beelen for buying the steel for reuse into a new structure? Did the already recovered steel elements reusable in the building? How did you implement his change? Were there agreements or regulations applied to the building?
9. When did the demolition of the project start and after what percentage of demolition did the PTSA approach for steel reuse?
10. As a demolition contractor, do you also directly source materials for your clients or are you aware of companies who do that?
11. As I understand from other actors involved, you were involved in the project from the early stages of the project. What were the major discussions carried out in the project?
12. What was the main driver for to shift from demolition and then reusing the elements?
13. How did the project change your business and impact your further development?
14. Is there a regulation in the Netherlands to conduct an asbestos survey before demolition?

Structural designers

1. Could you explain your experiences with involvement in the reuse of recovered structural steel processes?
2. Could you explain the testing process or inspection procedure of the donor building?
    a. What was the conviction that lead you to determine whether the identified steel could be reusable?
    b. What is the kind of testing and/or information you derived?
3. What do you think about the feasibility of incorporating the reuse of recovered structural steel elements?

   a. What were the critical factors involved in the realization of the projects to adopt the reuse of recovered structural steel elements?
   b. What challenges were you encountering while incorporating the ambition of reuse of recovered structural steel elements?
   c. What methods were adopted to deal with the impeding factors?
4. What are the major success factors that you identified?
5. What were the major decisions taken during the initial phases of the project, that were critical during the later stages of the project?
6. What was your collaboration with the steel contractor?
7. What was the commercial benefit or additional profit margin for IMd when facilitating the reuse of recovered materials compared to using new steel?
8. What is the major design consideration adopted when you design for reusing structural steel elements?
9. In your opinion, what measures should be considered to improve the utilization of the reuse of recovered structural steel elements?
10. How would you define the ideal process of carrying forward the ambition of reusing structural steel elements? (as the flow of process or roadmap)

Conclusion

11. In your opinion, what measures should be considered to improve the utilization of the reuse of recovered structural steel elements?
12. What changes would you be bringing into the early stages of the project different from the BP5, if you would go for another project?

Case Study Interview 1

The main drivers/business cases for the project were space and facilities. Space is office space, lab space, and facilities are everything that they need. Practically, these are the main propositions of why we are doing this.

A few years ago. I started developing this idea for BioPartner 5. There were three major reasons.

Reason 1

BioPartner 5 partners need the space to fulfil their needs and help start-ups, just as an independent needs extra space. Increasing our product and development model based on space.

Reason 2

That was then part of the Leiden Bioscience Park. My former job was also to develop the Leiden Bioscience part. I was the director of the leading Science Park, which is that part which is in development. The main aim was to create the area's movement, development, and activity. So the second goal is to create activity in the area.

Reason 3

The third goal was personal ambition. I wanted to do something monumental and make a statement. Then the ambition changed to developing the first energy-neutral lab in the Netherlands, based on solar panels. So my personal goal is to contribute on a social level to the development of the area. Then I realised that being the client, I could initiate giving orders and providing ambitions accordingly.

During the initiation phase of the BP5 project, the Gorlaeus building was torn down by dismantling its structural components. The architects saw this as an opportunity to reuse the elements in the BioPartner 5 building.

Foundation

The ground flooring or foundation is not concrete; instead, tiles were paved on the soil, which potentially saved us a lot of CO2 in the building. There are construction pillars, but no concrete on the floor.

The timing was very fortunate. The architect saw this building being deconstructed. Then they came up with the proposal that we could use some of the materials from the building being deconstructed. The architects then contacted the concerned authorities from the university to gather permission to reuse the materials. Yeah. And then they said, "Oh, maybe we can use some stuff." They make contact. The university had already given the orders to the demolition company, the Beelen next, and the architects got in touch with the demolition company and worked towards its realization. We were in the process of detailed design, then we found the steel. Then everyone had to look at their drawings again and see if they could incorporate the recovered steel. During the preliminary design phase, there was no ambition to reuse steel. However, during the detailed design phase, they found the opportunity to use the building materials when they found their availability. The university also agreed to store the steel at their property and transport it to the project site, which was only approximately 700m away. They had a lot of space, and there was a lot of cooperation from both parties.

The Gorlaeus building is owned by Leiden University. They had already collaborated with Beelen to deconstruct. I would say the project was a big success. So basically, financially we stayed within budget, and we were able to pull together a lot of cooperation with the university, demolition contractor, and architects. The prize of all these was the shift from an energy-neutral building to a building that reused structural steel elements and later added to circularity by reusing several other building products.

Was the additional cost related to the demolition as well as the purchase of reused steel and the specialized labour that you needed to realize the reuse of steel already included in the initial phases of the project?

No, because, when we started, the budget was based on traditional projects with all new steel and all new materials. The initial plan was for 19 and a half million, roughly the budget. The 19 and a half million we stayed within, but if you look at the division between the various components, you see that buying steel was much cheaper. We got the material for pretty much less. However, adjusting drawings, etcetera, is more expensive because we have to redo the drawings. So yeah, there is a different balance and spread between the expenses and efforts when we incorporate the reuse of steel. However, there is a dangerous market in the Netherlands. The people, especially the specialized labourers, are very expensive. We ran into this opportunity to reuse them. However, we had to redo most of the initial planning.

