ZIN (Brussels) - an example of sustainable transformation applied to high-rise building

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Abstract

The "ZIN in No(o)rd" project revitalizes the iconic 1970s WTC I and II towers in Brussels, creating a dynamic hybrid structure that includes offices, housing, a hotel, sports facilities, shops, and green spaces. This flexible design sets a new European standard for large-scale mixed-use buildings. Central to the project is radical reuse, with 95% of materials repurposed, including 30,000 tonnes of concrete rubble recycled into certified aggregate, reintroduced into the construction process. Key structures, including the cores and basements are preserved. Structural engineering played a crucial role, overcoming challenges such as reinforcing deep foundations (55m), using post-tensioned structures to redistribute high loads and minimize foundation interventions, and adapting the cores to withstand increased wind loads. The project balances sustainability and modern requirements, demonstrating how adaptive reuse and innovative engineering can achieve a transformative and sustainable high-rise renovation.

Keywords: high-rise buildings; sustainable architecture; circular economy; structural reuse; complex foundations; wind engineering.

1 Introduction

The ZIN project, located in the Northern District of Brussels, is a pioneering renovation of the iconic 1970s WTC I and II towers. These towers were initially designed as part of the "Manhattan Plan" that projected 54 towers all connected with walkways and a motorway (Fig. 1), with the aim of becoming an economic place at the heart of Europe. To achieve this dream, more than 11.000 inhabitants have been evicted from the old town, creating a traumatic contrast between the modern high-rises and the existing urban context of the city. The district's development was halted abruptly in the early 1980s due to the oil crisis, leaving large portions of the district undeveloped for nearly two decades. By 2020, the legacy of all this story is a purely mono functional district, with the first towers already becoming obsolete.

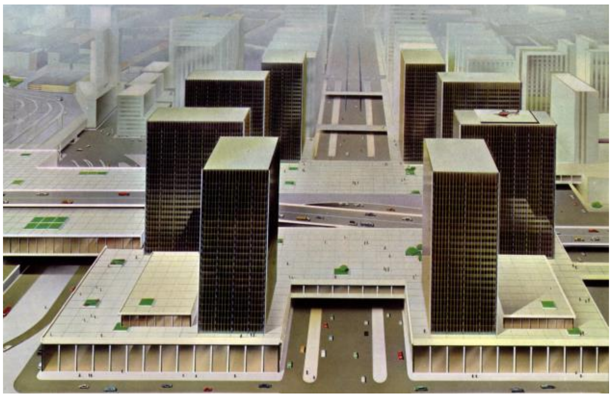

Figure 1: 1960' - Manhattan Plan for North District

The ZIN project represents a transformative step toward revitalizing the North District, with a bold approach to repurposing these towers while adhering to principles of sustainability and circularity. It embodies the ambition to reconnect the area to the city through a flexible mix of uses.

This paper explores the innovative solutions implemented in the project by the design team (Owner: Befimmo - Architects: 51N4E, Jaspers-Eyers, AUC - Structural engineers: Bureau Greisch) and how they contribute to sustainable development in high-rise building renovations. Specifically, it will highlight the technical challenges faced.

2 Project Concept – Hybridity and flexibility

ZIN represents a cutting-edge example of hybrid design, combining a range of functionalities within a single high-rise structure. The project's design is based on a mixed-use program, with 110,000 m² (+35.000m² basements) of space dedicated to offices, housing, a hotel, retail, and leisure areas, alongside extensive green spaces. This mix of uses is key to transforming the district into a dynamic, multifunctional environment, addressing the evolving needs of Brussels North District.

A central aspect of ZIN is the creation of a flexible, adaptive space capable of accommodating various uses over time. This is realized through the architectural concept called "Zebra" [1]. Rather than isolating the different functions into distinct, segregated floors (as is common in many mixed-use buildings), the Zebra Concept interweaves them (Fig. 2). The floors alternate between office spaces, residential units, and hotel rooms, allowing for maximum flexibility in the use of the building. This configuration enables tenants to move seamlessly between functions, increasing the building's adaptability and lifespan. The Zebra Concept is not just an architectural innovation; it reflects a deeper philosophy of urban design. The building itself is no longer seen as a static structure but as a dynamic, evolving entity. As needs change, the building's functions can adapt without significant renovations, providing long-term value for the district and its occupants.

A key challenge of the project is the limited floor-to-floor height in the existing towers, which is only 3.20 meters, far from what is considered for modern office and residential spaces (min 3.60m floor-to-floor height).

