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Visitor Centre 'Park Groot Vijversburg'

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For the design of the Visitor Centre of 'Park Groot Vijversburg' at Tytsjerk, The Netherlands, the limits of structural design are examined, resulting in one of the largest glass bearing structures. The architectural design is by Junya Ishigami and Marieke Kums of Studio Maks. In plan, the shape of the Visitor Centre is as that of a triangle being pulled firmly in three directions while maintaining a central hall. The architectural design exists of a glass façade with roof only. During the design it became clear that it was the architect's wish not to have any structural elements visible. The critical part of the wings is the cross section, since there is no possibility of adding a lateral resistant element in the section. Using the experience with glass balustrades, the structure is made with clamped glass sheets, that acts like a portal construction. The triangle shape of the main hall is capable of producing lateral support in all directions, just by in-plane actions. The roof structure of steel acts as the diaphragm fixing the triangular shape and distributing the forces to all three sides. By using only the glass façade the load bearing and lateral system is being formed, with simple mechanical principles and use of the spatial effect. All connections are proven techniques in glass balustrades and facades. Combining all these techniques into one building, with no additional structural elements, brings the design of glass structures an important step further. The visitor centre is planned for completion in 2016.

Keywords: Glass structure, minimalistic design, innovative

1. Introduction

The historical park of 'Groot Vijversburg' in Tytsjerk in the northern part of The Netherlands, was established in the 19th century and contains a rich flora and fauna, as well as botanical gardens and a historical villa. Throughout the year, the park hosts many events such as international exhibitions of contemporary art, musical performances, church services and excursions. The historical villa is being restored and extended with a visitor centre next to it. The park is close to the main city of Leeuwarden, which will be the cultural capital of Europe in 2018. The park with its visitor centre will play a major part in this.

This paper is about the structural design of the new visitor centre and give insight to the design of its full glass bearing structure.

2. Architectural design

Architects Marieke Kums of Studio Maks and Junya Ishigami were selected after a competition to design the new Visitor Centre. They designed it as an architectural project, with the aspiration of a building being part of the landscape of the park. The visitor centre is positioned next to a historical villa, and will be used for exhibitions, symposia and concerts.

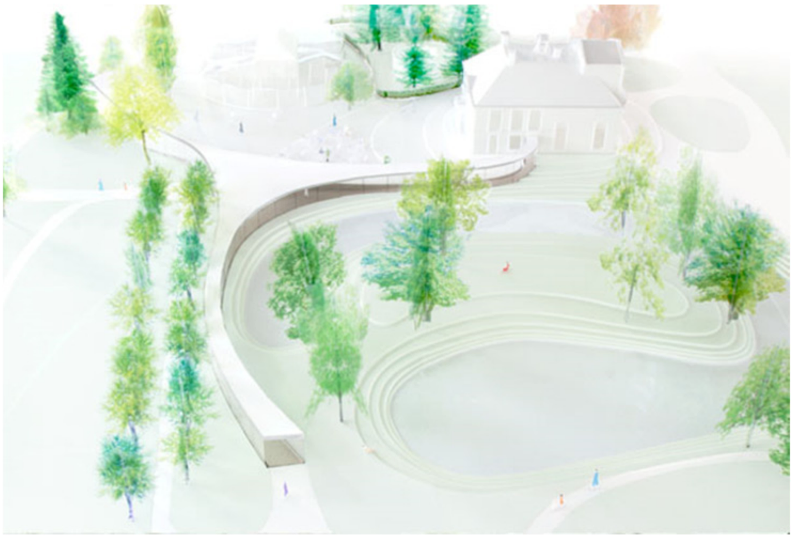

Fig. 1 Model of the new visitor centre.

The transparent design not only blends in with the natural surroundings of the park, but also keep the historical villa untouched in its appearance. In plan, the shape of the one storey building is as that of a triangle being pulled firmly in three directions while maintaining a central hall. These pulled wings lose their quality of interior space as one progresses along it, leaving only its wall, until they gradually become a path – naturally transforming into a park trail. In this way, the building establishes a large scale similar to that of the generous park, and at the same time, the enclosed space provides small scale ambiance and intimacy. The shape of the building connects to the natural shapes of the park. Furthermore, height differences are being used to create the right relationship with the villa and to optimize the visitor's experience.

