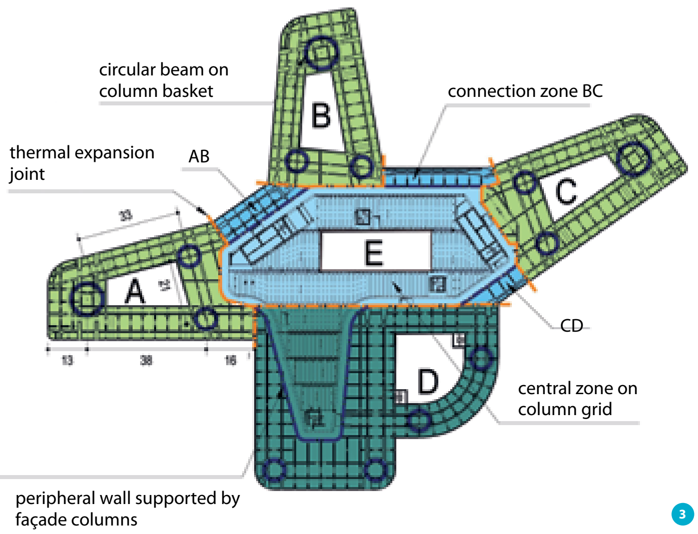
Application of post-tensioning in a concrete structure building

Hospital AZ Zeno in Knokke

In Knokke-Heist (Belgium) the new health care facility AZ Zeno is being built. Spreading over a 20 hectares ground, it houses a hospital of 360 beds, a rehabilitation center, a care hotel and public event spaces on a surface area of over 48 000 m².
The preliminary design stage began with a competition in 2007 and the inauguration is expected for the summer of 2017.

ir. Vincent Servais,
ir. Axel Rémont,
ir. Stephanie Pareit
Bureau Greisch

1 The new health care facility AZ Zeno in Knokke
2 Graphic design model: bird's-eye view on the hospital AZ Zeno
credits:: BURO II & ARCHI+I - AAPROG – BOECKX
3 General floor plan of the structure at the technical level



