Ultra-slim hybrid staircase pushes the boundaries of glass and concrete

(All photos: Hans Roggen.)

The recent renovation of the ABT headquarters in Velp, The Netherlands afforded the building a contemporary look. A true eye-catcher is the staircase in the lobby, which has been designed and constructed with the aid of the latest technology. The result is a unique piece of work, with an astonishing slenderness and multiple structural innovations.

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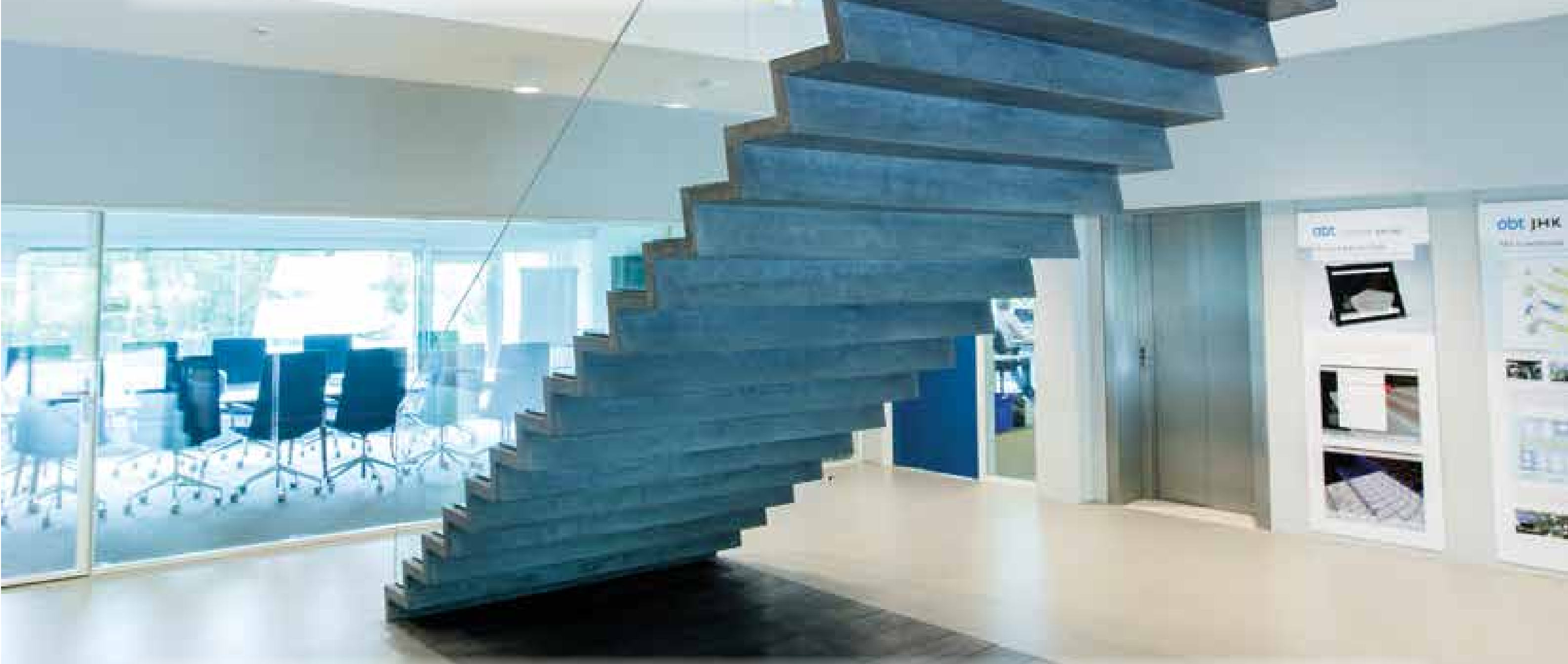
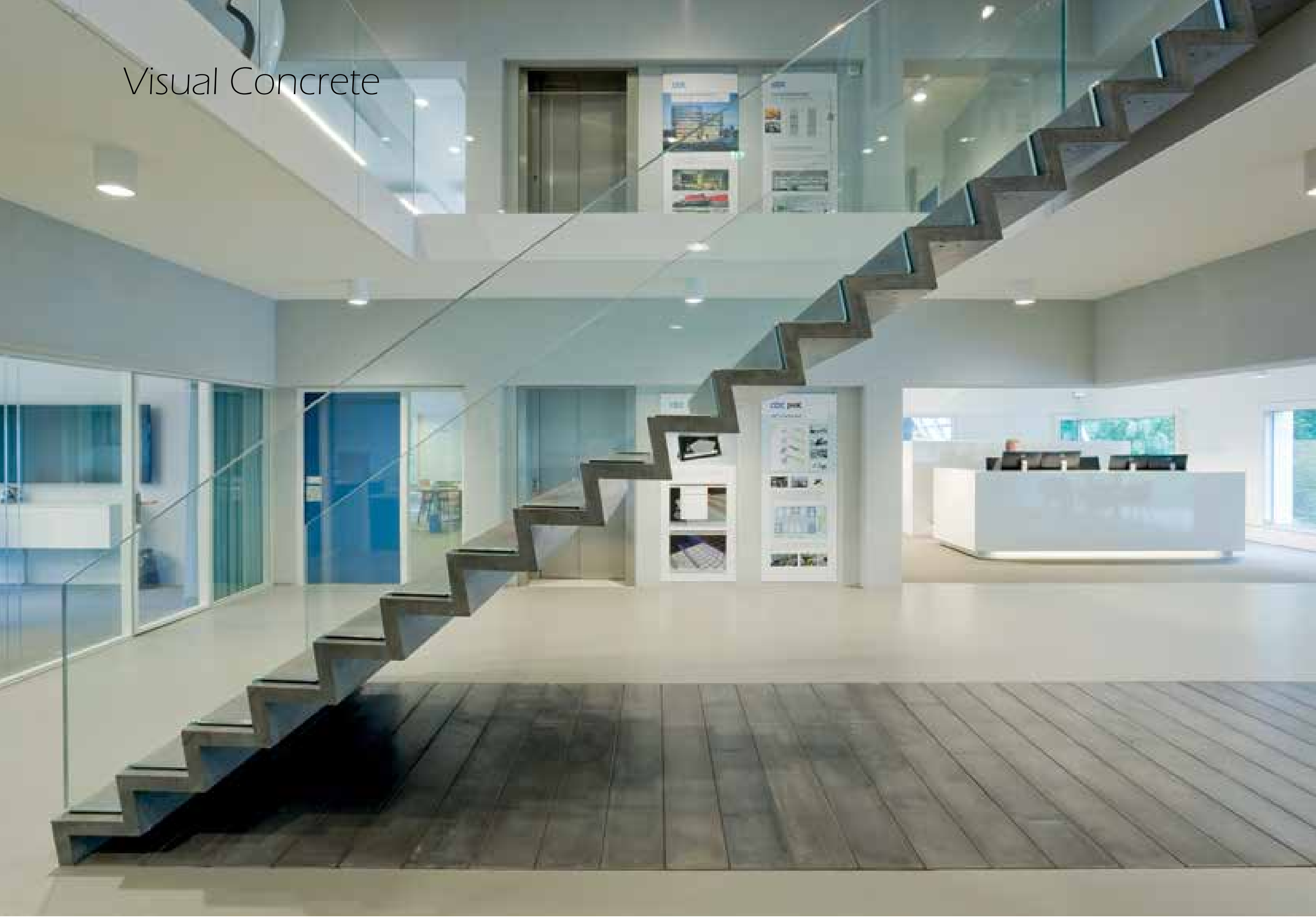


