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LIFE CYCLE ASSESSMENT OF DIFFERENT STRUCTURAL FRAMES APPROACH IN SWEDISH ROW HOUSE CONSTRUCTION: RECLAIMED CONCRETE, NEW CONCRETE, AND TIMBER

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ABSTRACT

Background and aim. The Intergovernmental Panel on Climate Change (IPCC) reported in 2019 that the building sector accounts for 21% of global greenhouse gas (GHG) emissions, with 18% originating from producing construction materials such as cement and steel. This highlights the urgent need to address embodied carbon in construction to align with climate goals. This study examines the potential of reusing structural materials, primarily concrete elements, to significantly reduce embodied emissions in the construction sector, which has increasingly focused on embodied carbon alongside operational energy efficiency.

Methods and Data. A lifecycle analysis compared the Global Warming Potential (GWP) of concrete elements reclaimed from an old building, conventional concrete, and timber construction for the structural frame of a row house.

Findings. Reclaimed concrete demonstrated the lowest GWP, achieving a 77% reduction compared to traditional concrete and surpassing timber. These findings indicate that reclaimed concrete elements can rival timber as a sustainable building material.

Theoretical / Practical / Societal implications. Prioritizing sustainable material choices and resource efficiency is crucial for the construction sector to meet increasingly stringent global climate targets. This study emphasizes the importance of reusing structural materials to lower carbon emissions during construction, contributing to a more sustainable built environment.

KEYWORDS: Carbon emissions, Circular economy, Life cycle assessment, Reuse, Structural elements

1 INTRODUCTION

The construction sector significantly influences resource consumption and greenhouse gas emissions (IEA, 2022). Boverket (2023) reports that the construction and real estate industries account for 21% of Sweden's annual CO_2 emissions, highlighting their critical role in achieving national climate objectives. These figures emphasize the urgent need for sustainable strategies to mitigate the environmental impacts of the building industry. The cement sector plays a significant role in global carbon emissions, with energy-intensive

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calcination processes constituting about 8% of worldwide CO emissions (Nikolakopoulos et al., 2024). Additionally, the construction sector generates over 40% of global waste, substantially intensifying its environmental footprint (Abubakar et al., 2022). The effects of the construction sector on carbon emissions and waste production present significant challenges to decarbonization goals (Sbahieh et al., 2023). In response, European Union initiatives like the Whole Life Carbon Roadmap and the Recreate project advocate for circular economic approaches, emphasizing the importance of material reuse and reducing reliance on virgin resource extraction in line with broader sustainability objectives (Norouzi & Masoud, 2021; UNEP, 2022a, 2022b). Transitioning to a circular economy is essential for achieving the ambitious targets of the Paris Agreement. Although advances in energy efficiency have lowered operational emissions, the focus has shifted towards embodied carbon, underscoring the vital importance of material choice and construction methods in reducing environmental impacts (Minunno, 2021).

While reusing concrete components from de-commissioned structures in new buildings is seldom considered a primary strategy for enhancing sustainability in the construction industry, concrete reuse has a long history with several successful applications demonstrating significant financial and environmental benefits. (Küpfer, Bastien-Masse & Fivet 2023).

Recent several researches highlight the growing emphasis on reusing concrete elements to reduce embodied carbon and advance circular economy principles in construction. Ahmad Al-Najjar and Tove Malmqvist (2025) conducted a Swedish pilot study with reusing concrete elements in new buildings, presenting a significant embodied carbon savings. The study highlights that reusing concrete elements offers greater carbon savings than recycling or using new low-carbon materials. Küpfer et al. (2023) critically reviewed 77 concrete reuse cases from Europe and the USA. They identified that reusing concrete pieces in new structures is not commonly practiced. Building on this, Küpfer et al. (2024) further explored the reuse of saw-cut reinforced concrete (RC) pieces from demolished structures to create new load-bearing floor systems, showcasing technical feasibility through structural testing and life-cycle assessments.

