

The Design Process of the Glass Structures of S21

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Abstract

The S21 railway project requires a large number of structural changes in Stuttgart, these include the construction of a new railway station. This new underground station consists of an approx. 447 m long and 80 m wide hall - a shell structure supported by so-called 28 chalice-shaped columns based on a design concept by Christoph Ingenhoven together with Frei Otto. The chalice concrete columns are open at the top and covered by steel-glass structures known as the so-called light eyes. The light eyes allow daylight to flood deep into the underground platform hall and minimizing artificial lightning. Furthermore, ventilation flaps in the transition areas between the glazed light eyes and the reinforced concrete structure allow natural ventilation and – through air exchange with the tunnel tubes – natural air conditioning. 23 light eyes have an anticlastical curved surface (a so-called translational surface) which can be covered with flat square laminated glass units. There are in addition also 4 flat light eyes. The 3 glazed grid shells (at the Bonatz Tower, at the subway station Staatsgalerie and on Kurt-Georg-Kiesinger-Square on top of a chalice-shaped column) form the entrance structures to the platform hall. The surfaces of the grid shells are triangulated torus sections with a curved vertical facade for the entrances. The resulting triangular meshes are covered with laminated glass. In addition to the complexity of the steel-glass structures itself, the expected deflections of the supporting concrete structure beneath have to be taken into account in the design.

Keywords

Project, Grid shell, Steel glass structure, Facetted, S21

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1. The Project S21

1.1. General

The Stuttgart 21 (S21) railway project requires a large number of structural changes in and around the city of Stuttgart. These include the construction of a new eight-track underground railway station and the subway station Staatsgalerie, the partial demolition of the former railway administration building, the redesign of squares and access roads around the station, and the renovation of the historic Bonatz building (the former station). But S21 is much more than just a railway station itself. The project includes 11 tunnels with 56 kilometres, as well as 42 bridges and around 100 kilometres of new tracks.



Fig. 1: Section of the project ©DB Projekt Stuttgart–Ulm.

1.2. The new railway station

In 1997 the architectural competition was won by Christoph Ingenhoven. Since 2009 Werner Sobek AG has been responsible for the structural and façade design of the new railway station, as well as various other components of this masterpiece of engineering.

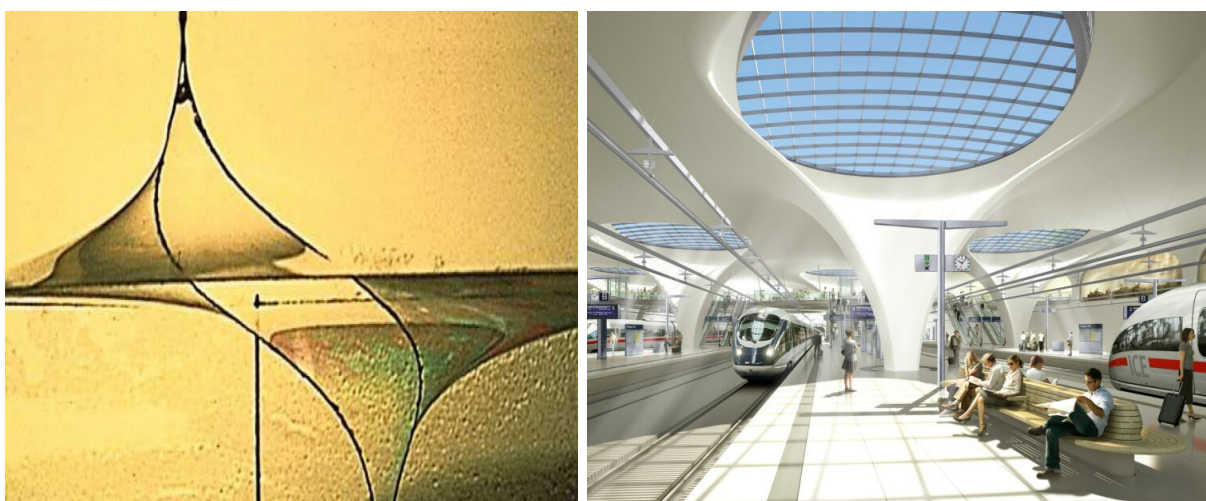


Fig. 2: Form finding and Visualization ©ILEK & ingenhoven architects.