When looking at the plan, two distinctive principle sections can be seen. One is that of the stretched wings, where the span of the roof is limited up to about 2m with a non-obstructed length of about 30-35m. The other one is that of the main hall, that has a triangular shape and a free roof span of about 10m.

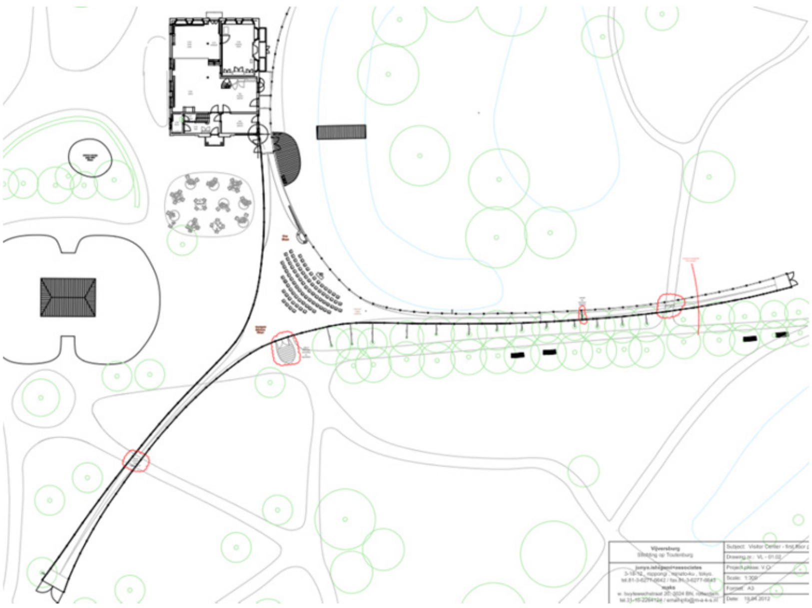

Fig. 2 Floor plan.

3. Glass as structural material

Since the Crystal Palace the fascination for glass structures has grown. To be able to realise buildings with glass structures, it is necessary for glass to be transformed into a reliable structural material.

At ABT, research has especially been focused on glass. More transparent structures can of course not be attained with better computational strategies alone, but can also be made by improving the properties of the potentially strong, yet brittle glass material. The safety of glass can be increased by making its surface less vulnerable. Damage to the surface immediately translates into a tremendous decrease in the strength of the glass.

A different method to improve the structural properties of glass, apart from the well-known techniques of hardening and laminating, is to transform a glass sheet into a single-bent or even double-bent surface. This can be done by heating the glass to such an extent that it becomes almost liquid so that it sags over the desired shape. This corrugated glass exhibits a much more favourable bending behaviour than normal glass. Furthermore, it is also stronger than a flat glass plate of the same thickness. The introduction of the corrugated glass plates puts an end to the need for framing, so that the structure becomes more transparent.

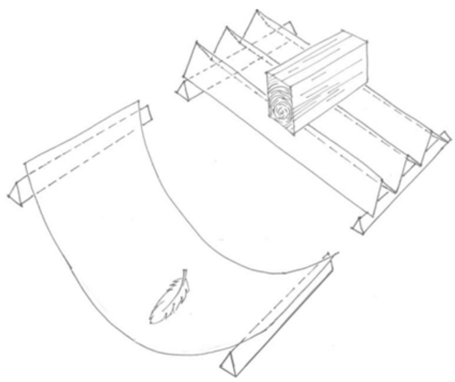

Fig. 3 With folded or corrugated glass much larger spans could be achieved than a single sheet.

These exceptional forms of glass have been used in the Casa da Musica in Porto, the MAS museum in Antwerp, and the theatre and conference centre in Tapei. The same effect can be reached with cold formed glass, yet only with different limits of the glass sheet dimensions and the radius of bending.

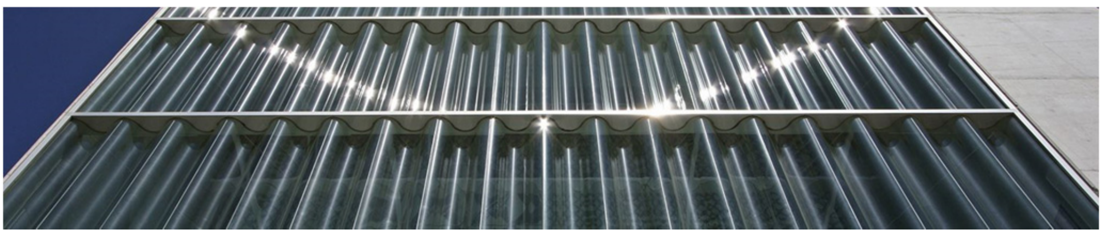

Fig. 4 Glass façade of Casa da Musica in Porto (OMA/ABT).