As a client, How open-minded were you with the additional resource requirements (time and cost) that will be incurred due to demolition, decommissioning audit, transportation, and considering the economic feasibility while reusing the steel?

We had the preliminary and final design developed, then just before distributing the final design, the opportunity was identified, and then we redid the design and finalised the design. So the initial budget planning was also carried out on that basis. Being an economist, I was not focused on the activity-based cost, but on the project cost. I always just look at the bigger picture of the project to determine the cost. I don't care whether we have to spend more on design because we had to redo all the designs and spend less on materials where we had the opportunity to reuse materials.

The project said we have a lot of uncertainty if we have to go with the reuse of materials. Of course, the materials will be cheaper. However, we have to redo the design, which makes the cost the same. Also, we are unsure whether the steel we bought will pass all the tests. The test results showed that it is possible to reuse steel.

Did you do the testing and certification before you bought the steel or after you bought the steel?

Well, it was almost around the same time. We had an initial investigation of the steel, and then we presumed that the steel would pass the test and bought the steel. Because the demolition was in full swing and we had to take a quick decision. When we need to use steel, we have to provide a fire-resistant coating that is also rough. The open steel beam with coating and being rough is not suitable for a lab, as it will collect dust and cannot be preserved in a clean room.

So during the process, we made some adjustments. The open / exposed steel sections in the labs were covered with wooden planks, and the walls of the different spaces were also separated by wood. This was only in the lab spaces and not in any other spaces.

What demands did you put forward to the designers and project team? Also, were you flexible with the design and structural specifications of the project?

I was very flexible with the project team. I understand the process is complex and a lot of cooperation is required to realise such projects. I was mainly focused on two things: budget and functionality, by which I mean efficiency. We need a lot of office space. We can't compromise on this fact as our development plan is focused on space. Our technical team wanted to develop bigger spaces and always insisted on developing smaller spaces. The office spaces and other areas don't need to be large.

Were there any particular decisions made in the early phase of the project critical to the successful implementation of reusing recovered steel?

No, because we found the steel at a later stage, and we didn't have the ambition to reuse steel. We had to change everything, and all decisions and developed designs were overturned. So something we did in particular to the specific requirements of the structure is that we covered the steel with wood for better functionality of the labs.

What were the project values identified in the early phase of the project?

- *Grants, funds, subsidies from municipalities?*
- *Other values or benefits that came later?*

The whole project kind of moved towards more circular ambitions. We reused materials for the toilets and reused materials for the staircase floors.

In a traditional building project, we build the spaces and half of them are generally empty. In our case, when we were developing, we never knew who would be the tenants for the space. So we decided to build spaces that were almost 25 or 50m2 in the design phase itself. During the development phase, the tenants came in. The architects were more involved in identifying materials that were eligible to be reused or available second-hand.

We didn't make an effort for grants or subsidies from the municipalities or any government agencies. During the initial identification of structural steel elements, the entire project decisions were influenced by finding an element of reusability in different components.

As a client, what challenges did you have to overcome that you may not have encountered in traditional projects?

The main thing was the extended collaboration requirement and communication to decide whether we were going to identify this particular material from the second-hand market or use the new materials. This happens whenever new components or elements are added to the project.

Whenever new additions were introduced to the projects, the discussion was made on whether this would cost this particular amount and whether you want to try finding them from the reuse market or do you want to go for new materials.

Do you consider the project a success?

- *Would you consider the option of reusing structural steel in future projects?*

Yes, of course, provided the materials are available.

- *What changes would you be bringing into the early stages of the project different from the BP5, if you would go for another project?*

From the beginning, we will be thinking about circularity. I am not saying we must be 100% circular, but I want circularity as a clear opportunity and ambition right from the start of the project. The successful realisation and reuse of structural steel elements had also a factor of luck, that we found this building being demolished at a nearby location, and the supplier also being a member of the board, we could skip through heavy communications and decisions. We had a societal view of development. We had good collaboration and a good project team to make this possible.

Therefore, when I go for Bio Partner 6, I would first be looking for available materials and then only be looking for the possibility to reuse those materials.

- *Will you opt for the same project team/ make any changes to the setup of the project team by bringing in or removing any particular actors in the early phase for future projects?*

That would be my first choice. I believe that the right project team and collaboration are the key aspects of the thesis.

Case-Study Interview 2

How did you and the client develop the business keys, as well as what were the major vision and goals of the client in the project charter that you developed?

Once we started to develop this project. There was no clear ambition about what the key focus would be in the project, so circularity was one of them, but not as stated in this sort of KPI or whatever, but then we started with the designer. We were already in the final design when the architect became aware of a project which was, let's say, around 500 metres away from the bioscience park, a former faculty building which was then being demolished. It appeared that the steel structure and the height of the building between the floors were the same as our building. So, initially, there was an estimation that perhaps it could fit.