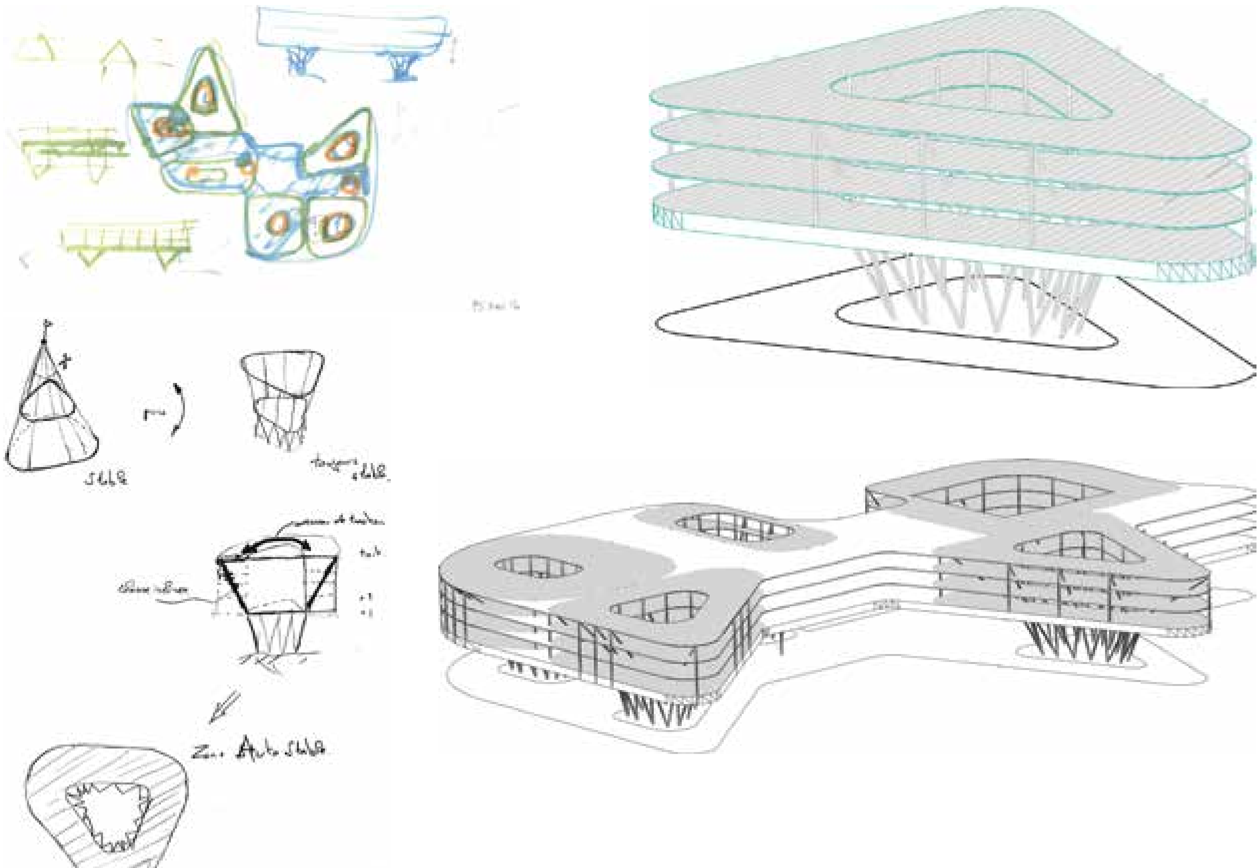
Architecture and landscape

The building seems to levitate above the landscape which gives a high level of transparency to the ground floor. Its design results from the ambition to avoid the feeling of entering a building when walking on the ground floor towards the hospital. The graphic design model of the complete building is shown in figure 2; figure 4 gives the starting structural concepts. The plan view of this low-rise building consists of a central zone, four wings and five patios (fig. 3). The building covers overall dimensions of approximately 200 m by 150 m. Above the open space at street level, the building consists of one technical level and three storeys. A basement is placed underneath the main part of the complex.
At the ground floor, the centrally located reception zone is surrounded by a 300 m glass façade that creates a seamless transition between the inside and outside, and is favorable to the integration of the building in the rural environment.
The same transparency and pleasant environment is pursued in the architectural configuration of the four hospital wings rising up from the ground and covering the outdoor space with its curve shaped undersurface. Each wing has a central patio; the corridor and rooms situated around the patios benefit from views on the landscape and abundant day light.

Structural conception

In the early stages of conception, several structural solutions were considered (fig. 4). Finally, the solution of a concrete box slab, positioned on a limited number of supports, is chosen to create the separation between the supporting deck and the upper structure, while the shape of the structural concrete directly stands out and does not require a non-structural skin. This solution is applied for the three almost identical wings A, B and C, and for wing D and the connection zones AB, BC and CD that are disposed around the central zone E (fig. 3). Each wing is composed of a double slab structure supported by three

4 Sketches and 3D simulation of the structural design in an concept stage
5 Simplified model used for shape determination and complete calculation model through wing D
6 Cross section through wing A



4

or four baskets of columns. These baskets are composed of 18 to 20 inclined steel tubes with outer diameter 298.5 mm that are arranged in two concentric circles (fig. 5).

A grid of vertical walls, varying in height from 0.70 m at the outer perimeter to maximum 3.30 m at the supports, connects the double slab structure consisting of two 250 mm thick plates and gives shear resistance to the structure. The walls are situated along the bearing directions and follow the disposition of the upper structure's columns, at its turn defined by the architectural grid of rooms and corridors with a typical span of 8 m (fig. 6).