Building on the insights from recent case studies, we now turn our attention to the reference carbon intensity data for Swedish residential buildings, which provides a crucial benchmark for evaluating the environmental impact of construction practices in this region. The total GHG emissions for erecting a traditional concrete structure (lifecycle stage A1-A5) was estimated to be around 350 kg $CO_{2\,e}/m^2$ (tempered floor area) in an LCA study for a six-storey multifamily house by (IVL, 2017). From voluntary building certification system, the up-limits and reference value of the upfront carbon (lifecycle stage A1-A5) of the multifamily building are 260 kg $CO_{2\,e}/m^2$ in Miljöbyggnad 4.0 and 310 kg $CO_{2\,e}/m^2$ in BREEAM (Miljöbyggnad, 2023; BREEAM, 2023)

This is representative of new Swedish energy-efficient multi-family buildings. Single-family houses and row houses with 1-2 stories have around half of that impact. The emissions for this category of houses average 164 kg $CO_{2\,e}/m^2$ and the most significant emissions occur during the A1-A3 phase (Boverket, 2023). The structure, including foundation, structural framework, façade, and roofs, accounts for the majority.
While previous research has thoroughly examined the environmental impact of new construction materials, few studies have systematically evaluated the feasibility of reusing concrete elements as a sustainable construction material alternative to either virgin concrete or timber.

This study examines and compares the Global Warming Potential (GWP) of three structural options for a row house in southern Sweden: locally reclaimed concrete, traditional structure using virgin cast-in-place concrete, and a structural frame utilizing light timber. Repurposing, recovering, and incorporating old concrete elements into new construction projects is often feasible. However, the environmental competitiveness of reclaimed concrete elements from decommissioned buildings as an alternative to timber remains underexplored. By systematically evaluating the climatic impact of the construction phase, the study aims to generate more insights into the environmental performance of structural building materials, emphasizing the importance of material selection in reducing carbon footprints. Through this analysis, the research advances sustainable construction practices, supports the adoption of reclaimed materials in alignment with global climate objectives, and fosters innovation within the industry, providing a robust foundation for informed decision-making in future projects. Given the construction industry's significant contribution to embodied carbon emissions, advancing sustainable building practices and informing policy on low-carbon construction strategies relies on determining whether material reuse offers a viable alternative to conventional and renewable materials.

This work distinguishes itself from other LCA studies of reclaimed concrete by employing a comprehensive methodological approach that includes an empirical evaluation of construction and installation impacts (A5) as well as an extensive sensitivity analysis of transportation emissions (A4). Unlike more conventional studies, this research utilizes real-world case study data to capture all environmental consequences of deconstruction, transportation, and reassembly. The findings provide new insights into emissions reduction and highlight how localized reuse techniques lower embodied carbon, thereby supporting the practical feasibility of reclaimed concrete in circular building designs. This study clarifies reuse techniques, aiding in optimizing low-carbon construction strategies.

The study directly aligns with European policy programs such as the Circular Economy Action Plan and the Whole Life Carbon Roadmap, which focus on reducing embodied carbon and fostering a resource-efficient construction economy through more reuse or recycling from non-hazardous construction and demolition waste (CDW).

2 METHOD

The article employs a Life Cycle Assessment (LCA) framework to quantify and compare the Global Warming Potential (GWP) of three structural alternatives for a row house. The LCA encompasses essential components of the superstructure, including the frame, upper floors, roof, stairs, and external walls. The methodology adheres to European standards, specifically EN 15978:2011 for building-level assessments and all of the product-level datasets in the study follow EN 15804 standard based on CML, ensuring compliance and reliability. The scope of the LCA focuses on life cycle stage A and the results in Section 3 illustrate the life cycle impacts within the GWP impact category, measured in kg CO_{2e} over a specified service life.

2.1 CASE STUDY DESCRIPTION

Built between 1966 and 1969 as part of Sweden's million-program housing initiative, the existing multi-family residential building in Drottninghög, Helsingborg, consists of prefabricated concrete components. The structure supplies structural elements for a new row house project. This study examines the feasibility of reusing these components—including super structure elements in both frame and envelope—within a circular building design to reduce environmental impact. The study forms part of a research project that explores the feasibility of reusing structural concrete elements from donor buildings for a new row house in Helsingborg, Sweden. Figure 1 shows the floor plan of the new apartments with a floor area of 97 m^2 and the wall structures. The walls are all assumed to be designed to have the same U-value.

