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Transparent Cubical Glass Building in Madrid

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An ultimately transparent glass building in almost cubical form of 30x30x21 m, to function as the future entrance building of the Santander Bancopolis complex southwest of Madrid. Conceptual design by architect Alfonso Millanes and structural design by Octatube. The structure is composed of ultra slender cable stayed tubular columns and trusses placed in a grid of 5m and cladded with insulated glass made from fully tempered outer panels and heat strengthened laminated inner panels. Size of all glass panels is 2.5 x 2.5 m². The insulated glass ensures additional stabilisation of the overall enveloping structure. The roof panels are partly twisted to obtain a fluent slope for drainage. The roof gutters are positioned at 2.5 m from the roof edge, thus creating a free glass edge. The side walls of the gutters are made of insulated glass panels. The glass type chosen is 'extra-white', emphasizing the glass cube as a sparkling crystal in the landscape.

Keywords: Quattro nodes, insulated glass, Tensile structural systems

1. Introduction

This paper describes the gradual and steady development in different areas of expertise in two decades, which has lead to the current state of the art building fabrication techniques for glass structures..

1.1. History of design of different glass cubes

In the history of the design & build company Octatube of Delft NL we have designed, co-designed and engineered, produced and built a number of cubical glass volumes. The cube is a prime and basic symbol if geometry in architecture, very recognizable ,but difficult to make in glass, especially in the larger volumes as construction (the way you put things together) and structure (the way loadings are forwarded from the glass panels to mother earth). We have designed these glass cubes as architects, structural engineers and industrial designers integrally in one. The prehistory of the Galss Cube Entrance in Madrid started 2 decades before. The use of cubes in art and architecture refers back one century to one of the first 'Cubist' paintings by Pablo Picasso: Les demoiselles d'Avignon' (1907). It shows a primary geometrical influence of the work of Paul Cézanne, who defended in his life compositions made entirely of simple geometrical forms, like cubes, cylinders, cones. It was Picasso, who took up this inspiration and used them for around a decade in a style which was called by art-critics as ‘Cubism’. Around that time he started to paint elevations combined with side elevations in detail. A front body and a side head, trying to make the 2D painting 3-dimensional. It took up to the 1980s before architects took up that idea in the so-called ‘De-constructivism’, in which buildings seem to have been formed from exploded parts of recognizable building segments, put together in a non-logical way. Coop Himmelb(l)au realized one of their first roof top office buildings in the Flackestrasse in Vienna in 1983 and in 1993 the Groninger museum. Currently their design for the Musée des Confluences in s under construction, an architectonic variation on the Cubist style of Picasso and Georges Bracque one century before. Cubes can go form simple cubes to complex assemblies of cubes and cubical segments. As a structure and a construction the lessons have to start form the simple cube, leaving the more complicated cubical arrangements for the higher classes of enlightenment.

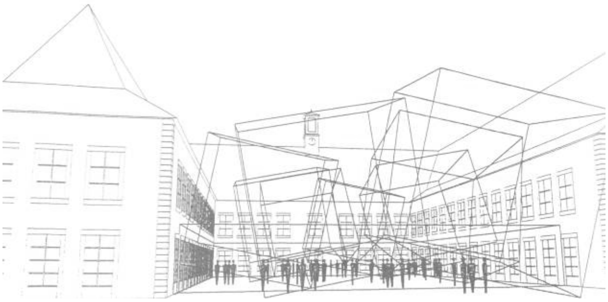


Figure 1: Design proposal for the European Business School in Wiesbaden by structural designer Mick Eekhout and sculptor Marijke de Goey as a composition of tumbling cubes.

2. Glass cube in Goor

The smallest cube measures 600x600x600 mm and is composed of 6 mm thick fully tempered glass panels, where the vertical corners are held together by glued stainless steel rods 6x6mm2. The upper panel is just glued on top of the wall panels. This cube houses a piece of art, in this case a neon sculpture designed by artist Marijke de Goey. This prototype was part of a series in glass cubes with different neon glass sculptures in the town hall of the Dutch town of Goor. The beauty was in the corner detail. The stainless steel rod was strengthening the cube against vandalism (fig.1).