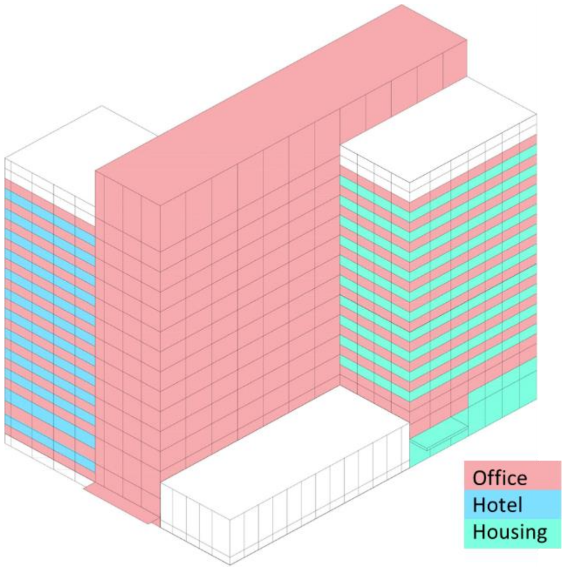

Figure 2: Hybrid design – Zebra concept (51N4E)

To address this problematic, one of the most striking features of ZIN is the "Capable Volume," a central double-height space designed to connect the two towers. This volume plays a crucial role in providing the necessary spatial flexibility for the building, offering an acceptable compromise with the limited height of the towers. With a floor-to-floor height of more than 6 meters and column-free spans of up to 15 meters, it provides expansive, adaptable space suitable for a variety of functions. The flexible nature of this volume ensures that as the building evolves, it can accommodate the changing needs of its users.

By introducing it, the project creates additional space without modifying the original structure too drastically. This intervention exemplifies the co-creation process between architecture and structural engineering, turning a potential constraint (the low floor-to-floor height of the towers) into an opportunity for innovation.

3 Maximising reuse - circularity

3.1 Structural feasibility of reuse

One of the most significant challenges of ZIN was determining the feasibility of repurposing the existing structure. The WTC I and II towers, built in the 1970s, had been designed to meet the standards of their time, which were far different from those required today. The project began with a comprehensive structural diagnostic of the existing building, assessing factors such as compliance with modern codes, wind resistance, fire safety, and acoustic performance. Our objective was to address these issues with technically viable solutions.

We evaluated various scenarios (Fig. 3), ranging from full preservation to complete demolition, assessing their impact on the final project. While increased demolition would provide greater design flexibility, it would also contradict the objective of circularity. Based on surveys, a crucial finding was that slabs, despite representing only 15% of the total structural mass of the existing situation, posed significant constraints in terms of structural integrity, fire safety, vibrations and acoustical performance. They consisted of composite floors with a 10cm concrete slab (on non-collaborative lost steel formwork sheet) supported by secondary metal profiles (with studs) spaced 1.5m apart.

After careful consideration, the concept team considered that the optimal approach to maximize material reuse while addressing the structural constraints of the existing building was to demolish the slabs while preserving the structural cores and basement levels, that were in perfect condition and suitable for reuse. By retaining approximately 85% (171,000 tons) of the original structural mass—including 40,000 tons in the cores and 130,000 tons in the basements—the project significantly reduced the need for new materials, minimizing waste and environmental impact. The preservation of these elements alone accounted for over 70,000 cubic meters of concrete.

3.2 Maximizing Material Reuse

In addition to the existing structure, the search for ways of upgrading existing non-structural elements (finishes, insulation, etc.) was a priority in the project. A big effort has been done with specialised partners to valorise, sell, give existing elements for reuse and/or recycling. At the end, 94% of the existing materials are reused, directly on site (62%) or by recycling (32%). 99% of the new materials brought into the building are Cradle-to-Cradle certified (Fig. 4).

