DESIGNING FOR REUSE WITH RECLAIMED CONCRETE FROM END-OF-LIFE BUILDINGS

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ABSTRACT

In response to the environmental challenges posed by the construction industry's extensive use of concrete, this research focuses on the reuse of load-bearing concrete elements from end-of-life buildings. Emphasizing the 'Design for Reuse' (DfReu) principle, the study aims to integrate reclaimed concrete into new construction projects. Four chapters delve into construction techniques, concrete reclamation methods, demountable integration, and a practical case study of the former Ministry of Social Affairs and Employment. The findings mark the feasibility of reclaiming structurally sound concrete, with the case study revealing substantial environmental benefits. This research contributes valuable insights to the global call for circularity in construction practices, urging a paradigm shift towards sustainability and adaptability.

KEYWORDS**:** *Material Reuse, Concrete Reclamation, Deconstruction, Designing for Reuse (DfReu), End-of-Life Buildings, Prefab Concrete*

I. INTRODUCTION

The construction industry's environmental impact has become a pressing global concern due to its substantial contribution to CO_2 emissions, resource depletion, energy consumption, and waste generation. In the Netherlands, initiatives such as 'Nederland Circulair in 2050' and the 'Transitieagenda Circulaire Bouweconomie' highlight the urgency to achieve 50% circularity by 2030 and 100% by 2050 (Arnoldussen et al, 2020). Despite these efforts, the construction sector's environmental impact remains alarming, accounting for up to 12% of global CO_2 emissions in 2020. (*Buildings and Construction*, n.d.)

The need for circular solutions, particularly in material recirculation and reuse, becomes clear, providing a way to address and minimize environmental impacts. Reusing materials emerges as a promising avenue to minimize construction and demolition waste, replace primary materials, and decrease the carbon footprint of the industry. This provides not just environmental advantages, but also substantial economic potential given the large volume of construction and demolition waste being saved. (Bertin et al., 2022)

Concrete, a widely used construction material globally, presents a significant challenge during demolition, often leading to serious amounts of waste. Notably, non-residential buildings that are reaching their end-of-life, such as the former Ministry of Social Affairs and Employment, often contain a vast amount of concrete in their structures. To address this challenge, a sustainable approach involves exploring techniques for reusing load-bearing concrete elements, paving the way for a more environmentally conscious construction industry. (Knutsson, 2023)

1.1 Objective and Research Questions

This research aims to propose a viable solution within the construction industry, with a focus on reusing existing concrete elements from end-of-life buildings that are still structurally sound. Emphasizing the 'Designing for Reuse' (DfReu) principle, the primary goal is to formulate methods and strategies facilitating the reclamation and the integration of reclaimed concrete for new construction projects.

The overarching question guiding this research is: "*How can reclaimed concrete from end-of-life buildings be effectively integrated into new building projects and create future ease of disassembly and reassembly*"? This question leads to four sub-related questions that provide a more specific context for answering the overall research question. These questions are divided into four chapters, as follows:

Chapter 1: "*Which construction technique with concrete is commonly used in end-of-life buildings and is suitable for reclamation*"? The chapter will focus on the choice of concrete construction techniques commonly used in end-of-life buildings, with a spotlight on the reclamation potential of prefab concrete in utility buildings constructed in the Netherlands post-1970. Chapter 2: *"What kind of techniques are used for concrete reclamation, and which techniques are suitable for which construction type"*? This chapter explores concrete reclamation techniques and their suitability for different construction types, emphasizing considerations before and during disassembly, stability assessments, and tools involved in the process. Chapter 3: "*How can reclaimed concrete elements be implemented in a demountable way for new construction purposes*"? The chapter concentrates on the integration of reclaimed concrete elements into new construction, introducing the principles of Design for Reuse (DfReu), emphasizing Materials Passports, and exploring demountable precast concrete systems and connection techniques. Chapter 4: "*How can a typical end-of-life building, planned for demolition, provide its structure to facilitate the reuse of concrete elements for a demountable building project*"? This last chapter engages in a case study of the former Ministry of Social Affairs and Employment, practically testing the theoretical framework. It assesses the potential for repurposing concrete elements, considers deconstruction processes, evaluates element properties, and estimates energy consumption.

II. THE USE OF CONCRETE IN THE NETHERLANDS

The question addressed in the first chapter is: "*Which construction technique with concrete is commonly used in end-of-life buildings and is suitable for reclamation*"? The main focus of this chapter is the reclamation potential of prefab concrete in utility buildings constructed in the Netherlands after 1970. The reason behind this choice is rooted in several key considerations, including the widespread use of concrete in buildings, clear demolition trends in recent years, and the characteristics of prefab concrete.

2.1 Concrete in End-of-Life Buildings

Concrete, making up about 80% of building materials in the Netherlands in both utility and residential structures, emerges as a crucial contributor to the environmental footprint of buildings (Arnoldussen et al, 2020). A thorough analysis of demolition data reveals a noticeable shift in the types of buildings undergoing deconstruction. The era of post-war housing, mostly built between 1945-1970, is seeing demolition due to quality concerns and evolving building standards (see Figure 2.1). But more interestingly, the research from Arnoldussen et al. (2020) reveals a significant proportion of younger non-residential utility buildings, especially those constructed after 1970, that faces impending demolition. This underscores the critical need to explore sustainable alternatives for the future of their materials (see Figure 2.1).

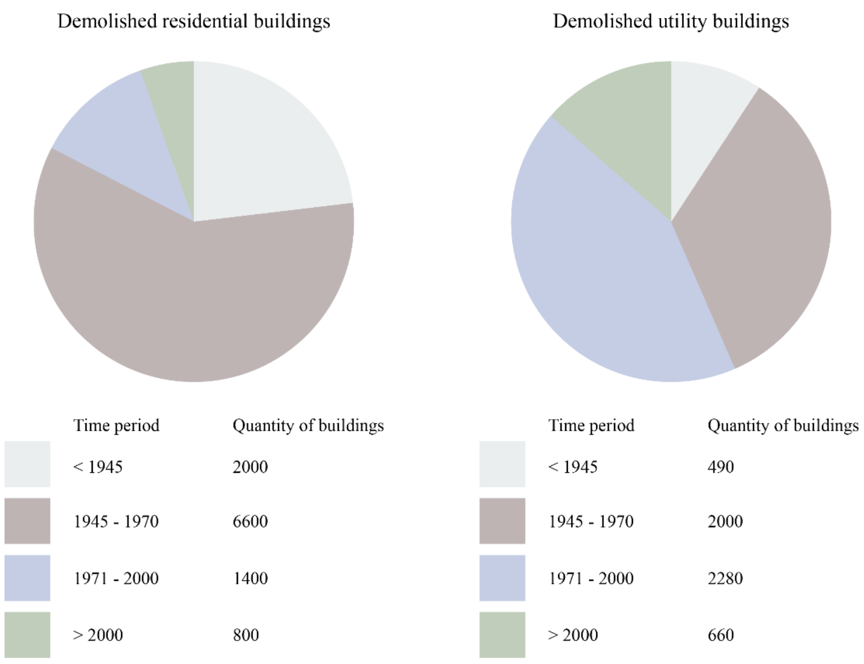

Figure 2.1 Demolished residential and utility buildings in the Netherlands (Adapted from Arnoldussen et al., 2020)

The material flow analysis of 2014 adapted from Arnoldussen (2020) (see Appendix A1) reveals that a significant volume of concrete is still being used in the construction of new residential buildings, making reclaimed concrete reasonably applicable for the construction of new housing projects. On the opposite side of the flow, a considerable portion of concrete comes from the deconstruction of utility buildings, primarily from buildings dating from 1971 to 2000. Concrete salvaged from demolished residential structures, mainly constructed between 1945 and 1970, is deemed practically non-reusable for a second life, especially dating from the early years. In the post-war years, concrete was being used as prefab construction material, but particularly in lightweight concrete hollow blocks where, once assembled, concrete was poured to create stiffness, making reclamation nearly impossible. It wasn't until the mid-1960s that prefab concrete structures began to be built on a larger scale, incorporating substantial walls and floors that simultaneously served as the load-bearing structure (BouwhulpGroep advies en architectuur, 2013). At the same time, an increasing number of in-situ concrete structures were built in the 1960s and 1970s. However, the limitations of these structures, particularly in load-bearing capacities, emphasize the threats of reclaiming from in-situ concrete (Andeweg et al., 2007). Additionally, difficulties can emerge during the reclamation of in-situ concrete, particularly when the cutting of reinforced steel becomes necessary. In-situ structures in the Netherlands typically use concrete of strength classes C20/25, C25/30, and C30/37, while prefab concrete demands higher strength classes, typically C35/45 or even C45/55 and C50/60 (thesis Janna Beukers, 2022). Reusing concrete elements from old buildings does not align with the systematic requirements of the building code (Bouwbesluit). Consequently, a solution must be devised to enable the safe construction using reclaimed prefabricated concrete. This is achieved through the principle of equivalence (gelijkwaardigheidsbeginsel), allowing the acceptance of solutions that are at least equivalent to the performance prescribed in the building code (*Het Gelijkwaardigheidsbeginsel Van De Omgevingswet - RegelMaat 2019, Afl. 6, P. 448 - Vakliteratuur Recht.nl*, n.d.). So, if hypothetically, you extract elements from in-situ cast concrete structures and intend to reuse them, you should consider these elements to act as individual prefab concrete components. Yet, the majority of in-situ concrete structures, with a maximum strength class of C30/37, then fall short of meeting the required strength class of prefab concrete, which now stands at a minimum of C35/45 (Braam et al., 2008). The reuse of prefab concrete elements is then considered preferable.

