Fixing of Glass Panes in Façades of Complex Geometry by Use of Twisted Profiles

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Abstract
Connecting an outer surface of complex geometry (for example a twisted, doublecurved or inclined singularly curved glass or metal panelling) to a building’s superstructure implies that façade panels meet floors or walls under a varying inclination.

The profile as developed by the author and Alcoa Architectural Systems (NL), offers a solution to cope with the varying angle. It is the first industrialised system for façades of non-standard geometry and includes systemised opening windows. The uniquely shaped glass panes of complex geometry are framed by an industrial façade system consisting of standardised components. The system consists of a backing profile which may be positioned parallel or perpendicular to a superstructure (thus standardising the connection of the façade to the wall, floor or column) and of a glazing profile which connects parallel to the pane (to enable for example waterproofing). The two profiles meet along a cylindrical surface. The backing profile provides structural strength; the hereto attached glazing profile is torsion weak.

Keywords: glass, façade, doublecurved, twist, profiles

1. Increasing geometrical complexity of façades
Architecture features an increasing complexity of façade geometry. The trajectory that usage of curved surfaces in mainstream architecture follows, starts with unfoldable surfaces and ends with freely doublecurved glass façades. First singlecurved surfaces (like cilinders) and conical surfaces become generally available. The straight lines in them have great advantages for measuring and production, and therefore overlap more with production and building techniques of today than double-curved surfaces. Usage of freely doublecurved glass panes to date is rare and limited to very small series of independently placed elements, like entrance canopies and interior screens. Twisted surfaces (‘ruled surfaces’) are fluently doublecurved and composed of straight lines (‘rules’). Their straight lines don’t intersect nor lie parallel, but their surfaces are not developable and therefore more complex to make than unidirectional surfaces. However, because of their being composed of straight lines, they are easier to produce and assemble than surfaces of free geometry. In line with this, recent projects of major architectural importance, like the Guggenheim Museum in Bilbao, do feature ruled surfaces, but not freely doublecurved surfaces.

Usage of transformed glass is increasing. The gap between on the one side architectural demand for total geometrical freedom and on the other side production possibilities is being closed from many sides simultaneously. Small projects of great geometrical complexity and labour-intensive character combine with highly industrialised production of panes with only a slightly greater complexity of transforming than standard products. Easy to produce surfaces are cheapest, and therefore most common. Large scale use of transformed panes requires acceptable prices and this implies in Western countries industrialised production.

2. Connecting panes to superstructures by framing systems
Frequently singularly curved surfaces are used in structurally glazed façades of office lobby’s and of public spaces like museums. Also interior walls often feature transformed glass.

A curved façade may only consist of a single panel between a top and bottom framing, for example when placed between a horizontal floor and ceiling. Or have free contours in for example a monolithic concrete shell.
But façades composed of multiple panels usually connect to either orthogonal or radial frames and structures. Often either their horizontal or standing lines are emphasised. Structural systems may also be hybrid, for example in long buildings with rounded ends combining orthogonal and radial grids.

Cylindrical and conical surfaces are easiest to connect along a flat floor or wall when they either meet along straight lines or when they have the rotational axis perpendicular to the connecting surface. When cylindrical or conical surfaces are inclined, they will, just like doublecurved surfaces, meet a floor under a varying angle. Inclined cylindrical surfaces have to date hardly been applied in buildings, whereas vertical cylindrical surfaces or inclined flat surfaces are quite common now. This is due to the complex connecting of an inclined cylindrical surface to a horizontal transom, as it must adapt to the varying inclination of the glass panes. Additionally its curved panes are difficult to produce as they, when unfolded, are not rectangular and therefore difficult to position in the furnace.

A common solution, for example in a structurally glazed lobby façade, is to reduce the meeting to a fine line. This for example happens when a glass pane is joined to a horizontal surface (floor or ceiling) by a line of sealant. Instead of the sealant joint, the pane may enter a small profile in the floor or ceiling, which is wide enough to enable some varying of the inclination angle. However, when the panel must be attached to a backing profile (for example to take wind loads, ensure sound insulation, or to make a parallel connection between the glass and the backing profile for waterproofing), then the meeting surface of backing profile and panel has a varying angle to the superstructure. The meeting surface between façade and superstructure will be singularly or doublecurved. The doublecurved surface may by approximation, be considered twisted, as the curvature of the meeting usually has a large radius.