4. Inspiration

Designs never stand on their own, also not a structural design. Although every design process has its unique objects, experience in previous projects is always used. Yet, when approved of techniques are brought together in a new setting, new ideas could appear.

The structural design of the Vijversburg pavilion was not contemplated to fulfil a designers' wish. Various earlier experiences with glass structure made it possible to take the next step. Some interesting projects, without its realisation the Vijversburg was not developed, are described below.

4.1. Glass balustrades

A common use for structural glass is for glass balustrades, where the glass is clamped in the edge of the floor, or only fixed to it by a few concentrated connections. In this way transparent barriers are created, without visible supports. The demands for this type of structure for strength and safety are high.

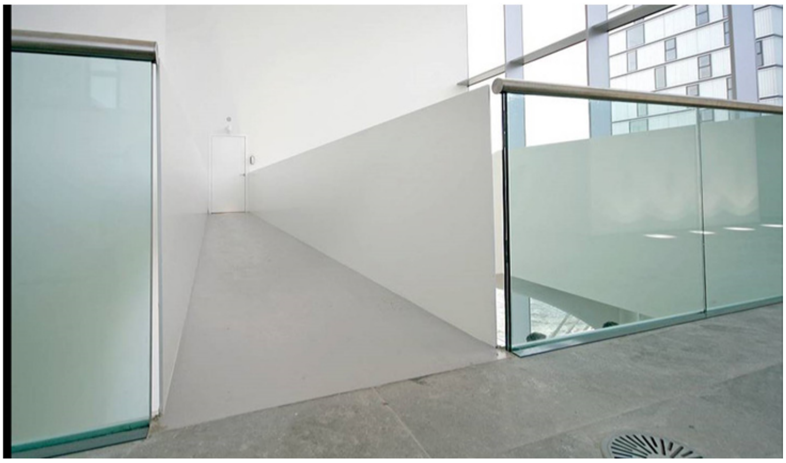

Fig. 5 Glass balustrade Kunstlinie Almere (SANAA/ABT).

Developments in designing glass balustrades are largely effected by the developments in the codes. An improvement of the latest Dutch code NEN2608 is the better acknowledgement of the capacity of laminated glass. This type of glass is essential for the safety of balustrades and glass structures in general. The joint action of the glass sheets when laminated is determined mainly by the stiffness of the interlayer (foil), influenced by time and temperature, and the deflection of the composite glass. This is measured by the coupling factor. When loaded with short duration loads, like a gust wind of 5 seconds, the joined action is much higher than long lasting loads like snow.

Another contributing factor is the actual length of the area where the shear stress is being taken by the foil. Sheets supported on two sides with a continuous load have a rather high joined action, while sheets only clamped at the bottom as with a balustrade, the joined action is rather low. When the laminated glass sheet is supported in point-shaped nodes only, the amount of joined action nearby the joints is even non-existent.

The strength of the glass depends therefore on the location in the sheet. Near the edges and especially near the boreholes the strength is reduced significantly because of small scratches when compared to the strength in the middle of the sheet. See the table, for strength at 5 minute loading for thermal hardened glass:

Table 1: Bending strength of hardened glass depending on location of cross section.

fmt;u;d	location	application
79.9	Middle	Four-sided supported sheet
73.9	Edge	Clamped glass balustrade
58.0	Hole	Point-shaped pinned glass balustrade

These aspects of strength play a role not only in the engineering but also in design choices, when developing a building as the Vijversburg, as will be explained later.

4.2. Glass cube Raaks Haarlem

The Glass Cube on the Raaksterrein in Haarlem, measuring seven cubic metres, is designed by Kraaijvanger architects and engineered by ABT. It serves as an entrance pavilion to the underground car park. Inside the lift shaft that leads to the car park can be seen.

