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Transparent, Complex, Sustainable Challenges for Contemporary Facade Engineering

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The tasks a façade has to fulfill in contemporary high-end architecture have become more and more complex and challenging. An innovative skin has to block a considerable amount of sun radiation in summer, while it has to prevent heating energy from getting lost in winter. At the same time the skin has to allow for a high amount of (controlled) natural lighting and (controlled) natural ventilation. On the other side the iconic character of "signature" architecture pushes for glass façades to become almost dematerialized, a development further reinforced by recent advances in modern glass technology. Contemporary façades have to reach high transparency rates and have to follow extremely complex geometries - while still fulfilling requirements with regard to energy consumption and user comfort. The arising challenges for the façade engineer are therefore immense. The present paper presents various examples of how these challenges can be tackled in an appropriate way that units functionality, sustainability, and aesthetics.

Keywords: Transparency, Complexity, Sustainability

1. Introduction

Transparent, complex, sustainable: these are the characteristics modern facades have to fulfill, especially in iconic buildings. How is it possible to achieve all three objectives simultaneously? Glass technology has allowed for impressive progress since modern architects such as Mies van der Rohe first conceived of glass facades as emblematic for "modern" architecture. Sophisticated double and triple glazings nowadays allow for a reduced heat loss in winter; selective coatings and various sun protection systems help to combine natural lighting with protection against overheating.

Some question whether the extensive use of glass in facades is sustainable. We believe that even fully glazed facades can be sustainable, provided they are designed and engineered accordingly. A sustainable façade has to allow for natural lighting and reduce energy consumption to a minimum, allowing the latter to be offset by the use of renewable energy sources, such as solar or geothermal energy. Moreover, materials used should be kept to a minimum and be recyclable. A proper combination of transparent and opaque parts may become fundamental in the search for a synthesis of transparency and sustainability – while keeping in mind that glass is a building material that can also be used for opaque buildings skins. In certain cases the client and the architect call not only for transparent and sustainable skins, but also strive for extreme geometrical complexity. The engineering work is then even more challenging, because of the increased difficulty in detailing, producing, and erecting such kind of facades.

A selection of recently completed projects show the different approaches and solutions developed by Werner Sobek for skins that not only fulfill the formal and aesthetical demands of contemporary architecture, but which are also highly sustainable – both with regard to their resource consumption and their influence on the overall energy consumption of the building.


a)


b)

Fig. 1a) Doha Convention Center, Qatar (HG Esch)   1b) Enzo Ferrari Museum, Italy (WSS)

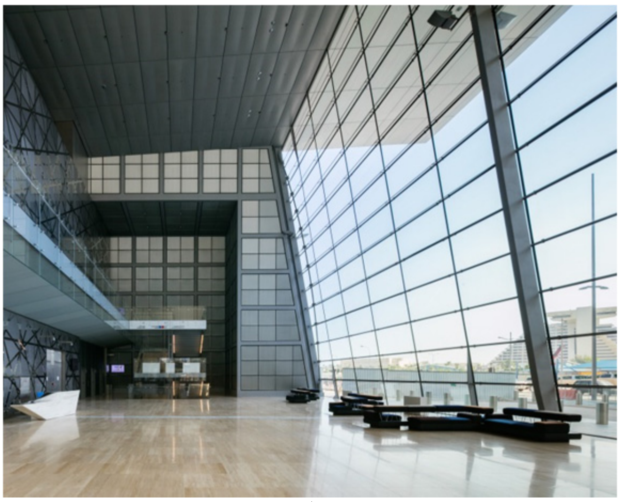
2. Transparent and sustainable skins

2.1. Doha Convention Center, Doha

The recently opened Doha Convention Center in Qatar aims at strengthening and outlining the role of Doha as a business hub in the Middle East. A special feature of the building is the transparent cable-stayed facade at the entrance areas along the southern and western sides of the building. How can such highly transparent facades be sustainable in a Middle Eastern climate? The answer lies in a combination of different solutions such as a cantilevering roof, a 10° façade inclination and the use of coated insulated glass units. Sun shading elements and partially opaque sections at the eastern and northern sides of the building (Fig. 3b) allow for the overall energetic balance of the building to be further optimized.