The analysis employed specific measurements from the donor building, sourced from an inventory of architectural records and structural features. When exact data was lacking, methodological consistency was upheld across instances by utilizing assumed values. These assumptions ensured comparability in LCA among new concrete, reclaimed concrete, and timber construction scenarios.

The study defines 1 m² of gross floor area (GFA) per residential unit as the functional unit over a 50-year lifetime. This clear definition ensures methodological consistency in the Life Cycle Assessment (LCA) and enables comparability between the construction scenarios analyzed.

To emphasize the environmental impact of material choices at design phase, only the product phase (A1–A3) and the construction phase (A4-A5) are considered in this study, while Stages B (use phase) and C (end-of-life) were excluded in accordance with Swedish climate declaration method. Although dismantling emissions for reclaimed concrete ensured methodological consistency, the study assumed that used components retain full functionality without additional maintenance.

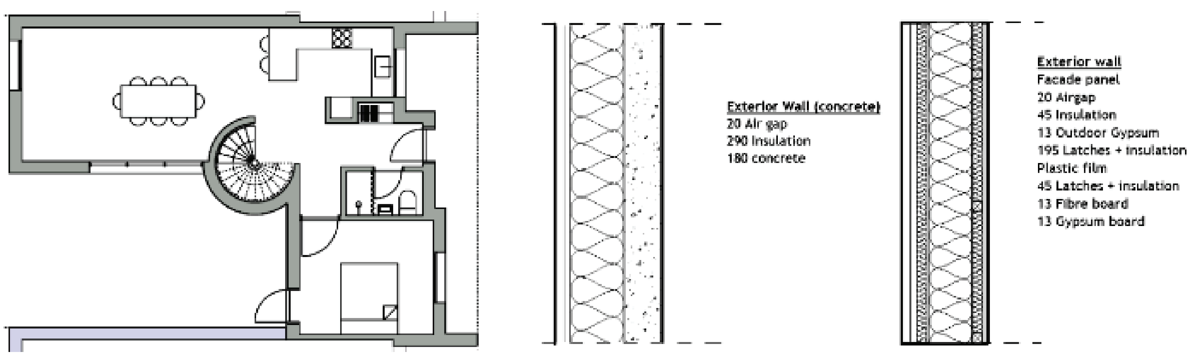

Figure 1. Left: Floor plan (two stories). Middle: Exterior wall in concrete. Left: Exterior wall in light timber

Three structural systems were evaluated:

Case 1: Structural concrete elements from an existing donor building are disassembled, inspected, transported, and reassembled without reprocessing, demonstrating direct reuse and minimizing resource extraction, waste, and embodied energy.

Case 2: A conventional system constructed entirely with virgin cast-in-place concrete is a benchmark for comparing reuse methodologies' performance and environmental impact.

Case 3: A light timber system exemplifying sustainable construction with renewable materials, low embodied carbon, and compatibility with circular construction, providing an additional comparative baseline.

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2.2 DATA COLLECTION AND COLLABORATION

Material quantities (A1–A3) were derived from design data, which included building information models, architectural drawings, and structural inventories provided by project representatives, primarily an architecture student from KTH. While the construction team validated logistics and practical aspects, the primary responsibility for material weights and quantities rested with the design contributors. Transport distances (A4) were estimated using standard averages integrated into the One-Click LCA tool, and construction emissions (A5) were based on benchmark data from similar projects. This structured and collaborative approach ensured accuracy and reliability when calculating the environmental impacts of reclaimed materials, adhering to EN 15804 standard based on CML methodology.