2.2 Different Time Periods

When an inventory and assessment of structural concrete is made, it is crucial to recognize the various types of concrete employed in different time periods. By looking at the historical aspects of concrete structures, one can learn from the changes by regulatory frameworks. These guidelines concerned fundamental design principles, calculation methods, and the oversight of reinforced concrete construction, which ultimately resulted in the establishment of the Eurocodes since 1990 (*EN Eurocodes | Eurocodes: Building the Future*, n.d.). This information, especially the strength class of concrete, is essential when assessing and comparing existing concrete with nowadays standards (see Appendix A2). Additional details and benchmarks can be found in the NEN 206-1 and the NEN 8005 for Dutch applications (*NEN-EN 206+NEN 8005:2016 Nl*, n.d.).

The evolution of the prefab concrete industry from the 1970s and 1980s onward has been marked by substantial development. Repeated elements, whether in smaller or larger series, were opportune for industrial production. The costs of these elements are low, allowing for highly economically attractive solutions. This is exemplified in floors, mainly hollow core slabs (HCS), where approximately 80% of all floors are executed in prefab concrete as industrial products (Bennenk & Huijben, 2013). The standardization of office building layouts, driven by the rise of rental offices, aligns seamlessly with the use of prefab elements, emphasizing rationality and flexibility. However, the energy crisis of 1973 and the subsequent recession prompted a shift in focus towards energy efficiency in building design. This transition led to facade innovations in insulation and climate control, restricting the use of prefab concrete primarily to structural elements as opposed to also its previous extensive application in facades (Rijksdienst voor het Cultureel Erfgoed et al., 2013).

III. (DE)CONSTRUCTION OF PREFAB CONCRETE

The second chapter addresses the following question: "*What kind of techniques are used for concrete reclamation, and which techniques are suitable for which construction type*"? This chapter explores concrete reclamation techniques, emphasizing considerations such as pre-demolition surveys and stability examinations. It covers common precast techniques, efficient deconstruction methods, and emphasizes post-disassembly checks for structural integrity in reclaimed elements for reuse.

3.1 Considerations Before Reclamation

Before reclaiming concrete from an end-of-life building, various aspects must be considered, including pre-demolition surveys, environmental impact assessments, condition surveys and documentation, concrete evaluation, and non-destructive testing methods for strength estimation. The selection of a removal method should consider numerous factors such as safety, finances, time limits, quality of concrete, quantities, location, aggregate hardness, compressive strength, environmental impact, specific risks, and utility locations (Committee & Institute, 2001). As most construction projects are unique, all deconstruction projects are as well. Therefore, a specific outline should be established for each particular building before deconstruction. However, some aspects of different projects can have similarities in the deconstruction phase, making it useful to gather knowledge and trends when planning a deconstruction.

Thorough examination of the stability of the building structure is crucial before disassembly to ensure worker safety. The suitability of concrete reclamation for different building projects, such as new apartment designs, involves considerations like fire resistance, size limitations, structural system, span direction and stability. Concrete reclamation also involves the development of using different methods for crack assessments, including visible damage assessment, ultrasound measurements, electromagnetic field strength meter readings, and concrete sampling for lab examination (Beton - Inspectie | Rijksdienst Voor Het Cultureel Erfgoed, n.d.). Disassembling precast concrete building structures requires extensive planning, analyzing future loads, reinforcement detailing, and connections against current codes (Beukers, 2022). When a precast building was built, its components were assembled in a specific sequence, with certain elements being temporarily supported. When dismantling the same structure, the disassembly follows a more or less opposite order. This means that certain elements may require temporary support again to facilitate the removal of other components. Consequently, it is crucial to conduct a comprehensive assessment of the building's stability during the disassembly phase before initiating the process (Salama, 2017). These considerations, along with the outlined key points, guide the exploration of concrete reclamation techniques and their applicability to different construction techniques.

3.2 Construction Techniques in Prefab Concrete

Within the precast construction industry, common construction techniques involving beams, columns, and floors employ various connection methods to ensure structural integrity and stability. Typical joints with compressive forces are crucial for supporting precast concrete elements, transferring their weight and imposed loads to foundations. Down below are the examples of the most commonly used joints described by Du Béton and Engström (2008).

Dowel connections (see Figure 3.1); involve steel dowels embedded in columns and inserted into beam holes. They transfer horizontal forces and add stiffness through semi-rigid behavior. These connections are later filled with grout or mortar to forge a stiff connection (semi wet connection). This part has to be removed carefully first to dismantle the elements. Beam-to-column dowel concrete connection is the most common connection used in the European precast industrial buildings (Minkada et al., 2021).

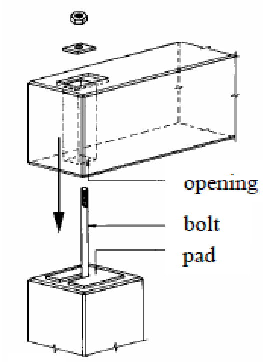

Figure 3.1 Dowel connection (Du Béton & Engström, 2008)

Steel plate connections (see Figure 3.2); function in a manner similar to dowel connections. They transfer horizontal forces by utilizing the height differences in the steel plates, preventing the beam from sliding relative to the column. In cases of substantial force transfer, it may be necessary to weld the plates together, if accessibility is feasible within the workspace (see welded connections).

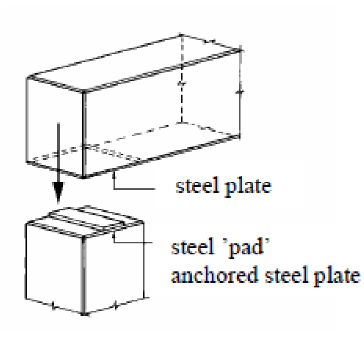

Figure 3.2 steel plate connection (Du Béton & Engström, 2008)

Grouted connections (wet connection) (see Figure 3.3); involve placing the precast elements in their designated positions and then filling the voids or gaps in between to create a stiff bond between the precast concrete elements. This job requires a high precision rate of chiselling and removing the grout between the prefab elements.

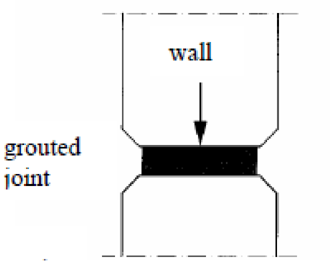

Figure 3.3 Grouted connection (Du Béton & Engström, 2008)

Welded connections (see Figure 3.4); prevalent in confined or heavily reinforced areas, employ methods like connecting components through projecting rebars or fully anchored steel plates. Welded parts between two concrete elements would have to be cut / sawn apart, but this brings in difficulties with placing the equipment in the right position, and sometimes leads to impossibilities in avoiding collateral damage.

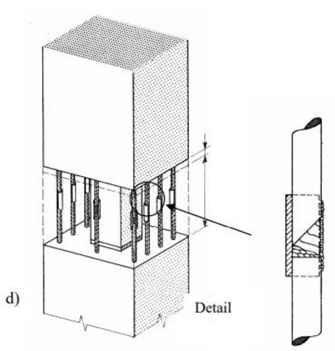

Figure 3.4 Welded connection (Du Béton & Engström, 2008)

3.3 Deconstruction Methods in Concrete

Precast concrete elements connected through various techniques offer different options for deconstruction based on a variety of ease and efficiency. Prefabricated (reinforced) components, manufactured with dry assembly methods and reversible assembly techniques like dowels, offer high deconstruction potential. (Semi)wet connections can be broken through force application while preserving the precast elements. Floor slabs without any structural concrete topping, for instance, can often be disconnected from each other by lifting one floor slab with a crane. This causes the unreinforced mortar connection between the slabs to break. Afterwards, the remains of the connection can be hammered off. However, this technique can pose problems when the wet connection is reinforced with steel bars or made with a strong mixture (Van Den Brink, 2020). If this is the case, various types of techniques can be used to dismantle the precast elements, including pneumatic hammering, diamond sawing, and hydrodemolition (Bertin et al., 2022).

Concrete deconstruction involves various techniques aimed at efficient and controlled removal of concrete structures. An overview of the most commonly used tools is given beneath (Committee et al., 2001).

Hand tools like pry bars, bush hammers, drills and pneumatic hammers are effective for small concrete removal tasks. Chiseling techniques can preserve original reinforcements for reconnection in the new building project, but with the pneumatic hammer there is a higher chance that the rebars and the surrounding concrete of the elements will be damaged. These methods are primarily useful for removing small pieces of concrete or mortar that are difficult to reach with heavier equipment.

Diamond circular saw blades are versatile cutting tools designed for use in a range of machinery, spanning from manually operated devices to 'walk-behind' semi-automatic equipment. Track-mounted saws are available for cuts in walls and the underside of slabs. Hand-held diamond saws are used for more practical applications such as smaller elements or more confined areas that are hard to reach. Prevalent diamond saws are capable of cutting through both concrete and steel (*What Are Diamond Saw Blades ?*, n.d.). The cutting action of the diamond saw is achieved through friction, and water is commonly employed during the process to prevent overheating and reduce dust. Although cutting speeds can vary we will assume a rate of 60 m/h when cutting a 200 mm thick floor (*CC3700E 3-Speed Electric Core Cut Walk Behind Saw*, n.d.).

Figure 3.5 (*Concrete Cutting, Stamped Concrete Patio, Pontiac, MI*, n.d.)