So then we analysed whether or not it was a feasible idea to use this steel. We identified most of the favourable factors for realising the reuse of steel. Therefore, we believed that this could be an ideal project to analyse the feasibility of large-scale reuse of structural steel elements. Then we decided we would do it. One of the main ideas from the start itself is if you want to make this fit in the business case, then we should put in less cost in labour as well. Therefore, make fewer adjustments in the steel construction because the materials are cheap but labour is expensive. But we managed to develop a smart design, which was one of the main parts of the success of this project. Initially, we also made a rough calculation of whether this matched with using new steel construction. Initially, when we did all the calculations, it turned out that both of them showed almost the same cost. However, the client was notified that other uncertainties could occur while reusing steel. The client was very positive about the whole idea, and this enthusiasm was the major driver of the successful implementation of the project.

Did you have a reference or belief that you followed throughout the project?

No. There were no examples. But it was the situation of the existing building, which you could analyse and was a very simple structure. We also figured out in the early stages that we could use the steel structures on the floor above each other. They could also be mounted in the same way. We did some repurposing on-site and arranged the transportation.

What difference do you witness between traditional projects and projects that incorporate the reuse of steel?

The execution of the demolition was already happening when the detailed design of the initial plan was completed. I would say the execution was ahead of the planning. We had to do extensive planning to make sure that the required materials were available on-site at the right time. The fact that the materials were identified helps to make sure that we have a definite availability of the product. Thus, it was fairly easy to make the plan. Currently, I guess the main problem is finding all the required available materials at the same time.

Was the demolition contractor mostly involved in the early stages of the process to make sure that the required materials were available on time?

Yes, they were. Also, they were very helpful in this regard. The beams and columns were located where they had to be taken out of the building initially and then placed in the model of the new building. At the start of the demolition of the building, all the columns and beams were marked so that there was better traceability of elements to locate the recovered beams and columns. Then there was close contact with the demolition contractor about how they should be handled.

It was also identified that the initially recovered beams had so many marks and dents that they had to undergo further welding or reprocessing to make them reusable. Because the demolition contractors are so used to the process of applying brutal forces to tear down the building. This creates lots of deformations in the recovered elements. To separate the concrete floor from the steel, they needed to slow down the concrete. The process of sowing often led to damage to the steel section while using a huge saw. Later, they didn't hit so deep to preserve the steel. Later, they became cautious. Once they were dismantled, they had bolts within them. But they were often difficult to dismount. The crane was used, and they often dropped the steel in the initial phase. Then, due to banging with other elements, there were dents in the elements and lots of repairing on the recovered elements.

One of the setbacks was that the old steel structures came with galvanised steel. So we wanted to make sure that the paint didn't contain chrome 6, which is harmful to health since it needs to be used in the interiors. If the steel construction is galvanised, then before cutting, it needs to be de-galvanised because of the fumes produced while cutting the steel.

You were also involved in the project team right from the start when the client had initially had the ambition of developing just an energy-neutral building.

Yes.

How did you respond to the transition from energy neutral building to a circular building to reusing steel?

The initial vision of making an engineered building was altered. It is still an energy-neutral building that found this opportunity. We found this a cost-neutral opportunity and potentially feasible. We, as a project team, had the ambition and enthusiasm to realise the requirement.

Do you find that in similar projects we can find the required materials for the design?

Well, it is still a question and a doubtful situation whether we will be able to find building materials of such a scale in the market. I know several initiatives are coming up to enhance the traceability of materials. You can just scroll through the platform to identify the characteristics of the particular material. But I guess it still demands lots of improvements. Over the past 2 years, there were some disruptions in the supply chain and there have been huge fluctuations in the price of steel. Apart from that, comparatively, they are readily available.

Did you witness that this large-scale reuse of steel project demanded extensive collaboration between all the actors when compared to traditional projects?

Yes, definitely. especially between suppliers or demolition contractors. You need good interaction for the exchange of information and common enthusiasm from these parties.

It was seen in the literature that in most similar projects, the demolition contractor was not involved right from the early stages of the project, which is very critical to the success of the project as well. Was the demolition contractor involved right from the start when you had the initial discussion and revised the business case?

Yes, he was involved in revising the business case. The enthusiasm came from them, and they had the willingness to make this work.

You were mostly involved with the whole setting of this project. So what do you think about the feasibility of incorporating large-scale reuse of steel elements into buildings?

The real challenge and difficulty are being certain that you find the right availability of steel at the right time. The BP5 is one of a kind, where you kind of had an ideal situation when the materials were available just 700m away. We also found a building with a similar building grid as well. It is also important to find low-cost labour to adjust the steel construction. It is very difficult to do that on a large scale.

Were you involved with the testing and certification of the recovered structural steel elements?

I was not particularly involved in testing. But definitely, I was involved in the process. We had to several factors. Especially in the structure, the beams and columns were used as T sections. They were welded together. Therefore, we had to test the welding used on the steel. The welding turns out to be not so good. Thus further strengthening needs to be brought into the connection of the structures.

Have you identified any regulations or particular protocols or laws being regulated or created by the government to implement the reuse of steel?

No. I haven't found anything as such. But you can ask IMd, the structural designers, as well. So once you are done with planning and designing, for building permits, the design needs to be approved by the local authorities. Since we were using all the reused materials, they were prepared enough to provide all the details of the connection, strengths and welding of the structure.

As the project management team, what were the managerial constraints that you faced with the implementation of this project?

