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Preface

For six decades, the Congress of the *Collegio dei Tecnici dell'Acciaio* (CTA) has represented one of the principal opportunities for exchange and discussion within the Italian steel construction community. Since the first Congress, held in Pisa in 1967, the event has travelled across Italy with the aim of promoting the culture of steel construction and fostering cooperation among researchers, engineers, architects, contractors, manufacturers and institutions. Over the years, the Congress has become the main meeting point for the three complementary actors which fosters the development of steel construction: academia, professional practice and industry.

The 30th edition of the CTA Congress marks an important milestone in this long-standing tradition. For the first time in its history, the Congress is being held in Rome, from 30 September to 2 October 2026, at the Centro Congressi Fontana di Trevi, in the heart of the Italian capital. The choice of Rome reflects the strategic role of steel structures in contemporary infrastructure, buildings, industrial facilities and special engineering works. It will also the contribution that steel construction can make to the transformation and renewal of the built environment and the infrastructure of tomorrow.

The theme selected for this edition, *Innovation, Reliability and Sustainable Development: All Roads Lead to Steel*, expresses the central challenges facing structural engineering today. Safety, sustainability and technological innovation can no longer be addressed as separate objectives. They are closely interconnected requirements that must be considered throughout the entire life cycle of a structure, from conception and design to fabrication, erection, operation, maintenance, adaptation, reuse and eventual disassembly.

Steel is particularly well suited to meeting these challenges. Its high structural efficiency, flexibility of use, industrialised production, suitability for prefabrication and rapid erection, together with its potential for reuse and recycling, provide engineers and architects with a broad range of opportunities. At the same time, the continuous development of materials, structural systems, fabrication processes, computational methods and monitoring technologies is expanding the boundaries of steel construction and renewing its role within the broader construction sector.

The scientific programme of the 30th CTA Congress reflects this breadth of perspectives. The contributions collected in these proceedings address steel and aluminium structures, major infrastructure and bridges, geotechnical works, tall buildings, industrial facilities, energy plants and special structures. Particular attention is devoted to seismic design, including isolation and energy dissipation, as well as to structural fire engineering and other accidental actions. Composite steel–concrete and steel–timber systems, together with structural systems made of cold-formed profiles, are also prominently represented.

The programme also encompasses advanced structural analysis and computational methods, fatigue assessment and welding technologies, erection procedures and bolted connections, and the assessment, maintenance and monitoring of existing bridges and

buildings. Corrosion, durability, reuse, structural circularity, innovative production technologies, additive manufacturing and digitalisation complete a framework that brings together established areas of steel engineering and emerging fields of research and application.

The Congress maintains the CTA tradition of linking scientific advancement with the experience of design and construction. General lectures focusing on research advances and recent steelwork project offer complementary perspective on the current state of the field. Invited contributions on the innovative design of major works and on the safety of industrial facilities further illustrate the importance of integrating scientific knowledge, engineering judgement, construction expertise and technological innovation.

A distinctive feature of the 2026 edition is the attention devoted to the transformations brought about by artificial intelligence and digital technologies. The international workshop *Artificial Intelligence and Steelwork Structural Design... Let's Get Started!* brings together fundamental concepts, optimisation methods, large language models and applications to the design of tall buildings and gridshell structures. Its organisation in collaboration with ARTISTE—Artificial Intelligence in Structural Engineering—highlights the growing role of data-driven and AI-informed approaches within structural design.

In parallel, the professional course on the fire resistance of steel structures addresses the regulatory framework, calculation methods, advanced numerical analyses and practical applications. Collaboration with the *Associazione Nazionale per l'Ingegneria del Vento*, the *Commissione per la Sicurezza delle Costruzioni di Acciaio in caso di Incendio* and ARTISTE demonstrates the Congress's commitment to creating connections among specialised scientific and professional communities.

The special session devoted to the Marangara suspension bridge in Rwanda has particular meaning for the Collegio. The bridge, co-funded by CTA and developed in collaboration with Bridges to Prosperity, shows how engineering expertise and collective commitment can generate a tangible social impact. It reminds us that structural engineering is not concerned only with technical performance, but also with accessibility, territorial development and the improvement of people's living conditions.

The papers included in this volume document the vitality and diversity of contemporary research and professional practice in steel construction. They present theoretical developments, experimental investigations, numerical methods, design procedures, innovative technologies and relevant case studies. Taken together, they provide a broad overview of the current state of knowledge while also identifying directions for future research, standardisation and practical implementation.