Another cutting technique is hydrodemolition using the Abrasive Water Jet (AWJ), which utilizes ultra-high-pressure water mixed with sand for localized concrete removal bit by bit. This technique offers advantages such as precise control, limited material losses, rapid execution without microcracks, preservation of steel rebars and it is suitable for both normal and high-performance concrete. The traverse speed, or cut speed, depends on factors such as material thickness, operating pressure, water flow rate, abrasive quality and quantity, the shape to be cut, and the desired edge finish (*Hydro Cutting Concrete*, 2019). Based on concrete cutting demonstrations, an assumption of a traverse speed of 6 m/h can be made (*An Engineer’s Guide to Waterjet Cutting*, n.d.). An additional advantage of employing AWJ is the potential integration with Computer-Aided Design (CAD) and robotic machinery, allowing for enhanced precision in manufacturing standardized components (*Hydro Cutting Concrete*, 2019).

Figure 3.6 (Aquaforce Concrete Services, 2021)

3.4 Structural Integrity of Reclaimed Concrete

According to Volkov (2019), certain technical considerations must be addressed before disassembling elements. These include evaluating the internal forces and moments at the potential disconnection point, ensuring the safety of the remaining structure, and assessing the rebar placement within the element. In precast concrete, connections typically have minimal bending moments because the elements are statically determined. However, complications may arise where elements like floor slabs, columns, and beams need to be shortened to meet the dimensions of a new building. If the cut is made near the connection, bending moments remain small and do not significantly impact structural behaviour. Floor slabs, like hollow core slabs (HCS), are generally unaffected by shortening due to a constant section and reinforcement throughout their length. Additional structural toppings that are placed on HCS increase the bending moment capacity. The column capacity is also usually minimally affected by shortening. Beams, on the other hand, are most susceptible to the effects of shortening, mainly due to variations in reinforcement configuration at the beam ends. Shear reinforcement near the support is typically denser, and cutting the end of a beam may reduce the bending capacity. However, since the length of the beam is decreased, the shear load due to the uniformly distributed load, will decrease as well. Checking and adjusting shear capacity may be necessary, but it is unlikely to significantly affect the load-bearing capacity of the beam. If needed, a method for enhancing the bending moment of a beam is the application of carbon strips. (Van Den Brink, 2020)

After disassembling concrete elements, it is crucial to thoroughly check and address any damages that may have occurred during the process, such as spalling of corners and edges. These damages should be repaired on-site or at the storage location to ensure the structural integrity of the elements before their reuse in a new building. In cases where missing concrete is in a tension area of an element, it also needs to be filled with concrete, although achieving precision may be more challenging. If the reinforcement is excessively bent or damaged, it can be replaced. A practical approach is to extend a piece of the old reinforcement from the concrete, allowing the new reinforcement bar to connect to the old one (Van Den Brink, 2020). Various mechanical coupling systems or welding can be employed for this purpose (see Figure 3.7). Careful consideration and appropriate repairs are essential to ensure the structural soundness of the concrete elements before their incorporation into a new construction project.

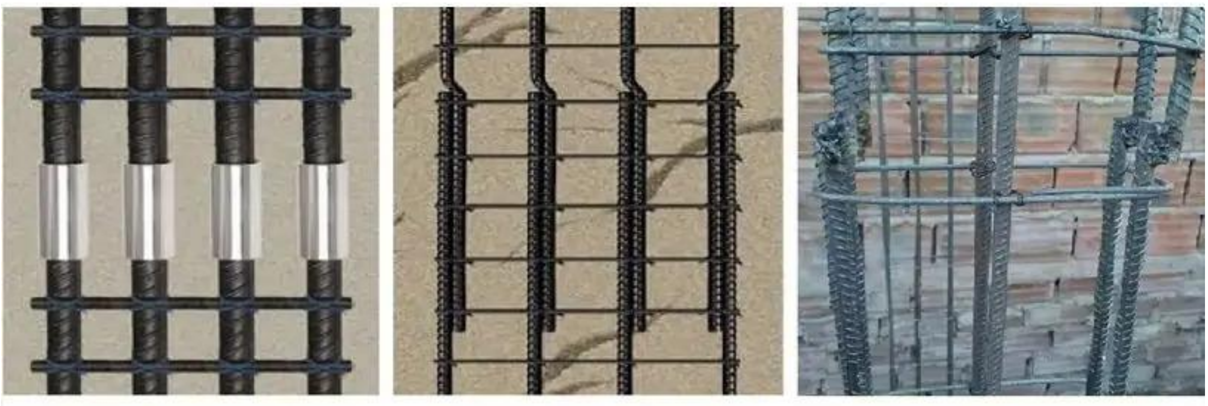

Figure 3.7 Coupling systems for rebars; coupling, lapping, welding (Daily Civil, 2023)

IV. INTEGRATION OF RECLAIMED CONCRETE

The chapter focuses on the integration of reclaimed concrete elements in new construction through the lens of Design for Reuse (DfReu), introduced by Gorgolewski (2017) and Iacovidou and Purnell (2016). The overarching question addressed is, "*How can reclaimed concrete elements be implemented in a demountable way for new construction purposes*"? The text provides comprehensive insights into the principles, practical applications, and concrete connection techniques. It also emphasizes the importance of the Materials Passport in the construction industry.

4.1 Design for Reuse and Materials Passport

Design for Reuse (DfReu) is introduced as a framework for incorporating reclaimed components into new construction designs. It involves maximizing the reuse of construction components and considers the dismantling process. DfReu draws from the concept of a reversible building, emphasizing the flexibility of the structural components of the building, to accommodate various functions throughout its life cycles. Similar to DfD (Design for Deconstruction), DfReu helps to avoid solid waste generation during demolition, extends building service life, and promotes element reuse. (Bertin et al., 2022)

The establishment of a Materials Passport is of great importance when designing for reuse (see Figure 4.1). To mine buildings effectively, it's essential to know the composition of the materials used, and this is where a Materials Passport comes in. It provides detailed information about the materials, products, and components used in a building. This information facilitates efficient recovery of valuable materials during demolition or renovation, preventing them from being discarded or dumped. (Block et al., 2020)

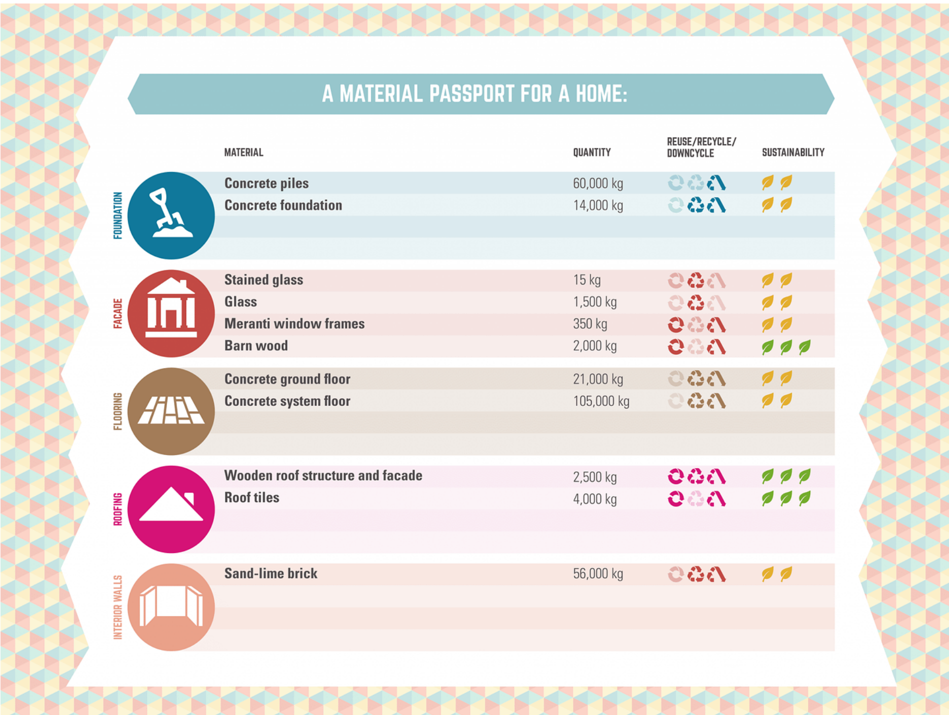

Figure 4.1 Simplified example of a material passport for a standard house (Block et al., 2020)

Design for Reuse principles are essential for ensuring that valuable components, elements, and materials can be disassembled for potential reuse or reconfiguration. Rios et al. (2015) argue that the economic benefits of DfD (/DfReu) will become more apparent as it gains acceptance. Pioneers of DfD (/DfReu) emphasize the role in conserving the value of materials and components (see Figure 4.2). According to Durmiševic and Yeang (2009), adopting DfD (/DfReu) allows buildings to adapt to changing user needs, promoting reconfiguration and reuse through the disassembly potential. Yet, it is important to maintain a constant dimensional system for achieving simplicity and flexibility in construction.