One of the things was that we were convinced that we had a smart and simple steel construction. We realised that we had to tender one of the contractors for that. Also, the construction industry was tense then. So if tender for a very complex design and detail, you will either end up getting no quotation or getting a high-priced quotation due to the perceived risk and uncertainties which the contractors see in the project. To mitigate this situation. We shortlisted a set of contractors and they gave us a quotation. Past the process, we demanded to meet the steel contractor during the tender process and talk about it. We explained how simple and well-organised the steel construction was designed, and it is fairly easy to adjust or mount it on the site.

Did you also look into some particular competencies within different actors involved in such a similar project?

I guess it's not rocket science. It's all about the enthusiasm and willingness of the actors involved in the project. But definitely, the project demands extensive collaboration and you need to organise a sufficient exchange of information.

Were there any particular control measures that were adopted in terms of time and cost? Because in this project, the demolition is an additional process, thus additional costs and time are incurred compared to the traditional project. Also, with the redesign, the same issues arise. So did you take any particular control measures in terms of time and cost?

No, time was not critical. Because the demolition was slightly ahead of the execution of the construction process. We had enough space to store the steel. So these challenges weren't there.

When you finally decided that you wanted to reuse the recovered materials from the demolition site, as I understood, it was already being demolished and then you went in with the proposal that you wanted to reuse the materials. Is that right?

Yes. The demolition has already started and has been going on for almost six months removing asbestos. Therefore, it was also a perfect time when we discovered the availability of the buildings.

Regarding the building insurance, did the insurers demand any additional documents or certification because you were using recovered steel?

No. I think that building permits are often provided by the local authorities, and the building insurers assume that this permit is sufficient.

I guess it's just the normal inspection that's done by the local authorities that are also sufficient for these kinds of projects as well, right?

Yes.

In your opinion, what measures should be considered to improve the utilisation of reused steel?

Well, I would say we need a set of databases where you can have a sort of guarantee that we have a certain availability of materials. I suppose that most of the databases are with smaller materials, and there are not many databases with large-scale heavy materials.

Case-study Interview 3

Could you explain your experiences with the involvement in the reuse of recovered structural steel elements or demolition to recover structural steel elements from buildings?

So before we start, we always make a complete initialization of everything we see, and that goes from the doors to toilets to steel structures and everything in between. Then, in the second phase, we look at what we can do with these materials, and what we can do with materials is mainly decided by how easy it is to take them out. And of course, how much revenue do we get when we sell it after we take it out? If something is very difficult to take out of the building and you get very little revenue for it when you sell it. It's often easier to just destroy it with the crane and then recycle it.

BioPartner is an example of a project we did. Gorlaeus was the name of the building that we demolished. We were demolishing, and we were already planning on specially demolishing this building- the Japanese demolition methods. With this demolition method, you don't actually take down the building with big scissors, so to speak, but you basically cut it into pieces and then take it down by crane.

So you cut a piece off and then you lower it with a big crane. We do this when we are in an environment that is very sensitive to sound and vibrations, such as a university. We were already planning on taking this building apart part by part. We were working on the removal of asbestos from the building, which took us one year.

Later, the architects and structural designers approached us to reuse the entire construction. They made a 3D sketch of the old building and picked almost 400 elements eligible for reuse. During the cutting process and after the cutting process, regular quality checks were conducted by the structural designers and other parties involved.

Do you have a database to store this information about the material availability even if it's coming up in the next year or two?

The 300 projects back then were chaos, and we used to take notes or make a word or PDF. So we developed an app, and with that app, we now build a small database for every interesting project that we do.

It's important to know the timeline of the project. The problem is that our horizon is very short. So we know where we're going to start next week. Maybe in two weeks. We know some projects that will start next year, but we have no idea when. We have quite a big pipeline of projects, but when we will start is very difficult to determine up until the moment that you have to start.

We have the problem of a mismatch in the demand and supply of materials. We rented a huge area in the Amsterdam Harbour area and we just stored the construction there because we knew where to go with it. But if the deconstruction is earlier than the construction, then we have to store it for some time.

How does the whole business work? Does the client or the building owner approach you with the building or structure that needs to be demolished? Then you take up the project, recover the materials, and then store the materials. Is that how it works?

No. We hunt for demolition projects, or the developer finds us. But look at all the materials that come from a building. They always belong to the demolition company or the deconstruction company. So all the materials are ours. Mostly, it's up to us what we do with it. But of course, what you see is that the better we are at creating value out of these materials, the cheaper we can deconstruct the company and the bigger the chance that the customer will take our offer.

Does the building owner pay you first and then will you be owning the material? Is that how it works?

It depends. Every quotation that we give to building owners consists of all the costs that we have to incur and all the revenues that will come from the materials. And usually, the building owner still has to pay us. But if the revenues are very high, we also sometimes pay the owner of the building. That does sometimes happen. Not very often, but it does happen.

In your experience, is there a good demand for reusing structural steel elements?

Since we work with fixed partners, we experience quite a demand. However, it is not the case with everyone. They might experience legal regulation or extended complexity. But yes, my experience is that construction demand at the moment is higher than what the market can offer. It's mainly because most of the steel that we encounter is not very easy to take out. So if we sell the steel, we have to get paid the scrap price, so to say, plus all the extra costs that we have to pay to take out the steel.