Each vertical side of the glass cube consists of nine glass plates measuring 2.35 m by 2.35 m. that are laterally supported with vertical glass fins, which are made from one piece of glass. The fins themselves are protected from buckling by steel cables. The roof has been placed on metal roof supports, consisting of a truss, with glass compression spacers. The lateral stability of the structure is provided by the façade, thus the sides of the cube. Also the roof acts as an diaphragm.

a)

b)

Fig. 6a) Glass cube Raaks, Haarlem (Kraaijvanger/ABT), b) with Glass fins and roof structure

4.3. Glass extension Dordrechts Museum

The existing building of The Dordrechts Museum, originally an asylum, is a monumental building in the heart of Dordrecht. The building has been extended and restored. Interventions are in clear contrast with the existing monument. The 'greenhouse' that was added as a terrace to the restaurant is fully transparent. The construction is built from only three glass elements: façade elements, glass beam, roof elements. The gutter of steel along the existing façade is the transitional element from new to old.

The glass sheets of the roof are carried by the glass beam, which itself is supported by the glass sheets of the façade. Roof and façade act as a diaphragm, the glass façade is load bearing. The glass beams are point fixed to the glass sheets of the façade.

a)

b)

Fig. 7a) Museum Dordrecht (Kraaijvanger/ABT), b) with Point-fixed support of the glass beams.

5. The structural design of the Vijversburg pavilion

5.1. From minimal structure to structure less

The two main principle sections, that of the stretched wings and that of the main hall, are treated differently, since they give different challenges. The critical part of the wings is the cross section, since there is no possibility of adding a lateral resistant element in the section. Various options have been tried.

Fig. 8 Options for structure of wings: a = portal, b = clamped columns, c = bracings.

Options for structural elements:

Table 2: Proposed options for structural elements.

Option	a) portal	b) clamped columns
Timber	100x250 @ 2m	75x225 @ 2m
Steel	RHS 150x100x6,3 @ 2m	RHS 120x80x6,3 @ 2m (G = 18 kg/m)
		Solid 85x85 (G = 57 kg/m)

It can be observed that clamped columns are better performing than a portal construction. Obviously, bracings are not possible on the inside, on the outside they are conflicting with the design.

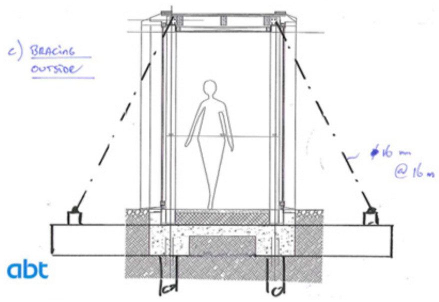

Fig. 9 Bracings placed outside.

Because the span of the roof of the main hall is too large, the structure of a portal cannot be used. For this part of the plan the help of the spatial effect is taken into effect. The triangle shape is capable of producing lateral support in all directions, just by in-plane actions. The roof structure of steel acts as the diaphragm fixing the triangular shape and distributing the forces to all three sides.

The architectural design exists of a glass façade with roof only. During the design it became clear that it was the architect’s wish not to have any structural elements visible. For the load bearing structure, at first it was tried to design very small columns in between the vertical glass panels of the façade. However, since in The Netherlands insulated glass (double glass) is obligatory, the sum of the width of the spacers in between the glass sheets and a structural steel column, even optimized to the most slender solid steel strip possible, was simply too much.

Instead of trying to find a compromise solution, a more radical path was taken: why adding a structure of steel when the façade itself could be load bearing? Glass is very much capable to be used for the structure, as many glass structures being built have shown. To fulfil the architect’s ambition, it was chosen to use glass as structural material.

Using the experience with glass balustrades, the structure of the wings is then made with clamped glass sheets, that acts like a portal construction. It carries a light weight timber roof. For the main hall the shear forces from wind are rather simple to resist in-plane. The support of the roof structure is of more concern. Because of the large span the roof structure has to be made of steel. Relative high concentrated loads from this structure have to be carried by the glass pane.