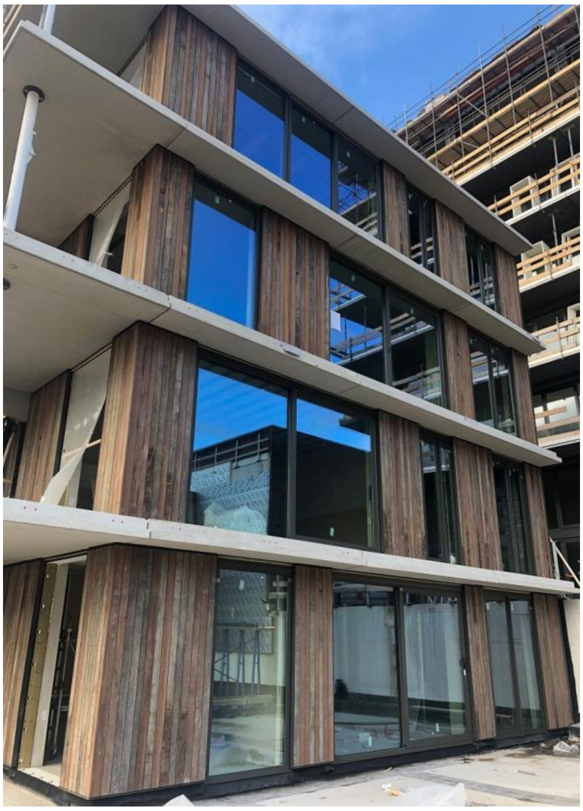

Figure 4.2 Project in Amsterdam, made with dismountable precast connections developed by Peikko. (*Circular Apartments in Buiksloterham Plot 20E, Amsterdam, Netherlands*, n.d.)

4.2 Benefits of Prefab Concrete Elements

Concrete is well known for its durability, with technical lifespans that can sometimes reach several hundreds of years, allowing multiple usage cycles (Salama, 2017). According to Bertin et al. (2022), reusing load-bearing elements is considered to be environmentally beneficial from the second usage cycle onward and especially when the number of reuse cycles increases. Nevertheless, it is essential to explore the long-term structural behaviour of the proposed connections and to take into account functional downgrading and losses occurring between usage cycles. Precast concrete elements are especially highlighted for structures with high transformation capacity and disassembly potential. They are deemed suitable for DfReu due to their quality, environmental benefits, and successful reuse in previous projects (see Figure 4.3).

Figure 4.3 Deconstruction project in Arnhem where all precast concrete elements, including floor slabs, facade elements, and core walls were reused at another location. (*Circulair Delven Van Kantoorgebouw Prinsenhof*, n.d.)

In the precast construction industry, dowel connections offer high demountability. Steel dowels are embedded in columns or beams and stiffened with mortar once joined. This dry pinned joint offers convenient disassembly in frame connections, aiding the deconstruction of reusable precast concrete elements. The downside of this connection technique are the large bending moments in columns, making it rather impractical for tall buildings (Ding et al., 2018). To address this, adding shear walls is recommended for high-rise buildings to reduce bending moments in the beam-to-column connections. According to Ding et al (2018), the use of high-strength grout can also enhance connection resistance, but it negatively affects the ease of dismantling the joint if needed in the future. The application of dowel connections and the corresponding method has thus to be considered when designing and depends mainly on the size of the new building.

4.3 Adapting Concrete Elements

Xiao et al. (2017) proposed a cost-effective moment resisting DfD concrete connection using welding instead of bolting. The method involves minimal cast-in-situ concrete for easy future deconstruction. Beam-to-beam connections are favored for DfD systems in concrete structures due to potential reinforcement continuity (see Figure 4.5). However, this method is not preferable if the reclaimed concrete components have to undergo significant adaptations to meet the technical requirements for this connection technique. Moreover, drastic modifications can influence the beam's bending resilience (Van Den Brink, 2020). On the other hand, if the adaptation is done once, it is ready to be reused for all following reuse lifecycles. Depending on the potential lifespan of the concrete and the lifespan of the new building, the design phase will tell if the adaptation is worth it or not.

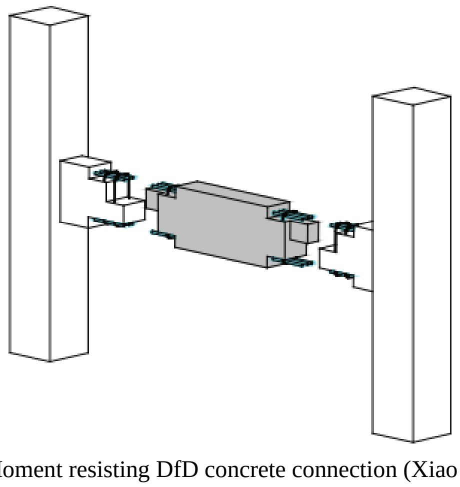

Figure 4.4 Moment resisting DfD concrete connection (Xiao et al., 2017)

Another proposed demountable precast concrete system is introduced by Cao et al. (2022), through mechanical fix joints using steel angles and tubes with high-strength friction grip (HSFG) bolts (see Figure 4.5).

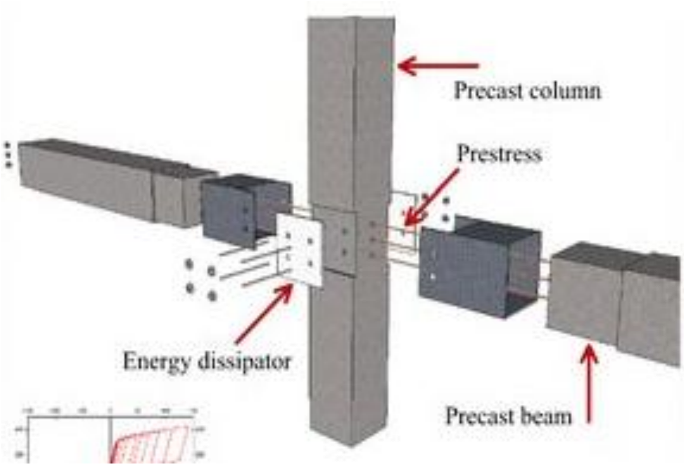

Figure 4.5 Demountable precast connection using tubes and bolts (Cao et al., 2022)

To use this hybrid technique adequately, the concrete elements have to be adjusted to fit in the building system, by cutting or sawing them into the right proportions. Beneficial is that the reclaimed structural elements don’t have to undergo internal adaptations, such as implementing new steel plates or rebars that have to be embedded in the concrete. An extra advantage coming with this building system is the high demountability of the structural elements for future perspectives (Høg, 2018). Once the modifications are done, the elements can easily be assembled and thus also be disassembled. This hybrid building system with precast concrete and steel connectors is therefore considered to be perfect for DfReu (Aninthaneni and Dhaka, (2014). What is important to realize is that concrete will be lost when cutting or sawing is necessary, and a considerable amount of steel will also be required to connect all the joints. This system will be particularly suitable in cases where the old connections are no longer applicable after extracting the concrete elements. Although there are not many projects built in this way yet, there are several researches suggesting significant potential with this construction system. A pilot project (see Figure 4.6) conducted by the Royal Swedish Institute of Technology demonstrates how this can work in practice, paving the way for future large-scale implementation (Corporación de Desarrollo Tencológico, 2022).

Figure 4.6 Pilot project by the Royal Swedish Institute of Technology demonstrating the reuse of concrete elements (Corporación de Desarrollo Tencológico, 2022)

For the reuse of concrete columns, Peikko developed a method where a shoe is fixed at the bottom of the column, which is mounted to anchor bolts in the foundation or columns below (see Figure 4.7 & 4.8). By bolting the column in four corners, stability is already reassured for the building. The column shoe is then casted with mortar to project the joints from external impacts. For the disassembly, the mortar is being removed by hydro-blasting while prevailing the concrete column. This method requires the adaptation when reclaimed concrete elements do not match the specific requirements for this technique. However, adaptations in the vertical axes have less influence in the bending moment of the concrete. (Yrjölä, n.d.)

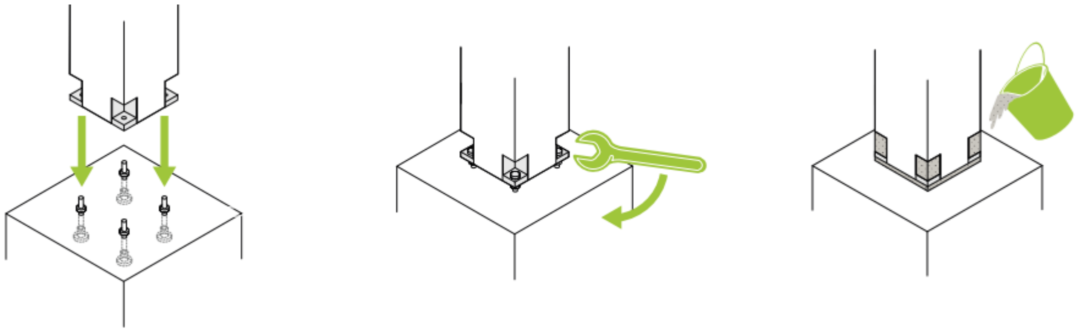

Figure 4.7 Reusable column by Peikko; assembling, fastening, casting (Peikko Group Corporation & Paananen, 2021)

The most convenient method for disassembling concrete slabs is by lifting the slabs loose from each other by force (Van Den Brink, 2020). So, when designing, it is essential to know the material strength properties of the mortar between the slabs to prevent unexpected challenges during dismantling processes in the future. A new construction method can be applied that also is developed by Peikko. The (reused) floor slabs are placed between two steel beams designed by Peikko where mortar is added in between the spaces. This technique helps to dismantle the floor slabs more easily when deconstruction is needed. This process is as follows; a cut is made along the beam disconnecting the slabs from the beam, followed by lifting the slabs up, and ending with chiselling off the remaining mortar from the beams, so that they can be reused again. (Peikko Group Corporation & Paananen, 2021)

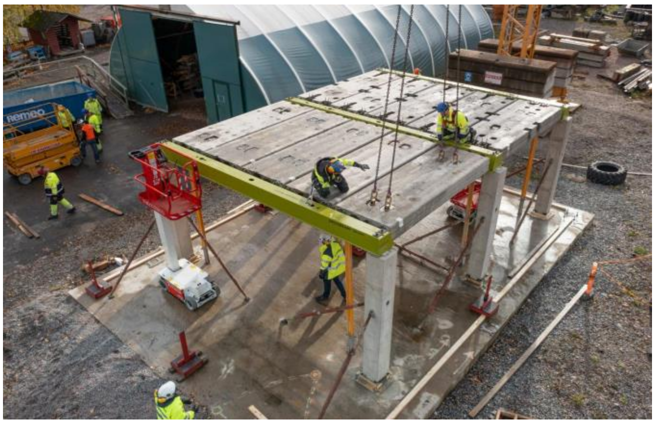

Figure 4.8 Construction techniques by Peikko involving reusable columns, beams and floors (Peikko Group Corporation & Paananen, 2021)

In essence, the choice of the best technique for implementing reclaimed concrete elements in a demountable way depends on the specific characteristics of the to be disassembled building and how the elements are interconnected.