The new underground railway station consists of a hall approximately 447 meters long and 80 meters wide. The hall consists of a reinforced concrete shell structure supported by so-called chalice-shaped columns. These 28 columns provide horseshoe-shaped bracing for the adjacent flat ceiling sections. The shell structure supported by so-called chalice-shaped columns is based on the design concept by Christoph Ingenhoven together with Frei Otto.

The chalice concrete columns are open at the top and covered by steel-glass structures known as the so-called light eyes. The light eyes allow daylight to flood deep into the underground platform hall and minimizing artificial lightning. Glazed grid shells (at the Bonatz Tower, at the entrance to the station Staatsgalerie and on Kurt-Georg-Kiesinger- Square on top of a special chalice-shaped column) form the entrance structures to the platform hall. In addition to the complexity of the steel-glass structures itself, the expected deflections of the supporting concrete structure beneath have to be taken into account in the design. The following steel glass structures will be presented: Regular Light Eyes (RLA), Flat Light Eyes (FLA) and Grid Shells (GS)

2. Regular Light Eyes

2.1. Design

There are 23 Regular Light Eyes (RLA) allowing natural daylight to enter the 447m long underground station and create a warm atmosphere with the visible sky above the tracks. These RLA consist of an anticlastic curved, glazed surface. The supporting steel structure is formed by a grid of rigidly welded steel profiles and a ring girder. The ring girder is supported on the chalice-shaped concrete column. The ridge of the RLA is formed by an additional tubular steel section that develops from the ring girder. Pendulum steel columns on the concrete edge support this ridge section. The ridge is also connected with the ring girder via tension rods. These RLA have a longitudinal diameter of 17.80 m and a transverse diameter of 15.45 m; the grid mesh has an edge length of 1.16 m.

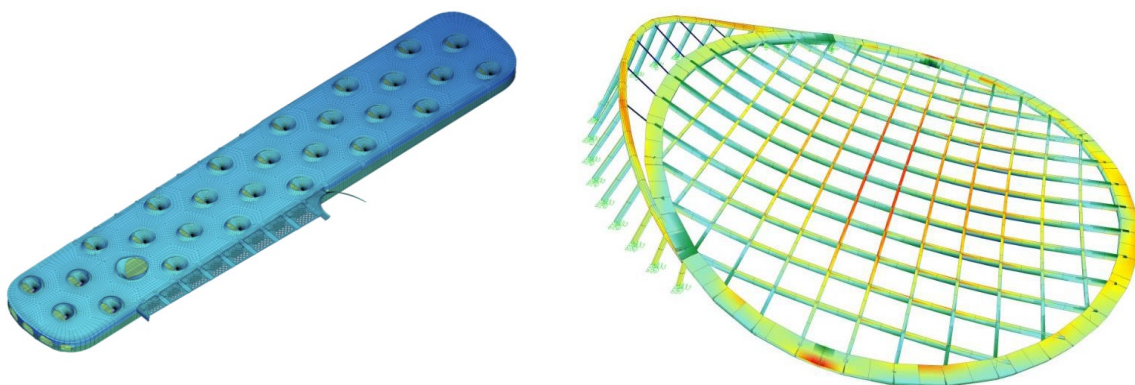


Fig. 3: FEM Modell of concrete structure and RLA ©Werner Sobek AG.