These proceedings are intended not merely as a record of the Congress, but as a resource for researchers, designers, manufacturers, contractors, students and all those involved in the development of steel construction. The interaction among these communities remains essential. Research contributes new knowledge and methods; industry transforms innovation into materials, products and construction technologies; professional practice integrates these resources into creative, safe and efficient engineering solutions. Their continuous dialogue is one of the defining principles of CTA and the foundation on which the future of steel construction must be built.

We wish to express our sincere gratitude to the authors for the quality of their contributions, to the invited speakers for sharing their knowledge and experience, and to the members of the Scientific Committee for their valuable work in reviewing and selecting the papers. Our appreciation also goes to the Organising Committee, the CTA Board, the scientific and professional partner associations, the institutional patrons, the sponsors and all those whose commitment has made the Congress possible.

Special thanks are due to Springer Nature for publishing these proceedings and for contributing to the international dissemination of the scientific and technical work presented at the Congress. The publication of this volume strengthens the connection between the long-standing Italian tradition of steel construction and the broader international scientific and professional community.

We warmly welcome all participants to Rome and to the thirtieth CTA Congress. We trust that the presentations, discussions and encounters generated by these days will encourage new collaborations, new research questions and new engineering solutions. Above all, we hope that this Congress will confirm the capacity of steel construction to unite innovation, safety, architectural ambition and environmental responsibility in the creation of a more sustainable built environment.

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A Comparative Life Cycle Assessment of Load-Bearing Structural Systems for Multi-Storey Buildings: Steel vs. Reinforced Concrete

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Abstract. The construction sector plays a pivotal role in global decarbonization efforts, requiring robust methodologies to assess and reduce environmental impacts across the building life cycle. In this context, this study presents a comparative Life Cycle Assessment (LCA) of load-bearing structural systems for multi-storey buildings, focusing on steel and reinforced concrete solutions. The analysis is based on a real case study: a 14-storey building located in Pisa, Italy, ensuring identical boundary conditions in terms of geometry, function, and location. Adopting a cradle-to-grave approach in accordance with EN 15978 and ISO 14040–44 standards, the study evaluates embodied carbon and Global Warming Potential (GWP) over a 50-year reference period. The methodology analysis focuses on the preliminary parametric assessments to testify the critical role of early-stage LCA in guiding design decisions and identifying environmental hotspots. Results show that the steel structural solution achieves a significantly lower carbon footprint compared to reinforced concrete, with reductions in CO₂ emissions, mainly due to lower material intensity and higher recyclability. The findings highlight the importance of material selection and circularity strategies in achieving low-carbon buildings. This research provides practical insights for designers, stakeholders, and policymakers aiming to support sustainable construction and accelerate the transition toward a decarbonized built environment.

Keywords: Life Cycle Assessment · comparative analysis · environmental impacts · steel building · recyclable material

1 Introduction

The construction sector plays a central role in the transition towards a decarbonized built environment. Buildings are responsible for a significant share of global energy consumption, greenhouse gas emissions, and resource use, not only during the operational phase but also through the production, transport, construction, maintenance, and

end-of-life management of construction materials and systems [1, 2]. While energy efficiency strategies have traditionally focused on reducing operational carbon, the growing relevance of embodied carbon is shifting attention towards the environmental impact of materials and construction technologies across the whole building life cycle [3–5].

In this context, Life Cycle Assessment (LCA) has become one of the most established methodologies for quantifying and comparing the environmental performance of buildings, construction products, and technical solutions [6]. Regulated by the ISO 14040–44 standards [7, 8], LCA allows the systematic evaluation of environmental impacts from raw material extraction to end-of-life scenarios. At the building scale, EN 15978 [9] provides a structured framework for assessing environmental performance across life-cycle modules, supporting the comparison of design alternatives.