V. DECONSTRUCTING A BUILDING

In the last chapter, a case study is introduced to test the theoretical framework in practice. The question addressed in this chapter is as follows: "*How can a typical end-of-life building, planned for demolition, provide its structure to facilitate the reuse of concrete elements for a demountable building project*"? The selected building that is being analysed for deconstruction is the former Ministry of Social Affairs and Employment. The methodology assesses the potential for repurposing concrete elements, considering deconstruction processes, element properties, and energy consumption.

5.1 The Building

The selected case study for this research is the former Ministry of Social Affairs and Employment, located in Bezuidenhout, The Hague (see Figure 5.1). The building is designed by the renowned Dutch architect Herman Hertzberger and was completed in 1990. Characterized by its unique architectural design and construction, the building is considered one of the icons of structuralism (www.architectuur.org, n.d.). It consists of interconnected octagonal units with a regular skeleton built from prefabricated concrete elements, allowing for flexibility in layout and future adaptability, Hertzberger explains in the podcast de Architect (Pit & Metz, 2022). With a total GFA of 60.000 m2, the construction features a repetitive pattern of equal spatial units, created by strategically adding or removing elements according to a specific pattern. This design approach enables a high degree of variability in the use and layout of the building, making it relatively easy to adapt to changing needs over time.

Figure 5.1 The Former Ministry of Social Affairs and Employment (Van Geest, 2023)

The use of prefabricated concrete elements is a key feature of the building's construction, allowing for a high level of quality and adaptability. The building's structure is primarily composed of prefabricated concrete columns, beams, and floor elements, which were carefully designed and detailed to facilitate efficient fabrication and assembly. The leading constructor for this project was Ir. R.J. van Foeken, from 'D3BN civiel ingenieurs'. (Ministerie van Sociale Zaken en Werkgelegenheid, n.d.)

The former Ministry of Social Affairs and Employment represents a significant example of innovative construction and architectural design. Its use of prefabricated concrete elements and thoughtful spatial organization make it an ideal subject for research on deconstructing and reusing concrete elements in future construction projects.

5.2 The Journey of the Building and its Fate

The former Ministry of Social Affairs and Employment has undergone a complex journey from its abandonment in 2015 to its imminent demolition, despite its notable adaptability owing to its construction and layout. To better understand the building itself and the reasons why demolition is on the agenda, Appendix B encompasses key events, ranging from the sale in 2016 to the current developments that have shaped its fate.

Since the building is planned for demolition while its concrete structure still functions in a technical way, it is essential to evaluate the potential for repurposing the functional concrete elements. To assess the environmental consequences, a thorough understanding of the deconstruction processes is necessary.

5.3 Element Properties and Load Capacity

In case of deconstruction, it is important to gather all possible information from documentations which are important for reusing. In order to reuse a structural element in a new situation, material properties should be known. Therefore, all available information about the structural element should be gathered by analysing architectural and technical drawings, element calculations and building codes. At first, all concrete elements in the existing building should be inventoried to gather an overview of all the to be extracted elements with their specific properties. In this case, the inventory is done via a 3D model of the building provided by the Architectural firm that designed the building and via archival documentations from Het Nieuwe Instituut (HNI) in Rotterdam. Appendix C1 provides a table with all the concrete elements in the building with its known properties.

To assess the viability of reuse, it is crucial to identify the intended future application for the structural element. By estimating the anticipated loads on the structural element in its future role, one can compare this with the element's loading capacity. This analysis aids in determining the structural element's suitability for its intended purpose in the future context. Since the scale of the GFA for the new program is twice as large (120.000m2) as the GFA of the current building (60.000m2) and the program must include open and public spaces, it almost is impossible to avoid vertical construction (*Anna Van Hannoverstraat 4: Toelichting*, n.d.). Therefore, a rough first estimation can be made for the future building, that the loading capacity (only based on the structural elements itself) can be up to 2.6 times larger than the current situation, see Appendix C2.

5.4 Deconstruction

The demountability of a structure relies heavily on how its various structural elements are interconnected. The ability to disassemble connections without compromising the initial function of the elements is a key factor in determining demountability. The design of the building plays a pivotal role in influencing demountability, as it dictates the ease with which connections can be dismantled while allowing the structural elements to maintain their intended functions. Since the selected building is constructed with precast concrete elements, the building offers a higher degree of demountability than an in-situ monolithic concrete structure. Yet, precast structures are not per se designed to be deconstructed, so there are various structural parts and connections that can be challenging to deconstruct. In Figure 5.2 a standard octagonal island is examined to be deconstructed step by step. Various methods from Chapter 2 are applied to dismantle the building in a specific order. The blue bars represent the cutting lines for the diamond saw, and the red bars represent the cutting area for the AWJ, see Appendix C3. The entire concrete's structure of the building can be disassembled by repeating the process of deconstructing an island. There are a total of 120 islands to be deconstructed.

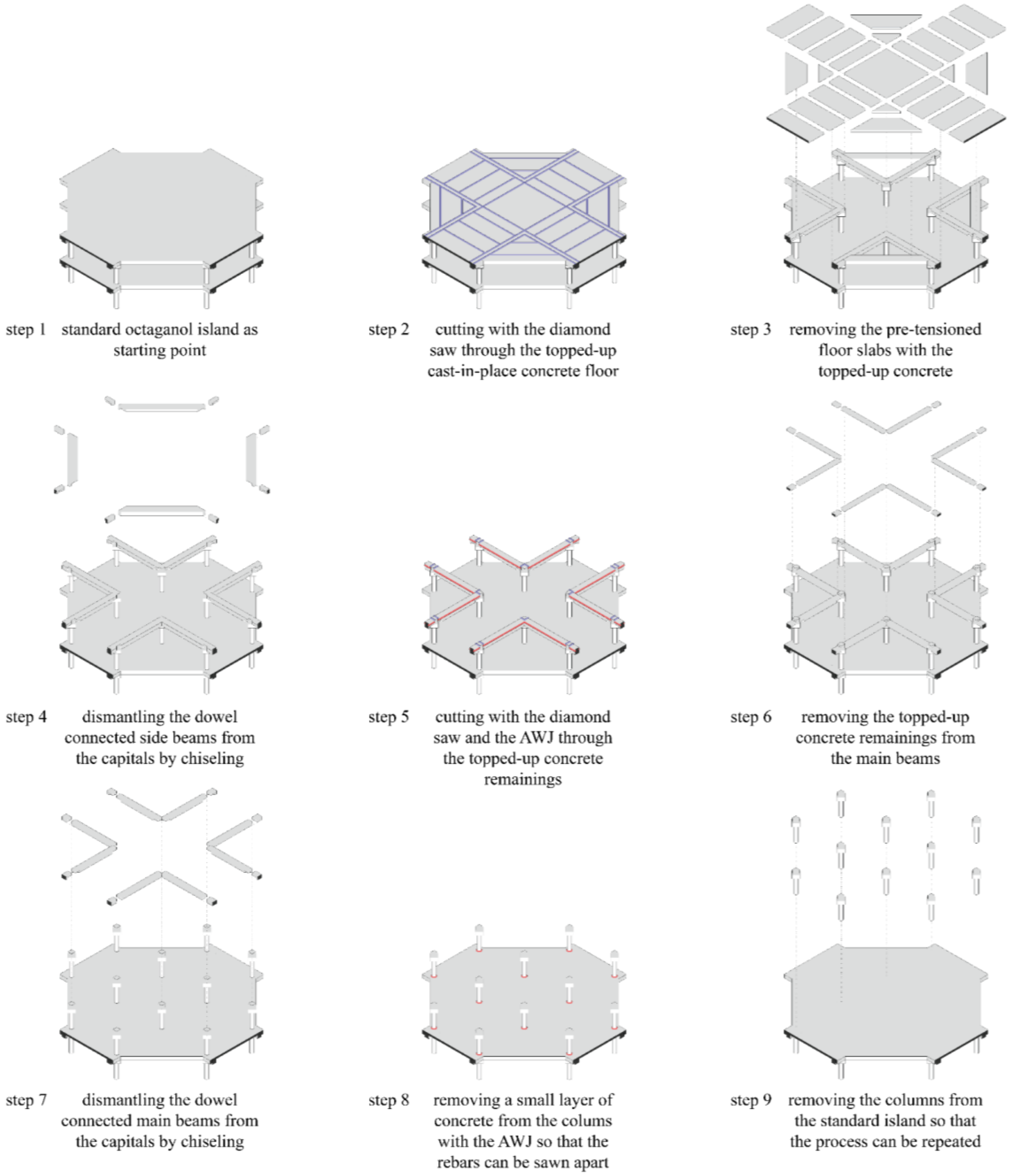

Figure 5.2 Deconstruction of a standard island

5.5 Post Deconstruction

If a structural element is deconstructed, it will first be transported for post-processing. Given that the new project will be built on the same site, the most efficient option for post- processing would be to do this on site. The way of post-processing a structural element strongly depends on the element type and the future situation in which the element will be implemented. Less required modifications result in less environmental- and economic impact (Bleuel, 2019), so reusing the existing dowel connections is preferable. In case that concrete or rebar damage occurs during disassembling or hoisting, it should be decided if the element is reparable and if this is affordable. For both the adaptation of the concrete and the steel reinforcements, technical tests are required and therefore the involvement and advice of a structural engineer is necessary. (Sun et al., 2020)