The field beams of the grid consist of triangular hollow sections with a height of $h = 200$ mm. These field beams are rigidly connected to milled steel nodes. The ring girder consists of a quadrilateral welded hollow section. The grid has a saddle shape. Such a double curved surface, a so-called translational surface, can be covered with flat glass units. Single glazing with laminated glass units are used. The glazing is designed for snow and wind loads as well as for live load but without slip resistance on top for walking. A surrounding stainless steel railing is supposed to prevent any person to enter the glazing.

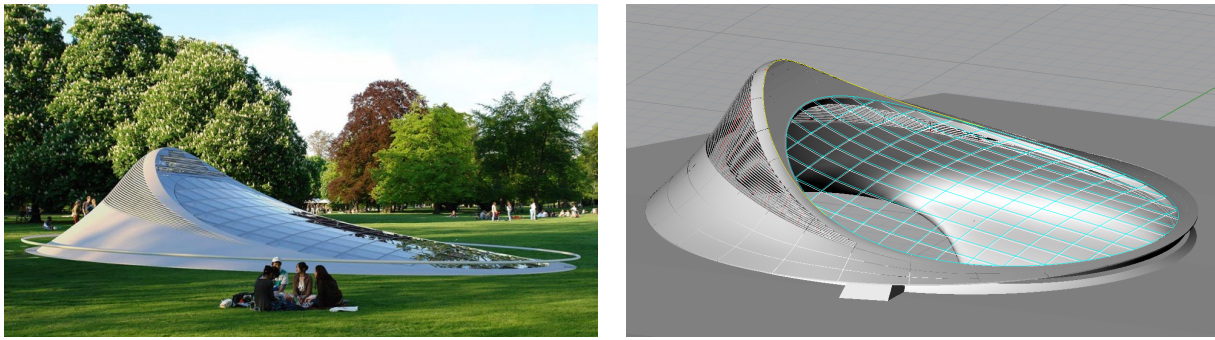


Fig. 4: Visualization – Rhino Modelling ©Ingenhoven architects & Werner Sobek AG.

The ridge beam is connected with tension rods to the ring girder. In between the tension rods operable glass louvers are installed. Allow natural ventilation and through air exchange with the tunnel tubes – natural air conditioning. Furthermore, in the transition areas between the ridge beam and the reinforced concrete structure there are systems installed for ventilation and smoke exhaust as part of the fire safety concept. Curved stainless steel pipes with openings in between cover this system on the outside and inside.

2.2. Realization

The steel structure was prefabricated in the shop and then shipped in 8 segments to the field erection. The welding sequence in the shop and in the field was optimized by the contractor seele GmbH to avoid distortion. The work on site was carried out in a tent to protect against the elements. The tent structure also functioned as a portal crane for the installation of the steel structure and its glazing.

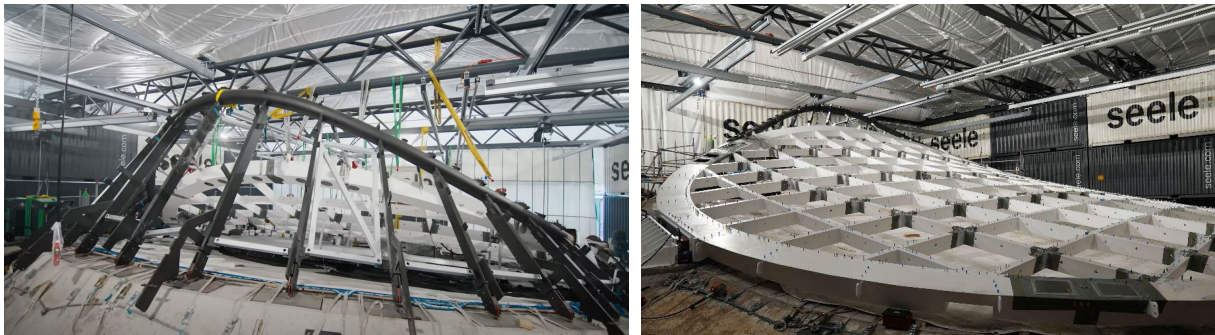


Fig. 5: Ridge beam and its supporting columns - steel grid with its ring beam ©Werner Sobek AG.