2.3 LIFECYCLE ASSESSMENT (LCA)

The LCA study evaluated the environmental impacts of the structural frameworks, highlighting distinct phases (A1–A4) for the reclaimed concrete. The use of reclaimed structural elements refers to components sourced from existing buildings. This ensured that the impacts from disassembly, inspection, transport, and reuse were thoroughly captured for accurate comparison. Calculations were performed using the OneClick-LCA educational edition, generic environmental product declarations (EPDs), and industry-average data, standardized to one square meter (m^2) of gross floor area over a 50-year lifespan. OneClick LCA was chosen as a calculation tool for its holistic functions in terms of comprehensive environmental impact databases and consistent methodology in line with EN 15978. The system boundary included the material production phases (A1–A3), the transport phases (A4), and the construction and installation phases (A5).

Data and information about the properties and quantities of the materials used are provided by the project designers. Since specific product data was unavailable at the early design phase, associated environmental impact data has primarily been obtained from the Swedish National Board of Housing, Building and Planning's climate database. Where generic data from the Swedish National Board of Housing, Building and Planning's climate database is missing, localized generic climate data from One Click LCA has been used. In A4, generic transport data (distance and transport mode) has been used based on typical transport data for each material. Generic transport data has been retrieved from the Swedish National Board of Housing, Building and Planning's Climate Database. In A5, we followed Swedish climate declaration context, encompasses waste management, energy use, and on-site emissions.

Accordingly, the localized generic data from One Click LCA has been used at the construction phase for the inclusion of construction site vehicles, machinery and equipment. Energy impacts in A5 were modeled for fuel, etc. but only for excavation and backfilling, which was calculated using project-scale averages, considering machinery, fuel, and electricity consumption. Construction waste and the management of donor materials were also included, creating a comprehensive framework to evaluate the role of recycled concrete in advancing circular construction practices.

3 RESULTS & DISCUSSION

3.1 DIFFERENT STRUCTURAL MATERIAL'S PERFORMANCE

The comparative GWP results of the three alternative structural structures studied is presented in Figure 2. The results show substantial differences in environmental impact between the three cases, with reclaimed concrete as the most sustainable option.

Reused concrete reduces Global Warming Potential (GWP) by 77% compared to virgin cast-in-place concrete, demonstrating its superior environmental performance. While timber benefits from renewability and carbon sequestration, its emissions remain higher at 75 kg CO_2 e/m^2, whereas reused concrete achieves a significantly lower 36 kg CO_2 e/m^2. This highlights reclaimed concrete as a key low-carbon option in sustainable construction, aligning with previous research (Bertin et al., 2022). By eliminating emissions from cement production and raw material extraction, reused concrete substantially cuts embodied carbon.