When the deconstruction process is known, the available building elements can be categorized and counted (see Figure 5.3). The design of the new building is heavily influenced by these elements, obtained during the disassembly of the building. The composition in which they were originally assembled will serve as the primary guideline for reconstructing the new building. However, not everything will be directly replicated, as the new challenge pertains to housing, with requirements that may significantly differ from the current office-oriented structure. Consequently, the new design will also play a small role in determining the use of these elements, making some of them less suitable for reuse in their original form and corresponding connections.

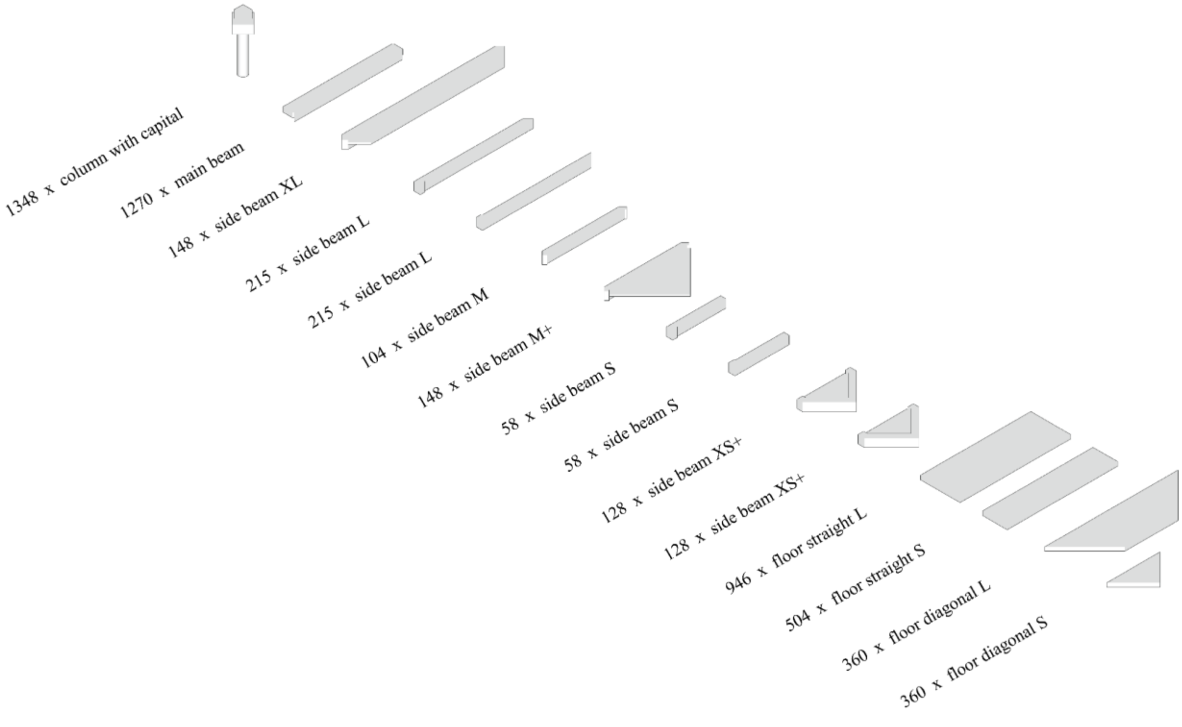

Figure 5.3 Reclaimed concrete elements of the entire building

To establish a sound design, a careful balance must be struck between utilizing as many elements in their original state as possible and incorporating techniques from Chapter 3 where necessary. Some 'old' connection techniques, for instance, may prove challenging to disassemble in the future, necessitating modifications. Thus, a distinction can be made between elements that are directly reusable, those requiring adjustments, and those no longer usable for structural purposes. In the latter case, a decision must be made on whether they can be repurposed or if downcycling is necessary.

Based on Figure 5.2 it can be observed that elements obtained through sawing or the use of the AWJ will require adaptations from Chapter 3 due to the severed connections. Elements with dowel connection on the other hand, are considered directly reusable and hence require minimal to no adjustments. Because the design of the building is yet to be made, and since the design of the new building plays a small role in determining the purpose of the elements, it is not yet possible to establish a full inventory with modifications for each and every element.

5.2 Energy Consumption Analysis

In the following section an estimation of CO_2 emission is made as a first step to check the viability of the cutting methods in comparison with the concrete produced for the construction of the former Ministry of Social Affairs and Employment.

In this assessment, three different equipment for disassembling the building are considered; the chisel hammer, the diamond saw and the abrasive water jet (AWJ). The latter two processes generate sludge and slurry, which are byproducts. However, these aspects have not been considered in the subsequent analysis of energy consumption. The energy consumption of hoisting and storing the elements are neither considered. In Appendix D1, all the necessary chisels, saws and cuts are established for all the structural elements, resulting in an estimation of CO_2 produced by disassembling the concrete structure of the building, see Appendix D2. This comes down to 51 tonnes of CO_2. A similar calculation can be made to determine how many tonnes of CO_2 has been emitted only for producing the concrete structural elements of the building. This amount of CO_2 embodied in the whole concrete structure comes down to 5844 tonnes of CO_2, see Appendix D3.

In contrast to traditional demolition, deconstruction is a more time-consuming process. The average deconstruction rate typically ranges from 50 to 100 square meters per day. Additionally, deconstruction demands a higher labour input. While traditional demolition may only require 1-2 workers, deconstruction often necessitates 4-5 workers. (Jabeen, 2020)

VI. CONCLUSION

This research has undertaken an exploration of the challenges and opportunities related with reusing concrete elements in the construction industry, with a particular focus on the Netherlands. The urgency to address the environmental impact of the construction sector, highlighted by global concerns about CO_2 emissions, resource depletion, energy consumption, and waste generation, triggers a deep dive into circular solutions, specifically in material recirculation and reuse. The research centred around the primary objective of reusing existing concrete elements from end-of-life buildings with a structurally sound structure. The overarching question guiding this matter: "*how can reclaimed concrete be effectively integrated into new building projects, ensuring future ease of disassembly and reassembly*", has led to a thorough exploration divided in four chapters.

The most common construction methods with concrete were examined in end-of-life buildings, highlighting the reclamation potential of prefab concrete in utility buildings constructed in the Netherlands after 1970.

This foundational understanding has set the stage for the following chapter, delving into concrete reclamation techniques and their suitability for different construction types. Stability assessments, pre-demolition surveys, and considerations before and during disassembly lay the groundwork for

ensuring the structural integrity of reclaimed elements. In the prefab concrete industry, several typical joints are commonly used, and all have their own characteristics. The importance of understanding the composition of the elements and its connections is necessary to determine which tool where and how to use to disassemble a concrete structure effectively.
The integration of reclaimed concrete elements into new construction, primarily through the lens of Design for Reuse (DfReu), emphasizes the principles of a reversible building and highlights the importance of Materials Passports. Several modification techniques and demountable systems are available if the reclaimed elements do not match the DfReu principles already.
In the final chapter, a case study is practically tested in the theoretical framework that has been worked out in the previous chapters. The potential for repurposing the concrete elements is high, as the concrete is still structurally sound, and most of the elements show ease of disassembly. In the disassembly of the entire structure, various deconstruction processes are involved and assessed to calculate an estimated energy consumption for deconstruction, which can be compared to the environmental impact of demolishing the building. The total CO_2 emissions from deconstruction are more than 100 times lower than the total embodied CO_2 in the concrete structure, which would be considered as ‘lost’ when demolishing the building. In addition to that, when reusing the elements, no new materials are required for the structure of the building, thereby avoiding additional CO_2 emissions associated with the production of new materials.

This research significantly contributes to a comprehensive understanding of challenges and opportunities related to reusing concrete elements in the construction industry, aligning with the global call for circularity in the built environment. The insights provided are valuable for industry stakeholders, policymakers, and researchers, emphasizing the need for a paradigm shift towards practices that not only reduce the environmental footprint of construction but also foster a more adaptable and sustainable future. Despite the technical viability of reclaiming concrete, achieving economic viability necessitates a radical change in our current economic approach towards natural resources. The shift towards full deconstruction and the efficient reuse of concrete should take place across various stages of the construction sector.