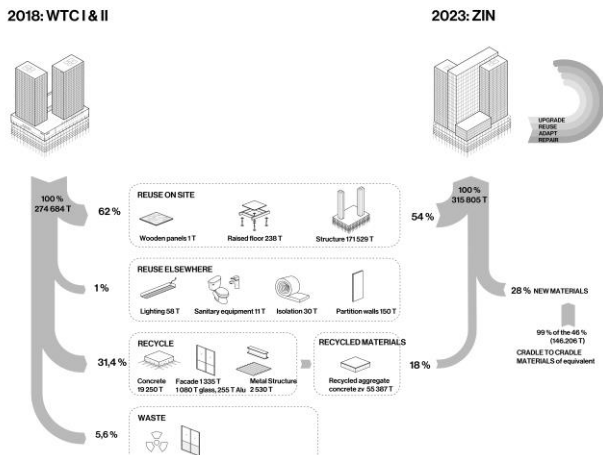

Figure 4 : Material flow – reuse – recycle – C2C

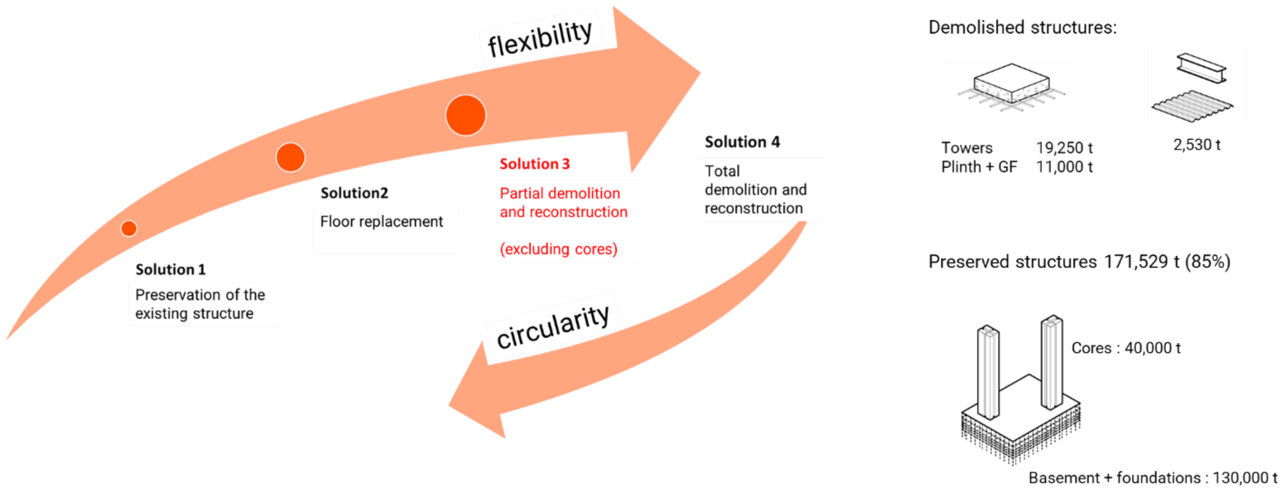

Figure 3 : scenarios for reuse of existing structure vs. circularity

The use of C2C products guarantees that the materials used in construction can be fully recycled or safely reintegrated into the environment at the end of their useful life.

3.3 Recycled concrete aggregates

The project became one of the first in the Benelux region to create a large-scale supply chain for concrete made from recycled aggregates. These aggregates, created from the demolition of the existing floors, were processed (sorted, crushed, mixed) into high-quality concrete reintroduced into the new construction, reducing the need for raw materials. This closed-loop system has been made locally within a 15 km radius of the site (Fig. 5).

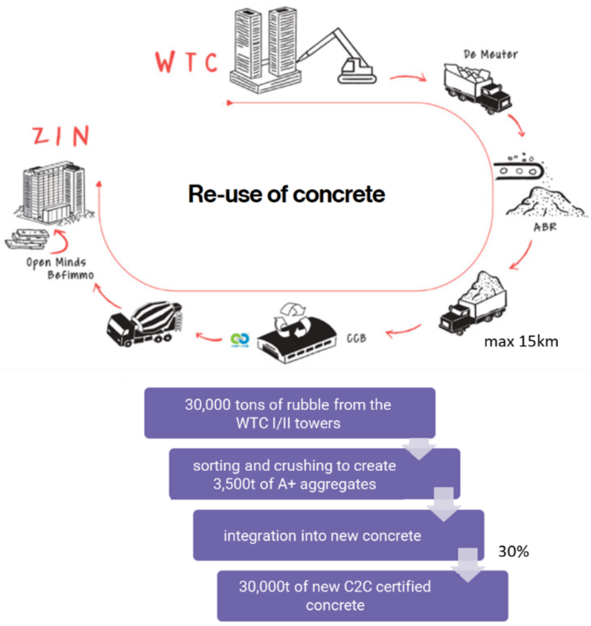

Figure 5 : Recycled aggregates supply chain

4 Structural Engineering challenges

The creation of the "Capable Volume" connecting the two towers is a key element of the architectural design that allowed the reuse of existing structures by offering a new perspective on the limited floor-to-floor height fixed by the existing cores. However, it also introduced significant technical challenges, particularly in terms of interaction with wind forces and vertical load distribution.

4.1 Wind Load Analysis

When considering the cumulative bending moments on both cores, the presence of the "Capable Volume" reduces wind forces in the X direction (-19% due to the decreased cumulated surface area and modification of form factor) but significantly increases wind forces in the Y direction (+27%), which presents a challenge for justifying the existing cores (Fig. 6). To confirm these wind loads, wind tunnel tests were conducted.