Are you aiming for a margin where you try to recover the materials as cheaply as possible? Absolute.

Do you source for areas where you can store the materials right on the demolition site, or do you also lease out the storage space? Does that add a different cost?

Yeah. We have our circular hubs, one in Amsterdam and one in Utrecht, but those are quite small. So those are not very suitable for the storage of large amounts of steel. So if we have large amounts of steel, we rent space somewhere, but we try to store it on site. In the case of the Gorlaeus building, the site was not used for some time, so we could store the materials there for some time, which saved us transportation costs and storage costs.

The whole risk is transferred to the demolition contractor, right? Once you sign the contract with the building owner, he just pays you, and it's all about making a business out of the materials and making it cost-effective. It's all on you, right?

Absolutely

Could you explain the pre-processes that you carry out before the demolition, like the decommissioning audit? Do you conduct a demolition audit and store the relevant information that could be further used or sell it to the next client?

So we make a full input theory of all the interesting projects that we do. With this database, we try to find new owners for all the materials in this building. We try to reuse the materials as much as possible. We also follow the graphical model involved in the reuse, where reusing on-site is the best option. If that is not possible, we go further in the circle to analyse other possible options.

As I understand, the Gorlaeus building was a 10-story building, and you turned down almost eight floors from there. Still, the two stories are preserved as a bike park or something within the university. So how much steel was recovered from these materials and what percentage of the steel was used in the BioPartner 5 building? Did it match the demand and supply?

I know that we reused 400 elements, which added up to 165 tonnes.

Were there any other projects that recovered the steel from this building? Was it the same amount of steel that was recovered and reused?

Yeah, and some of the steel was recycled.

Do you prefer to make the recovered steel elements eligible for reuse or do you just sell them for recycling? Which is more economically viable for you?

To be honest, recycling has a lower risk, and the financial viability is the same. So our margins are the same. But our risks with reuse are much higher. Because of the steel twists, it will be our risk, and if we didn't, we would have invested a lot of time, energy, men, and everything into this piece of steel. If it's twisted, then it goes to scrap, and then that's our risk. So there's no difference in our profit, so to speak. But the risk is much bigger with direct reuse. We still prefer that method because we believe it's the future. And we believe that and we want to be a front-runner when it comes to circularity. We believe that you only become a front-runner if you execute projects, not in theory and not on paper, but in reality. So we accept this higher risk and, luckily, we can because we are quite a big company. So we can invest all the extra hours and we can take the extra risk. But if you look at it from a financial point of view, I think it's smarter to recycle today. Whether that will change, I think recycling will still be the sensible option.

Do you have any idea of the current price of new steel and scrap steel?

I think the beam iron, the construction iron, is worth $0.36 per kilo of scrap value. New construction is still €1000 per tonne on average. Those are not the exact numbers, but it's about that.

The price difference itself comes in at around 700 or 650 euros.

Yeah, but you do need that money. Part of the money goes to us because we have to put extra effort into cutting it and removing the rest of the building first very gently and get a lifting crane instead of demolishing it with a crane. With different types of material, we will need more time. So part of that, $0.70 or $0.62, goes to us. And the part goes to the construction company that has to put the steel back together. Because their job gets a lot more difficult when they have to use old steel instead of new steel, and a part of that money goes to, for instance, those who have to source the steel.

What is the information that different actors require during the demolition process? When you prepared the decommissioning audit, what kind of information did you store or collect?

We tried to get as much information as possible, so we tried to get construction drawings and stuff like that. But in theory, there is very little information about the project that we have to demonstrate, though we find most of the information in the field through visual inspection, testing, and measuring. But we usually have very little information.

Was this database useful for the other actors, and was it compatible with their design tools?

Yeah, this project was almost four years ago, 3.5 years ago. So it was different. Back then, we did not have a lot of things that we have now, such as the app on which we make the database. Back then, we had even less information than we do today.
So I think almost all the information that we gathered on site. We, along with IMd, went into the building together, and we measured everything together. So it was like a mutual thing. For this specific project, what you see now is that we have gathered much more information ourselves. Then, of course, we share that information with, in this case, IMd or any other buyer.

How did you manage to maintain the traceability of the materials after recovery?

Well, we didn't, to be honest. We sometimes work with QR codes or with tags. Now we don't have a management system in which we track materials. It's not really in our interest to track the materials at all costs. However, some of our clients value it very much. So then we track their materials.

Are you involved with the repair or reprocessing of the recovered materials?

No, it is mainly taken up by steel contractors. Later, further reprocessing or repairs are mostly conducted by the steel constructors.

Is there also the involvement of a steel fabricator to take care of the repairs?

No. I suppose it is the steel contractor who is in the best position to make these repairs or organise the repurposing. because they are experienced in similar work and are familiar with the design. The addition of an extra layer of an actor as a steel fabricator can create additional uncertainty. He gets to know the materials better and the accountability of the construction could also be given to the contractor.

Was there an extended collaboration between steel contractors and demolition contractors? Did you like a protocol to be followed in the dismantling process that could better serve the steel contractor?

The Gorlaeus building was not designed for demolition. Thus, the tolerance limit on deformation level and depth of cutting was communicated and determined with steel designers and contractors.

What control measures could improve the potential of reusing steel?