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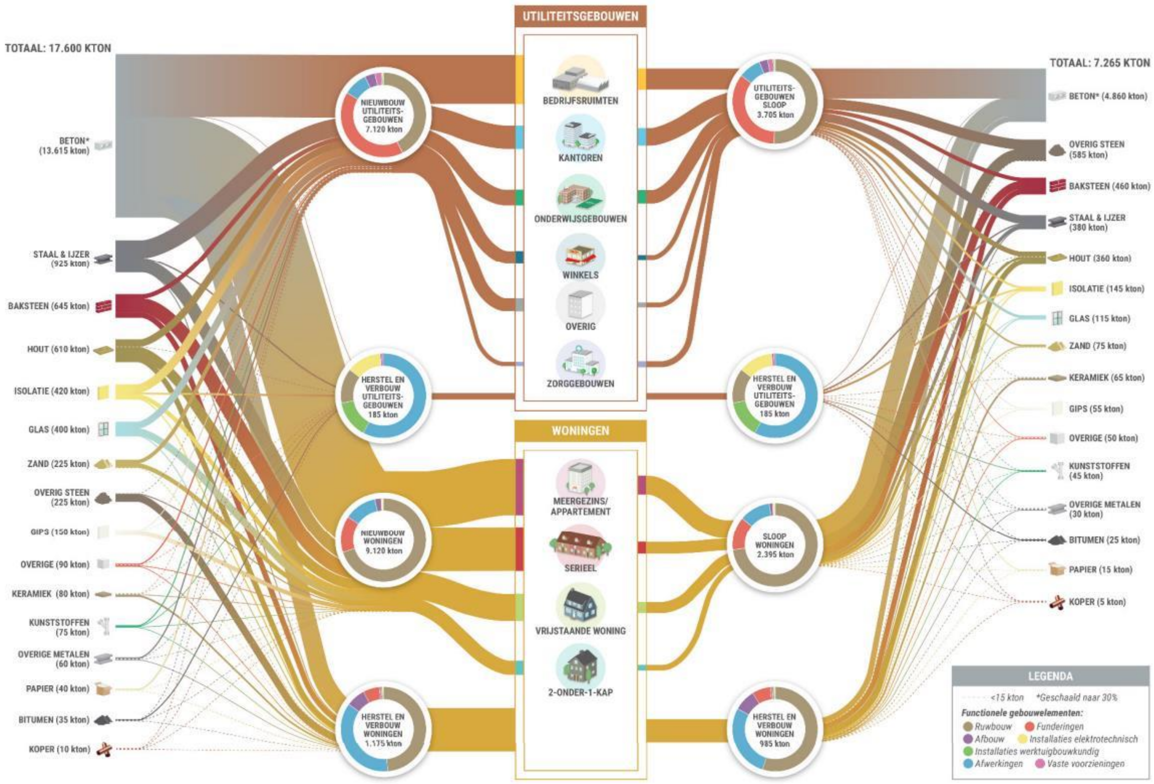
APPENDICES

Appendix A1



Mass balance between materials of housing and utility buildings in 2014 (*Beukers, J. M., 2022*)

Appendix A2

Old norm	Concrete grade	Concrete grade Eurocode 2 (2012)
GBV 1962	K160	< C8/C10
	K225	C12/C15
	K300	C8/10 – C12/15
VB 1974/1984	B30	C20/25 – C25/30
	B45	C30/37 – C35/45
	B60	C40/50 – C45/55
VBC 1995	B25	C12/15 – C20/25
	B45	C30/37
	B65	C40/50

Concrete compression strength properties from different time periods (*Beukers, J. M., 2022*)

Appendix B1

The Journey of the Building and its Fate

Sale and Initial Plans (2015-2016):
In 2015, the building became vacant after the ministry's departure, and in 2016, it was sold by the Rijksvastgoedbedrijf to Litoro Investments for €23 million. (Reconstructie, Archiweb 2023)

Redevelopment and Initial Challenges (2016-2018):
Litoro Investments, initially aimed to demolish the building and construct new buildings. However, conflicts arose as the municipality of The Hague at first favoured redevelopment, while Litoro and later MRP Development leaned towards demolition. Despite exploring redevelopment possibilities from 2016 to 2018, differences emerged between architect Herman Hertzberger and developer VORM, with the latter citing the incompatibility of the building with the new program's scale and urban design principles. (Reconstructie, Archiweb 2023)

New Plans and Political Shifts (2018-2021):
External parties engaged in redevelopment studies, presenting various plans. In 2019, MRP and VORM proposed a new plan for two thousand residences and other functions. By the end of 2021, the municipal council approved demolition, coinciding with a new emphasis on housing development by increasing the GFA from 60,000 m2 to 120,000 m2. (Reconstructie, Archiweb, 2023)

New Developments and Approval (2021-2023):
VORM became the sole owner, collaborating with Barcode Architects for new plans. The design included two blocks with four towers, each 75 meters tall, housing offices, public facilities and approximately 1200 residences. (Anterieure overeenkomst, Archiweb, 2023)

Zoning Plan for Anna van Hannoverstraat (Present):
Despite different protests, including those from Herman Hertzberger and AHH, on the 14th of December 2023, the municipal council of The Hague approved various plans, including the zoning plan for the site. The redevelopment aims to support growth in living and working spaces and enhance the train station area of Laan van NOI, necessitating the demolition of the building to accommodate the construction of 120,000 square meters on the site. The path is now clear for developer VORM to apply for the building permit, with construction anticipated to begin in the fall of 2024. (Raad stemt in met plannen, Archiweb, 2023)

Appendix C1

Book page nr. *	Type	Strenght classification *	Amount (excl. loss)	Dimensions in mm (length width height)	Cubic meters (m3)	Cubic meters total (m3)
p. 4	Columns + capital	B45: CC30/37 – C35/45	952	Ø 550 x 2550 + 990 x 990 x 530	1,29	1228,08
	Columns + capital	B60: C40/50 – C45/55	396	Ø 550 x 2550 + 990 x 990 x 530	1,29	510,84
p. 25	Main Beams	B45: CC30/37 – C35/45	1270	7080 x 690 x 530	2,46	3124,20
p. 40	Side Beams XL +	B45: CC30/37 – C35/45	148	10900 x 490 x 530	3,37	498,76
p. 26 & 27	Side Beams L 1&2	B45: CC30/37 – C35/45	430	7700 x 340 x 530	1,30	559,00
p. 47	Side Beams M +	B45: CC30/37 – C35/45	148	5450 x 340 x 530	0,95	140,60
p. 36	Side Beams M	B45: CC30/37 – C35/45	104	5450 x 340 x 530	1,69	175,76
p. 19	Side Beams S 1&2	B45: CC30/37 – C35/45	116	3490 x 340 x 530	0,64	74,24
p. 49	Side Beams XS +	B45: CC30/37 – C35/45	156	2900 x 350 x 530	1,19	185,64
	Floors straight L	unknown	946	7700 x 2560 x 250(+50)	4,55	4304,30
	Floors straight S	unknown	504	3850 x 2560 x 250(+50)	2,28	2152,15
	Floors diagonal L	unknown	360	8560 / 3430 x 2560 x 250(+50)	3,87	1393,20
	Floors diagonal S	unknown	360	3430 / 0 x 1720 x 250(+50)	0,73	262,80
Total	15		5890			14610

Inventory of concrete elements and its properties (*Adapted from Ministerie van Sociale Zaken en Werkgelegenheid, n.d. & 3D model AHH, 2023*)

Appendix C2

Type	Amount for one standard island	Cubic meters (m3)	Cubic meters total (m3)	Weight (kg) *
Columns + capital	12	1,29	15,48	38700
Main Beams	8	2,46	19,68	49200
Side Beams XL +	4	3,37	13,48	33700
Floors straight L	12	4,55	54,6	136500
Floors straight S	4	2,28	9,12	22800
Floors diagonal L	4	3,87	15,48	38700
Floors diagonal S	4	0,73	2,92	7300
Total	48	18,55	130,76	326900

	Standard 1 island	Max. now 8 islands	Max. potential ** 21 islands
Height (m)	3,54	28,32	74,34
Weight (kg)	326900	2615200	6864900
Factor of previous	1	8	2,6

References

* https://www.onlinebetoncentrale.nl/category/beton-storten/ — * weight of 1 cubic meter of concrete: 2500 kg

** Adapted from an interview with Laurens Jan ten Kate, AHH (2023) — ** max. allowed construction height for new plans: 75 m

Calculation of potential load capacity based on max. allowed construction height (*Adapted from Online betoncentrale B.V., n.d. & L.J. ten Kate, 2023)*

Appendix D1

	Type	Amount (excl. loss)	Chisels per unit	Saws per unit	AWJ per unit	Total chisels	Total saws	Total AWJ's	Chisels in meter	Saws in meter	AWJ's in meter	Total chisels in meter	Total saws in meter	Total AWJ's in meter
	Columns + capital	952	-	-	1			952			0,55			523,60
	Columns + capital	396	-	-	1			396			0,55			217,80
	Main Beams	1270	2	-	1	2540		1270	0,28		7,1	711,2		9017,00
	Side Beams XL +	148	2	3	-	296	444		0,53	3,75		156,88	1665,00	
	Side Beams L 1&2	430	2	-	2	860		860	0,53		0,29	455,8		249,40
	Side Beams M +	148	-	2	2		296	296		3,69	0,34		1092,24	100,64
	Side Beams M	104	2	-	-	208			0,53			110,24		
	Side Beams S 1&2	116	1	-	1	116		116	0,53		0,34	61,48		39,44
	Side Beams XS +	156	1	1	1	156	156	156	0,53	2,77	0,29	82,68	432,12	45,24
	Floors straight L	946	-	3	-		2838			4,07			11551	
	Floors straight S	504	-	3	-		1512			4,07			6154	
	Floors diagonal L	360	-	3	-		1080			3,57			3856	
	Floors diagonal S	360	-	2	-		720			3,43			2470	
Total	15	5890				4176	7046	4046				1578,28	27219,06	10193,12