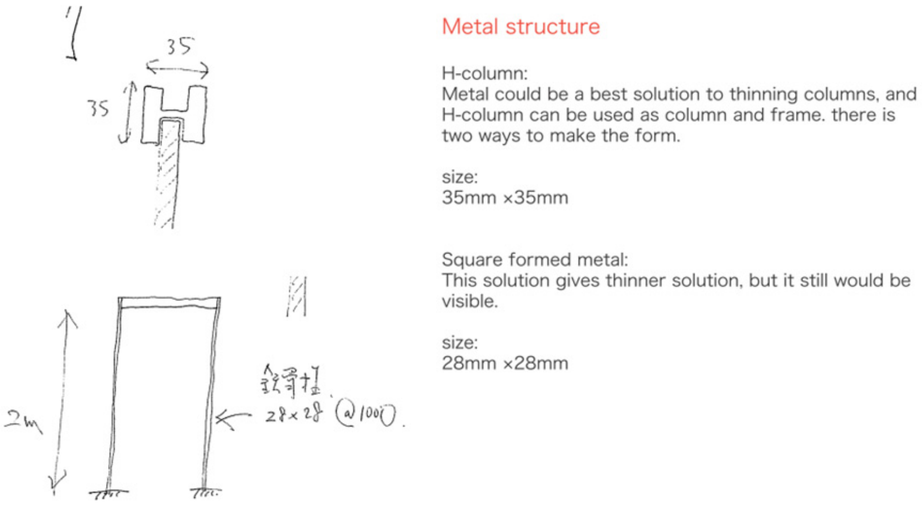

Fig. 10 Proposal from Japanese structural engineer for small columns in between panels.

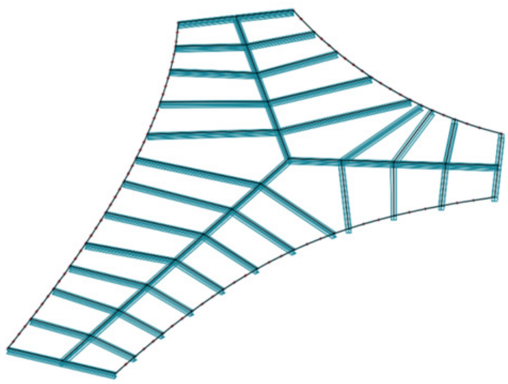

Fig. 11 Roof structure of steel beams.

The glass panels of the Vijversburg project are built up with a load carrying laminated inner glass panel and a single outer glass panel (insulated glass). The outer glass plate increases the stiffness of the total glass panel but this is not taken into account. The inner plate is checked in the normal situation with two unbroken glass plates and in the exceptional situation with one broken glass plate. In the extreme event of collapsing of the total glass panel, beams in the roof structure can carry the loads of the roof to the adjacent glass panels. In fact a third load path is created for extra safety.

Because of the flatness of the glass panels in combination with bending due to wind load, buckling was a main focus. The buckling force is highly dependent on the shear stiffness of the soft foil between the glass panels. In The Heron Journal Vol. 52 No 1/2, '*Buckling of laminated glass columns*' (Blauwendraad J., 2007), formulas are derived to take the stiffness of the foil in account with buckling control. As it occurred, the exceptional situation with one broken glass pane and only one glass pane left was determining, so in fact the influence of the foil was no issue for this project. In fact, since the mechanical principles of the structure are quite simple, most of the calculations performed are hand calculations.

5.2. Detailed design

The success of structural glass buildings depend almost completely on the right detailing. In this design the two most important connections are the clamped glass connection of the wings and the concentrated support of a steel beam on the glass pane of the main hall.

For the wings the technique is inspired of that of the glass balustrades. The height of the arms varies up to 2,6 meter which is the most striking difference in comparison to balustrades (which have a common height of maximum 1,2 meter). This resulted to higher forces and deformations compared to balustrades. As the deformations were unacceptable high using only a clamped connection at the floor, a structural system with clamped connections at the floor and roof connection was chosen.

At the floor the detail is comparable with a detail for a clamped balustrade. Because all the glass panels are curved and have to be connected to a curved concrete rising, a detail has been developed that can take the tolerances between the concrete and the glass, with as little as possible peak stresses. These preconditions lead to a clamped detail with an injectable adhesive mortar specially for glass structures.

