

Geometry, mechanics and the environment: integrated transparent thinking

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Keywords

1=glass

2=geometry

3=post breaking

4=cold bending

5=interlayer

Abstract

Free-form design is mostly focused on techniques for defining surfaces, but, when designing a transparent skin, one must also consider multiple technical parameters (e.g. glass mechanics, post-breaking behaviour, production techniques and interlayer properties) as well as environmental aspects.

The use of flat glass panels as structural elements is not a new concept, and, today, even curved glass can be used structurally. The stiffness resulting from the curvature can lead to very efficient structural performance, as exhibited by the Bouygues Headquarters staircase in Paris. Of course the structural use of glass must not preclude the comprehension of safety and post-buckling behaviour, which are determined by the properties of the glass and the interlayer.

New production techniques have become critical in assuring the economic viability of double-curvature skin. The innovative techniques of the two-step cold bending process, employed for the toroidal skin of the Strasbourg TGV station is a first step in this direction. This project has also demonstrated that an appropriate climate strategy can transform a potential "greenhouse" into a pleasant environment for daily use. Last but not least, the Elm Park (Dublin) and San Paolo-Intesa Tower (Turin) projects demonstrate that building skin design need not be limited to the facade but can incorporate the whole building by taking advantage of all available thermal mass for the storage of energy. It has taken more than a century to master all of these parameters.

This mastery, combined with today's technology, enables us to design the latest generation of transparent double-curvature envelopes that are perfectly adapted to modern public spaces.

Introduction

Bicton Garden Green House is an emblematic precedent to the current trends in free-form design that are so fashionable today. The double-curved surface of this greenhouse can be considered freeform because it only approximates a sphere. The glass is used structurally and contributes to the global stability of the structure by transferring the in-plane shear stress from arch to arch. Moreover the use of glass is not only for the sake of the transparency but plays an environmental role in creating a tropical environment in the temperate climate of the north of Europe.

The geometry, the structural use of glass and the environment control are all considerations that characterise the current architectural debate, and the seeds of this debate were already present in this historical building of the beginning of the XIX century.

It took almost two centuries, and the efforts of several generations of architects, to completely master these subjects and to develop them into transparent free-form design. Bruno Taut's Glass Pavillion showed the interest in transparency, but the technology of the time was not developed enough to resolve the complexity of detailing for such faceted geometry. Buckminster Fuller was inspired by transparency as

a tool for controlling the environment, but the glass world was not ready. The destruction of the Biosphere's polycarbonate skin by fire embodies the lack of confidence in a challenging but fragile material such as glass. It was only in the early eighties that glass had begun to be used structurally, and the Willis Faber and Dumas Headquarters facade designed by Martin Francis (an early partner of RFR) represents one of the first relevant structural applications of this material.

Since its creation in 1982, RFR has been interested in glass, investigating both transparency and the structural application of this fascinating material. Starting at the beginning of the year 2000, RFR broadened its investigations into geometry and the environment as complementary subjects when researching the dematerialisation of the building envelope.

The recent projects presented here show the current design approach and the manner in which the above-mentioned topics relate to one other in the creation of new forms.



Figure 1 and 2
Bicton Garden greenhouse and Buckminster Fuller Biosphere in Montreal





Figure 3 and 4
Facade of the Miramar palace extension.

From architectural forms to structural schemes

Architects are now focusing on highly articulated shapes. An enormous amount of technical effort goes into the resolution of issues associated with the skin technology forgetting that single and double-curved glass is very efficient in term of its structural behaviour if properly used.

Miramar shops

The facade of the extension of the Miramar palace on the Croisette in Cannes (2008, arch. Moatti-Riviere) cannot be considered as real "blob" architecture, but the architectural emphasis lead to a wave facade marked by a sinuous and twisted glass strip acting as a translucent canopy in order to shade the shop windows.

Geometry and technology

The economical and technical viability of the at once gentle and random "tape" effect of the facade and canopy is based on the rationalisation of the perimeter of the building. This is done according to sections of circles coordinated with the layout and dimensions of the glass elements.

The non-rectilinear shape of the perimeter allowed us to take advantage of the curvature effect and to optimise the glass thickness with respect to the different radii. Moreover, the setting out of the facade and of the canopy was developed with respect to large surfaces of glass and, in particular, to the largest format toughened, conical glass available on the market.