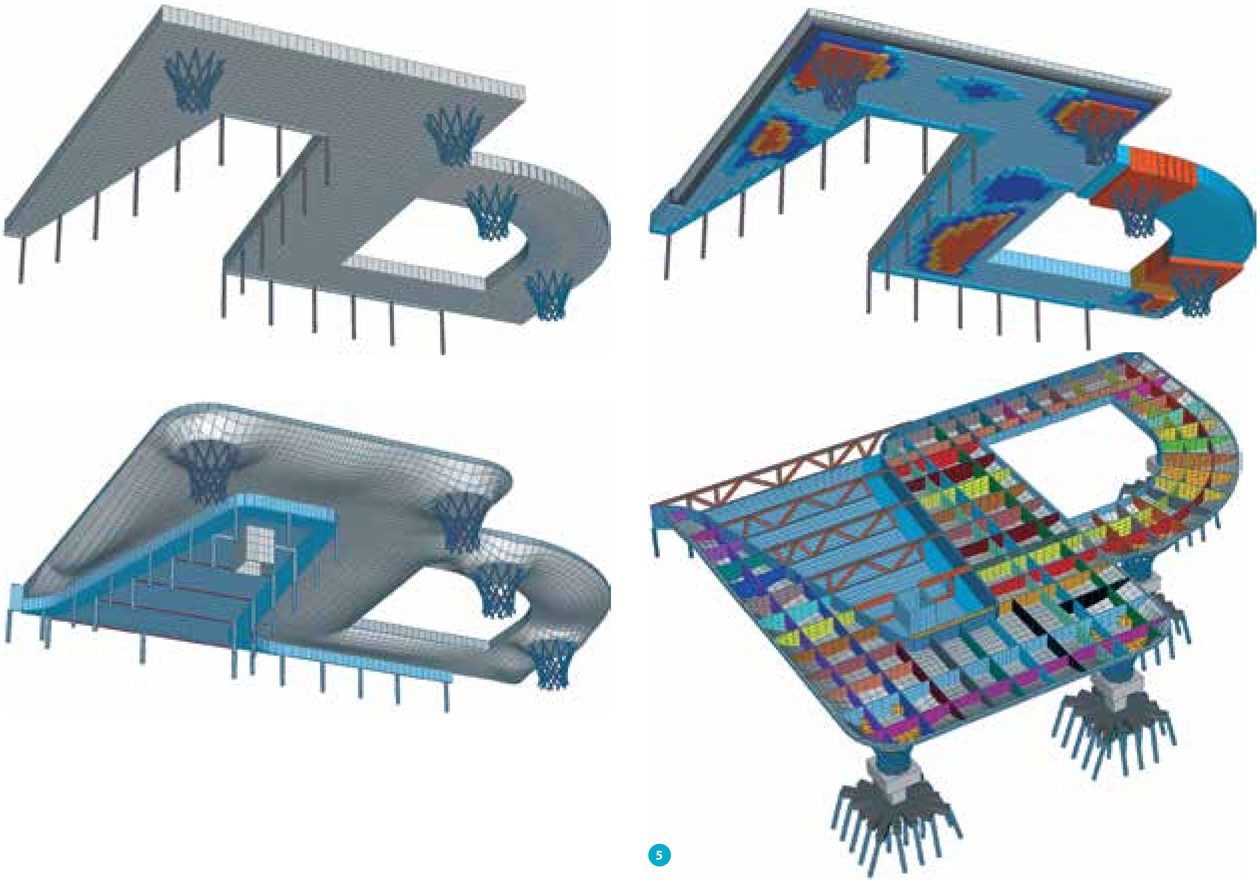
The upper plate of the box slab is horizontal and supports the three levels of hospital rooms with a classical column and beam structure. The lower plate is curved to create a cloud-like shape that enhances the lightweight appearance of the building. It is an aesthetically attractive solution that also reflects the structural behavior: additional height and structural capacity is created at locations where bending moments are important (fig. 5). The complex geometry, the 30 to 40 m spans and the limited height of the structure have led to a cast in situ prestressed post-tensioned solution in C40/50 concrete.

In the central zone E, it was important to provide free space in the reception area. Therefore a one-storey-high steel truss structure has been created at the first floor to support the regular column grid of the levels above. Only the vertical shafts and few columns remain on the ground floor. The truss level has a horizontal floor slab and offers the space to accommodate large technical installations. Technical ducts are connected to this equipment and branch out to the wings of the hospital passing through the hollow space between the cloud's slabs.

