▲ FIGURE 1: GREENERY AT THE ENTRANCE OF BIOPARTNER 5, LEIDEN

BioPartner 5

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IMD RAADGEVENDE INGENIEURS

BioPartner 5 in Leiden is the first large-scale application of the donor skeleton principle developed by IMd Raadgevende Ingenieurs. Almost two-thirds of the steel structure (165,000kg) consists of reused structural steel, which was collected from a nearby laboratory building on the Leiden Bio Science Park. The structure is also designed in such a way that it can be easily dismantled at the end of its lifespan. For these sustainable achievements, BioPartner 5 won the Dutch National Steel Award 2022. The jury named the project 'a clear benchmark for circular building'.

Incubator

BioPartner 5 is a pioneering incubator building on the Leiden Bio Science Park. The building aims to accelerate the development of the Leiden University campus in Oegstgeest, which is still a relatively empty area. The building has a floor area of approximately 6,200m^2 and consists of flexible offices and laboratories for start-ups and various shared facilities. It also provides meeting places that contribute to an inspiring work environment.

Reducing material

Together with Popma ter Steege Architecten, IMd Raadgevende Ingenieurs designed the building structure, which consists of steel columns and beams and concrete hollow core slabs. Stability is provided in one direction by wind braces and in the other direction by moment resistant portal frames. Before the design phase of BioPartner 5, donor steel had only been applied in small scale projects. Because of the lack of experience, project partners used to consider this application to be risky and financially unappealing. Also, during the preliminary design of BioPartner 5, the starting point for

▲ FIGURE 2: BIOPARTNER 5 IS AN INCUBATOR BUILDING AT THE LEIDEN BIO SCIENCE PARK

the structure was conventional new steel. In this phase, the architect and structural engineers optimized the structural design. By minimizing column spacing to a grid of 3.6m, the structure could be kept slender resulting in a minimal amount of steel.

De- and remountable

To further explore the sustainable possibilities, the ambition was set to make the building de- and remountable, so that structural elements can have a second life when the building no longer meets user requirements. Thanks to IMd's expertise regarding sustainable structural design and the close cooperation with the architect, a lot of valuable structural expertise was added early on in the design phase. This approach has resulted in mostly bolted connections and smart detailing of the hollow core slab supports.

Donor steel

During the design phase, the news came out that the nearby Gorlaeus building from 1963-1971 was going to be demolished. These news immediately led to a reconsideration of the sustainability goals for BioPartner 5. The new goal was to apply the maximum possible amount of reclaimed steel from the existing building, upgrading it from a demolition building to a donor skeleton. In the end, almost two-thirds of the steel construction (165.000kg) of the new building was harvested from the Gorlaeus building. Furthermore, existing

Paris proof thanks to donor steel

Largely because of the circular approach and reuse of structural steel, the total CO_2 emissions of BioPartner 5 were reduced by 40%, making it the first building in the Netherlands to comply with the demands of the Paris Agreement.

The sustainability goals, achieved without losing sight of costs, have been applauded on different occasions. In 2021, BioPartner 5 became the runner up of the Cobouw Duurzaamheid Award, Dutch Design Award and Circular Award. In the same year, the project won the audience award of the Rijnlandse Architectuurprijs. And in 2022 it won the Dutch National Steel Award.

For IMd Raadgevende Ingenieurs, BioPartner 5 was the third project in a row to win the prestigious Dutch National Steel Award; a hattrick! In 2018 the award was won by Tijdelijke Rechtbank Amsterdam and in 2020 by the Renovation shops Hoogstraat 168-172 in Rotterdam. With the extensive application of donor steel in BioPartner 5, it is safe to say that we have now passed the experimental phase.

▲ FIGURE 3: REUSED STEEL IS KEPT IN SIGHT IN VARIOUS PLACES, SUCH AS IN THE RESTAURANT

floors and masonry rubble have not gone completely to waste as they have been applied in green facades, stimulating a greater biodiversity.

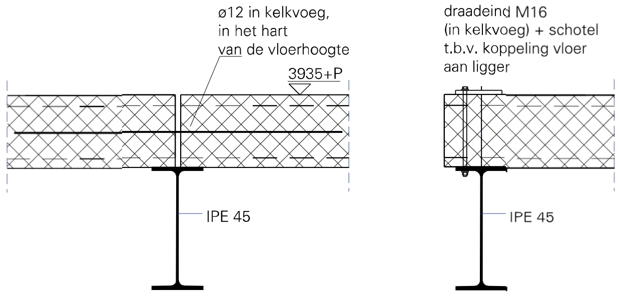
In a couple of locations, it was necessary to use new steel elements to keep the consequences on labor and costs within budget and to stay within the timetable set for the project. For the foundation, it turned out to be hard to find donor elements. A completely prefab concrete foundation was considered, but was not feasible because of to the need of many unique elements. In the end, the foundation was built traditionally: prefab concrete piles and in-situ cast beams.

