Glass facades: present and future challenges

Lucio Blandini [1, 2]

1 ILEK, University of Stuttgart, Pfaffenwaldring 7+14, 70569 Stuttgart, Germany

2 Werner Sobek AG, Albstraße 14, 70197 Stuttgart, Germany

Nowadays facade designers are challenged by a considerable number of performance requirements challenge, among others the continuing search for more transparency, often in combination with restrictive energy requirements or with extreme loading conditions such as bomb blasts: Four selected projects presented in this paper demonstrate how these challenges can be successfully addressed in the design process. However, despite the sophisticated engineering tools available nowadays, the article also shows where (and why) more innovation and research work is needed in the future. These innovations are required to allow for significant reductions in the consumption of resources and in the production of emissions and other forms of waste by the building industry. One way to tackle this challenging task is the use of more dynamic, adaptive facades, which are able to react to changes in environmental conditions and in user comfort requirements. Even if this approach requires a certain input of energy and a higher degree of complexity, it is expected to substantially contribute to a more sustainable use of resources in the future.

Keywords: transparency, energy performance, sustainability, digital tools, adaptivity

1 Introduction

The search for ever more transparency has been a driving factor for architects for a long time: 100 years ago Mies van der Rohe sketched his vision of a dematerialized high rise tower for a competition in Berlin. During his all life, he kept on pushing the boundaries, searching for a synthesis between what is technically possible (in terms of glass sizes and performances) and his own architectural vision. This approach has since been shared by several generations of architects. The common approach has nonetheless led to many different forms of architectural languages.

The fact that engineers and manufacturers have taken up the challenge resulting from the quest for transparency has led to a remarkable progress of glass facades [1] and many outstanding designs [2]. This development was particularly important over the last four decades, thanks to the use of design methods adopted from the mechanical and aeronautical industries. At the same time the performance requirements imposed on facades – among others driven by energetic constraints – as well as the increased geometrical complexity of certain designs have further increased the level of difficulty to be faced by all planners involved. Even if the computational performance of modelling, simulation and

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calculation software has become a powerful supporting tool, obtaining a meaningful synthesis between the performance required and the architectural vision is still a considerable challenge.

It has therefore to be asked if a facade whose physical and thermal properties remain almost unchanged - no matter the inside/outside temperatures, the level of sun radiation or the user requirements to be dealt with - is the right answer. Moreover it is questionable if a more or less "static" architecture is the correct expression of a society which is increasingly dynamic and interactive. The search for more dynamism in architecture is nothing new. Its roots lie in the theories and considerations of Siegfried Giedion and Lázló Moholy-Nagy; however, this approach has so far lead to very little transformation in the built architecture. This has to change. There are even more challenges to be faced in the future: in consideration of the (ab)use of resources and the emissions and waste caused by the building industry, the call for more sustainable buildings has to be addressed urgently. Following the Triple Zero® concept developed by Werner Sobek (zero resources, zero emissions, zero waste [3]), new solutions and approaches have to be developed. One promising strategy to address these three tasks is to increase the use of recycled elements and to develop digital tools to better support this target. Advanced modelling methods such as BIM can support the designers in documenting the materials used and in developing the most appropriate assembly/disassembly strategies. More than that is needed, though; engineers, architects and manufacturers have to combine their forces to push the boundaries. This has proved to be a vital ingredient for the impressive development of glass facades in the past. It will certainly prove key for other developments in the future. In the following a selection of case studies shows which sophisticated solutions were recently adopted to achieve transparent and performing glass facades. In addition to it an outlook on research work gives a hint of how glass facades may develop in the next decades to deal with the building sector's urgent task to reduce the use of resources and the production of emissions and waste.

Figure 1-1 Enzo Ferrari Museum, Modena (Italy). (© studio 129)

2 Case studies: transparent and high performance facades

Highly transparent glass facades can nowadays be achieved by using either glass fins or pre-stressed cables [4] as main bearing elements.