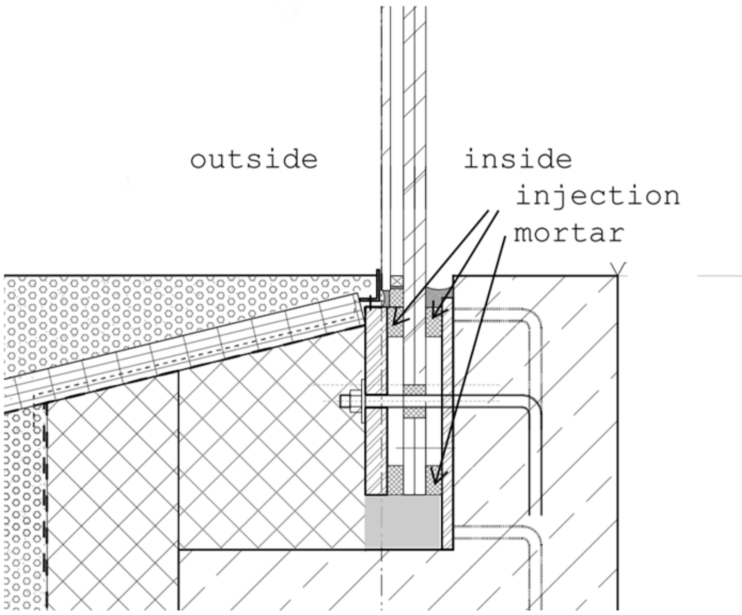

Fig. 12 Detail of the floor connection at the wings.

An additional advantage of the adhesive mortar is that the mortar can take shearforces due to wind suction on the roof and shear forces due to in plane forces because of stability. Although the last point is no issue for the detail of the wings, it is an issue for the detail of the main hall. To avoid unexpected stresses at the transition between the two structural systems the same detail is being used at both locations. A bolt is being used to clamp the outer steel plate to the concrete rising. A spacious hole in the glass prevents peak stresses. When the mortar would fail in taking shear forces the bolt can take the forces after some deformation.

The preconditions for the roof detail are similar to those for the floor detail with some extra preconditions. For the wings a stiff connection with the steel roof is needed to reduce the deformations. For the main hall the detail must be suitable to initiate the horizontal and vertical forces from diaphragm action of the roof to the glass. And for both connections the vertical loads of the roof have to be initiated to the glass panels.

The roof is made of steel profiles and wooden beams, with concentrated loads on the glass panes. The position of the roof beams is chosen at ¼ and ¾ of the edges of the panel so that vertical loads can be spread even in the glass panel. A stiff lateral beam, realised by a vertical plate with horizontal stiffeners at the back, minimises local peak stresses.

The vertical loads of the roof are initiated by a horizontal plate on top of the glass. Between the steel plate and the glass at first polyacetal blocks are proposed, but because of tolerances between the two laminated glass plates of the panel an injectable mortar is applied.

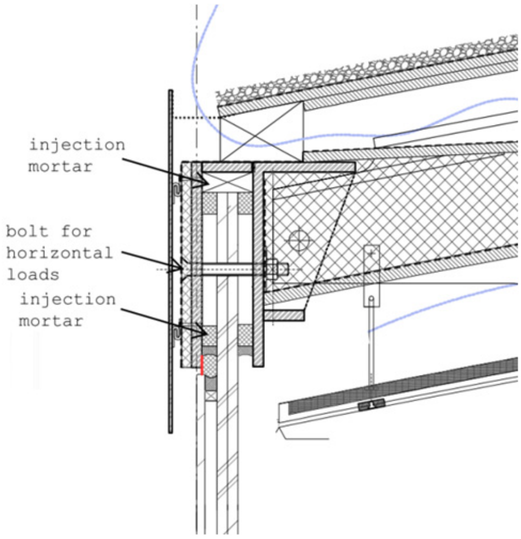

Fig. 13 Detail of the roof connection at the main hall.

5.3. In conclusion

By using only the glass façade the load bearing and lateral system is being formed, with simple mechanical principles and use of the spatial effect. All connections are proven techniques in glass balustrades and load bearing façades. Combining all these techniques into one building, with the effect that no additional structural elements are needed, brings the design of glass structures an important step further. The visitor centre is planned for completion in 2016.

Fig. 14 The central hall of the pavilion under construction.

Fig. 15 End of wing, under construction, visible is the clamping in the foundation.

6. Project info

- Location: Tytsjerk, The Netherlands
- Architect: Studio MAKS, Marieke Kums
- Associated architects: Junya Ishigami
- Client: Stichting Op Toutenburg (Mart Lenis)
- Engineering: ABT B.V. (Han Krijgsman, Diana de Krom, Jeroen ter Haar, Gyuszi Florian)
- Program: Visitor center / auditorium / gallery, meeting spaces & offices, green houses, performance areas
- Building area: 1,000 sqm (10,764 sqf)

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