We have a lack of regulations and protocols, and the current regulations and legislation are well-developed and designed for the reuse of steel. At the moment, it is quite complicated and lacks clarity in the process. If these factors are better developed, more parties will get more comfortable with being involved in the process.

Do you also require a demolition permit from the local authorities, and do they demand particular documents for verification?

A construction/demolition plan needs to be developed. Control measures for noise and the safe removal of asbestos are critical factors. This plan includes the process of demolition and the resources/machinery used.

What measures could improve the potential of reusing steel?

A lot of parties are involved in making the process of adopting circularity and reusing materials easier. The frontrunners are involved in developing protocols explaining the conditions in which particular materials are eligible for release. They invest in circular hubs and knowledge-building platforms. Developing a matching platform with a database of available materials. They identify the future potential of reusing and are investing in expanding their scope in achieving the same.

Do you experience a variation in the perspective of the client involved in the reuse projects?

Clients like government parties are very interested in these approaches. We need to prove that we adopt a circular approach in all the processes. 80-90% of our clients have a positive attitude, but definitely, price is a very important factor. The condition in the current scenario should be that the circular options are the most economically feasible.

Do you see that over the years, the client has had a positive mindset towards exploring the possibilities of reusing steel?

Yes, especially now that the prices of virgin steel materials are exploding, which makes reuse a more economically feasible option. Also, the prices of burning materials are going up.

What are the success factors you identify in the reuse projects?

Information about the building that is going to be demolished as early as possible to facilitate the work of other actors involved in the project. Extensive communication is important. Also, we identify that the client or actors who approach the demolition contractor should at least have a vague idea of what materials are required and in what quantity. However, after developing the detailed design, it is pretty late to explore the availability of materials. It is also important that the project team is flexible with the idea and the design. The type of steel and the length are also critical factors for the demolition contractors to identify the material availability.

Is the time frame in which the demolition of the donor building is carried out and the execution of the new project a critical factor, considering the storage-related issue?

It depends on the complexity of the projects. If the project generally requires a bunch of standard-sized steel elements, it is not wise to store the materials for more than a year or so, as they could be available at a later stage as well.

Case-study Interview 4

What do you think about the feasibility of reusing structural steel elements on a large scale?

At the moment, it is in a niche stage. We don't have a structured supply of donor materials, so it's mainly the demolition contractor who is involved in the supply, and they have a relatively smaller market there. There are several initiatives for the marketplace, but they are not very established. The demand for new steel is way greater than the availability of steel from demolished projects, which means the supply will not be sufficient to meet the demand. At the moment, it is more expensive than new steel. When we did the project, we made a design, and various contractors were asked to provide a quotation for the design. The contractor said that if we make it traditionally and use new steel, we could do it more cheaply than usual. However, the enthusiasm of the client took the project forward. The client was aware that the project could be a bit more expensive right from the start of the project. So more budget was allocated taking into account these factors. Thus, we were able to stay within budget. The contractor said this could be economically feasible and our experience with the BioPartner 5 project is that we were able to stay under budget. But in general, my experience with other projects shows that it turns out to be a bit more expensive.

Was the project more commercially profitable for the parties involved?

Well, the project involves additional work and additional risks and uncertainties are involved within the project. I would say the project was less economically profitable. However, it was very profitable for our experience and exposure in the market, and we can do these kinds of projects in the future as well.

It is the enthusiasm that takes all the actors forward. We will have to ask for a specific additional budget for such a project. In most reuse projects, it is a puzzle to model the existing projects to see and identify all the elements in the building and how we can reuse them in the new building. Then we have to recalculate the various members. The additional work is to model the existing building elements to see how we can reuse them. Then we have to make them undergo several tests and inspections to determine their quality. We also need additional time to convince the local authorities. We also see deviations in recovered materials. Then we will be forced to ask for an additional budget.

Could you explain the testing and certification process? So initially you just have a visual inspection and then what convictions determine that the steel is feasible to be reused in the new building?

First, we do the archival data study. We try to look for drawings and calculations or any available certificates about the steel. If there are drawings that depict the steel quality, we can just do some tests to verify if it's true. Then you don't have to conduct a bunch of tests for each element. It will be more or less verification of what you have already found on paper.

If there is no archival data, then you can do some calculations based on where the element was used and whether the load will be lower in the new building compared to the old one. Then you have to do some additional testing to see the material's strength and identify the materials used. Since the steel will be repaired or altered further, you will have to see if the material characteristics are weldable further. If existing connections are reused, the welded connections, then the welded connections are critical. The quality of the welding should be checked.

When you identify the available materials from the materials, do you also define a tolerance limit?

We even define the tolerance limits or deviation limits on new steel as well. Certain deviation limits are acceptable for the materials. If there are deviations, we need to check if they go into critical positions. If you see them in critical positions, if we need to take particular measures to correct them, or in the worst situations, we might have to cut the steel parts. We also check, in the recovered materials, whether the deviation falls under the acceptable limits for deviation in the new steel.

What are the material characteristics that determine whether the steel is reusable?

Yes, definitely. Strength is the main factor. Weldability is also an important factor, and it depends on the composition of the material. Also, if you are reusing the welds in the elements, weld tests should be conducted.