2.1 Etihad Museum, Dubai

The entrance building of the Etihad Museum in Dubai shows the last generation of glass fin facades developed by the author. The Museum was designed by Moriyama and Teshima (Toronto) to celebrate the foundation of the UAE in 1971: in the union house, a small round pavilion in front of the Etihad Museum entrance, the seven emirs signed the grounding act on December 2, 1971. Seven is therefore also the number of inclined wood columns supporting the double curved roof; they are inclined by 21° to symbolically represent the seven pens on the historic piece of paper. This is also recalled by the roof geometry. The column inclination is relevant for the engineering of the glass fin facades, since the fins had to be inclined to match the overall layout and rhythm of the main elements.

This design decision led to the necessity of using the glass facade elements structurally as bracing device; a special connection detail system between fins and glass panes was developed to allow for such a structural use of the glass elements without affecting the need for thermal movements. Despite the transparency achieved by the facade, the g-value of the insulated glass units is relatively low (18 %). This was achieved by using selective coating and a customized silk printing. The overall energetic performance is improved by the presence of the cantilevering roof; a computer-based shadow analysis helped to optimize the silk printing layout in order to find the best possible synthesis between the envisioned transparency and the required energetic and daylight targets. The performance of the facade could be improved even further if the screening elements or the behavior of the facade could react actively to changes in the sun radiation through the different times of the year.

Figure 2-1 Etihad Museum, Dubai. (© HG Esch, Hennef)

2.2 Grand Egyptian Museum, Cairo

The author engineered six cable facades to allow for a free view from the interior of the new Grand Egyptian Museum in Cairo towards the three Pyramids of Gizeh. The museum design by Heneghan Peng Architects (Dublin) is a parametric chamfered triangle in plan, thus allowing for open views to the pyramids from the different internal areas. As a result of the parametric setting, the six facades have different heights and different spans, yet are characterized by the same detailing and same cable sizes. Complex iterative calculations were carried out to optimize the pre-stress forces of every single 30 mm cable to achieve a max deflection of 1/50 of the free span, while still respecting the warping limits of the double insulated glass unit. This was coordinated with the facade contractor, Roschmann. A cantilevering roof protects the facade from direct sun radiation, especially in the hot summer period. The building is expected to be inaugurated in the second half of 2021.

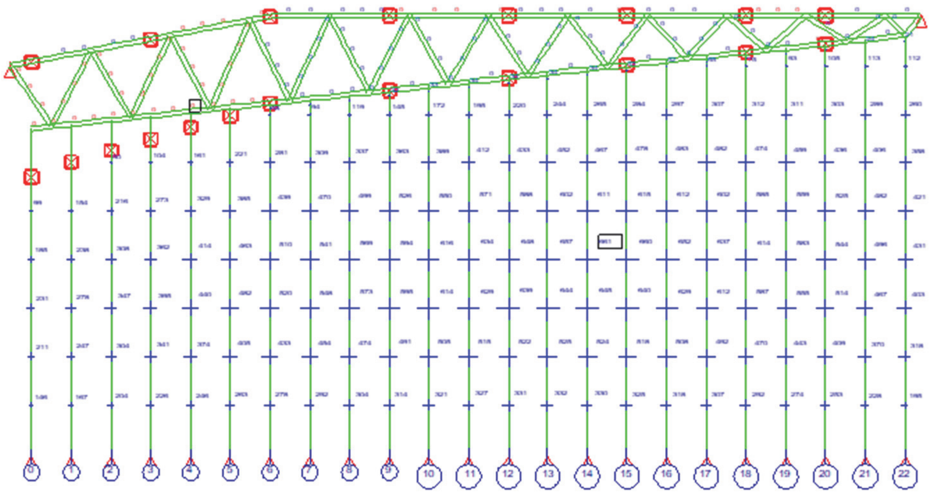

Figure 2-2 Grand Egyptian Museum, Cairo (Egypt). Structural analysis of one of the six cable facades. (© Werner Sobek AG)

