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DEVELOPING DOUBLECURVED ARCHITECTURAL GLASS

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1. Context

The availability of modelling software in the last two decades instigated an increasing demand by architects of double curved building elements. Such surfaces are important to designers. They imply a great increase of the available semiotic vocabulary inherent to the use of shapes and offer functional advantages when for example minimising outer surface or wind forces on a building or wind hinder in the environment. To realise them in an industrialised country for a reasonable price, necessitates using the newest techniques and stimulating the process of innovation. However, industry often does not yet comply with this demand. Demand still is too small and too varied in quantity and component dimension to make an integral innovation of the production process feasible. Glass plays a crucial role in future developments. Most clients demand the use of glass in their buildings, for example to admit daylight. Without double curved glass, no smooth double curved façade can be made. When for example freely curved aluminium panels are to connect to flat or unidirectional curved glass panes, all connections will vary. Industry will not invest highly in developing a complete new production line of 3D transformed elements if necessary adjoining elements (of other industries) are not yet on the market, and the demand in the near future will be small and extremely varying.

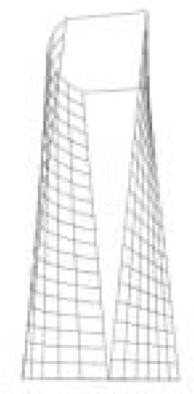
2. Bridging the gap

The gap between available production means and actual demands by architects is being bridged from all sides simultaneously. Architects come up with a wide range of demands, varying from small quantities of freely curved elements, to great series of elements that feature big repetition and relative small geometrical complexity. On one side by showing their complex shaped designs, architects stimulate industry to deeply invest in innovating for an emerging market, on another side industry offers components realised with small changes to existing production processes. However, transition to a new industrial era in which all elements may vary in geometry and quantity, goes slow.
Within the growing possibilities that computerising of building industry offers, it is essential to make efficient use of available means and give direction to the developments. On governmental level the demand of the market should be supported by commissioning a series of buildings of increasing complexity and sufficient scale to enable to write of a large part of the necessary investments. The impact on industry will be much larger than the initial investments, as it will give alienated industries a major impulse to develop additional products. Thus industries will distinguish themselves by their innovating qualities, and at the same time the environment will be visually enriched.
This article focuses on the implementation of newly transformed kinds of glass. In a series of models the use and materialising possibilities of twisted surfaces was studied. Twisted surfaces consist of straight lines. They are to be placed between the freely double-curved surfaces and the unfoldable surfaces, like cones and single-curved surfaces. The designs vary in degree of deformation, repetition,

and in height of buildings. The straight lines were made use of for dimensioning and production. To give direction to producers and building investors, models were elaborated showing build-up of façades and floor plans. The latter often are of new kind.

3. Examples of twisted surfaces in architecture

Models with twisted surfaces show examples of possible uses. Just like when using rectangular shapes, the possibilities to vary and combine are countless. The models were drawn because the subject is so new, that the building participants had to be shown possible uses of the material transformations they were working on.



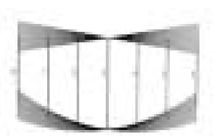
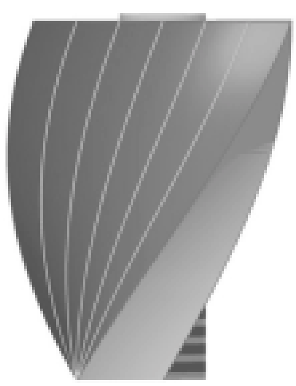


Figure 1. **Figure 2.**

This is **tordo**: a building with an orthogonal organised internal structure in which floors and walls meet under straight angles. It is relatively easy to build, as only the facades at the front and backside have been (slightly) twisted, and the rules connect to the superstructure.