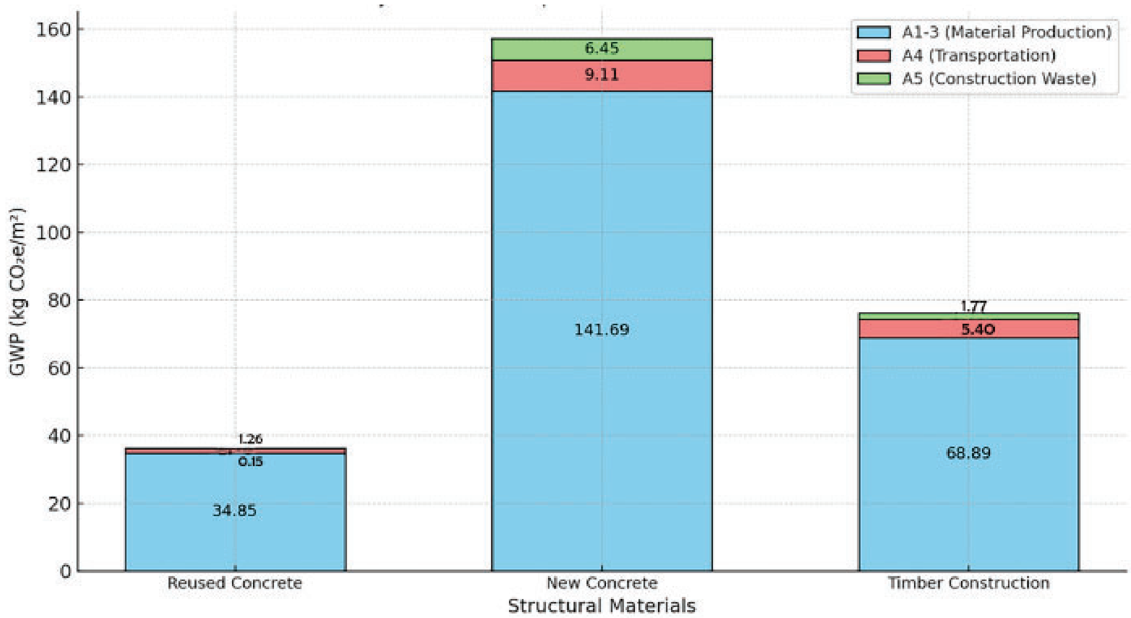

Figure 2. Global warming (GWP) from row house construction using reclaimed concrete elements, conventional virgin concrete and light timber across the lifecycle phases A1-A5

The study confirms that reusing structural concrete significantly lowers environmental impact, outperforming both traditional concrete and timber. Conventional concrete, with its high 157 kg CO_2 e/m² emissions, remains the least sustainable due to cement production's carbon intensity. Cement manufacturing is among the most polluting industrial processes, contributing heavily to CO_2 emissions through limestone calcination and high energy demand. These findings align with national standards, such as the Swedish benchmarks for small residential structures (Boverket, 2017), reinforcing the urgency of adopting alternative structural materials.

Although timber is widely regarded as a sustainable building material, its comparative impact depends on long-term carbon storage and sustainable forestry. Conventional GWP assessments often exclude biogenic carbon storage, affecting timber's relative performance. While timber construction contributes to emission reduction goals, its effectiveness depends on responsible forest management and material longevity (Andersen et al., 2022).

This study strongly supports reclaimed concrete elements may become a low-carbon alternative for structural applications. Its substantial GWP reduction underscores its role in circular construction while maintaining structural integrity. Additionally, localized reuse strategies and optimized transportation further enhance environmental benefits.

3.2 LCA STAGE CONTRIBUTIONS AND SENSITIVITY ANALYSIS

Accurate quantification of embodied carbon emissions and identification of mitigation potential relieve a comprehensive understanding of contributions from various life cycle stages. This section examines the proportional GWP impact through material manufacturing (A1–A3), transportation (A4), and construction waste management (A5). The percentage distribution of GWP over each scenario's various stages of the lifespan is illustrated in the figure. A thorough life cycle stage analysis further emphasizes the critical impact of material production (A1–A3) on total emissions. It can be found that the conventional concrete demonstrates a pronounced concentration of greenhouse gas (GHG) emissions in early life cycle stages (A1-A3), contributing 141.69 kg CO_2 e/m²of its total emissions from raw material extraction and production. This highlights its reliance on carbon-intensive virgin resource processing. In comparison, the lumber derives 68.89 kg CO_2 e/m² of emissions from A1-A3, reflecting energy demands in forestry operations and sawmill processing, while the reclaimed concrete shows a markedly lower A1-A3 share at 34.85 kg CO_2 e/m², as recycling bypasses resource extraction and reduces manufacturing energy. The 72.8 kg CO_2 e/m² reduction in A1-A3 emissions for reclaimed concrete versus conventional concrete directly correlates with avoided virgin material use. This supports circular economy principles by demonstrating that reusing structural materials minimizes upstream impacts.

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In every case, the findings indicate that stage A1–A3 (life cycle stage of product stage) primarily contributes to greenhouse gas emissions, highlighting its significant influence on overall environmental performance outcomes.