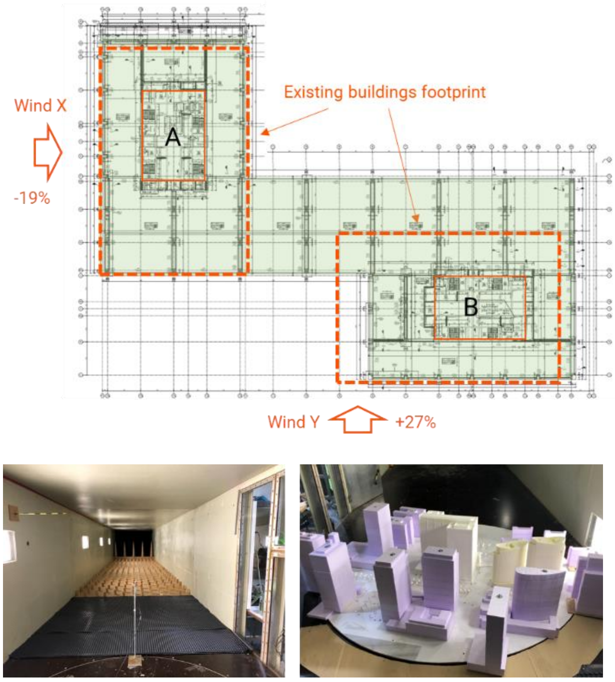

Figure 6a Modification of wind forces – 6b. wind tunnel tests

In the original configuration, the two cores were clearly independent. The cores were not optimally positioned: the weak axis of each core was aligned with the highest wind load direction in both building. Additionally, the cores were offset, which resulted in significant torsion.

Based on initial structural modelisation, we found that connecting the two existing cores via the floors of the "Capable Volume" would enable a more optimal redistribution of wind forces between the cores. In particular, we observed that the moment acting on cores A and B for a wind direction in the Y-axis was nearly identical (Fig. 7). Despite the increased loads, core B was less stressed than it was when the towers were independent. The connection between the two cores allows for the mobilization of the increased stiffness and resistance of core A. The moment in core A is significantly higher than what it experienced for a wind direction in the Y-axis, but it is still within the capacity it could withstand along its weak axis for a wind from the X direction. Thanks to this connection, torsion in the cores is also avoided, as it is taken in bi-flexion by the two cores thanks to the floors.

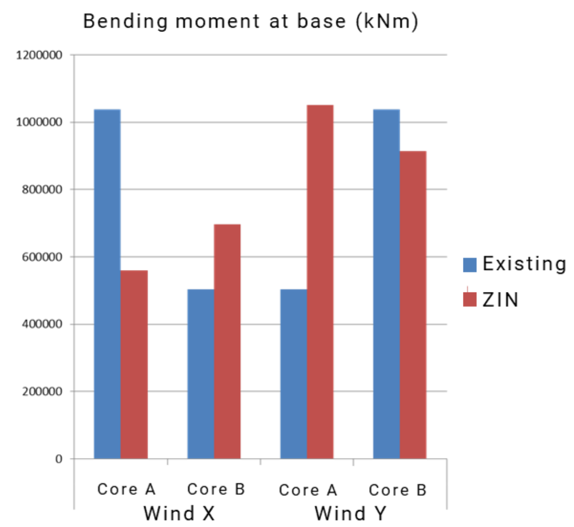

Figure 7 Wind distribution between two cores

Based on this observation, detailed structural modelling, and a precise analysis of the reinforcement plans for the existing cores, we were able to definitively validate the resistance of the cores (both horizontal and vertical reinforcement in the projected configuration) in compliance with current design standards (Eurocodes).

However, it was found that the stress level on the lintels in the proposed configuration exceeds their capacity. Although the maximum moment remains the same, it acts in a direction perpendicular to the original situation (the lintels in the longitudinal direction of the cores are now the most stressed, while those in the transverse direction are less stressed). Reinforcements using steel plates were applied.

Interestingly, while the Capable Volume could initially be seen as a constraint due to the increased forces it generates, it ultimately became the solution to this problem.

4.2 Reinforcement of existing foundations

The modifications to the existing structure, particularly the addition of the "Capable Volume," have a significant impact on the foundations and presented one of the major structural challenges of the project.