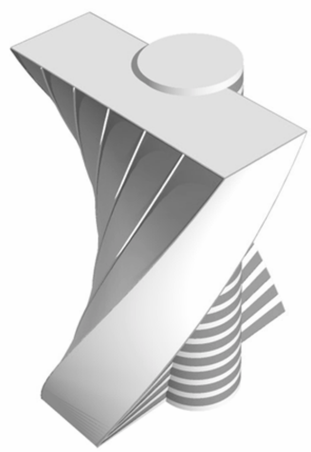


Figure 3. **Figure 4.**

This a **twister**: the floors are positioned with a rotation in a vertical direction. In a cylindrical core some building components (such as the elevators) rise vertically, while other components (such as the sanitary units and the stairs) rotate in conjunction with the rectangular office wings. The varying interposition of the components, results in a different plan in the core on every floor.

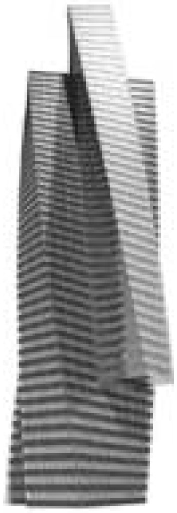


Figure 5.

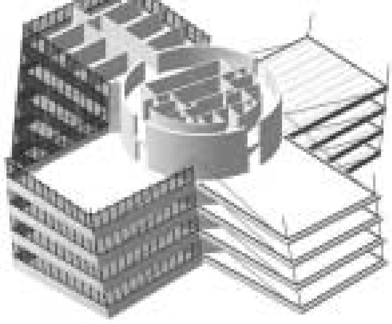


Figure 6a.

Figure 6b.

This 150m high twister is composed of 2 perpendicularly intersecting volumes. It is conventional in use; as a result of the only slight twisting of +- 0,5' per m1, the façades hardly incline. The volume as a whole looks spectacular, because the many slightly twisted elements, add up to the considerable twist of 70'. There is an enormous repetition of parts; the window frames and the glass are to be bent cold. To prove the feasibility of the system, a mock-up was made of the façade, measuring 2,4x4,8 m. A corridor acts as an intermediate between the concrete core that rises without rotation, and the light steel wings that hang from it. They rotate 1,5' further on each floor. [1] This project has been tendered by the industries for all parts of major importance, including the installations for climatising and façade cleaning. The model can quickly be adjusted to suit a client for a different location.

Figure 7.

In this symmetrically composed twister, 60 m high, 2 wings rotate in opposite directions around the cylindrical core. The side facades are not twisted but cylindrical. Because of the contrary rotation of the wings, the floor plans in the core vary on each floor. The cylindrical concrete core is essential for stability. The reflection of a twisted facade in a twisted facade, results in unexpected images.

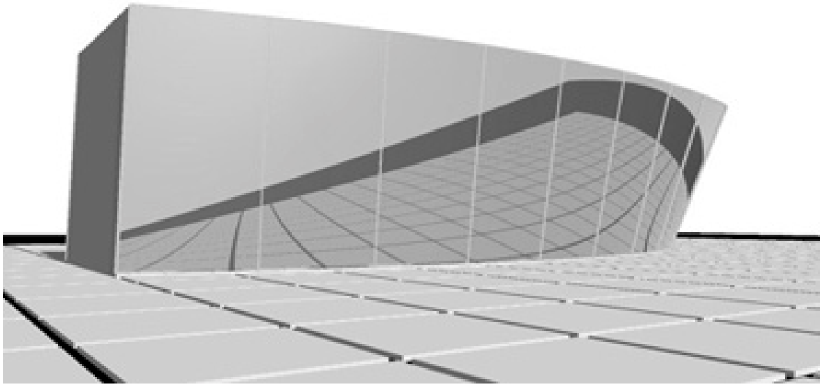


Figure 8.

In low-rise tordo's the deformation of the reflection at street level is investigated; reflections of car lights, or if the spectator moves himself, of street lanterns, will move with a varying speed over the façade and transform.