Among the different environmental indicators considered in LCA studies, Global Warming Potential (GWP) has gained particular relevance due to its direct connection with climate change mitigation policies and whole-life carbon assessment [10–12]. GWP expresses the contribution of greenhouse gas emissions in terms of carbon dioxide equivalent and is increasingly adopted as a key metric for evaluating the carbon footprint of buildings [13–15]. Its relevance has been further strengthened by the revised Energy Performance of Buildings Directive, Directive (EU) 2024/1275 [16], which introduced the requirement for Member States to ensure that the life-cycle GWP of new buildings is calculated and disclosed in the Energy Performance Certificate (EPC) [17]. To implement this requirement, Commission Delegated Regulation (EU) 2026/52 [18] established the Union framework for the national calculation of life-cycle GWP, defining a harmonized methodological basis for the assessment, reporting, data hierarchy, life-cycle stages, and building elements to be considered. Within this regulatory framework, GWP is reported in $\text{kgCO}_2\text{eq/m}^2$ over a 50-year reference study period, supporting the comparability of results and reinforcing the role of LCA as a design-support tool from the early project stages.

Load-bearing structural systems are among the most influential components in determining embodied carbon, particularly in multi-storey buildings [19]. The choice between different structural materials, such as steel and reinforced concrete, can significantly affect the quantity of products used, the construction process, the design of foundations, and the potential for reuse, recycling, and recovery at the end of life [20]. For this reason, structural design should not be evaluated only in terms of mechanical performance, cost, and construction feasibility, but also through quantified environmental indicators able to support informed and evidence-based decisions.

Steel and reinforced concrete represent two of the most widely adopted structural solutions for multi-storey buildings [21, 22]. Reinforced concrete is traditionally associated with high material availability, massiveness, and consolidated construction practices. Steel structures, on the other hand, are characterized by high strength-to-weight ratio, industrialized production, dry and off-site construction processes, adaptability, and high recyclability. These characteristics make steel particularly relevant in the context of circular construction, where material efficiency, design for disassembly, reuse, and recycling are key strategies for reducing environmental impacts throughout the building life cycle.

Despite the growing number of studies applying LCA to building structures [23–26], comparisons between alternative structural systems are often affected by different assumptions, geometries, locations, functions, or data sources. This limits the possibility of deriving robust and project-specific conclusions. Therefore, comparative assessments based on real case studies and equivalent boundary conditions are needed to better understand how structural choices influence embodied carbon and to provide practical guidance for designers and stakeholders.

This paper presents a comparative LCA of two alternative load-bearing structural systems applied to the same multi-storey building case study located in Pisa, Italy. The analysis compares a steel structural solution with a reinforced concrete alternative, maintaining the same architectural configuration, location, function, and non-structural elements. The study focuses specifically on GWP as the main impact indicator, with the aim of assessing the influence of the structural system on the embodied carbon of the building.

The objective of the paper is twofold. First, it aims to quantify and compare the GWP of steel and reinforced concrete load-bearing structural systems under equivalent design conditions. Second, it aims to demonstrate the potential of LCA as an early-stage and detailed design-support methodology for guiding structural material selection in multi-storey buildings. The results are intended to support designers, engineers, construction stakeholders, and policymakers in the transition towards low-carbon and circular building practices.

2 Case Study

The case study selected for the comparative Life Cycle Assessment is the Torre Nord building, located within the wider Parco delle Torri development in the Cisanello district of Pisa, Italy. The building is a 14-storey tower with an overall height of approximately 50 m and a gross floor area of 5,365 m². The project concerns the refurbishment and completion of an existing unfinished building, originally designed with a steel load-bearing structure. The refurbished building is mainly intended for office use, while the ground floor includes commercial and food-service areas. From an architectural perspective, the tower is characterized by a compact and vertically organized layout. The office floors are designed around the central reinforced concrete core, which presents stairs, elevators, and the main vertical service spaces. The core also forms part of the lateral load-resisting system.

The present study compares two hypothetical new-construction scenarios applied to the same building configuration, in order to assess the environmental implications of different structural choices under equivalent design conditions. The two scenarios considered in the study are: Scenario A, based on a steel load-bearing structure, and Scenario B, based on a reinforced concrete load-bearing structure. Both scenarios are designed to provide functionally equivalent structural solutions for the same multi-storey building. The comparison is focused on the load-bearing system and related structural components, while all non-structural elements are kept identical. The same building plan, floor-to-floor organization, usable areas, façade configuration, and functional layout were adopted in both alternatives, so that the comparison focuses on the environmental effects associated with the load-bearing structural system.

2.1 Structural Scenarios

Scenario A considers the new construction of a steel load-bearing structure that replicates the structural configuration of the existing building. The vertical structural system consists of CHS columns in S355 steel, with variable sections according to the building height. The horizontal structural system is composed of steel beams, including HE, IPE and UPN profiles, and composite floor slabs. The slabs are made of galvanized corrugated steel sheets with a concrete topping and electrowelded reinforcement mesh.