For safety reasons the opening to the station hall beneath was temporary covered with safety net, also used as a working platform.

There is currently a step between the steel structure of the RLA to the supporting concrete structure. Since the roof of the underground railway station is supposed to function as a square with partial greenery and transition to the park soil and humus will fill that gap in the end. This later additional soil loading and corresponding deflections including long term effects have to be taken into account in the design of the RLA.

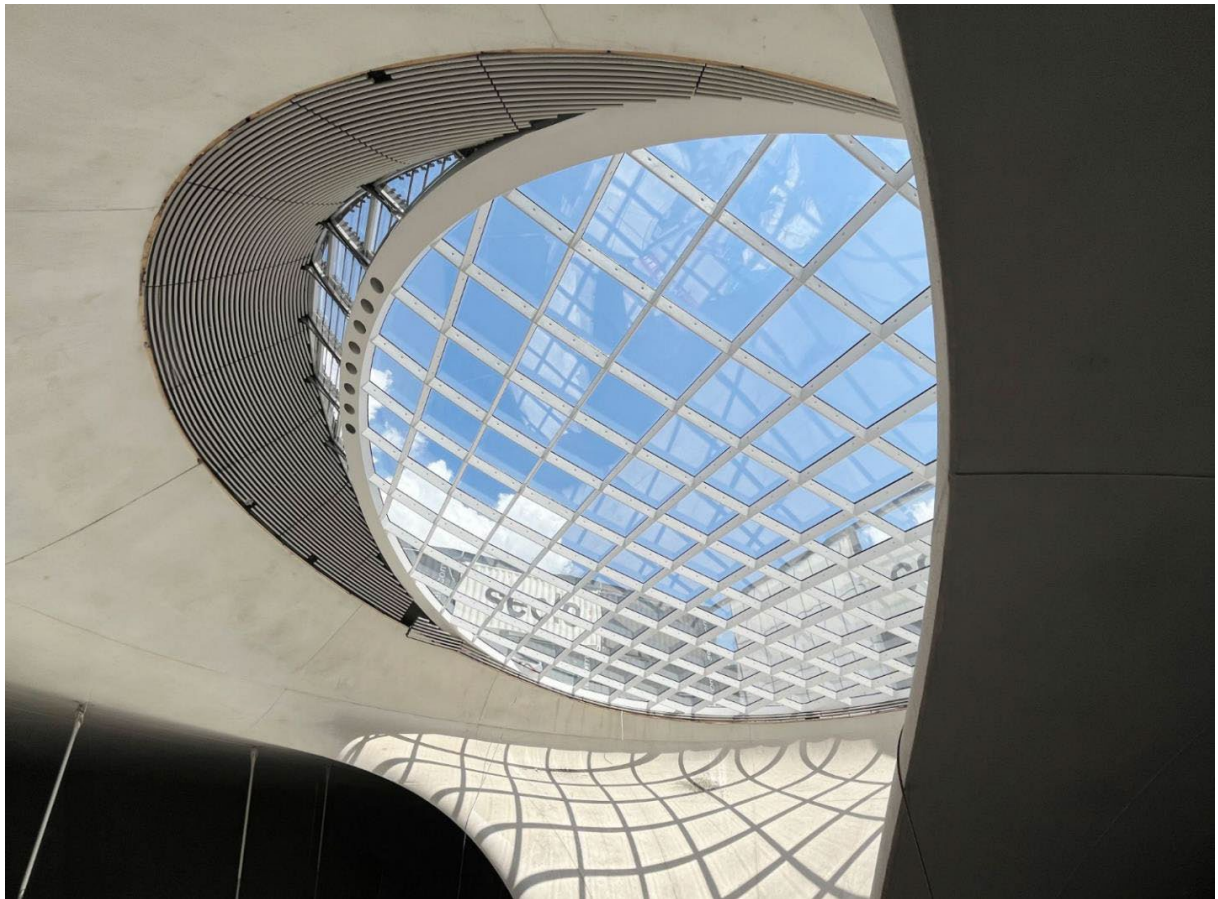


Fig. 6: View from inside and outside of RLA ©Werner Sobek AG

3. Flat Light Eyes

3.1. Design

At the northern end of the station hall, there is an entrance located on the Kurt Georg Kiesinger Square. This paved square forms the drop-off area with the taxi stands as well as a walkway to the new city district. Four flat skylights, the so called Flat Light Eyes (FLA) are located there. At the beginning, some-shaped and flat structures have been investigated. The intension of a walkway lead to flat structures with walk-on glazing. The use of walk-on glazing outside might be problematic due to the risk of damage. Therefore, the top glass pane should be replaceable. A concept of a laminated glazing with a replaceable top pane was introduced. In the case of damage the top pane could be replaced and the station below would be still under service. In the further design process a surrounding railing was introduced keeping persons off the glazing and acts also as impact protection for vehicles. The concept of the replaceable top pane has been kept and also applied for the Regular Light Eye (RLA).

The supporting steel structure is formed by a circular grid of welded steel profiles with a diameter of 15.45 meters. The rectangular openings have an edge length of approximately 1.20 meters. The field beams consist of triangular hollow sections with a height of $h = 300$ mm. The field beams are rigidly connected to a surrounding ring girder. The ring girder is supported on 12 bearings on the concrete structure.