4.2.1 Existing foundation system

The site's geotechnical profile consists of a sequence of layers with varying compositions and permeability:

- +/- 11m of heterogeneous layer (filling, sand) with high permeability
- +/- 10m layer of sand with clay (top of the Ypresian formation), moderately permeable
- +/- 32m layer of clay with sandy material (Ypresian formation), with variable consistency and very low permeability
- A very compact sandy layer (Landenian formation), located at a depth of 53 meters

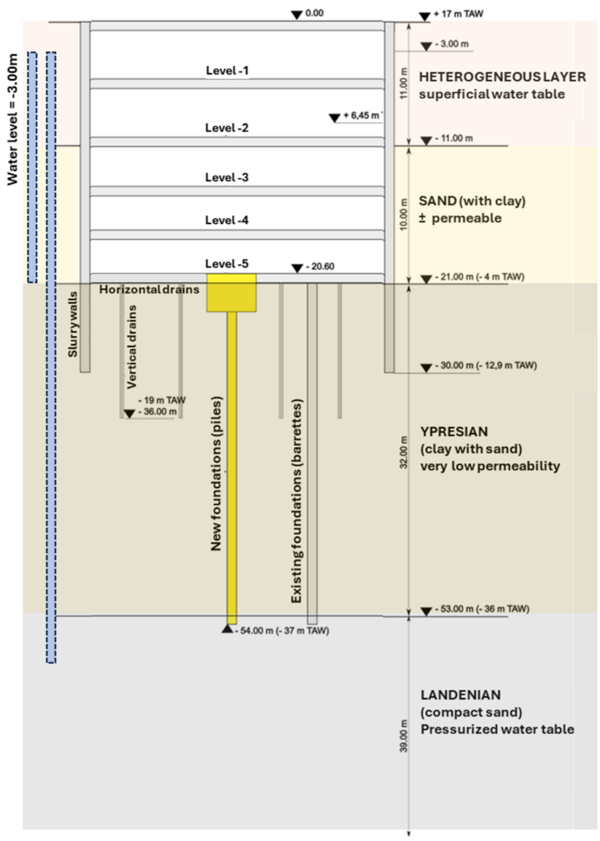

Figure 8 : Geotechnical profile and basement

The existing building has five levels of basements. The existing cores and tower columns are founded on deep barrettes resting on the highly resistant Landenian layer. The basement enclosure consists of slurry walls (80 cm thick) anchored in the impermeable Ypresian clay, creating a waterproof barrier for the basements. In the initial design, the slab at the -5 level consists of a draining raft (a network of drains placed below the raft and connected to pumping chambers), which was not designed to withstand water pressure beneath the slab but allows to control leakage of water through the Ypresian clay.

The distribution of loads in the new configuration differs significantly from the initial configuration. A substantial portion of the studies focused on assessing the capacity and reinforcing the foundations. To accurately address this, we conducted a comprehensive calculation of the existing situation (load distribution and capacity of the existing barrettes), based on current standards. That indicates an admissible stress at the level of the existing barrettes between 5.5 and 6.2 MPa (depending on the shape factor), corresponding to a load capacity ranging from 19,000 to 28,000 kN (SLS). By comparing this with the future load distribution, we can identify areas where the existing foundation capacity may be insufficient and requires reinforcement.

4.2.2 Deviation structure to reduce number of reinforcements

For the "tower portions" of the structure, new columns are primarily aligned with the existing ones, and the existing barrettes are reused without significant reinforcement. Regarding the “Capable Volume”, some existing foundations require reinforcement, while entirely new foundations must be created for areas outside the existing tower footprint, with loads reaching up to 37,000 kN (SLS).

As it will be detailed later, the creation of foundations from the existing basement is a highly complex operation due to the interaction with the existing structure. It quickly became apparent that it would be more efficient to limit the number of new foundation locations, even if it meant supporting higher loads. To achieve this, we designed deviation structures to redirect the loads from the inner columns to the outer axes, reducing the required number of foundations from 22 to 13 (Fig. 9).

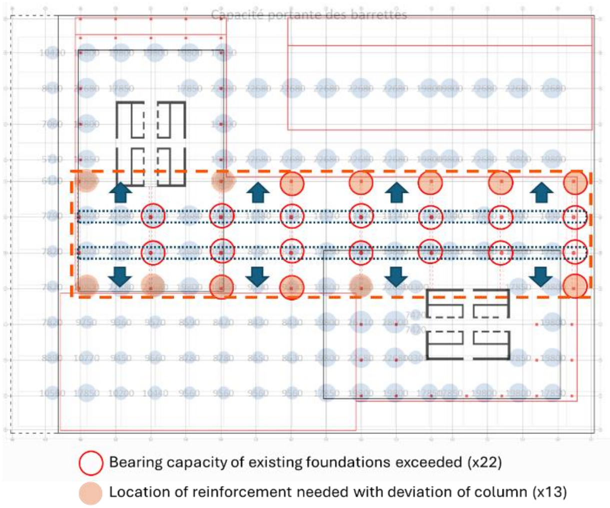

Figure 9 Reduction of foundation reinforcement thanks to the deviation of columns