The anthracite-coloured staircase resembles a folded piece of concrete with glass panels that serve as balustrades. To keep the glass and the concrete this thin and slender, the materials had to form a hybrid structure. In addition, the architect's wish was to avoid any stiffening in the concrete element of the staircase, and the structure had to be fully monolithic and jointless. Also the glass had to consist of a single panel.

Similar stairs have been made before, but they never achieved this degree of slenderness combined with these design requirements. The fact that the glass follows the shape of the steps is extraordinary, since it requires extremely high tolerances. In addition, stairs as slim and wide as this one have never been made without the use of supporting ribs or additional supports in the centre. The height of the glass balustrades provides the structural stiffness to the overall staircase. Similar concrete steps are often made up of segments and do not have a monolith appearance. For a smooth surface, the staircase was poured on its side with formwork on both sides.

Method of construction

The concrete staircase was made with prefabricated concrete. To get the staircase in situ, a special frame was developed to facilitate the transport and the positioning. During its positioning, the staircase was structurally anchored into the building. A special load was placed on the staircase, through which it underwent a part of the material creep. This process was monitored very closely. Following the preloading, the staircase was



measured and the glass was manufactured according to the measurements. The glass was connected to the concrete. The connection is unique of its kind and had to be developed specifically for this application, consisting of a steel strip glued to the glass edges and bolted to the concrete. After installation of the glass handgrip, the structure could be used.

Bearing capacity

The staircase spans a distance of almost 6m and has a thickness of about 50mm. Its slenderness ratio is set at 84. To get an idea of this slenderness, most concrete structures in The Netherlands are made with a slenderness ratio between 10 and 25. Therefore this construction is four times slimmer than any current standard.

As such, this took the materials to their very limit. The stresses within the concrete of the stairs are unprecedentedly high. The construction was calculated with specialised software, which showed that the stresses in the concrete – especially during the construction and the deformation process – are far too high for any types hitherto of concrete developed. There are several high-strength mortars already on the market but the tension capacity of these mortars was far too low for the staircase. In order to obtain sufficient tensile capacity and shear capacity, self-compacting ultra-high-strength concrete (SCUHSC) was used. In order to obtain sufficient tensile capacity, a special SCUHSC mortar had to be developed. Furthermore, the reinforcement ratio is around 2%; by comparison, a conventional concrete slab has an average reinforcement ratio of 0.5%.