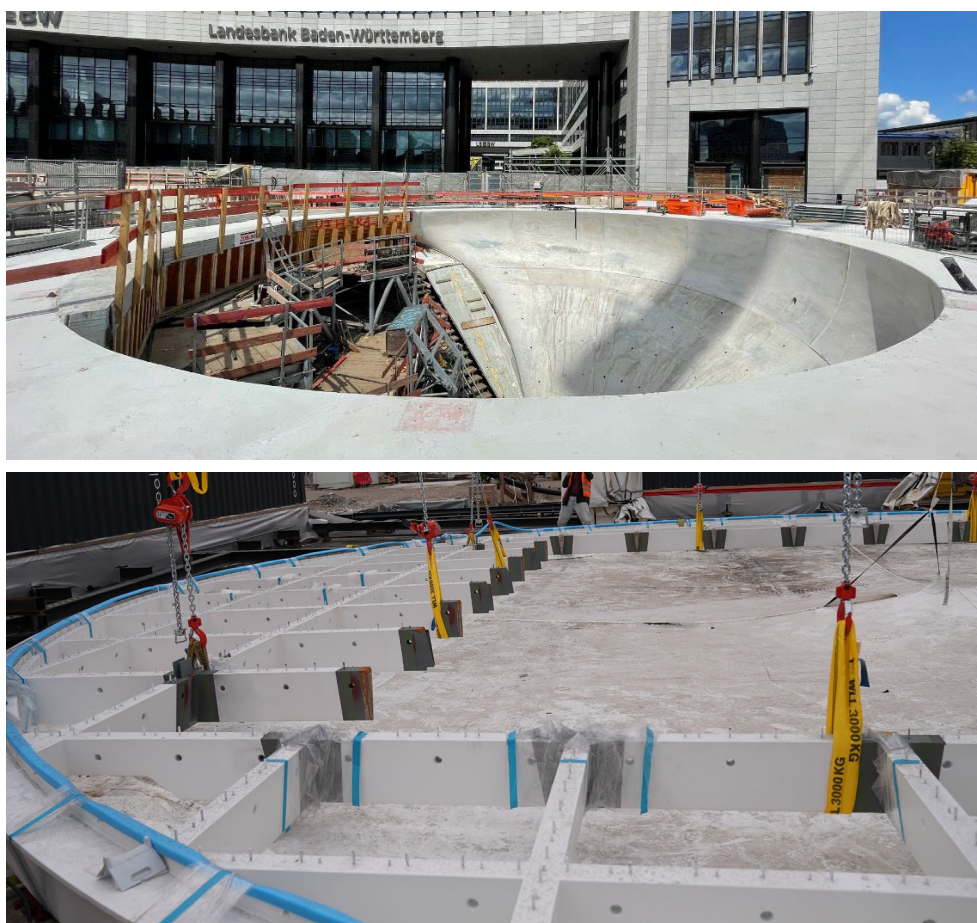


Fig. 7: Section of the project ©Werner Sobek AG

3.2. Realization

Similar to the Regular Light Eye (RLA) the steel structure of the Flat Light Eye (FLA) was prefabricated in the shop and then shipped in segments to the field erection. The work started with the ring girder sections and filled with the inner segments. A tent protected the work and workers against the elements.

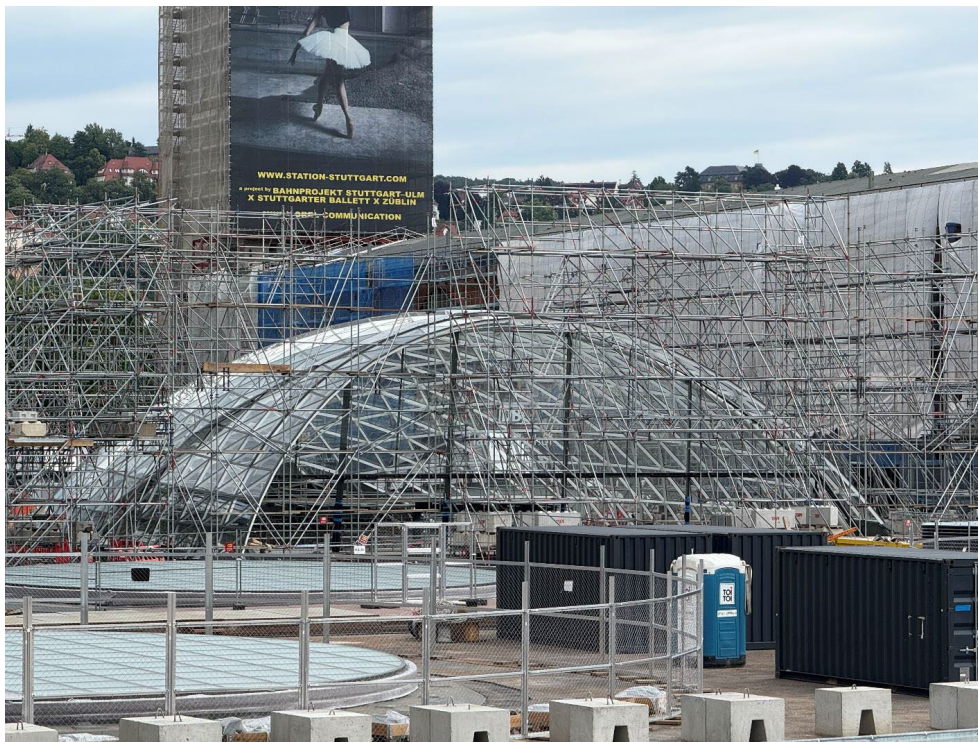


Fig. 8: Flat Light Eye in front of the Grid Shell on the Kurt Georg Kiesinger Square ©Werner Sobek AG.

4. Grid Shells

4.1. Design

Three glazed grid shells (at the Bonatz Tower, at the subway station Staatsgalerie and on the Kurt-Georg-Kiesinger-Square on top of a chalice-shaped column) form the entrance structures to the platform hall. A fourth grid shell to the new city district Europaviertel has been designed but its execution is currently not taking place and depending on the further plans of the new city district.