The prefabricated columns (made of ultra-high-performance concrete C90/105) are inclined over five levels to re-align with the outer axis (Fig. 10). Given the significant load on the inner columns (26,000 kN), this redirection generates a large horizontal force of 8,000 kN at the ground floor slab level (for each deviation, spaced with 15m). This force is managed using high-strength post-tensioning bars (6x Ø75mm with yield limit = 1860MPa). To accommodate the increasing loads during the construction phase and mitigate potential deformations, a phased approach was implemented for the post-tensioning system, following the progressive loading of the building and preventing overstressing the structure during construction (Fig. 11).

A specially designed steel component with a complex geometry (made of welded plates) addresses the issue of significant stress concentrations, which are difficult to manage in concrete elements. It integrates the high compression stresses at the intersection of the inclined columns and the vertical facade columns, as well as the post-tensioning force.

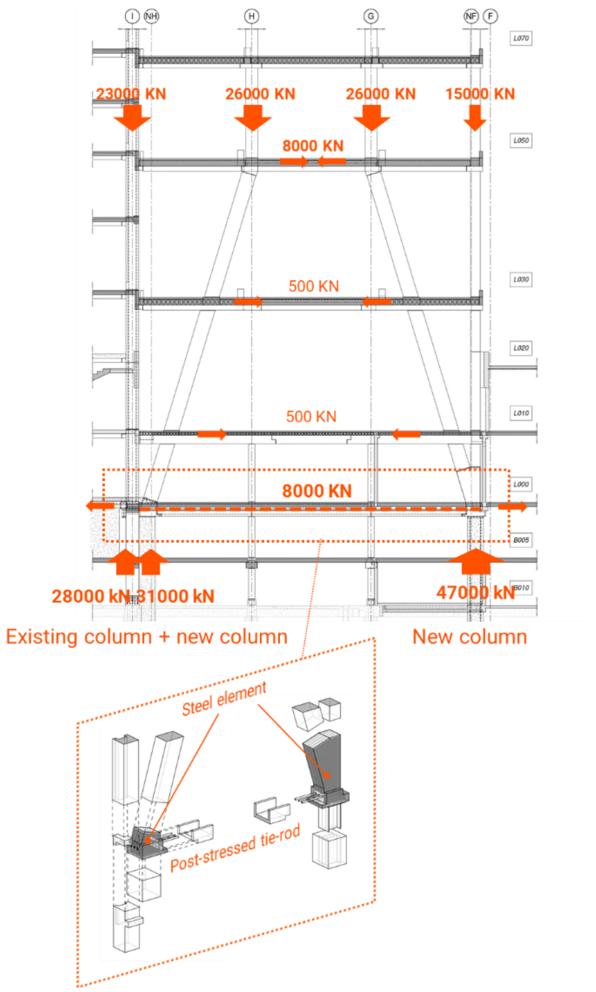

Figure 10 Details of deviation structures

The bars in the tensioning system are integrated into injected ducts after the final load has been applied (with no adherence during tensioning). These ducts are embedded in U-shaped partially prefabricated beams. Redundancy is provided through passive reinforcement to ensure the structural robustness in case of any issues with the prestressing bars.

What was initially seen as a constraint for structural engineering turned out to be a fantastic opportunity for the architecture. The inclination of the columns, combined with the large height of the Capable Volume, creates extremely generous spaces on the lower floors, which correspond to the building's main entrance (Fig. 12).

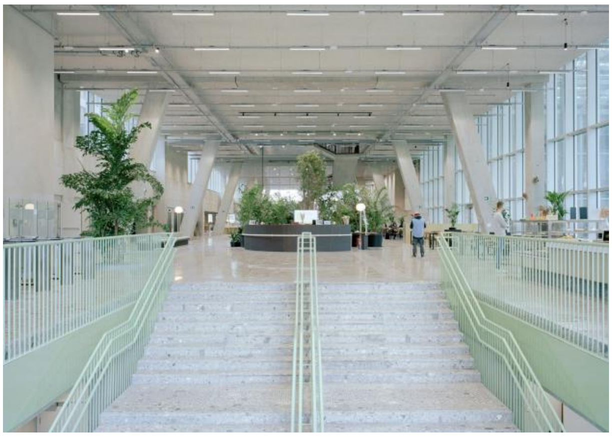

Figure 12 View from level 1 - deviation structures

4.2.3 Drilling piles from basement -5

To remain compatible with the existing system and avoid significant differential settlements, it was essential to carry these loads in the Landenian layer, 32 meters below the existing -5 level from which these foundations will be built. The technique used consists of drilled, tubed (diam 470mm) and injected piles. Cement grout injection is performed during drilling from the lost drilling head (diam 670mm) to increase the friction

Figure 11 : Different stages of the reconfiguration of WTCI/II into ZIN

between the casing and the ground. The pile head is anchored for a minimum of 50 cm into the Landenian layer (which is very difficult to drill due to its compactness).