In your opinion, what could be the chronological order of the processes involved in such projects?

Well, it depends on the complexity of the project. In a very square standard design, you can maybe first design and then look for materials. But for complex buildings, you could make a preliminary design and then look for materials in the market. However, currently, the market for donor materials is not sufficiently established. Then, in my opinion, that's an option. But if you get sufficient time for project execution, then it will be fine if you have ample time for sourcing the materials from the market. It will be more expensive if we hold the project intentionally to source the recovered materials. But if the market gets more established, then it will be more possible. So at this point, you need to be more pragmatic, and I believe that the donor materials should be leading the design process.

What are the success factors that you identify in projects with the reuse of recovered steel elements?

- The design should fit the available materials.
- Carefully choose which elements could be fitted with reused materials and which elements should use new steel. This is applicable for components as well, which take into account connection and welded parts.
- The testing should be conducted in the early phases of the project.
- For complex buildings that fall under execution class 3, especially high-rise buildings, the reusing of steel elements may not be an option to consider because there are additional strength and quality requirements for the steel.
- Disassembly of the materials is different from the demolition of the building. Specific instructions should be communicated to the demolition contractor, explaining the protocol for careful disassembly. The protocols for storage of the materials and transportation of the recovered materials should also be addressed.
- It is important to find an excess of materials that could provide sufficient materials for the construction. It is common for materials to undergo different deformations.
- All the players need to be committed to the process. It could be quite common that you might be subject to several uncertainties or deviations from what is planned. Therefore, the commitment and enthusiasm of the actors involved in the project are important.

Who performs the repairs on the recovered steel elements and what are the particular instructions given to the steel contractors?

Some elements might be too long or too short. Then they come up with solutions as they are experienced in dealing with similar tensions. We validated the approach.

Is it common that the new steel also undergoes several deformations when reaching the site?

Yes, definitely. But in the case of the donor materials, it is often seen that they undergo several stages of the recovery processes or cycles like dismantling, storage, and transportation. This extended handling can cause more deformations when compared to new steel.

Do designers tend to overdesign when they have a mindset that they are designed to incorporate the reuse of steel?

Yes, we tend to stretch the tolerance limit. Then we tend to be more conservative and give more margin because we think the materials might have undergone deformations. This also reflects the lack of availability of materials as well. This way, we try to increase the incorporation of reuse of materials into the design. If the design includes new steel, then we can develop a design that is more optimised.

In your opinion, what methods can improve the potential of reusing structural steel elements?

- Imposing a larger tax on new steel elements. If the tax gets higher, then you have better margins to realise the reuse of steel.
- Now we are dependent on clients who are enthusiastic about doing such projects and have the ambition to take the extra mile.
- Also, as environmental assessments get stricter and more efficient, the motivation and urge to reuse materials improve.

What changes would you be bringing into the early stages of the project different from the BP5, if you would go for another project?

We developed a way of modelling where we choose elements from the donor materials to be used in the new building. We developed a mindset to prepare detailed design calculations earlier in the process to assess the reusability of the materials. We also developed a protocol to address the points of tension and communicate with the demolition contractor. We used this to prove to the contractors, clients, and local authorities that we are experienced in the process.

Do you demand particular information from the demolition contractor to be retrieved from the decommissioning audit?

At the initial project meetings, we define the protocol for the demolition contractor and communicate the requirements right from the start.

What do you think about incorporating a stakeholder like a sourcing manager into reuse projects?

If you have already found a donor building in the market and you tend to design around them, then such a party is not critical. However, if you are developing a design first and then looking for donor materials, then the role could be an interesting position to be included in the project team.

Is developing a flexible design considered an approach which could improve the utilisation of steel?

Yes, because, considering the current scenario, developing a detailed design and then trying to source materials from the market will be a very difficult process to be successful.

Is there a protocol or guideline available in the Netherlands that can be followed?

No, they are currently in the process of developing one.

Do you see that there is a positive nature to reusing steel in buildings?

There might be some uncertainties or risks reduced for some parties involved. Most of the parties involved in the industry involved in the reuse projects are pioneering in the field. So, over time, as the codes and protocols are developed, more parties will be capable of doing the same.

Were the local authorities positive towards the designing and reusing of steel in buildings?

It depends and varies from different municipalities. In the early design stages, we had meetings with them. We addressed the tension points they had regarding the design or execution.

Appendix C: Design principles and critical factors that could improve the potential of reusing structural steel elements

As several industry experts account, there are two major considerations in the design process which need to be addressed for the successful implementation of the reuse of structural steel elements.

If the design is developed first and then efforts are made to obtain the necessary materials to fit in the design, then taking into account the trends of the industry we may not be able to discover pertinent recovered materials for reuse. The designer must take this into account and create a flexible design. Following such an approach, we might be able to increase our chances of finding materials that are suitable for the design. This gives you more choices since there are additional sizes and steel profiles that you may use to meet the design requirements and the functionality of the components (Interview 7). A simple design with more standardized components and readily accessible steel profiles and sizes are also advised. The sourcing options are further limited if a complicated design is created.