Working method

Popma ter Steege Architecten and IMd Raadgevende Ingenieurs worked closely together in a design team. As a first step, the steel elements that could possibly be reused were identified, coded on site and included in a 3D BIM-model. A structural analysis was then performed on the original design of the donor skeleton to determine to which level of degree the existing structure had been loaded. After testing steel samples, the steel quality was proven to be close to S235. To build in an extra safety margin and overcome possible deviations in steel quality, the decision was made to keep working with a permissible steel stress of 180MPa.

Subsequently, the existing preliminary design for a conventional new steel structure was checked to see if it was suitable for

▲ FIGURE 4: CONSTRUCTION OF THE DONOR STEEL FROM THE GORLAEUS BUILDING



▲ FIGURE 5: (A) MIDDLE BEAMS (SOURCE: BOUWEN MET STAAL) AND (B) DEMOUNTABLE DETAILS OF HOLLOW CORE SLABS ON STEEL EDGE

the application of the available donor steel. In the existing grid of 3.6m the donor beams would have an overcapacity. Altering the grid to 5.4m could be possible, but did not fit the desired layout of the floor plans, so it was decided to maintain the 3.6m grid. The overcapacity was used to provide stability in one direction. This was made possible by reusing moment resistant connections between columns and beams. In this way, even bigger connected parts of the old building could be reused.

Protocol

Together with the architect, IMd developed a protocol for the allowable deviations in sizes, skewness and permissible damage due to demolition work for the steel profiles. Overall, this was a workable protocol for the contractor. Some elements appeared to be too damaged or were not properly stored, which caused additional deformations and required reparation and even replacement.