![Fig 2 varying meeting angle along the by approximation linear meeting of pane and floor/wall](image)

![Fig 3a glass touching framing profile either at its top or bottom edge](image)

![Fig 3b glass touching profile along milled doublecurved surface](image)

![Fig 3c glass touching tube along helix](image)
Connecting an outer surface of complex geometry (for example a glass or metal panelling) to a building’s superstructure implies that façade panels meet floors and walls under varying angles. Panels in curtain walls usually connect to backing profiles to take wind loads, and to enable water, wind, sound and fireproofing. They are fastened to substructures within the superstructures’ grid of columns and floors. The frames usually form screens of horizontal lines related to floors or, in frontal view, orthogonal grids related to both columns and floors.

Superstructures can connect in various ways to panels of varying inclination. If a relatively thick beam of rectangular section is used, the panels will according to the meeting angle, connect either to the top or to the bottom edge of the beam. This complicates measuring and assemblage considerably, especially when two panels join just at the meeting with the beam, or when the inclination thus changes that along the beam the meeting changes from one edge to another. Also tubular beams may be used. Contact lines between panels and tubes are helical: they touch along a line only. All panels along a tube have identical connections, which is advantageous. But when making a glass façade, often a parallel surface to the pane is needed to ensure fire and soundproofing.

Wooden rectangular beams enable other solutions. They may have one side milled to obtain a parallel contact surface to the curving glass pane. Milling costs can be avoided by using very slender profiles of substructures. Such profiles connect to panels along straight or single curved lines, like a ship’s L-shaped steel beams welded to the hull. There the positioning line for the profiles is clearly defined. This is very timesaving. However, building industry is different from shipbuilding. Façades hardly ever are welded. In architecture, linear connection lines can be created by tapering the beams or transoms. Then panels may be fastened along the tapered end by a line of hinges. But hinges often don’t suffice for water, sound and fire proofing between panels, especially when internal walls connect to the façade at the profile.

The above drawings show two positions for the axis of rotation of a conventional framing system relative to a superstructure. The sections show angled and perpendicular meetings. They have their axis either in the centre of the superstructure and panelling or central between the profiles. Other positions of the axis have similar effects on the transforming of profiles. The axis also functions as measuring line for production and assemblage. In both examples the varying inclination has serious implications for the transforming of the transoms and mullions:
- a varying of connecting angle and distance between profiles and superstructure
- a varying of distances between profiles
- a varying in height and angle of connections to surrounding façade segments

Fig 3d: glass touching steel beam/profile along a straight or single curved line

3e: glass attached by hinges along line

3f: profile perpendicular to glass implies varying of meeting angles, heights and distances to the superstructure (floor/wall/column)

Fig 4ab: angled and perpendicular meeting of structure and profiles, rotation axis within panels and profiles level with edges of floor

Fig 4cd: angled and perpendicular meeting of structure and profiles, rotation axis between profiles and constant distance between profiles
- a helical bending and additional twisting of the profiles.
The fine elaborated sections of conventional aluminum framing profiles make accurate bending and twisting, if possible, economically unfeasable.

3. The Twist-principle

Fig 5a: Façade profile divided in a straight or single curved structural profile and a torsion weak glazing profile, meeting each other along a cylindrical contact surface. All connections between façade and superstructure are standardised; no complex bending.

5b: Sections through aluminum Alcoa-Twist-profiles
5c: Photograph of Alcoa-AA100Q-Twist prototype with annealed twisted glass

A conventional aluminum framing profile must be singlecurved or doublecurved and be additionally twisted to connect with a parallel surface to a freely doublecurved glass panel. Curving and additionally twisting an aluminum profile of simple section is complicated and labour-intensive. The complex sections of most framing profiles don’t allow complex bending.