In contrast, it becomes difficult for the project team, which includes architects, designers, and contractors, to determine what materials, quality, and quantity implications of elements are needed to achieve the functioning of the structure based on the business case and client's requirements. The project team will also have to engage with several prospective parties during the sourcing stage, such as demolition contractors, (reuse) steel stockists, and several more parties holding a database of information regarding the market's available materials. In these circumstances, the parties engaged in procuring the materials must know the attributes and requirements the components should meet (Interview 8).

It is crucial to use a more adaptable and iterative design approach in light of both of these circumstances and the effects they have on the initiation phase. The project team may think about creating a conceptual design that will include building functions and satisfy the business case. The composition of the materials is specified in the structure's outline to meet the requirements of the building, and it may also include the tolerance limits or permitted deviations from the element specification in the design. Several interviewees noted that this may increase the likelihood of finding additional features that might be suitable for integration into the design with minimum alterations. Furthermore, even after sourcing a set of elements that could fit into the design, further adjustments or alterations could be made to the design that could enable more reuse of structural steel elements. This process continues until the sourcing of materials is completed. Also based on the analysis of critical points in the design, the designers could choose between virgin materials or recovered materials. If the recovered materials need to be used at critical load points in the design and are identified with particular deformations which could affect the stability of the structure, then the designers would consider using virgin materials for that section. Therefore, as mentioned earlier, this iterative design process helps the project team to proceed further in the exploration and exploitation of available opportunities in the market.

- Early on, the client, design team, and contractor must show a sincere commitment to the notion of reuse (Interview 3; Interview 4, Interview 5; Interview 7; Interview 9).
- Early consideration of the use of reused materials is advantageous since it gives more time to locate steel sources (Interview 4, 5).
- In the early design phase, giving a general idea of the sizes and lengths of steel sections makes it easier to locate sources for the salvaged steel (Interview 1; Interview 8).

- There needs to be a better connection between the demand for reclaimed steel and its supply. It would be useful to have access to a schedule of demolition projects, each with a brief project description (Interview 6).
- The ability to accommodate the available steel sizes is made possible by the design approach's flexibility. Since standard steel diameters are more likely to be accessible as recovered, using them in the design helps. Due to the limited supply of this kind of salvaged steel, long spans might be problematic (Interview 1).
- The design should be flexible enough to accommodate different structural element depths since the servicing system and the availability of recovered steel may need adjustments. Designing a flexible structural zone that can accommodate multiple structural solutions can help achieve this (Interview 1).
- Steel storage might be a problem if it is discovered very early in the process. However, there may be steel stockists that are prepared to store the steel for a long time. Additionally, it is conceivable to rent out storage spaces to store salvaged items at a comparatively cheap price (Gorgolewski et al., 2008).
- It is not a feasible option to store the identified steel for a very long time if the sourced steel is nearly meeting a more readily available type of steel profile. It could be an option if a considerable amount of steel sections belong to specific profiles that are not easily traceable and are critical to the developed design (Interview 8).
- It matters what kind of contract is employed for the building. In comparison to a standard tender contractor, a management contractor could be more eager to accept the project goals of reusing materials (Gorgolewski et al., 2008).
- If steel is being collected from ongoing demolition projects, timing is crucial. A minimum of two to three months (depending on the quantity necessary) should pass before the recovered steel is required for the new project. If the two projects, demolition and construction, are closely coordinated, success is more likely. The timing issue might be resolved by purchasing the steel beforehand and storing it until it is required (Interview 6).
- If the steel originates from a project for which original documentation is available, identifying its structural qualities will be simpler (Gorgolewski et al., 2008). This documentation reflecting the historical usage of the materials helps to fewer the testing of the materials.
- If the state of the reclaimed steel surface is not well established, determining the cost of fabrication may be challenging. The accuracy of the fabrication bid would be increased by a detailed description of the salvaged steel that included pictures or a chance to view it (Interview 8).
- Quality control is crucial throughout the deconstruction of steel to prevent damage that can render the steel useless (Interview 6).

Mitigation measures to limit the challenges associated with reusing structural steel elements

As mentioned earlier, currently the availability of materials for reusing are from buildings that were already in use for the past 25-50 years or even more. It is a well-known fact that buildings were not designed with a vision that these materials can act as a material bank for future buildings. This limits the possibilities of safe extraction of materials from the buildings in such a way that they can be incorporated into the new building. A new design approach is gaining greater prominence in the industry recently, which is design for reuse. In this approach, buildings are designed with the ambition of recovering the materials and using them further in a new building. Architects considering the possibilities of the same and the willingness of the client to explore its possibilities are critical factors that can improve the potential of reusing structural steel elements. The limited protocols available suggest following a simpler design which includes similar elements and connections with minimal different types of steel sections and connections. Thus including a limited range of materials and specifications can improve the potential of reusing the structural steel elements.

Often, a lack of awareness of the direct and indirect benefits is witnessed among the client and project actors. Improving the same by communicating and motivating them, especially the financial benefits and the commercial potential of adopting the practice of reusing structural steel elements can facilitate more interest and demand. As the industry is changing and businesses today are often steered by sustainability, clients are interested in ESG-related benefits, accreditations and certifications like LEED, and BREAM. Framing the business case and benefits associated with reusing structural steel elements helps in developing the enthusiasm and willingness of the clients to explore and exploit the opportunities further.