Fig. 2 View of the south facade (HG Esch)

The entrance facades have been engineered by prestressing stainless steel cables horizontally over max 180 m between two bow-strings. A more traditional vertical layout of the cables was not possible, since the long-span roof could not be used for vertically prestressed cables. The south façade (which is 297 m long) was therefore divided into two segments, thus matching the movement joints of the main structure. Each facade segment is subdivided into modules by hinged steel columns. These columns are 20 m high and stand at a distance of 18 m to each other. They reduce the free span of the cables under horizontal loads and also act as tie-backs for the roof structure.



a)

b)

Fig. 3a) View of the east-end of the south façade (HG Esch) 3b) View of the north-west façade edge with sun shading fins (HG Esch)

The insulated glass units measure 3.0 m by 1.4 m. Their dead load is hung from the top by tension rods which are placed at every vertical joint. The glass clamps (Fig. 4a) are placed at a distance of 300 mm from the vertical joints. The free span could thus be reduced and the glass thickness optimized. The cable clamps transfer wind loads to the cables just by contact; therefore their size could be kept to a minimum. Given the long spans to be dealt with, keeping control of horizontal deflections and of the resulting warping in the insulated glass panes was a particular challenge. Steel fins with different heights were therefore planned at the top and the bottom (Fig. 4b). Their specific stiffness against wind loading allows for an optimized and gradual deflection shape, thus reducing the amount of warping at the corner glass units.

a)

b)

Fig. 4a) View of the façade cable clamps (HG Esch)   4b) View of the base details (HG Esch)

All the details and particular solutions developed for the Doha Convention Center help to increase the level of transparency to an astonishing level. The coherent approach towards minimizing the loadbearing structure not only confers a very elegant appearance to the façade, but is also an important contribution towards making the structure sustainable with regard to the use of natural resources.

2.2. Maison de l'Histoire Européenne, Brussells

The ‚House of European History‘ in Brussels was commissioned by the European Parliament. It is to offer visitors the opportunity to learn about the history of Europe and to take a critical look at the questions facing Europe today. The project was planned and designed by Paris-based architects Chaix & Morel and JSWD Architects from Cologne. The museum is housed in the Eastman building, which was built during the 1930s in the heart of what is now the European quarter of Brussels. Originally built as a dental clinic, the building had to be comprehensively refurbished and extended to be able to fulfill the requirements of a modern museum. The conversion plans include an extension on the courtyard, which is enclosed on three sides, as well as the addition of three stories.

a)

b)

Fig. 5a) Competition Rendering (Chaix & Morel)   5b) View of the construction site (Chaix & Morel)

The new facade has been conceived as a double skin façade: The outer skin consists of an energetically sustainable mix of opaque and transparent glass elements; the former are placed in front of concrete cantilevering boxes, the latter are set in front of a triple-glazed thermal skin. Openings in the outer skin have been optimized to allow for natural ventilation of the cavity between inner and outer skin, so that cavity overheating can be prevented. The façade offers a high degree of transparency in combination with excellent user comfort and an efficient energy system.

a) b)

Fig. 6a) Site view of the outer glass fin skin (WSS) 6b) Site view of the outer opaque glass skin (WSS)

Both the transparent and the opaque elements forming the outer skin have a custom designed line pattern printed on them: this optimizes the amount of solar energy passing through the outer skin and at the same time gives a uniform appearance to the whole facade. Due to the different heights of the existing storeys all the facades elements have different heights. The height of the transparent glass fins varies between 3 and 14 m: the highest fins are located at the south-western and north-western corners. Here the laminated glass has been also used as a bracing element to enhance transparency. Moreover, several details were specifically developed to enhance the overall minimalistic appearance of the outer skin.