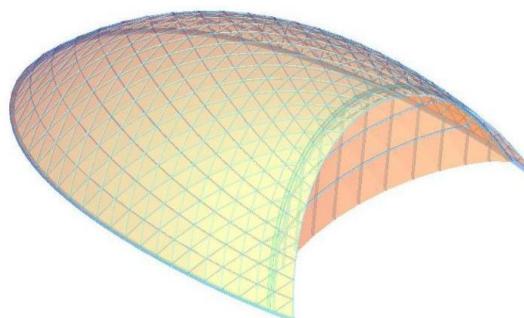


Fig. 9: Visualization – FEM Model ©ingenhoven architects & Werner Sobek AG.

The shape of the grid shell is defined by torus-shaped cutout. All grid shells are similar, but still unique. The surface shape was triangulated with an optimization tool in order to achieve as similar beam lengths and angles as possible. Thus, an optimally constructible and aesthetically appealing was found for all grid shells. The grid shell is constructed as a steel structure whose supporting framework consists of rigidly connected steel beams. The field beams consist of triangular extruded steel profiles with a height of $h = 110 \text{ mm}$. The beams are welded to individually milled steel nodes. The beams are rigidly connected to a continuous edge beam which is supported on bearings to the concrete structure. The free edge of the shell is further supported by an arched girder that connects to the edge beam. This arch girder allows the entrance into the shell and the station below. A vertical glazed façade with sliding doors forms the entrance structure. This entrance facade is curved in the plan view and also inclined to the outside. The steel mullions lean with an oblong hole connection to the arch girder to allow vertical deflections of the grid shell and prevent the load of the grid shell from being transferred to the vertical facade. The grid shell cantilevers beyond the arch girder to provide shelter for the entrance area. Laminated single glazing is used as the hole station hall is an unheated structure. Depending on the angle of the glazing bird protection glazing with horizontal frit is used.

The grid shell is designed for snow and wind loads. The wind tunnel investigations to determine the wind load scenarios took also the inside wind conditions due to train movements in the tunnels and station hall into account.