The steel structural system is combined with a reinforced concrete core, with stairs and elevators, and reinforced concrete foundation elements. The foundation system includes a reinforced concrete raft and 37 foundation piles. This scenario represents a lightweight and industrialized structural solution, characterized by dry construction processes, high prefabrication potential, and high recyclability of steel components.

Scenario B considers the new construction of an equivalent reinforced concrete load-bearing structure. In this scenario, the steel columns, steel beams, and composite slabs of Scenario A are replaced by cast-in-place reinforced concrete elements. The vertical structural system consists of reinforced concrete columns with variable diameters. The horizontal structural system consists of 240 mm thick solid reinforced concrete slabs, also designed to ensure continuity in the balcony areas.

Table 1. Main characteristics of the two structural scenarios considered in the comparative LCA.

Component	Scenario A	Scenario B
Vertical structure	CHS S355 steel columns	Circular reinforced concrete columns
Column dimensions	From 406.4 x 20 mm to 273 x 6.3 mm	From Ø500 mm to Ø350 mm
Horizontal structure	Steel beams and composite slabs	Reinforced concrete beams/slabs
Slabs	Corrugated steel sheets with concrete topping and electrowelded mesh	240 mm solid reinforced concrete slabs
Core	Reinforced concrete core	Reinforced concrete core
Foundations	Reinforced concrete raft and 37 piles	Reinforced concrete raft and 46 piles
Main material	Structural steel and concrete topping	Reinforced concrete

Compared with Scenario A, the reinforced concrete solution requires a different foundation configuration due to the higher structural mass. The foundation system includes 46 piles, corresponding to 9 additional piles compared with the steel scenario, and an increased reinforcement ratio in the foundation raft. The average reinforcement ratio is assumed to be 300 kg/m³ for columns and 125 kg/m³ for slabs.

The two structural scenarios are summarized in Table 1.

3 LCA Methodology

The comparative assessment was developed according to the Life Cycle Assessment framework defined by ISO 14040–44. The methodological structure follows the main LCA phases: goal and scope definition, Life Cycle Inventory, Life Cycle Impact Assessment, and interpretation. In this study, the interpretation phase is presented together with the results in Sect. 4, in order to directly discuss the environmental meaning of the outcomes obtained for the two structural scenarios. The analysis focuses on Global Warming Potential (GWP), expressed in kgCO_2eq and $\text{kgCO}_2\text{eq/m}^2$ of gross floor area, as the main indicator for climate-change mitigation and structural decision-making.

The workflow includes two levels of analysis: first, a preliminary assessment was performed with Carbon Designer 3D, integrated within One Click LCA, to compare the two alternatives during the early design stage; second, a detailed design-stage assessment was performed in One Click LCA using project-specific quantities derived from design documentation and BIM-based modelling. This combined workflow allows rapid early feedback and following refinement through more accurate data.

3.1 Goal and Scope

The goal of the study is to quantify and compare the GWP of two functionally equivalent load-bearing systems for the same multi-storey building. The functional unit is 1 m^2 of gross floor area (GFA), and results are expressed in $\text{kgCO}_2\text{eq/m}^2$ GFA. The reference study period is 50 years.

The system boundaries include the main embodied-carbon modules related to the structural systems: A1–A3 production, A4 transport to site, A5 construction and installation, and C1–C4 end of life. Operational energy and water use are excluded because the objective is to compare structural alternatives rather than operational performance. Building services, furniture, and external works are also excluded. Since both scenarios share the same architectural and functional conditions, the assessment isolates the contribution of the load-bearing structure and related components.

3.2 Life Cycle Inventory

The Life Cycle Inventory was developed using a combination of primary project data and environmental datasets available within the LCA software platform. Primary data were derived from the design documentation and project information of the Torre Nord case study, including structural configuration, material specifications, element dimensions, and quantities.

The preliminary inventory was developed through Carbon Designer 3D, using standardized input parameters related to the building geometry, location, number of storeys, function, and main construction systems. This phase allowed the two structural alternatives to be compared during the early design stage, when detailed quantities are not always fully available but design decisions can still significantly influence the final environmental performance.