Calculation of needed actions to deconstruct the building (*Adapted from Figure 5.2 & 3D model AHH, 2023*)

Appendix D2

	kW	Minutes per meter	Total amount in meter	Total minutes	Total hours	Total kWh	CO2 / kWh (kg) *****	CO2 emission (kg)
Chisel hammer **	0,65	5	1578,28	7891	132	85,49	0,37	31,63
Diamond saw ***	22,4	1	27219,06	27219	454	10161,78	0,37	3759,86
AWJ ****	75	10	10193,12	101931	1699	127414,00	0,37	47143,18
Total					2284	137661,27		50935
~ flights from Amsterdam to New York ******			51					

Calculation of energy consumption for needed actions to deconstruct the building (*Adapted from How Much Is a Tonne of CO_2?, n.d. & Wat Betekent CO2? En Wat Is De CO2-footprint Van Je Huis? : NN, n.d. &(An Engineer's Guide to Waterjet Cutting, n.d. & CC3700E 3-Speed Electric Core Cut Walk Behind Saw, n.d. & Manutan B.V., n.d.)*

Note: Numbers used in the calculations are based on data abstracted from different sources or based on estimations by watching videos

Appendix D3

	Average manufacturing kg of CO2 / m3	Total concrete in building (m3)	Total CO2 embodied in total concrete of the building
Cement *	350		
Concrete *	50		
Embodied *	400	14610	5843828
~ flights from Amsterdam to New York ******			5844

Calculation of embodied CO_2 in concrete of the building (*Adapted from How Much Is a Tonne of CO_2?, n.d. & Wikipedia contributors, 2024*)

REFLECTION

Looking back, my research and design project on the reuse of load-bearing concrete elements from end-of-life buildings has been a journey filled with both challenges and valuable insights. As I look back on my approach, it becomes clear that while certain aspects have worked effectively, others have presented notable room for improvement.

The core objective of my research was to propose a viable solution for integrating reclaimed concrete into new construction projects, aligning with the principles of Design for Reuse (DfReu) and addressing the pressing environmental concerns within the construction industry. The comprehensive understanding of the urgency for circular solutions, as outlined in the introduction, provided a solid foundation for framing my research objectives and methodologies.

One aspect where my approach proved effective was in conducting a thorough investigation into various construction techniques, concrete reclamation methods, and demountable integration strategies. This foundational research allowed me to develop an understanding of the challenges and opportunities related with reclaiming concrete elements, particularly in the context of end-of-life buildings. Additionally, the practical case study of the former Ministry of Social Affairs and Employment served as a real-world validation of the feasibility and environmental benefits of my proposed approach.

However, upon reflection, there were areas where my approach could have been further refined. One such area lies in the translation of theoretical frameworks into practical architectural design solutions. While I successfully managed to integrate reclaimed concrete elements into my design project, I encountered challenges in ensuring architectural coherence and aesthetic integrity. This resulted in a deeper reflection on the balance between sustainability goals and architectural considerations, highlighting the need for a more holistic approach that integrates environmental principles with design aesthetics.

Furthermore, the feedback provided by my mentors throughout the development of my project proved extremely helpful. Their insights and constructive criticism helped me to reevaluate certain aspects of my approach, particularly in terms of architectural language. I carefully considered their suggestions and recommendations, incorporating them into my work to refine and enhance the overall outcome.

In essence, my journey of research and design has been a continuous learning process, characterized by ongoing refinement and adaptation. While there were moments of doubt and uncertainty, particularly regarding the ambitious nature of my sustainability goals, my commitment to reduce the environmental footprint of (de)construction remained strong. Moving forward, I recognize the importance of a balancing between idealistic objectives and practical realities, using feedback and insights to develop a more nuanced approach on sustainable design practices.

1. **What is the relation between your graduation project topic, your master track Architecture, and your master programme Architectural Engineering?**

My graduation project, focused on the reuse of structural concrete elements from end-of-life buildings, is deeply connected with the principles of the Architectural Engineering programme. This programme emphasizes innovative solutions in engineered architectural design and urges students to address contemporary societal challenges. My research and design project align perfectly with these goals by proposing sustainable practices in construction, specifically through the circular use of materials. The master track Architecture within the Architectural Engineering programme supports the development of adaptive and sustainable architectural solutions. My project on reusing concrete elements directly responds to the programme's goals by seeking innovative, environmentally friendly alternatives to traditional demolition and new construction. By emphasizing Design for Reuse (DfReu), my work shows the programme's commitment to sustainability, adaptability, and reducing environmental impact.

2. **How did your research influence your design/recommendations and how did the design / recommendations influence your research?**

The research conducted in the first half of the year significantly influenced the design phase of my project. Initially, my research aimed to understand the feasibility of reusing load-bearing concrete elements, examining construction techniques, reclamation methods, and the practicalities of demountable integration. These findings were crucial in shaping the design strategies for the second phase. For instance, the knowledge gained about the structural integrity and reclamation potential of concrete elements informed the design of a building that not only incorporates reclaimed materials but also follows principles of reversibility and ease of future disassembly. The case study of the former Ministry of Social Affairs and Employment demonstrated that reclaimed concrete elements could be successfully integrated into new structures, highlighting both environmental benefits and practical challenges.

Conversely, the design phase provided insights back into the research, particularly in refining the practical application of DfReu principles. As I designed the building, real-world constraints and feedback from mentors required adjustments to the theoretical framework developed during the research phase, resulting in architectural and innovative implementations in the final design.

3. **How do you assess the value of your way of working (your approach, your used methods, used methodology)?**

The approach for this project involved a thorough initial research phase followed by a design phase based on the findings. This dual-phase approach proved effective in balancing theoretical exploration with practical application. The method of focusing on a specific case study (the former Ministry of Social Affairs and Employment) allowed for concrete, actionable insights rather than purely abstract concepts. The methodology of combining literature review, practical case studies, and design experimentation ensured a better understanding of the subject matter. By using the Design for Reuse principle as a guiding framework, I was able to develop design strategies that are not only environmentally sustainable but also technically possible to a certain extent.

4. **How do you assess the academic and societal value, scope and implication of your graduation project, including ethical aspects?**

Academically, this project contributes valuable insights into the field of sustainable construction and architectural engineering, also regarding that research on reusing concrete for structural purposes is still relatively limited. It connects theoretical research on material reuse and practical architectural design, offering a model that can be further explored and refined in future studies Societally, the project addresses urgent environmental concerns by proposing a shift towards circular construction practices. The reuse of concrete elements reduces CO_2 emissions, preserves resources, and minimizes waste, contributing to broader sustainability goals. Ethically, the project advocates for a more responsible use of resources, challenging the norm of demolition and waste in the construction industry. It promotes the idea that sustainable practices are not only necessary but also achievable with the right approach and commitment.

5. **How do you assess the value of the transferability of your project results?**

The results of this project are highly transferable, particularly within contexts facing similar environmental and construction challenges. The methods for assessing the feasibility of concrete

reclamation and the design strategies for integrating reclaimed materials can be adapted and applied to various building types and contexts.
Furthermore, the principles of Design for Reuse and the use of Materials Passports can be implemented across the construction industry, encouraging a broader shift towards circular economy practices. By demonstrating the viability of these approaches through a specific case study, the project provides a model that others could follow.

Self-Developed Reflection Questions

1. **How did feedback from mentors and peers shape the development and outcomes of your project?**

Throughout the project, the feedback from my tutors played a crucial role in improving both the research and design stages. Their constructive criticism helped me pinpoint practical challenges and areas that needed enhancement, both in architectural and technical aspects. Especially the message that I wanted to tell with my project and the story telling aspect were points of interest for me. The exchange of ideas and suggestions ensured development of my project, and therefore, I owe my tutors a big thank you. Thomas, Jos, and Paddy, I'm grateful for all the hours of effort you've put into helping me. It was a pleasure to learn from each of you, so major thanks for that!

2. **What were the biggest challenges you faced during the project, and how did you overcome them?**

A problem that I encountered almost throughout the whole year were the following questions I often asked myself: "What am I actually doing?", "Isn't it a bit absurd to completely disassemble a building and then reassemble it?", and "Is this even financially viable?" These are all questions I was aware of, and sometimes I had multiple and varied answers, or sometimes no answers at all. As my project progressed, I became increasingly aware that my strategy and vision might be too ambitious for the reality we unfortunately have to deal with. Sustainable building often requires more money, time, and effort, which makes it unattractive to many developers. However, this does not mean we should avoid this topic; quite the opposite. I believe we must seek solutions to make sustainable building profitable so that we can create more awareness among developers, who often lack it. And precisely therein lies the essence of my project, by planting a single idea: showing that there's a different approach to construction and deconstruction than just tearing down buildings. It might take more resources and time, but in the long run, it's beneficial. The profit isn't just about money; it's about making the construction industry more sustainable and the environment healthier. This goal has kept me going through tough times in my studies, reminding me why I started: to lessen CO_2 emissions and work towards a better climate.

Looking Ahead
In the final part of the graduation period, I will focus on refining the design to address any remaining technical and practical challenges identified during the reflection. Additionally, I will prepare a final presentation that effectively communicates the project's goals, processes, and outcomes, highlighting its potential impact on the construction industry and broader environmental sustainability efforts.