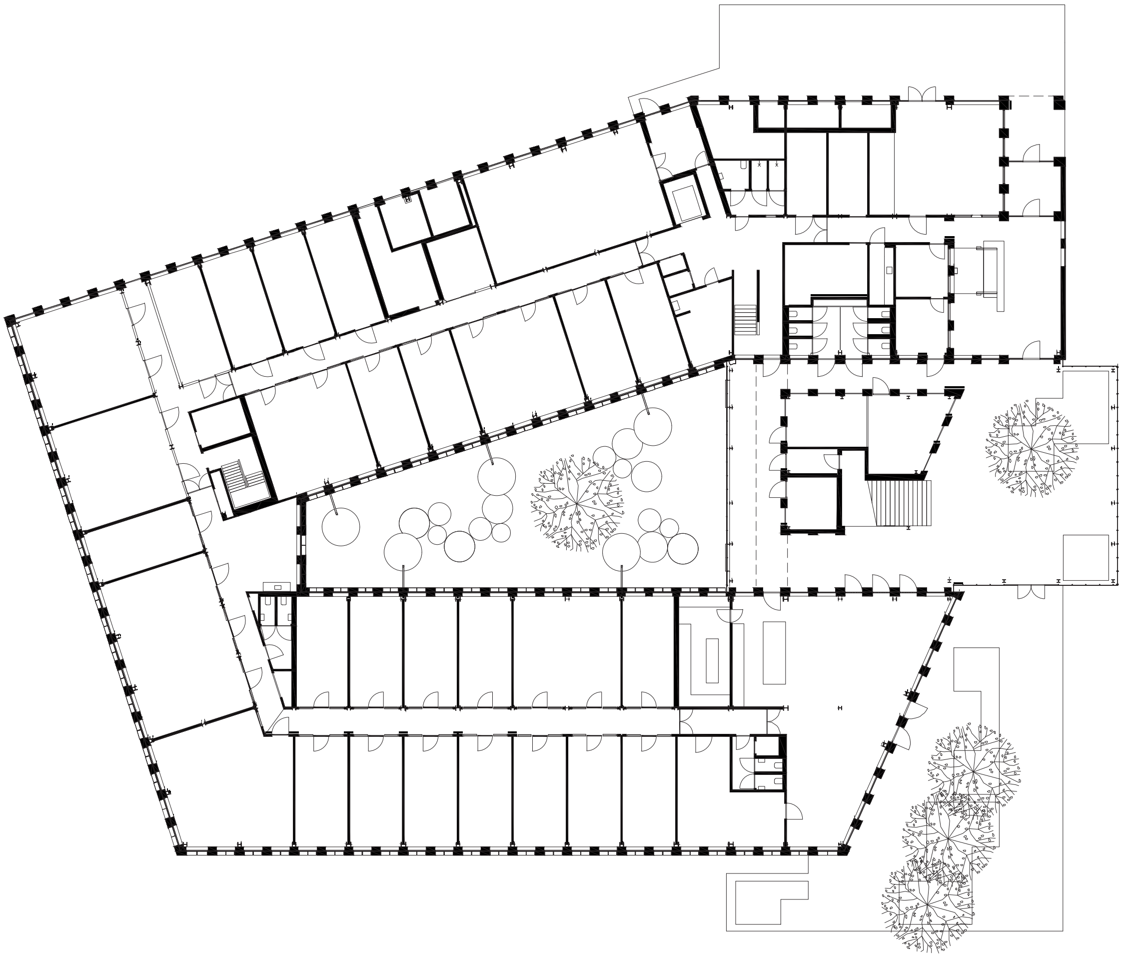
Testing the harvested material

To determine the structural characteristics of the harvested steel elements, various samples were taken, and destructive tests were performed. Additionally, the chemical composition of the steel was analyzed, to see if it was suitable for welding. After removing the paint layer, it turned out that the steel was galvanized, which makes welding very difficult. A few details needed to be changed in bolted alternatives, but here the design strategy of working with as many bolted connections as possible appeared to be useful. By avoiding welding, it was not necessary to remove the zinc layer, which typically needs to be done in a factory, and thus much transport cost and CO_2 footprint were avoided.

Destructive testing was done on several welds of the existing steel. Some of the welds of the moment resistant connections didn't meet the requirements and needed to be strengthened with bolted connections in a later stage of the project.

Details

The connections between the hollow core slabs and steel beams needed to be demountable, but the slabs provide a function in stability (diaphragm action). Therefore, careful design of these connections was needed to ensure adequate diaphragm behavior. Threaded rods were bolted at the top flanges of edge beams (see figure 5a). After placing the hollow core slabs, steel plates were bolted onto these rods and the joints between slabs were filled with mortar. Disassembly is



▲ FIGURE 6: FLOOR PLAN OF LAYER 0 (©PTSA)

possible by removing the steel plate and sawing the hollow core slabs loose so they can be lifted out. The same principle has been applied at the project Tijdelijke Rechtbank Amsterdam. At the middle, reinforcing bars ø12 were placed to prevent rotation of the beam in the event of uneven floor loads as well as for the transmission of the wind loads (see figure 5b).

Adjustment to the reused steel profiles was done on site as often as possible in a temporary demountable workshop to limit transportation. IMd worked closely together with the steel constructor in this phase.

Close collaboration

When working with a donor skeleton, the design phase is much different from a new construction. During the whole design phase, all project partners worked closely together as a team. Everyone was willing to look further beyond their own assignments and responsibilities. For IMd, this resulted in developing the demountable design strategy, doing additional engineering work on the steel details, drafting a protocol for allowable deviations, coordinating the testing campaign and inventory of the steel to achieve the necessary confidence on design quality.

The tendering process was unconventional as the potential contractors were not asked to give a presentation but were invited to the construction site of the Gorlaeus building to come and inspect the steel, where the design team gave a presentation, covering everything that had already been worked out. This made it possible to detect the enthusiasm and craftsmanship of the tendering contractors.

The close collaboration was also acknowledged by the jury of the Dutch National Steel Award: "Every effort has been made for this incubator center with laboratories and office spaces. By bringing together the right people and construction partners, an infectious chemistry has been created and the mission to build with previously used building materials and raw materials has passed with flying colors."

Final thoughts

Currently, the application of a donor skeleton still requires additional engineering time and attention to implementation. The extra costs for these efforts are compensated with savings on raw materials. The circular character of BioPartner 5 made it commercially attractive for the various tenants who want to settle in a sustainable building. Now that the application of a donor skeleton has passed its pioneering phase and more experience has been gained, it offers an excellent starting point for construction projects that are both sustainable and commercially attractive. **U**

SOURCES

Photography: René de Wit

Architect: Popma ter Steege Architecten

[1] Terwel, K. C., Moons, M., & Korthagen, P. (2021). Lessons learned from using a donor skeleton in a 3 storey office building. 62-69. Paper presented at IABSE Congress, Ghent 2021: Structural Engineering for Future Societal Needs, Ghent, Virtual, Belgium. https://doi.org/10.2749/ghent.2021.0062

[2] Terwel, K.C., Moons, M., & Korthagen, P. (2021). BioPartner 5: een veldlab. Bouwen met Staal, December 2021.