The detailed inventory was developed using project-specific quantities obtained from the design-stage documentation and BIM-based modelling. The building model was

developed in Autodesk Revit and the relevant material quantities were transferred to One Click LCA through the dedicated workflow. The modelling process enabled the association of building elements and material quantities with environmental datasets, including Environmental Product Declarations and generic datasets available in the One Click LCA database.

For Module A4, transport impacts were calculated using the default transport scenarios available in One Click LCA for the selected material datasets. These scenarios consider road transportation by heavy-duty trucks over representative average distances between the production facility and the construction site. The same modelling criteria were applied to both structural alternatives; therefore, the differences in A4 impacts mainly reflect the different quantities and total masses of the transported materials.

The end-of-life stage was modelled through Modules C1–C4, including demolition or deconstruction activities, transport of waste materials, waste processing, and final disposal. The adopted end-of-life scenarios were based on the datasets and default assumptions associated with the selected materials in One Click LCA. Structural and reinforcement steel were assumed to be recycled and reused as materials, while concrete was assumed to be processed and used as energy source.

3.3 Impact Assessment

The Life Cycle Impact Assessment focuses on Global Warming Potential as the only impact category considered in the paper. GWP was selected because it represents the main indicator for evaluating the contribution of buildings and construction systems to climate change. It is expressed in kilograms of carbon dioxide equivalent and allows the different greenhouse gases emitted throughout the life cycle to be converted into a common metric.

The impact results are analyzed according to three complementary perspectives: total GWP of each structural scenario; GWP distribution across life-cycle modules; GWP contribution by structural element and material category.

This structure makes it possible to identify the main environmental hotspots of each scenario and to understand the drivers behind the differences between the steel and reinforced concrete solutions. The interpretation of the results also supports the discussion of material efficiency, structural configuration, and circularity potential as key aspects for reducing embodied carbon in multi-storey buildings.

4 Results and Interpretation

This section presents and interprets the results of the comparative Life Cycle Assessment conducted on the two structural scenarios. The interpretation follows the two levels of assessment described in the methodology: the preliminary early-stage assessment and the detailed design-stage assessment. The results are then discussed according to life-cycle modules, structural elements, and material categories, with the aim of identifying the main environmental hotspots and the drivers behind the differences between the two scenarios.

4.1 Preliminary Early-Stage Assessment

The preliminary assessment shows that Scenario A, corresponding to the steel structure, achieves a GWP of $453 \text{ kgCO}_2\text{eq/m}^2 \text{ GFA}$, while Scenario B, corresponding to the reinforced concrete structure, reaches $555 \text{ kgCO}_2\text{eq/m}^2 \text{ GFA}$. The reinforced concrete scenario therefore presents an increase of approximately 23% compared with the steel scenario (Fig. 1).

This result highlights the value of early-stage LCA for structural decision-making. Even when the design is not yet fully detailed, a preliminary assessment can identify the lower-carbon option and indicate the elements that most affect embodied carbon. In this case, the advantage of the steel scenario is mainly related to its lighter structural configuration, composite slabs, and reduced material intensity compared with the reinforced concrete alternative.

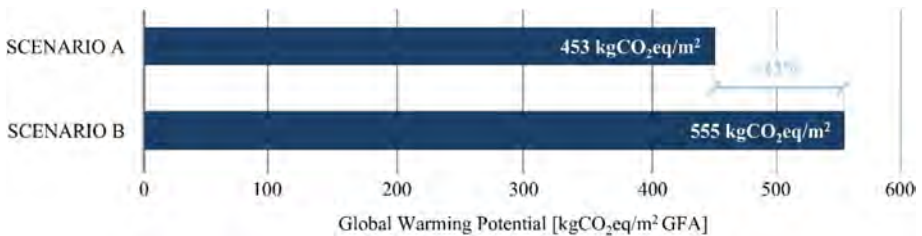


Fig. 1. GWP comparison of the preliminary early-stage assessment.

4.2 Detailed Design-Stage Assessment

The detailed design-stage assessment was performed using project-specific material quantities derived from the design documentation and BIM-based modelling. The quantities were implemented in One Click LCA in order to refine the results obtained during the preliminary phase and to quantify the GWP of the two scenarios with a higher level of detail.