The fixing techniques correspond to the different boundary conditions. The facade panels are held in top and bottom channels with patch fixings along the mullions. On the other hand, the canopy is fixed using only "rotules," because it was necessary to place the support in the middle of the glass in order to minimise the span and take advantage of the bottom cantilever. The fixing "rotules" are also designed keeping in mind the post-breaking behaviour of the laminated glass which will hang like a curtain in case of the breakage of both glass panes

Bouygues Headquarters stair

The Bouygues Headquarters stair (Paris 2006) differs from other structural stairs in its geometry, which is curved in plan, and in its use of a new strategy

of gluing glass elements and thereby transferring forces by contact instead of using mechanical fittings.

The horizontal vault

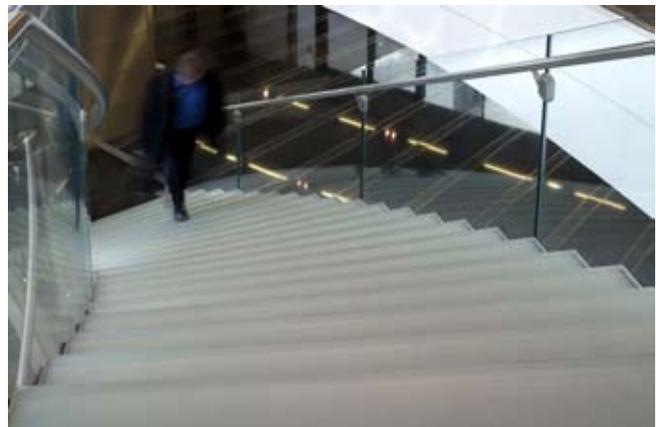
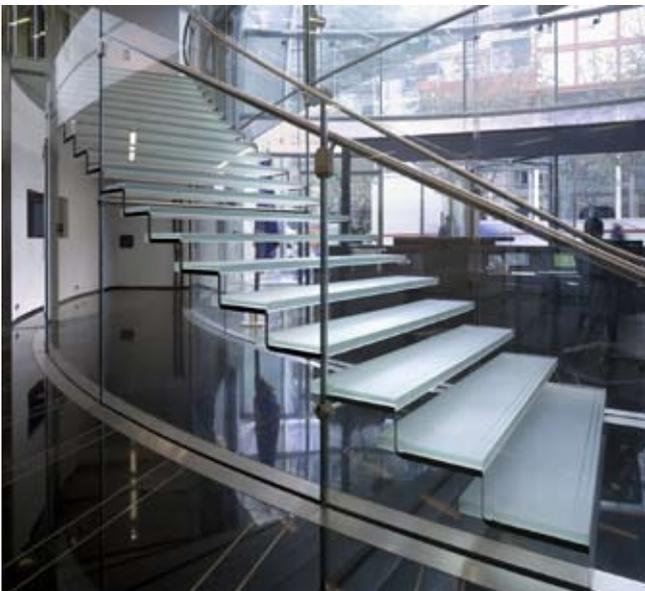
The stair is curved in plan and is contained by two glass walls spanning between the two main load-bearing structures of the building. The exterior curved glass wall acts as a horizontal vault and is anchored to the two robust load-bearing pillars at its extremities, thus arch effect horizontally stabilizes the whole stair. In order to assure the structural continuity necessary for enforcing the arch effect, the glass panels are pre-stressed one against the other by an upper edge cable so that they behave as a single element.

Gluing fixing

Instead of bearing on mechanical fittings, the glass steps are "simply" placed, bearing on the two retaining side walls. Each of the curved side walls is a triple laminate the two external layers of which are full-height and the internal layer of which is cut according to the stair/step profile to provide the horizontal bearing surface. Therefore, each step bears directly on this free



Figure 5 and 6
Glass stair in the atrium of the Bouygues Headquarters



edge of the internal glass layer and is fixed using only structural silicone.

The post-breakage behavior

The new structural scheme has been developed bearing in mind the usual considerations about the fragility of glass, as well as post-breakage considerations. Both the fail-safe and damage approach are applied, but according to a sequential principle: each glass element can sustain a certain level of damage with only a partial reduction in performance. However, any element (step or side panel) can also be completely omitted without causing the collapse of the stair. Each step is a quadruple laminate of heat-strengthened glass, and all of the layers can break while still guaranteeing a residual strength. The triple-laminate side panels will guarantee a solid bearing even if one of the layers is broken. Moreover, each glass panel can be removed and an alternative load path is provided by the adjacent panels, assuring the staircase's integrity.

Technology

Faceted skins are the current solution for realising transparent envelopes of double curvature. When designing skins of double curvature, the production technology becomes critical to the realisation of an envelope that is coherent with architectural requirements and economical considerations. Cold bending and single curvature panelization now constitute an alternative to double-curved glass.