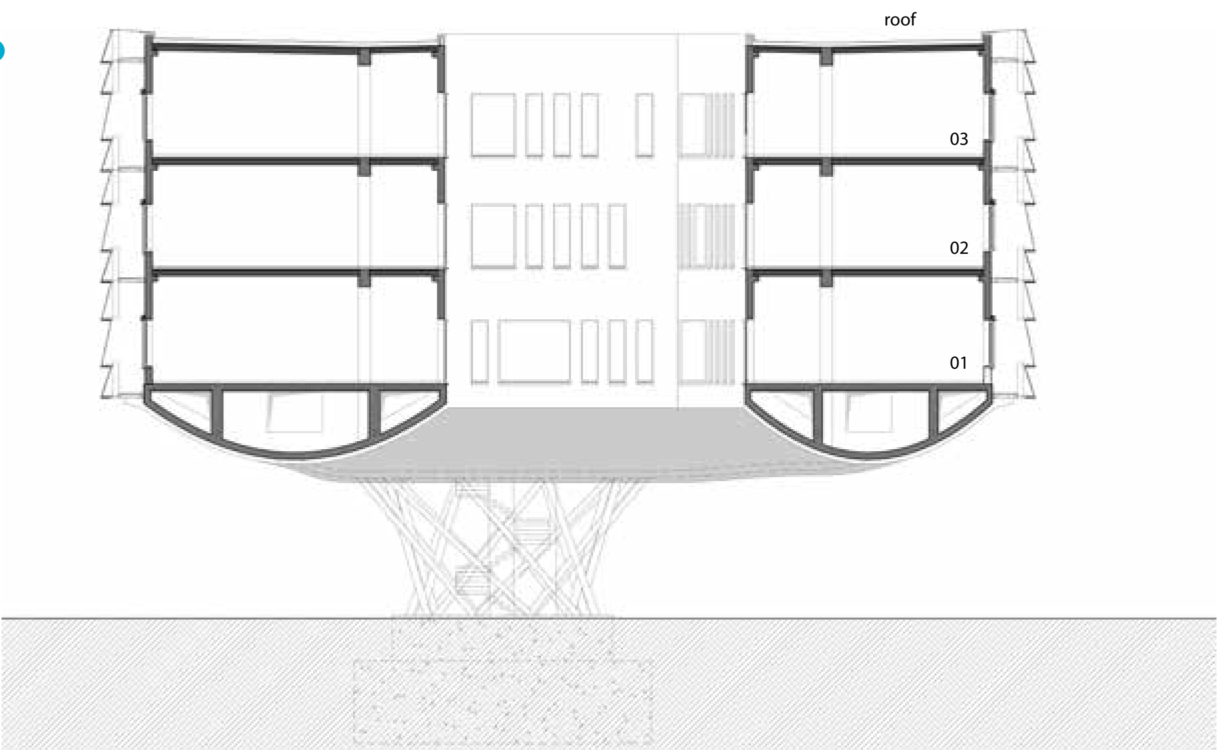
The building is founded on large concrete slabs, reinforced by foundation piles. Under the concentrated loads, mainly below the baskets, the foundation piles prevent excessive deformation. Under the basement, located under the central zone and wings B and D, these piles are loaded in tension when the groundwater level is high.

Shape optimization

The shape of the lower plate is determined by both architectural and structural constraints. Indeed, architecture imposes geometric and aesthetic constraints such as:
- the small height of the concrete slab on its external border;
- the height of the concrete slab its transition to the central zone;


5

6



- an identical height for all supports;
- a minimum height of the structure to provide the space needed for the technical ducts between the upper and lower plate;
- a minimum height below the lower plate to allow fire rescue access.