The results of the detailed design-stage assessment are presented in Fig. 2 and confirm the trend observed in the preliminary assessment. Scenario A achieves a total GWP of $550 \text{ kgCO}_2\text{eq/m}^2 \text{ GFA}$. Scenario B achieves a total GWP of $603 \text{ kgCO}_2\text{eq/m}^2 \text{ GFA}$. The reinforced concrete scenario therefore remains more impactful than the steel scenario, although the relative difference is reduced compared with the preliminary assessment.

The reduction in the percentage difference between the two stages can be attributed to the refinement of material quantities and the inclusion of more specific design-stage information. Nevertheless, the results confirm that the structural system has a measurable influence on building-scale GWP and that the environmental advantage of the steel scenario is maintained when project-specific data are used.

4.3 Contribution by Life-Cycle Module and Structural Elements

The analysis by life-cycle module shows that the highest contribution to total GWP is associated with the production stage (A1-A3) for both scenarios (Fig. 3). This result is

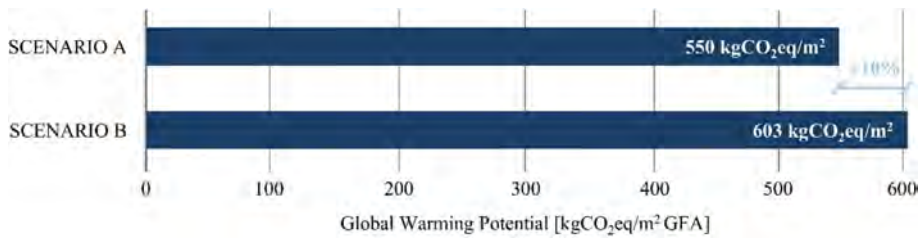


Fig. 2. GWP comparison of the detailed design-stage assessment.

consistent with the focus on embodied carbon and structural materials. In the steel scenario, relevant contributions are associated with structural steel profiles, reinforcement steel, corrugated sheets, and concrete components. In the reinforced concrete scenario, ready-mix concrete and reinforcement steel dominate the production-stage impact.

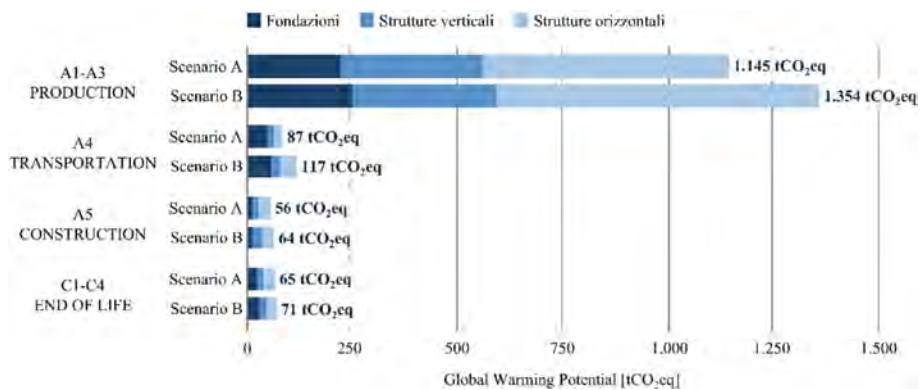


Fig. 3. GWP comparison by life-cycle module for Scenario A and Scenario B [tCO₂eq].

Transport (A4), construction and installation (A5), and end-of-life modules (C1-C4) contribute less than A1-A3 but remain relevant for the comparison because the two systems imply different material quantities, logistics, and construction processes. The steel scenario is associated with a higher level of prefabrication and dry assembly, while the reinforced concrete scenario requires larger quantities of cast-in-place materials.

The interpretation by structural element highlights foundations, vertical structures, and horizontal structures as the components most affected by the choice of structural system. Horizontal structures are particularly relevant: in Scenario B, 240 mm solid reinforced concrete slabs require significant concrete and reinforcement quantities, whereas Scenario A uses lighter composite slabs based on corrugated steel sheets and concrete topping.

Vertical structures also contribute to the difference. Scenario A uses CHS steel columns with variable sections, while Scenario B requires circular reinforced concrete columns with diameters from 500 mm to 350 mm. Foundations further increase the difference because the higher mass of the reinforced concrete scenario requires 46 piles

instead of 37 and a higher reinforcement ratio in the foundation raft. Overall, the lower GWP of the steel scenario is mainly linked to its lighter load-bearing configuration and reduced material requirements.