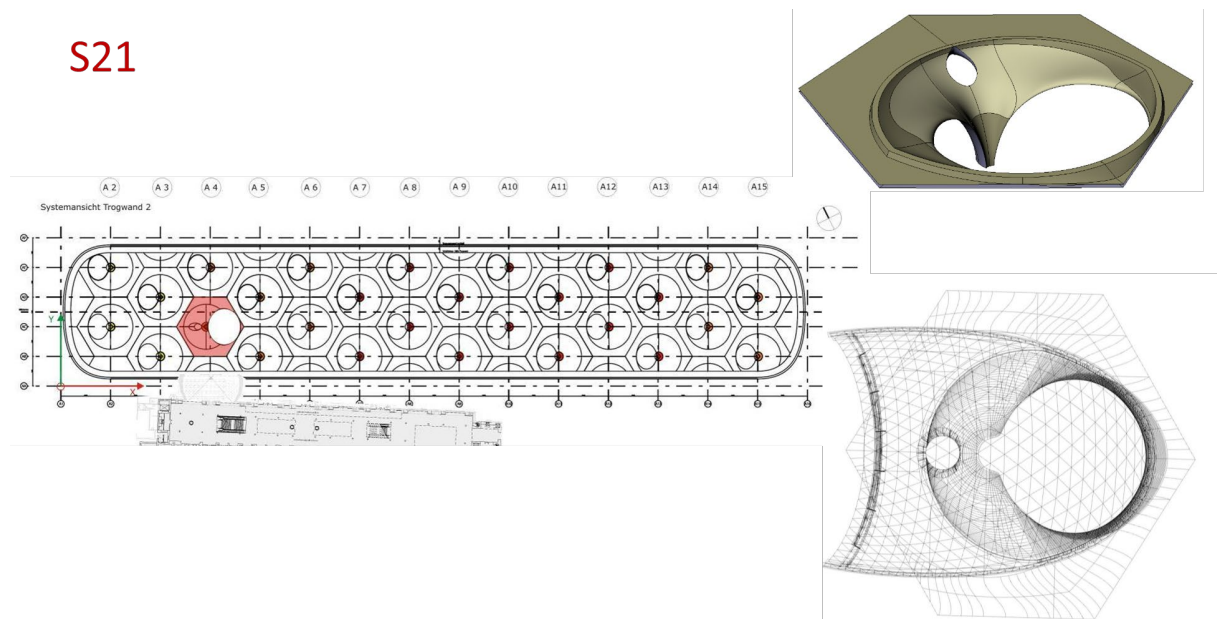


Fig. 10: Grid shell on special chalice-shaped column ©Ingenhoven architects & Werner Sobek AG.

The grid shells are supported on more or less flexible concrete structures. Especially the grid shell on the Kurt-Georg-Kiesinger-Square which is located above a special chalice-shaped column requires special attention. The expected long-term deflection behaviour of the free form concrete structure needs to be taken into account for the design of the steel grid and its glazing. These settlements of the concrete structure result in forced deformation for the bearing supports of the steel structure. Additionally the concrete structure provides spring stiffness to the bearing supports of the grid shell that have to be taken into account while designing the glass-steel-structure.

4.2. Realization

A huge scaffolding was installed for the erection of the steel structure on site first. The prefabricated steel structure was shipped in segments to the field. The work started with the ring girder alignment on the concrete structure. Prefabricated steel ladders have been put onto the scaffolding, aligned and welded together. Tents to protect especially the glazing work have been used as well here.



Fig. 11: Steel & Glazing work on site ©Werner Sobek AG.



Fig. 12: Opening of the Grid Shell Staatsgalerie with the Light Eyes behind ©DB Projekt Stuttgart–Ulm.

5. Summary

The S21 railway project requires a new railway station in the heart of Stuttgart. This new underground station receives daylight and ventilation through glass and steel structures—the light eyes. The access to the station is via glazed grid shell structures. Both are iconic steel glass structures. Even though the original design idea from 1997 dates back almost 30 years, the project S21 represents the highest level of engineering and construction excellence as well as a timeless design.

Acknowledgements

Such a project required an extremely high level of commitment and trust from everyone involved, not least on the side of the client, architects and engineers together with the contractors.

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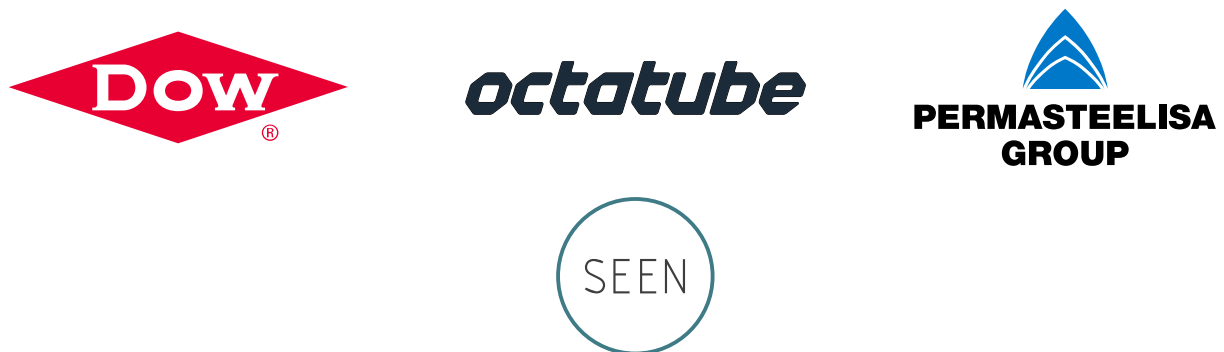
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