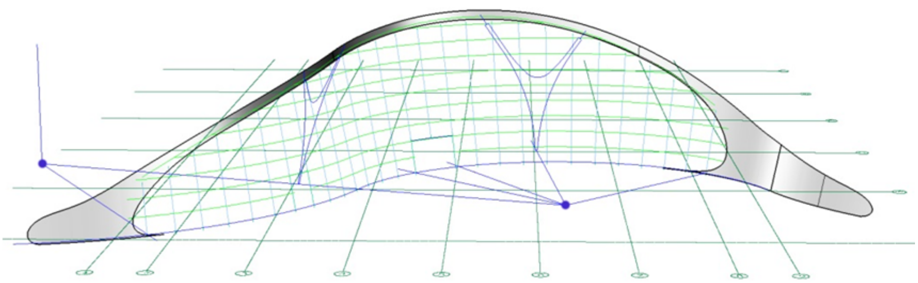
3. Iconic and complex skins

3.1. Enzo Ferrari Museum, Modena

The museum dedicated to Enzo Ferrari in Modena plays with the duality between the renovated historical building where Ferrari was born in 1898 and a futuristic exhibition gallery designed by the late Jan Kaplicky (Future Systems, London). The gallery embraces the masonry building, whereas its sculptural form is clearly inspired by sport car design. From the gallery the view converges through the transparent curved façade to Ferrari's birth house - it is as if you were looking through an oversized car windshield. The glass façade is made of insulated glass units with argon filling; this helps to reduce heat losses in winter. Horizontal sun shading elements and solar control coatings reduce the cooling loads in summer, still allowing for a high degree of natural lighting for the exhibition area.

Fig. 7 Enzo Ferrari Museum (Studio 129)

The overall energy balance is optimized through the high performing metal skin: Below the yellow coated aluminum profiles, thermal bridges have been avoided by using a foamglas insulation layer with a custom developed adjustable point support system. Cooling and heating are provided by a special geothermal type of heat pumps with thermal exchange elements placed underground at a depth of 130 m.



a)

b)

Fig. 8a) Geometrical description of the façade (WSS), 8b) erection of aluminum skin (Studio 129)

Given the geometrical complexity of the building envelope, the engineering philosophy chosen for the façade of the Enzo Ferrari Museum in Modena was to maintain a relative simple geometry for the facade panels. These were adapted to the different geometrical situations by means of complex customized detailing. The geometry of the 11 m high cable-stayed glass façade is defined by two intersecting conical surfaces, which inclined towards the interior by 12.5°. The sinuous form of the façade was accomplished using straight cables and regular planar glass units. These had to be cut with specific angles to match the conical geometry. Only the upper glass units have a less regular geometry, due to their 3D-curved edge. This edge is the result of the intersection between the roof surface and the conical façade surfaces. Special details were developed for the top of the facade, solving parametrically all the different connection situations between the irregular glass units and the supporting steel structure. The geometric result of this intersection edge is a 3D-curved circular hollow steel girder with a length of 62 m. The curved girder has a diameter of 1,000 mm. It constitutes a top-side support for the cables of the facade. The girder was geometrically optimized, resulting in the definition of 13 segments which could be curved only in one direction. The steel elements were fully welded on site.

a)

b)

Fig. 9a) View of the glass fixing and cable clamp (Studio 129) 9b) View of the façade with sun shading elements (Studio 129)