The author developed with Alcoa Architectural Systems the Alcoa-AA100Q-Twist system to connect panes of varying inclination. It consists of two profiles. A backing profile which is straight or single curved and is positioned (by preference) parallel or perpendicular to a superstructure, thus standardising the connection of the façade to the wall, floor or column. The second profile is the glazing profile which has a connecting surface parallel to the glass. The two profiles meet along an essentially cylindrical surface.

Whereas the backing profile provides structural strength, the hereto attached glazing profile is torsion weak. The glazing profile of complex section meets the demands of water, sound and fireproofing. It can be bent/twisted by hand to about 10° per metre, which suffices for most façades. The connection to a superstructure may be standardised in fitting and angle, for example to make perpendicular or parallel meetings with floors or columns. This industrialised system consisting of standardised profiles makes doublecurved façades economically feasible. It is part of the new façade system that Alcoa markets in most of Europe.

A prototype was made, measuring 2 x 2 m and rotating a maximum 18’ per m1. The annealed twisted glass was made on a flexible mould, essentially made of straight tubes.

A twisted façade with straight backing profiles is easy to make. The backing profiles are straight and the twisting glazing profiles can be assembled by hand. Freely doublecurved façades are made by bending the backing profiles of simple section in 1 direction and by subsequently manually bending and twisting the glazing profile.

Fig 6abc drawings of freely doublecurved prototype nr 2 measuring 2x2 m with an opening window
Fig 7 Drawing of one of the twisted and curved top transom profiles

To demonstrate that the framing system is also suitable for doublecurved surfaces, a new prototype is in production, which has a straight bottom transom, while the top and sides are single curved with a radius of 4m. It will additionally feature an opening window, and thus be the first framing system for doublecurved façades, with optional, opening windows.

4. Twisters

Twisting of profiles is generally avoided in building industry, but offers feasible solutions for making façades of complex geometry. On a bigger scale rotation of floors offers the possibility to make doublecurved buildings with a repetition of efficiently organised rectangular floors. Twisters, as buildings with a vertical rotation axis may be called, have a great repetition in façade elements too, enabling reduction of production and assemblage costs.

5. Optimising of rotation axis position

Fig 9ab alternative profiles with rotation axis on centre plane through panel

The first prototype was made of profiles developed for conventional façade geometries. This reduced development costs. A new generation of profiles has now been made, in which façade and roofing profiles are basically identical. The system therefore is highly adequate for doublecurved façades in which horizontal and standing surfaces fluently connect. Some aspects of the system may be optimised.

Lines through which a façade surface is defined and measured, may coincide with the rotation axis of the glazing profiles. This especially in twisted surfaces will be advantageous, for not only the backing axis can then be straight, but also the sides of the glass panes. If a glazing profile lies aside a straight rotation axis, the edges of the glass panes will be helical and the panes will no longer be built of straight lines but of helices. Thus glass measuring is complex. If the straight rotation axis lies in the glass pane, measuring will be minimised and pane contours will also be straight there. Less points are needed for measuring of components as well as for assemblage. Especially when materialising façades of complex geometry, it is important to reduce the amount of work involved in measuring.

With the prototype the market can be tested and stimulated. Other producers will join in, introduce alternative techniques and develop adjoining elements.

6. Summary

Architectural use of curved façades increasingly implies
varying meeting angles between glass panes and structure. The author describes geometrical aspects of curved façades and elaborates on an industrialised aluminum framing system. This system consists of two profiles connected along an essentially cylindrical surface. One profile is stiff, the other torsion-weak. The combination allows parallel fastening to both structure and glass panes. The principle is illustrated with a prototype.

7. Conclusions
1 Twisting of profiles offers new possibilities for materialising façades of complex geometry
2 An industrial aluminum façade system for freely doublecurved facades is feasible

References

Acknowledgements:
Alcoa Architectural Systems (Harderwijk), Van Tetterode Glasatelier (Voorthuizen), Glasbuigerij Bruining (Dordrecht), Glaverned (Tiel), Eijkelkamp (Goor), Hellevoort Visuals (Amsterdam), Van Campen Aluminium (Lelystad), TO&I of the Faculty of Architecture at Delft University of Technology, all in The Netherlands.