The *Twist* window system

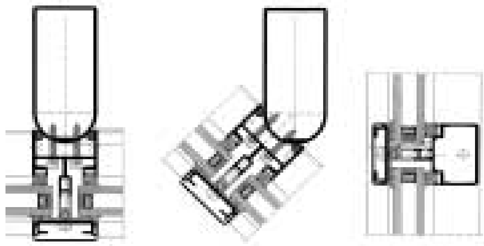


Figure 9. **Figure 10.**

This is an industrially produced framing system for twisted façades, with annealed twisted glass. The glass was transformed on an adjustable mould build of bars. The framing system combines a stiff backing profile, (which for example is positioned parallel to floors or walls), with a glazing profile, that lies parallel to the twisting (or if preferred freely double-curving) glass-surface. (2) The system connects up with the newest Reynolds framing system for the European market, and complies with the various national standards. By also curving the backing profile (for example in 1 direction), the framing system also can be used for freely doublecurved façades.

Freely doublecurved panels

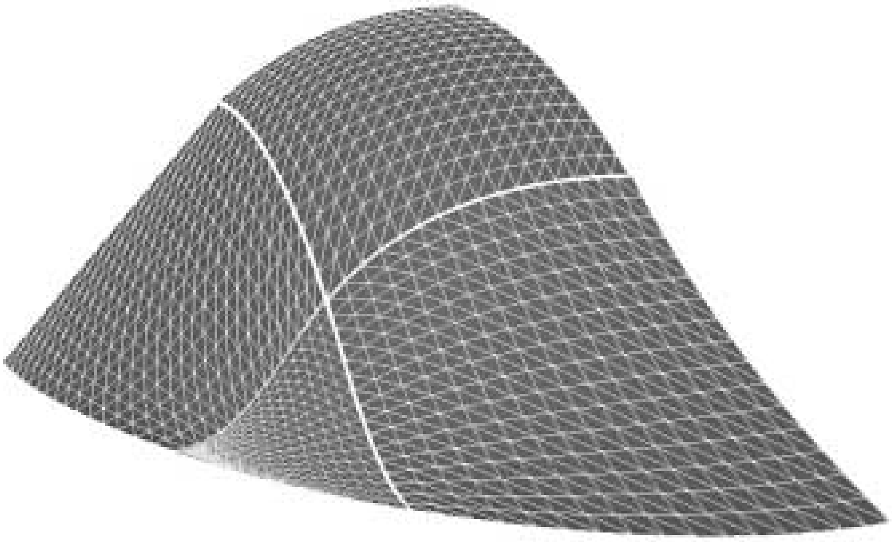


Figure 11.

Figure 12.

Moulds were milled from polystyrene. These subsequently were used to cast concrete moulds. In this metal panels were transformed by explosion forming. In this process a metal plate is positioned on the concrete mould and then pressed in its shape against the mould by sealing them in plastic and then making a vacuum inside. Next the mould and panel are placed in a water reservoir, for example consisting of a plastic foil in a metal framework. Explosives are being placed in the reservoir above the metal panel, and ignited, which induces the transforming of the metal plates. The moulds also were used to transform glass panels by heating. The milling process allows study of different suspension patterns for glass in an oven, thus pragmatically getting insight into glass behavior on a next to be developed adjustable mould.

4. Conclusions

- It is possible to make annealed twisted architectural glass on an adjustable mould.
- It is possible to make an industrially produced window framing system for twisted and double-curved façades.
- Twisted glass façades are a feasible option for buildings.
- Cold bent glass can be used to realise a (by close approximation) twisted façade.
- The use of cad-cam driven production processes decreases considerably the price of freely curved panels.

Note 1: This building was designed in collaboration with architect Pi de Bruijn, building developer Volker Wessels Stevin, structural engineers ABT, and the participants mentioned in note 2

Note 2: The system was developed in collaboration with:

- Reynolds Architektuursystemen, Reynolds Special Products and Van Dool Constructies
- Van Tetterode Glasatelier, Eijkelkamp and Glaverbel
- Hellevoort Visual

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