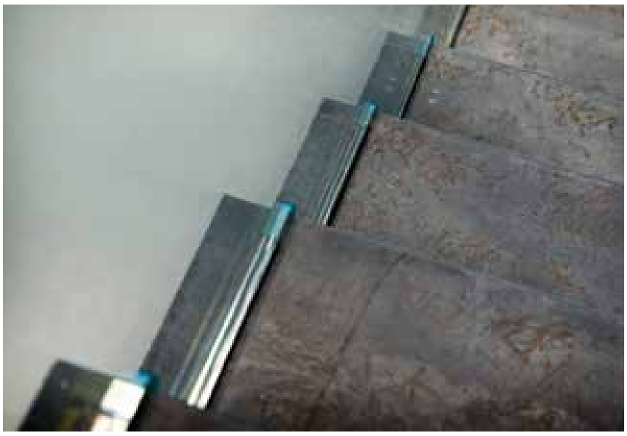
Symbiosis

A number of reinforcement bars are provided by way of smooth steel. This has to do with the bonding behaviour of the reinforcement of the concrete. Ribbed steel was used to reduce the anchoring length of the bar, resulting in a smaller crack width. If thin-ribbed bar diameters are used in SCUHSC, the anchor length is too small, which means that bars may break, even at low strains. In order to obtain a perfect symbiosis between the fibres and the reinforcement, smaller-diameter reinforcing bars were made using smooth steel. The sharp corners of the staircase also dictated the use of smaller-diameter reinforcing bars. Larger bars could not achieve the bending radius necessary to follow the shape of the staircase.

Reinforcement

As may be appreciated, there is very little space left for the reinforcement. To prevent the reinforcement from breaking, the bars in a number of spots were provided with loops. When reinforcement is unconfined, there is insufficient concrete around the reinforcement, so that the bar under tension may be pulled out from the concrete.

The staircase was calculated in several stages and for several scenarios. For example, the concrete element of the staircase is sufficiently strong to bear the ultimate limit state loads without the handgrip. But the concrete



element will not be rigid enough to meet the service limit state demand, especially with regard to vibration. By the use of a rigid connection of the concrete and the glass balustrades, the concrete and the balustrade will work together. Possible creep in the concrete part may increase tension in the connection and increase the stresses in the glass. This situation was also taken into account, with a low stiffness of the concrete and with the glass bearing parts of the weight of the staircase. All these innovations made it possible for the staircase to be made with sufficient anchored reinforcement, which allowed the staircase to absorb the high stresses that occur because of this particularly slender design.

Pouring process

Due to the extreme slenderness, the great width of the staircase, its monolithic design, anthracite-coloured mortar and the large amount of reinforcement, pouring via a normal process was not possible. Various tests were carried out to resolve this issue.

The pouring process was improved until the optimum combination of measures was achieved. The first tests showed that the air was difficult to expel: not only did air bubbles stick to the box but also large areas did not receive any concrete. The concrete is fed into a narrow space, flows in a narrow stream to the bottom of the staircase and causes a problem when the concrete begins to flow laterally at the top of the casing. The air is closed off at the top, meaning the concrete level at the bottom can no longer rise; this would need expulsion of the air closed in by the concrete layer at the top of the casing. In contrast to normal concrete, which is less viscous, the air will not pass through the concrete to the top of the mould. The air chamber is closed.

Options

Once again, this problem showed how ambitions are often ahead of the present state of technology. Several solutions were considered to improve the process.

Options considered were vibration and pumping under pressure; however, adding internal vibration energy was not possible. When a vibration needle is inserted into self-compacting viscous mortar, the impact energy is immediately picked up by the surrounding mortar. The needle vibrates within its own little hole in which it will start to move. Consequently, the vibrating needle gets very hot, because it captures its own vibrating energy. In the case of external vibration of the mould, a similar problem arises. The vibration energy is passed on locally, but it hardly enters the surrounding concrete mortar. An option could be to apply shocks to the mould but this would increase the risk that the shape is affected – a distortion of only a few millimetres could have a disastrous effect. For the same reason, high-pressure pumping of the concrete from the bottom of the mould was not an option. In this case, the concrete pressure would become too high to guarantee the shape resistance of the mould.

Combination of solutions

After careful consideration, specialist engineers from ABT and Romein Beton devised a combination of solutions. These ideas were then tested. A day after the pouring test, the casing of the test piece was removed and the result was visible. The test mortar had proved to be successful and the test piece was fully filled with concrete thanks to the unique combination of solutions, one of these being special air ducts used in the casing, as well as a particularly fine-grained compaction technology.

Tests

In order to guarantee the carrying capacity of the staircase, additional tests were carried out. Prior to the development of the staircase, the mortar was tested with the fibres. Furthermore, the concrete with the fibres was tested in combination with the reinforcement and the hybrid behaviour of the material was examined. It was important that the reinforcement worked well with the fibres. One of the findings of the research was that certain reinforcements must not be provided with ribs. As the connection between the glass and the concrete is completely new, this had to be examined as well, resulting in a one-of-a-kind hybrid staircase. ■

Ultra-slim hybrid staircase, Velp, The Netherlands	
Architect	JHK
Engineering	ABT
Contractor	Cornelissen
Concrete supplier	Romein Beton
Glass supplier	Si-X
Glass manufacturer	Thiele Glas