2.3 Our New House, Vienna

The driving target for the new facade of the refurbished headquarter of the Association of Austrian Social Insurance Agencies in Vienna was the achievement of strict energetic standards (EnerPhit Standards) without compromising the minimalistic design of the architects (Chaix & Morel, Paris), who won the competition in September 2015. The intended emphasis on vertical elements for the double skin facade was achieved by allowing for natural ventilation mainly through vertical perforated aluminum fins. The level of perforation as well as the overall opening dimensioning was calibrated by means of computer-based simulation. The triple insulated glass unit with argon filling is protected against direct solar radiation by shadowing elements placed in the cavity between the two skins; this way g values below 10 % with a light transmission of up to 47 % can be achieved. The presence of protected deployable solar shading devices allows for a certain variability of the facade due to the external environment and the weather conditions. Yet the range of adaptivity must be improved in the future to better react to differing conditions. Moreover, as yet not enough attention has been paid to the embodied energy of the facades or to their recycling: this is essential to have an overall picture in terms of ecological footprint of a building. The exclusive focus on the insulating effect can no longer be deemed by itself to be a sufficient benchmark for the sustainability of a building envelope.

Figure 2-3 Unser Neues Haus, Vienna (Austria). (© Wolfgang Thaler)

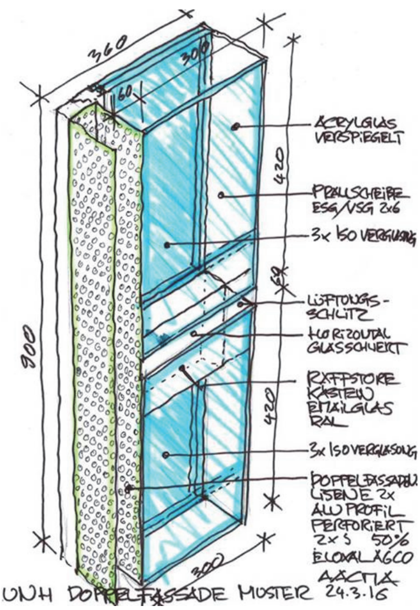

Figure 2-4 Sketch of a facade element – Unser Neues Haus, Vienna (Austria). (© Chaix&Morel)

2.4 Kuwait International Airport, Terminal 2

The performance requirements to be achieved in the glass facades of the new *Terminal 2 of the Kuwait International Airport* were even more challenging than those of the preceding two projects. The Terminal was designed by Foster and Partners (London) with the aim of creating a modern and innovative hub in the Middle East. Following the overall parametric design, the facade's double curved geometry has almost no degree of repetition through the terminal; the geometry of the 84 facades is generated parametrically to allow for more height in the central part. The author and his team were in charge of the detailed engineering of the facade after the tender had been awarded to Limak Kuwait as general contractor. The challenge was on the one hand to define a double insulated glass unit with a high light transmission (49 %) and a relative low *g*-value (24 %), thus setting a new benchmark in the region. Shadowing in the summer hot months is achieved by the roof, which cantilevers up to 50 m [5].

The main challenge was to ensure this performance also for the facade areas, which must withstand bomb blast loadings. Sophisticated calculation tools were used to carry out the necessary dynamic analysis for the facade steel structures and for the insulated glass units. Moreover, a detailed BIM model (up to LOD 400) was prepared to carry out the necessary clash checks and to support fabrication of the geometrically complex parametric facade with detailed information. In the future such tools could be used in a more radical way, for instance by implementing a plan for disassembly and by considering how to recycle the different components once the building is dismantled. In general a life cycle analysis should be mandatory in the future in order to be more precise in the evaluation of the embodied energy and of the overall energy balance during the building's overall life span.

Figure 2-5 Facades of Kuwait International Airport, Terminal 2, Kuwait. (© Limak)

3 Research work

3.1 Adaptivity

For nearly two decades adaptive skins and structures have been an important research topic at the ILEK in Stuttgart [6]. This research work was further boosted by the installation of the Collaborative Research Centre (CRC) "SFB 1244" in 2017. This interdisciplinary research endeavour of fourteen institutes of the University of Stuttgart aims at investigating how adaptivity can provide solutions to build for more people with less resources and without emissions. Since 2017, the research group has been working on the exploration of the basics, potentials and implications of the integration of adaptive elements into load-bearing structures and envelopes. As a result of the first research phase a circa 36.5 m tall demonstrator high-rise was designed and engineered. For this architects, civil and mechanical engineers and system dynamics experts worked within an integral process [7]. The steel structure is currently under construction on the University Campus in Stuttgart-Vahingen; it is planned to be completed by September 2020. The tower is located next to the ILEK on the University campus: the erection of the steel structural testing are scheduled for spring 2021. In summer 2021, the upper floors will be clad with an adaptive liquid crystal facade and with adaptive membrane facades. Further adaptive façade elements will be installed and tested in the coming years. A life cycle analysis