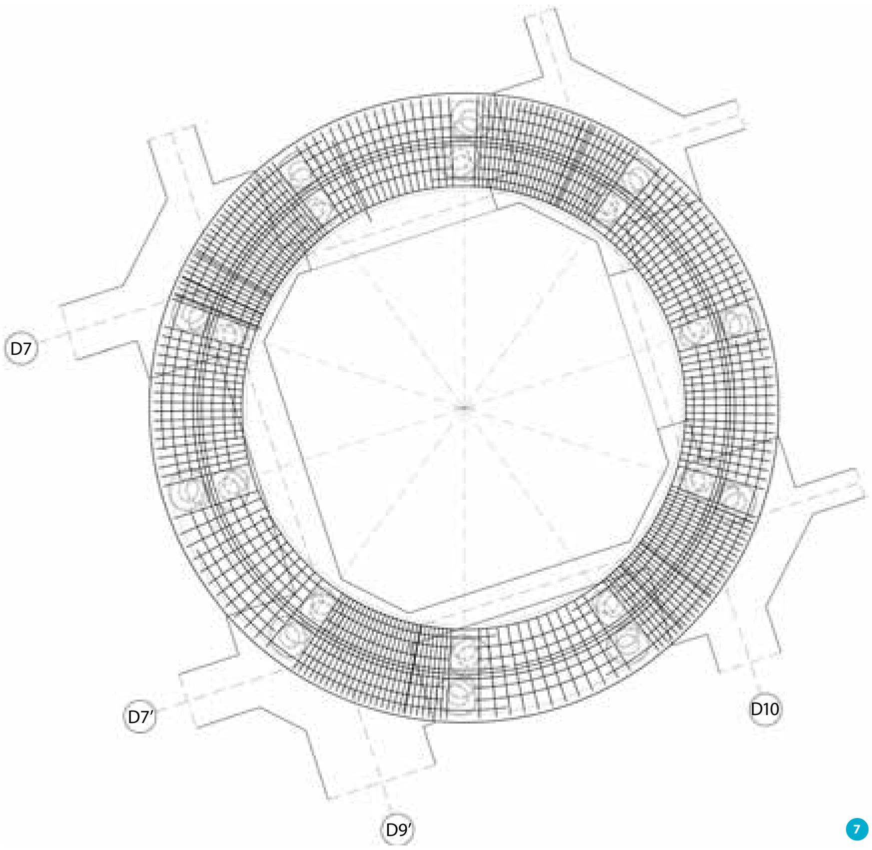
The general structural concept is to set the height of the double plate slab proportionally to the bending moments. For this purpose a first 3D finite element model was built. In this model, the double plate with vertical walls is simplified to one equivalent plate with variable thickness. Internal forces are analyzed and the thickness of the plate is defined for every

7 Drawing of the reinforcement of the ring beam
8 Transversal and longitudinal cross sections of wing A
9 Complex steel reinforcement of the bottom plate of box slab and the ring beams
credits: JL DERU
10 Posttensioning cables on the structural bearing axes of wing A