The placement of the piles was a complex task, requiring careful consideration of execution constraints (conflicts between the drilling mast and the basement floor beams), but also ensuring a minimum distance between the piles to avoid group effects and to maintain compatibility with the reinforced existing barrettes. Performing these pile installations from the -5 level, with a limited clear height of 2.10 meters, posed a real technical challenge (Fig. 13). The new piles and existing barrettes are connected by a 2-meter-high “pile cap”.

A particularly challenging aspect of the execution process is related to the presence of a pressurized water table in the Landenian layer (beneath the clay layer) with pressure similar to that of the superficial water table (3m below the surface) (Fig. 8). The issue was that by drilling these piles from the -5 level, we would penetrate the impermeable layer and create a direct connection between the basements and the Landenian water table, leading to a "geyser" flooding the basements. Before proceeding with the piles, we had to lower the Landenian water table by about 20 meters using 8 extraction wells distributed around the building, which was maintained throughout the entire foundation installation period. The operation, which required pumping approximately 50 m^3/h, was continuously monitored to ensure the stability of the situation and to observe any impact on the immediate surroundings of the site.

5 Environmental Impact

By focusing on material reuse, minimizing waste and efficient design, ZIN sets a new benchmark for sustainable high-rise renovations, proving that large-scale buildings can be transformed with minimal environmental impact. By preserving 85% of the original structure, including the cores and basements, ZIN has been able to mitigate a substantial amount of embodied carbon.

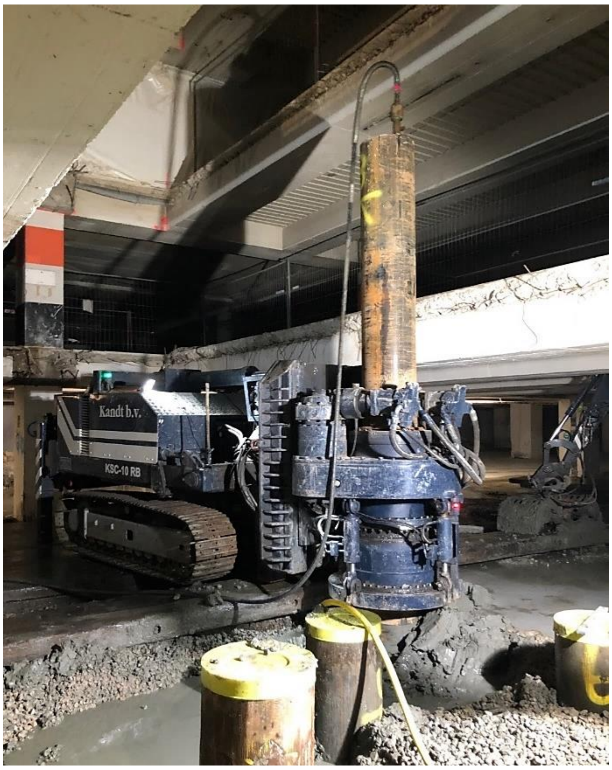

Figure 13 : Drilling the piles from -5 basement

The upfront carbon (module A) associated with the building’s structure has been mitigated of approximately 50% (compare to a realistic benchmark for efficient new construction), representing a diminution of 184kgCO2/m², or 21,400 tons of CO2 in absolute (Fig. 14). When considering the total building's upfront impact (including façade, finishes, MEP) the reduction in embodied carbon is estimated at 33%.

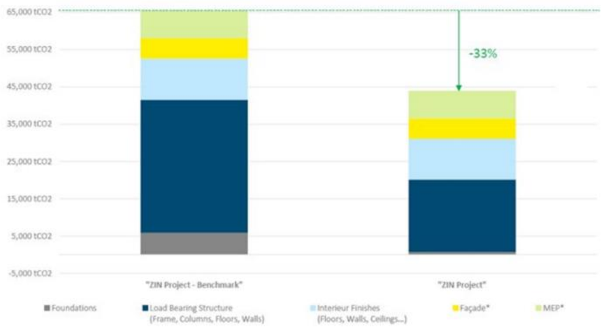

Figure 14 : Upfront carbon mitigation (Befimmo)