(LCA) supported the different design phases [8] with the aim of testing the environmental impact of the different solutions envisioned. Four planning stages with different levels of information were proposed. Especially in the early design phases this helped to select the most promising solutions. In the opinion of the author this is a powerful method that should be more extensively integrated in the design and planning process in the future to achieve a more sustainable approach to buildings in consideration of their overall life cycle.

Figure 3-1 Demonstrator high-rise with integrated adaptive elements. (© Weidner ILEK)

Investigations were also carried out on the possible architectural designs of adaptive skins. Moreover, innovative technologies were developed in order to manipulate relevant properties to better react to the variation of external agents such as climate and the needs of users. This work will be further extended in the coming years, with the aim of designing and developing several systems. The most promising ones will be shown and extensively tested in the demonstrator high-rise thanks to the funding receiver by the DFG (German Research Foundation) for the period 2021–2024.

3.2 DigitalTWIN

Another field of research is the integration of digital tools in the design, construction and recycling of building skins. One of the challenges in developing innovative solution for the building industry is the latter's fragmented character. This is to the changing responsibilities throughout the building's lifecycle, different standards and regulations and partners that change constantly during planning, construction and operation. Since 2019, the author has been part of an interdisciplinary team with partners from different industry and research groups with the aim of improving the value-creation chain of building skins by means of interdependent, interactive systems. The project is called DigitalTWIN (Digital Tools and Workflow Integration for Building Lifecycles) and is funded within the scope of the "Smart Services World II" programme by the German Federal Ministry for Economic Affairs & Energy. In Digital-TWIN an open platform, more advanced broadband communication systems and computer vision technologies are the selected means to simplify planning, production and coordination with the building site. This way all users in the different phases are provided with a reliable, flexible and upgradable communication and management infrastructure [9]. In the field of facades different concepts have been investigated so far: among others a system was developed in which the integration of sensors, AR-Glasses and edge computing allows for a fast and intuitive control of motorized shading devices. This can support facility managers during maintenance.

Figure 3-2 Interaction between users and facades by means of AR-Glasses and edge computing. (© Peter Neusser. seele)

4 Conclusions

The selected projects presented in this article have shown how challenging it is nowadays to combine the search for transparency with the different performance requirements imposed on facades. Designers and engineers have to fulfill the energetic requirements, to cope with geometrical and loading complexities, and to provide the comfort needed by users.

Adaptive systems are one way to improve the capacity of the facade to react to different external and internal conditions (sun radiation, dynamic loadings, energy requirements, user comfort, cooling and heating needs, etc.), thus leading to skins which match better varying conditions. This approach can also help – with the support of life cycle analysis – to optimize the use of natural resources and to limit the amount of emissions and waste. Considering the large impact of the building industry on the environment it is mandatory to push for further innovation, especially in the facade industry.

Digital tools can support this target by simplifying and optimizing the exchange of data between the parties involved in the design and construction process. This would be an important contribution to overcome the fragmented character of the building industry. In other industrial fields the digital revolution has already led to positive results, improving efficiency, reducing the use of resources, and smoothening the interfaces between the different phases and stakeholders. In these industries the need for recycling was introduced already a long time ago, among others in the mechanical and aeronautical sectors; in consideration of the large amount of resources needed for building activities it is about time that the building industry also increases the reuse of materials (urban mining) without further exploiting natural resources. Digital tools can be helpful for building up in a material cadaster and in providing information how to assemble and disassemble the different components to allow for a better recycling quota.

In general, all these technologies can lead to a tighter interaction between adaptive facades and users, thus generating a new field of more dynamic architecture, with a positive ecological balance over the whole life cycle. More than hundred years after the first visions and theories for a kinetic architecture were developed, the status of research and the technological progress is now finally reaching an adequate level to allow for architecture to better match the dynamic and interactive character of our society as well as the need for a more sustainable use of resources.

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