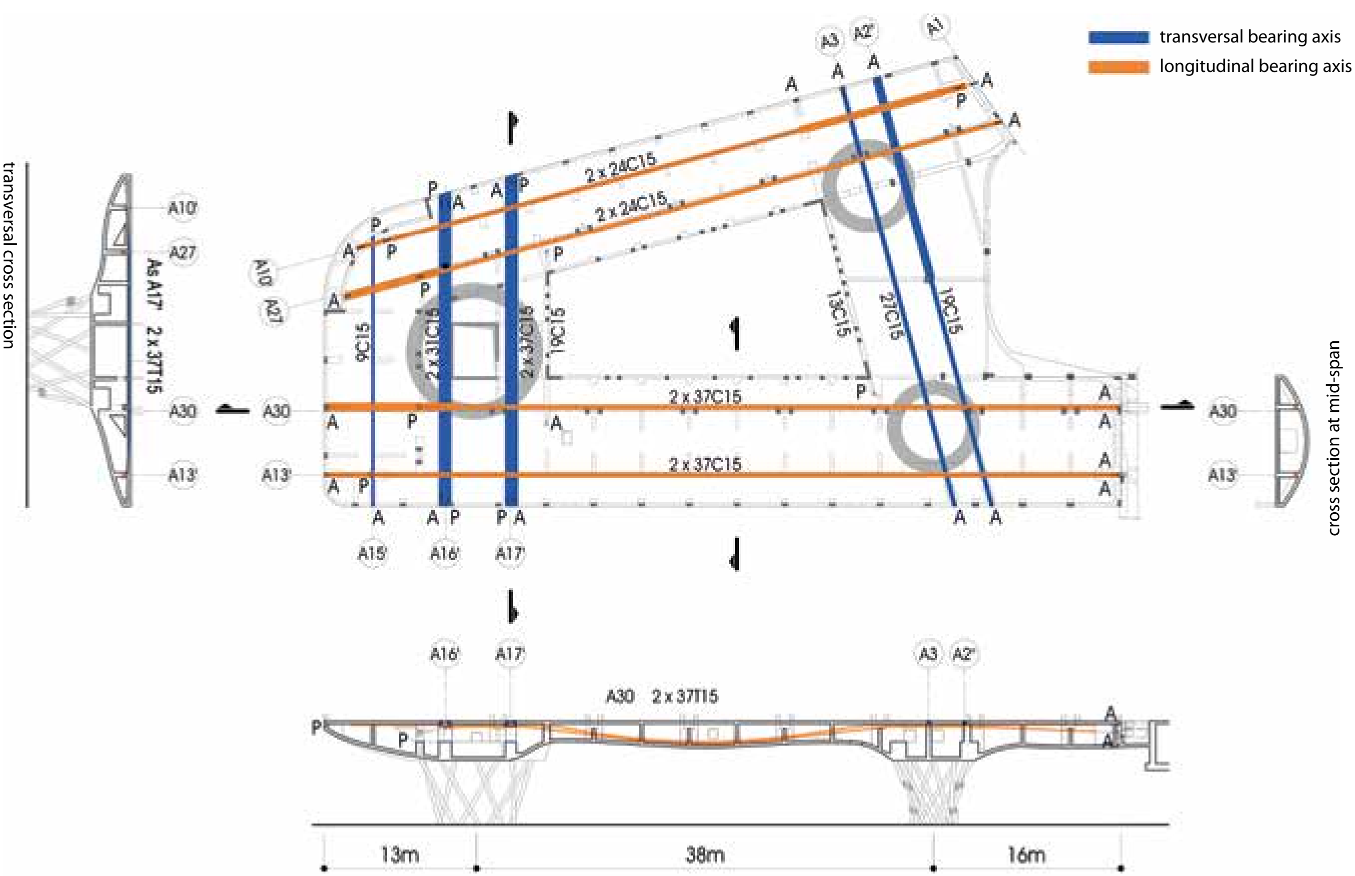
point of the surface. This is an iterative process since modification of the plate thickness causes stress redistribution. This process is carried out by an algorithm assigning, for each finite element of the slab, the optimum height regarding the bending moments in both principal directions. A manual correction is completed to avoid too many and too abrupt variations of height. Based on the modeling results, a precise 3D draft model of the structure is created. It is used to build a precise finite element model, including the representation of the upper plate, lower plate, and vertical walls. This is the final model used for further calculation.

Structural model

The 3D finite element plate model allows a realistic simulation of the overall structural behavior including effects of prestressing, creep and shrinkage, foundations and soil stiffness, and finally phasing stages of the construction. This model creates the possibility:
- to compute the stresses in all the different walls and plates;
- to determine the locations, the amount and the trajectories of prestressing cables;



7



8
longitudinal cross section

9

10

- to evaluate posttensioning losses due to restraints at supports and long term effects;
- to study the interaction between the different zones A, B, C, D and E, for example differential deformation at thermal expansion joints, and forces acting between neighboring wings;
- to evaluate displacements and their evolution over time and during the stages of the construction, taking into account creep and shrinkage effects;
- to define pre-cambers of the upper plate and the edge line of the double slab in order to respect limited tolerance for the disposition of the upper structure and the windows.

Conception and details of posttensioning

The vertical walls on the main bearing axes (fig. 8 and photo 10), are each provided with two ducts containing a number of strands varying between 19 and 37, introducing a compressive force of 170 kN per strand after losses. One of the design criteria to define the posttensioning forces in each axis is to avoid cracking of the concrete in serviceability state, for durability reasons and to limit deformations. To reach this goal, the trajectories of the cables are adjusted to compensate tensile stresses that correspond to the bending moments. Thus, the compressive posttensioning force is applied in the upper plate above the supports, and in the lower plate at mid-span.