In the A4 (transportation) stage; the distances in sourcing materials play a crucial role in transport-related emissions, as Figure 3 illustrates. Compared to 5.8 % for new concrete and 2.3 % for timber, reused concrete has the lowest transport emissions at 0.4%, highlighting the enhanced carbon efficiency of localized material reuse. The study's material reuse strategy defines transportation distances as "short" or "medium." Initially, transportation emissions were assessed for an inspection station only 150 meters from the construction site in the case with relocated concrete elements, indicating a "short" distance. To evaluate the sensitivity of emissions to increased transport requirements for the reclaimed concrete elements, an alternative scenario considered an inspection station located 25 kilometers away ("medium"). The sensitivity analysis results (Figure 4) indicate that in the case of a reused concrete structure, a medium transport distance can lead to more than ten times the A4 emissions compared to a short transport distance. This finding emphasizes the urgent need for implementing regionally optimal sourcing policies to reduce the environmental impact of transportation in supply chains for building materials. Although A4 emissions are secondary to those from material manufacturing (A1–A3), their overall contribution to embodied carbon remains significant, particularly for goods transported over long distances. The results highlight that achieving the best carbon reduction outcomes in building projects depends on proximity to reuse locations, effective logistical planning, and minimized reliance on transportation. In the A5 (construction and installation) stage, emissions primarily arise from on-site energy consumption, equipment operation, and construction waste management. While reassembling and deconstructing recycled concrete components does generate emissions, these amounts are still significantly lower than those resulting from cement production in traditional concrete. The clear environmental benefits of material reuse greatly enhance circular building practices compared to the exploitation and processing of virgin resources. Further quantitative studies on on-site emission reduction strategies, energy-efficient deconstruction and reassembly processes, and improved waste disposal methods will improve the efficiency of A5 operations. Addressing these issues is crucial for optimizing circular building methods, lowering embodied carbon, and promoting sustainable material reuse systems. The findings reinforce the necessity of combining localized reuse strategies with efficient construction techniques to enhance GWP reductions during the A4 and A5 life cycle phases.

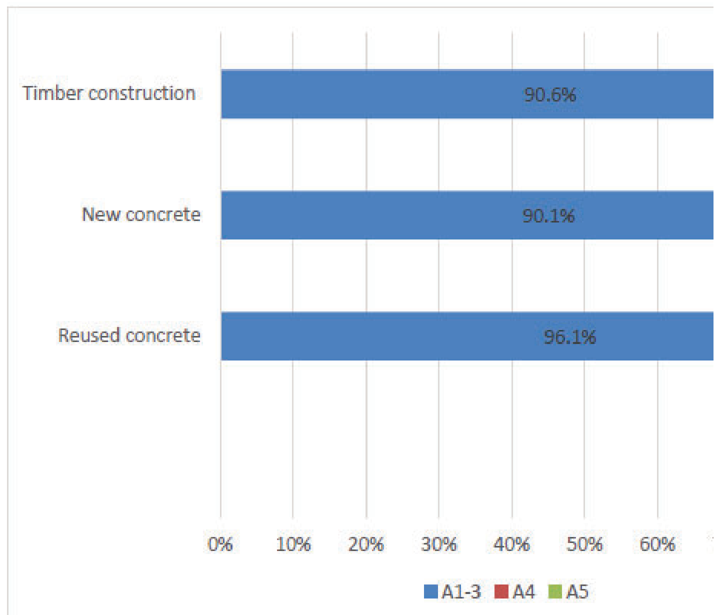

Figure 3: Proportion of GWP (kg CO_{2e}/m^2) for structures based on reclaimed concrete elements, conventional virgin concrete and light timber. Blue stands for material production, red for transportation and green for construction waste.

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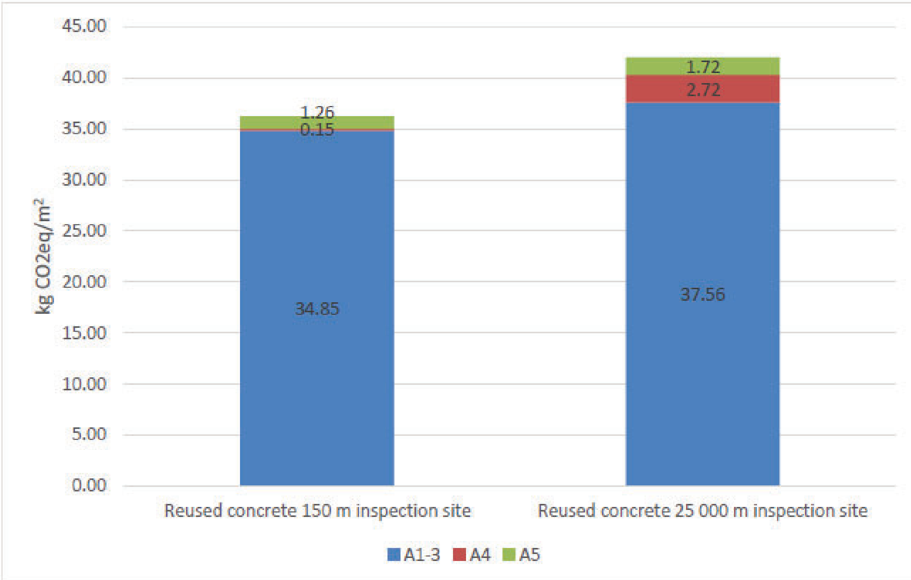