4.4 Contribution by Material Category

The material-category analysis explains the differences between the two scenarios (Fig. 4). In Scenario A, structural steel represents a major contribution to GWP; however, the overall impact remains lower because the steel structure requires lower total material quantities. In Scenario B, ready-mix concrete and reinforcement steel are the dominant contributors due to the larger volumes needed for slabs, columns, and foundations.

The results confirm that structural environmental performance cannot be assessed only through the impact factor of individual materials. Building-scale GWP depends on the interaction between material intensity, structural efficiency, construction technology, and design assumptions. In this case study, the higher specific impact of some steel components is compensated by lower quantities, lower structural mass, and reduced foundation requirements.

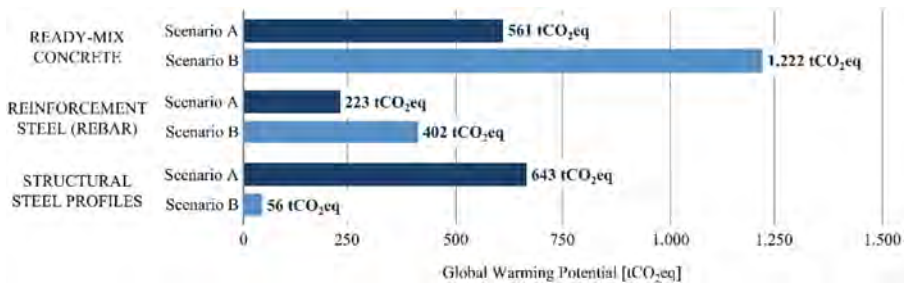


Fig. 4. GWP comparison by material category for Scenario A and Scenario B [tCO₂eq].

5 Discussion and Conclusions

The comparative LCA confirms that the selection of the load-bearing structural system can significantly influence the GWP of multi-storey buildings. In the analyzed case study, the steel scenario shows lower GWP values than the reinforced concrete alternative in both the preliminary and detailed assessments. The preliminary comparison indicates a 23% increase for the reinforced concrete scenario, while the detailed assessment confirms the same trend with 550 kgCO₂eq/m² GFA for steel and 603 kgCO₂eq/m² GFA for reinforced concrete.

The main drivers are material intensity and structural configuration. The reinforced concrete solution requires larger quantities of concrete and reinforcement for slabs, columns, and foundations, and its higher mass leads to additional foundation requirements. Conversely, the steel scenario benefits from a lighter structural configuration,

composite slabs, and reduced foundation needs. The study therefore confirms that comparative assessments should be conducted at the building or structural-system scale under equivalent boundary conditions, rather than through direct comparison of individual material impact factors.

The real refurbishment project also underlines the relevance of circularity strategies. The existing steel structure is recovered and reused for the completion of the building, demonstrating the potential of structural reuse to reduce demand for new materials and avoid production-related impacts. Although this benefit is not quantified in the two new-construction scenarios, it indicates an important future development for LCA-based structural design. Steel structures are particularly suitable for circular approaches because of their recyclability, potential for disassembly, and possible reuse after inspection and verification.

From a methodological perspective, the two-step workflow proved useful. The early-stage assessment provides rapid feedback when design decisions are still flexible, while the detailed assessment refines the results through project-specific quantities and more accurate modelling. This confirms the role of LCA as a design-support tool rather than only as a final verification procedure.

The study has some limitations. Results are case-study-specific and should not be generalized without considering geometry, spans, foundation conditions, datasets, transport distances, construction processes, and end-of-life assumptions. Moreover, the paper focuses only on GWP, which is central for climate-change mitigation but does not represent the complete environmental profile of the two structural systems. Finally, benefits and loads beyond the system boundary are not quantified; therefore, reuse, recovery, and recycling are discussed qualitatively rather than through Module D.

Future research should include Module D to quantify reuse and recycling benefits, as well as sensitivity analyses on EPD selection, transport scenarios, recycled content, and end-of-life pathways. Additional studies could compare hybrid systems and investigate how structural optimization and circular design strategies can further reduce whole-life carbon.

In conclusion, the paper demonstrates that LCA can effectively support the selection of low-carbon structural systems for multi-storey buildings. For the analyzed case study, the steel load-bearing structure achieves lower GWP values than the reinforced concrete alternative, mainly due to lower material intensity, structural efficiency, and reduced foundation requirements. In a context increasingly oriented towards whole-life carbon assessment, the systematic use of LCA represents a strategic opportunity to guide more informed and climate-conscious structural design choices.

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