Based on the LCA (Life Cycle Assessment) analysis, the Overall Carbon Impact over a lifetime of 60 years is estimated to be:

- Upfront Embodied Carbon (Module A – construction stage): 377 $kgCO_2/m^2$
- Whole Life Embodied Carbon (Module A, B – use stage, C – end of life): 572 $kgCO_2/m^2$
- Whole Life Embodied Carbon (Module A, B, C, D – reuse & recycling): 501 $kgCO_2/m^2$

6 Conclusion

ZIN is a groundbreaking example of how sustainable and circular principles can be applied to the renovation of high-rise buildings. By prioritizing material reuse, innovative engineering, and close collaboration, ZIN sets a new benchmark for sustainable urban development.

A key lesson from the project is the importance of co-creation in overcoming complex challenges. The success of ZIN stemmed from the seamless collaboration between architects, engineers and developer, who worked closely at every stage, actively contributing to shaping the building's design. This integrated approach allowed for innovative solutions that would have been difficult to achieve through traditional, sequential methods. In renovation projects with significant constraints, this type of collaboration seems essential.

ZIN also contributed to the development of new supply chains, creating opportunities for material reuse and setting a precedent for future construction projects. The project demonstrates how hybrid design, flexible spaces, and a circular economy approach can transform outdated buildings into sustainable, adaptable spaces. ZIN sets a precedent for future construction projects in Belgium and beyond, demonstrating that circularity can be effectively applied on a large scale.

7 References

[1] 51N4E, l'AUC, Jaspers-Eyers architect, Befimmo. *How to not demolish a building*. Ruby Press, 2024.

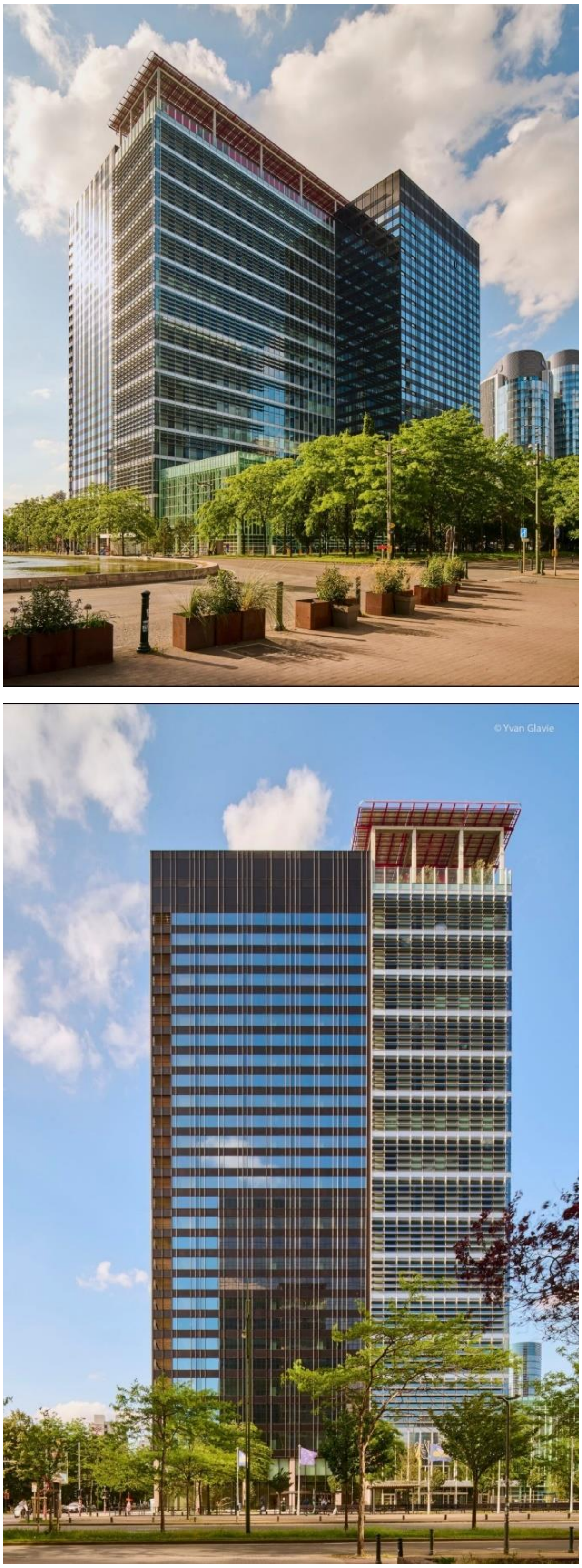

Figure 15 a/b : ZIN after construction