Figure 4: Sensitivity analysis of emissions with increased transport, assuming a 25 km inspection station ("medium" distance).

Carefully constructed assumptions and calculations ensured methodological consistency and validity. When accurate donor building data was unavailable, assumptions were derived from industry standards, past LCA assessments, and legal requirements. BIM models, architectural drawings, and structural inventories were utilized to estimate material quantities, ensuring the precision of resource utilization. While project-scale data predicted energy consumption and emissions during construction (A5), project-specific logistics and typical industry norms helped determine transport distances. Variations in transit lengths, construction energy consumption, and material processing impacts were evaluated using sensitivity studies, thereby assessing the robustness of the assumptions. In compliance with EN 15804 and EN 15978 criteria, the OneClick LCA tool was used for lifetime computations to ensure methodological accuracy. All assumptions and data limitations were documented clearly to enhance transparency, thereby improving the reliability and repeatability of the research. The assumption was made that the cement and concrete industry is highly localized globally. The average travel distance for in-situ concrete is 16km, while the average distance for concrete's raw materials is 48km (ICE,2023). To be economically competitive, localized sourcing of reuse material is crucial. When transportation distances were raised to "medium" for the relocated concrete, the transport suddenly accounted for twice as much. A "long" distance would have significantly impacted the reclaimed concrete case and shows that proximity in transportation is a critical factor when assessing construction waste (A5) and material reuse initiatives.

4 CONCLUSIONS AND RECOMMENDATIONS

This study compares the environmental performance of three structural solutions—reused concrete elements, new cast-in-place concrete, and timber—through a life cycle assessment (LCA) perspective. The findings demonstrate that reusing concrete elements significantly reduces embodied carbon emissions, positioning it as a key strategy for sustainable construction. Very few examples of reusing concrete elements exist so far, probably because building with virgin concrete is cheap. However, by avoiding the carbon-intensive cement production process, reclaimed concrete can lower the Global Warming Potential (GWP) of building frames by approximately 75%, saving over 100 kg CO_2 e/m² of floor area. Therefore, this potential should be investigated more as a viable low-carbon alternative for the construction industry.

Timber construction is widely recognized for its environmental benefits, offering a 52% reduction in GWP compared to conventional concrete. While timber is renewable and sequesters carbon, its processing emissions and durability limitations impact its overall sustainability. Although timber performs better than virgin concrete, reused concrete emerges as the most effective option for reducing embodied emissions, reinforcing the importance of circular economy strategies in construction.

Achieving sustainable construction requires context-specific solutions that balance carbon reduction with practical considerations such as cost, structural performance, workability, and material availability.

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Expanding material reuse faces logistical barriers, including transportation distances, infrastructure limitations, and concerns over the long-term strength of reclaimed materials. To overcome these challenges, future research should explore metrics beyond GWP, such as durability and economic feasibility, strengthening reuse infrastructure as well as innovating design and engineering methods to facilitate material reuse in structural applications.

The results align with EU climate targets by supporting decarbonization in the built environment and promoting sustainable material management. Reclaimed concrete not only reduces waste but also advances low-carbon, resource-efficient construction, making it a fundamental strategy for climate-resilient building design. By prioritizing material reuse and minimizing embodied emissions, the construction sector can take significant steps toward carbon neutrality and a circular economy.

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