Strasbourg TGV station

In the case of the Strasbourg TGV station (2007, arch. AREP/Duthilleul) a new glass shell creates a new space in front of the existing train station making it possible to host new services that are required for the expanded utilization of the station.



Cold-bent glass

Cold bending is not a new technique, but for the realisation of this project it has been further refined. Typically, glass panels are elastically bent on site when they are mounted on the supporting structure. In this case, they are bent before lamination, providing the advantage of achieving the tighter radii necessary to match the architectural geometry.

Environmental strategy

The Strasbourg TGV station is also interesting for its low energy approach which leads to the realisation of a fully glazed, south-facing atrium using neither air-conditioning nor mechanical ventilation.

A complex thermal strategy based on natural ventilation has been developed, which is made possible in part by the glass composition which limits solar gains. Fresh air is drawn in from the adjacent metro line and extracted at the top of the atrium, where the glass shell overlaps the existing building. Additional air enters through the doors at street level, assuring a consistent flow, which is necessary both to cool the space and to provide comfort for the occupants of the atrium. This active strategy complements the passive strategy of reducing the solar energy gain. This is achieved by the application of a ceramic frit on the top of the shell where the sun's rays penetrate the shell with an angle close to 90 degrees. A film Southwall XIR 72/47 further reduces the solar apports. A low-e coating applied on the inner side limits the heat radiations toward the hall.

"Fondation Louis Vuitton pour la Création"

The project of the "Fondation Louis Vuitton pour la Création," designed by the American architect Frank Gehry, represents the challenge of replicating the complexity of his Bilbao museum with the additional constraint of transparency. The nature of the geometry is the key parameter of the

project. The range of shapes has been limited to free but developable forms which can be approximated by families of glass panels. The complexity of the geometry directly raises technological questions about how to produce the glass panels and how to fix them over a non-repetitive and non-regular structure. New production plants for single curvature toughened glass have extended the domain of possible solutions, making it possible to cold bend glass in situations where it would previously only have been hot bent. New and more resistant interlayers offer the possibility of producing thinner, more flexible laminates which can be adapted to a random support structure. Further, the design of bespoke connections based on advanced machining and casting processes allows us to create fixing devices that have the capacity to adapt to the diverse conditions of the support structure.

Environment

Environmental strategy has an increasingly important role in architecture. The energy crisis and global warming due to carbon emissions oblige us to reduce the energy consumption of buildings and force us to define new strategies for heating and cooling. This issue is even more fundamental when dealing with transparent buildings of large volume. The energy gains are often important enough to put into question a project's economical and environmental sustainability. On the other hand, increased comprehension of low-speed air movement has enhanced our understanding of natural ventilation, which opens up new possibilities for transparent architecture and enlarges the range of the utilisation of glass.

Elm Park Development

The skin of the Elm Park buildings (Dublin 2008, arch. Bucholz Mc Evoy) is conceived as an environmental tool to create a low energy building. The double façade, which faces south, is supported by an independent wood structure that creates a dialogue with

*Figure 7 and 8
Double facade of the
Elm Park building*



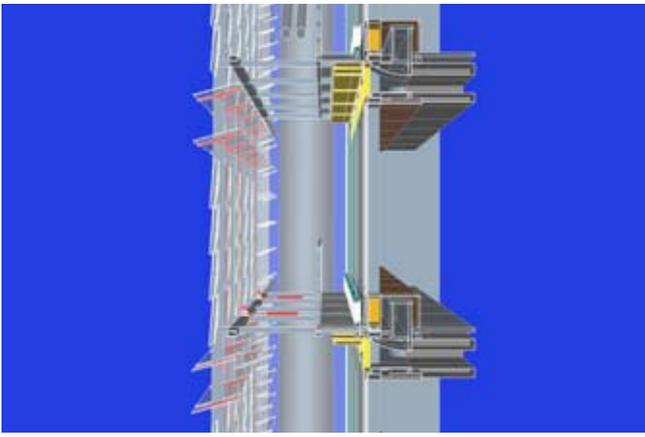


Figure 9 and 10
Lower screen and double facade of the San Paolo-Intesa Tower

the surrounding park and natural landscape.

The double façade is not to be considered as the addition of a second skin to the building but, rather, as a global device conceived together with the other façades. Its function concerns the function of the whole building. The difference in pressure in the façade cavity creates a transversal ventilation of the building: the South façade extracts hot air while the North façade allows cool air to enter the building by operable slots at floor level. At night, the transversal air circulation is still active, but the air intake is realized by louvers at ceiling level so that the air cools the exposed concrete slabs. The mass of the slab is used as a thermal timer; during the day, the slab, with its lower temperature, helps to contain the rise in the temperature of the office spaces.