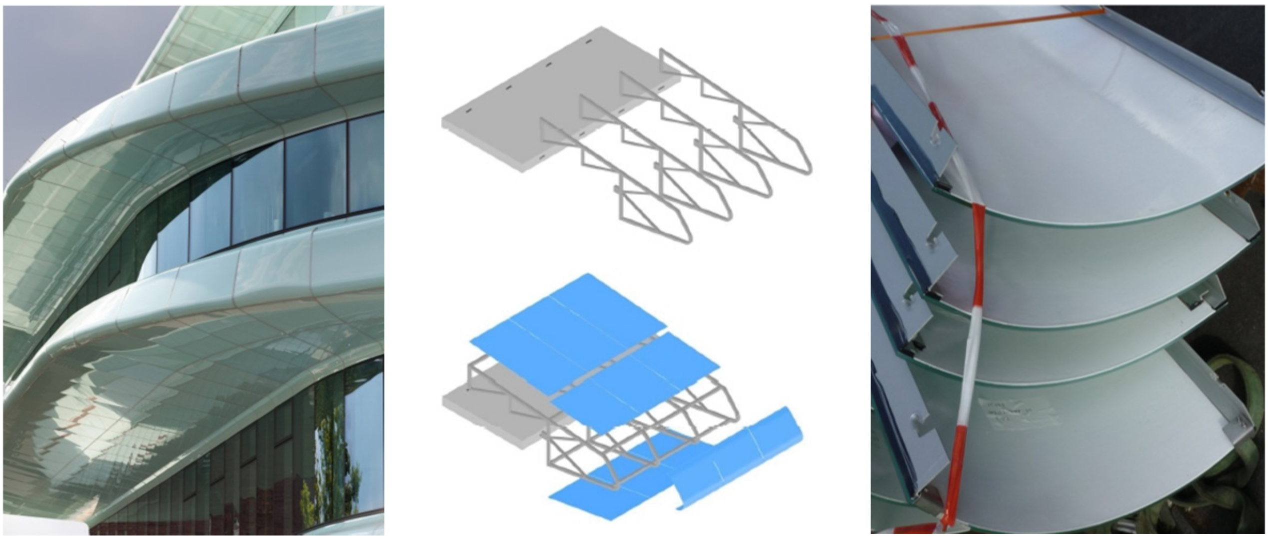
A set of vertical stainless steel cables (each with a diameter of 32 mm) supports the flat insulated glass units. On the outside these units are made of a 10 mm fully tempered glass pane, while on the inside they are made of two 6 mm heat strengthened glass panes laminated with a high performing SentryGlas®Plus interlayer, so as to optimize the glass thickness. Special attention was paid to controlling the deflections of the whole façade as well as the warping of the most critical insulated glass units by optimizing every single cable pretension force. The façade engineering of the Enzo Ferrari Museum was a considerable challenge, due to the required transparency and the geometrical complexity in conjunction with the energy and comfort requirements that had to be met. Such complex freeform skins call for a change in the planning process from 2D drawings to 3D digital models. Despite the computational progresses in approaching such complex skins, the detailing, production and erection of such envelopes remains a very demanding task.

3.2. Fraunhofer Institute, Würzburg

The Fraunhofer Institute for Silicate Research in Würzburg has been extended by a new building housing a laboratory and industry-scale engineering facilities. The competition was won by Zaha Hadid Architects. According to the architectural concept, the five-storey building traces the course of the ‚Luitpoldstraße' before swinging around towards the existing buildings. This design feature creates a three-cornered forecourt, car parking spaces and an area for taking deliveries. Even if most of the skin is made out of glass panels, the architectural choice of combining opaque glass panels with transparent glass panels led to a sustainable approach to the energetic balance of the building.

Fig. 10 View of the Fraunhofer Institute (Christoph Seelbach)

A major feature of the design is a three-dimensional external envelope completely made of glass, as a reference to the silica research objective of the institute. The freeform-curved white glass panes have a high geometric complexity; in addition, the architects had excluded any visible fixings. Werner Sobek developed an innovative solution and tested it on a full-scale prototype. Monolithic glass panes were curved by using special molds and backpainted with polyurethane to allow for a residual safety mechanism in case of glass breakage.



a) b) c)

Fig. 11a) Façade partial view (Christoph Seelbach) 11b) Method of fixing of the cladding glass panels (WSS)
11c) Monolithic curved glass panes with aluminium adapter frames and polyurethane white back-painting as safety layer (WSS)

In general, the glass cladding is fixed to a steel truss substructure by means of aluminum adapter frames, with screws inserted through the joints between the panels. The frames are bonded with structural silicone at the back of the panels (Fig. 11c). In areas higher than 8m, and/or overhead, it was considered necessary to introduce a redundant fixing. Therefore, two sets of adapter frames were used. The first one is fixed to the steel truss substructure as anywhere. The second, redundant frame has a certain play of several millimeters. If, against all testing and designs, the first frame should fail, the glass panel will fall down only few millimeters before being caught by the second line of adapter frames. At the same time, the gap indicates that there is a problem with the first frame, and the panel can be disinstalled and repaired.

4. Conclusions

Werner Sobek has designed many iconic skins. The individual solutions presented in this paper show some possible answers on how to address the challenge of achieving facades that are transparent, complex and sustainable at the same time. The innovative character of certain solutions requires that all the involved parties from the clients up to the contractors share the will to push the boundaries within a reasonable extent. Therefore good teamwork has been essential for the success of the projects shown above: especially the early involvement of the manufacturing companies, as well as the late involvement of the designers during the construction phase has allowed for the intendet design to be translated into built reality.

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