As the global 3D finite element model does not suit to analyze local behavior, additional models are created to study details and connections. An example of this type of detail is the ring beam between the box slab and the supports. At the top of each basket structure, a concrete ring beam makes the interface between the lower plate of the concrete cloud and the steel tubes (fig. 7 and 12, photos 9 and 11). To obtain minimal visual

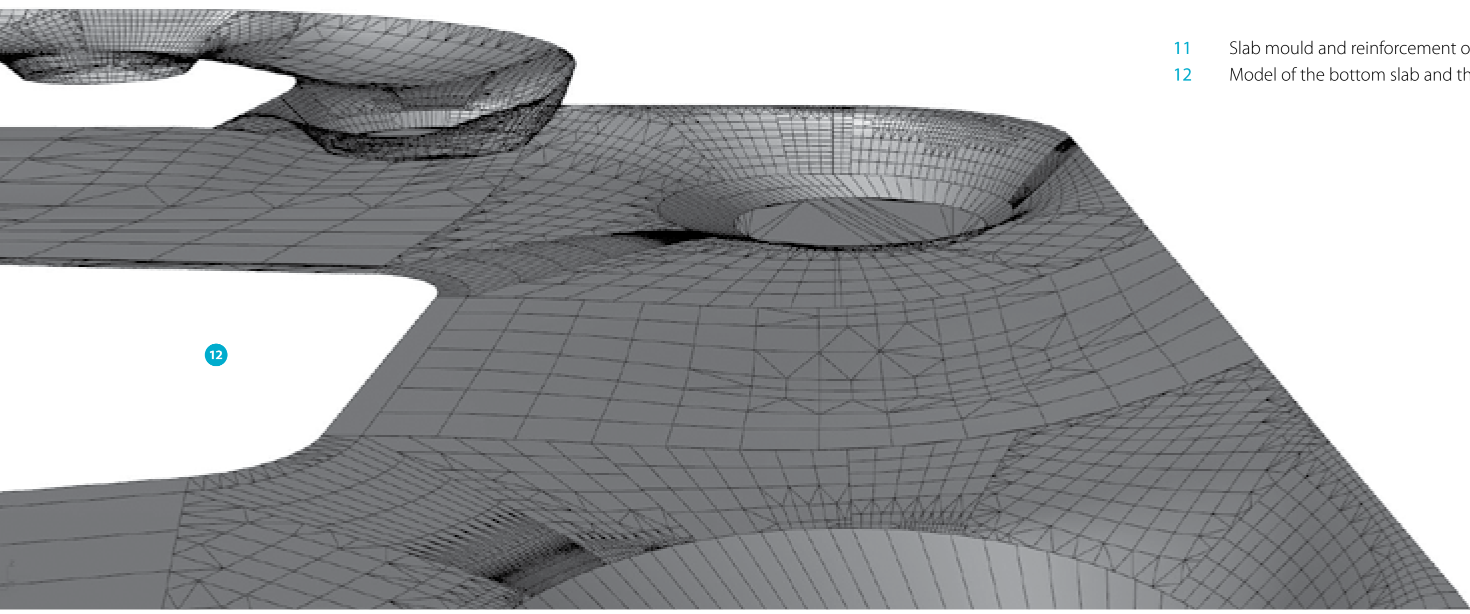
impact, both the ring beam and the column heads are sunk into the cloud. The ring beam's most important function is the redistribution of the vertical loads transmitted by the shear walls into the different columns. The ring beam also allows resisting the horizontal component of the compressive forces arriving on one side through the inclined lower plate, and on the other side by the tilted steel columns. Given the eccentric position of the beam compared to the lower plate, torsion had be taken into account. This results in highly steel reinforced zones.

Conclusion

The realization of the new hospital in Knokke-Heist is a one of a kind in health care construction. The structural concept is remarkable due to its high level of transparency throughout the building and its imaginative geometry. It requires a structural design that includes unusual techniques for both calculation and construction of a low-rise building. Realistic and complete 3D modeling allows to take into account all structural behaviors and interactions. Combined with advanced execution techniques like posttensioning and precise realization of the complex geometry, this project successfully integrated architectural idea with the optimized bearing structure. ☒

● PROJECT DETAILS

developer vzw Gezondheidszorg Oostkust
architect Temporary association BURO II & ARCHI+I - AAPROG - BOECKX.
stability Greisch – structural design of the ground level and technical level; SCES – foundations and prefabricated structure of the upper levels
technical equipment Ingenium
contractor BAM contractors



11 Slab mould and reinforcement of the ring beam
12 Model of the bottom slab and the ring beam