The extraction strategy also takes advantage of the aerodynamic effect of the dominant wind from the sea which creates a depression over the roof. This augments the pressure differential between the base and the top of the double façade, thereby making the chimney effect even more efficient.

San Paolo-Intesa Tower

The San Paolo-Intesa Tower (Turin 2013) designed by Renzo Piano further develops the principle of using the thermal mass of the floor slabs. The tower presents two double facades facing East and West, respectively, and its outer skin is composed of operable glass louvers pivoting horizontally in strategic locations. In winter, the outer façade acts as a shield, reducing the thermal losses.

In mid-season and in summer, the system functions on the basis of an active strategy of openings. As in the case of the Elm Park building, the façade functions differently during the day than during the night. In the daytime, the glass blades are opened every four levels in order to create a chimney effect and extract the hot air from the cavity, thus reducing the thermal gain of the building. At night time, transverse ventilation is created, but in a completely different way from the Elm Park building. In this case the air is not drawn through the office space but into the slab itself, which has a transversal cavity to allow the air to flow across the building. Such transverse

ventilation is possible because both the glass louvers at the slab edge and the slab flaps are opened simultaneously. The aerodynamic difference in pressure due to the shape of the building is sufficient to draw the air through the slab with the advantage, in this case, of refreshing both the floor and ceiling surface, doubling the cooling effect.

Musée de la Dentelle et de la Mode

The façade of the "Musée de la Dentelle et de la Mode" (Calais 2009, arch. Moatti-Riviere) embodies both environmental and geometrical issues resulting in a strong architectural effect. The double curved semi-transparent glass surface, visible from the outside, is the first layer of a double façade, which has the double role of controlling the internal lighting conditions and creating a skin with high thermal performance.

Geometry

The shape of the two main façades of the museum corresponds to an architectural expression, but is rationalized according to geometrical principles. This has allowed the form

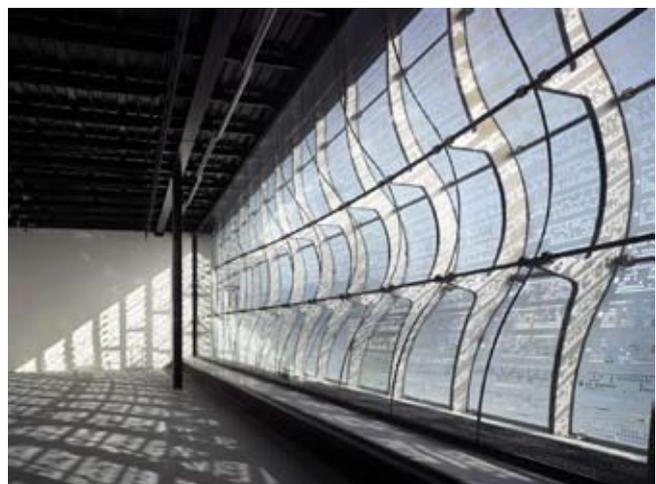


Figure 11 and 12
External and internal view of the main facade of the "Musée de la Dentelle et de la Mode"

to be conceived in terms of primitive shapes and not as a surface. The surface is created by varying the diameter of three circles along the length of the building. This principle allows for the easy creation of precise moulds which are all different and which generate a non-repetitive surface characterized by two axes of symmetry.

Environment

The severe thermal requirements didn't allow for single glazing, and double glazing was not a viable option given the tight radii and the difficulties of producing two perfectly parallel glass planes out of two different moulds. This is to say nothing about the cost issue. In order to achieve similar thermal properties, the double glazing has been exploded and transformed into a double facade composed of two double-curved skins. This solution allows for the perception of the shapes both from the outside and the inside, as originally intended by the architect. The use of single glazing for the two skins and the generous dimension of the cavity (necessary for the maintenance) create a risk of condensation under adverse climatic conditions. To avoid such a risk, the cavity is naturally ventilated, and the openings are optimised both to remove the heat during the summer and to control the temperature gradient along the transversal section of the cavity while ensuring a consistent insulation.

Conclusion

A great deal of progress has been made in both technology and theory in the last twenty years, with a particular acceleration within the last five years. It is now possible to realise incredibly complex shapes that are completely transparent and are intended for a social, everyday use. What was in the XIX century only a space to replicate a tropical climate in Europe can now be a train station or even a museum. The dream of the "masters" and "intellectuals" from beginning of that century of absolute transparency is just now starting to come true.