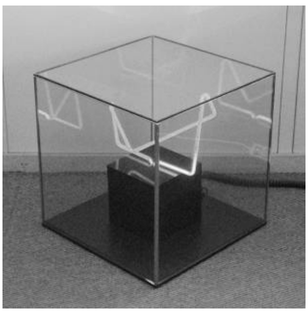


Figure 2: Glass cube in Goor.

3. Glass cube proposal for the Centraal Museum in Utrecht and the Flower shop in Rotterdam

In 1988 cubical glass pavilions were designed by architect Wiek Röling and structural Mick Eekhout as pavilions for a Dutch Museum in Utrecht. The project was not realised. Just before we had that developed a method in which we could joint 3 x 3 panels into one big glass panel. Our target at the time was a stable glass plane of 6 x 6 m2, structurally bonded together by connectors, cables and compression rods. The fist step was not even prototyped properly when the idea came up to make a 3D cubical pavilion. However, we did not know how to do it. From the drawings one could analyse that the corners, where the roof plane would lay upon the wall elements and the corner between two vertical walls were not solved. How to introduce larger forces from one plane into another? We did not know, 20 years ago (fig.2).

Hardly one year later architect Kas Oosterhuis came to Octatube and together we conceived a glass flower shop on the famous Lijnbaan, where the problem of the connection between roof plane on the wall plane and the wall-to-wall connection was neatly solved as a separate cubical tubular structure was safely introduced. The cube measured 12x12x6m in height and was subdivided into units we knew of 6x6m2, weach composed of 3x4 or 4x4 panels. The design drawing indicated that the roof panels were 1.5x1.5m2, smaller that the maximum panels available form the industry of 2.14x2.14m2. We were not sure structurally. But the ambition, the dream was on the table. This structure was conceived in single glass panels, fully tempered. Also this structure was not realised, but their publication in a book as the starting point of Dutch Glass structures [Ref.1: Stressed Glass, Zappi or Product Development for the Nai.] served its purpose (fig.3).

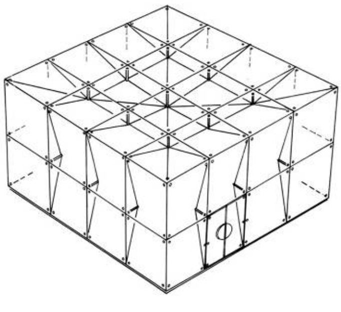


Figure 3: Glass cube proposal for the Centraal Museum in Utrecht.

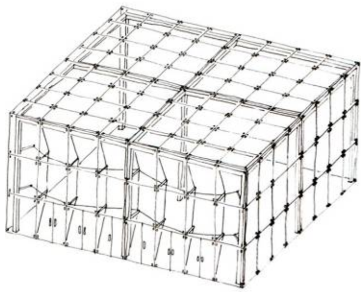


Figure 4: Flower shop on the famous Lijnbaan in Rotterdam.

4. Glass Music Hall in the Exchange of Berlage, Amsterdam

In 1989 Mick Eekhout designed the structural scheme for an all-glass envelope for architect Pieter Zaanen to house the concert and rehearsal hall for the Chamber Music Orchestra of the NedPhO, the Dutch Philharmonic Orchestra. Pieter came to Mick after a modest publication of the study model of Rik Grashoff, one of Mick's early students at Civil Engineering. The model was built for a Boosting publication [Ref.2: Tussen traditie en experiment].(fig.4).

Figure 5 Experimental model of glass. Structural glass panels 1989.

This hall had to measure 10x22m in plan and around 10 m in height. Architectonically, built inside of the famous exchange building of dr.H.P.Berlage from 1903, it had to be a built volume completely independent of the existing building. Also maximum transparency was required. Built on separate piles driven through the cellar floor, the concrete floor structure would enable a completely independent glass box, a reversed giant glass battery box. During a number of design brainstorms with Pieter Zaanen, the idea came up to have one of the two walls not parallel, to improve the acoustics as flutter would be minimised. The structural system of tiny cables or tensile rods and short compression studs was designed pre-stressed between the roof and concrete floor structure.

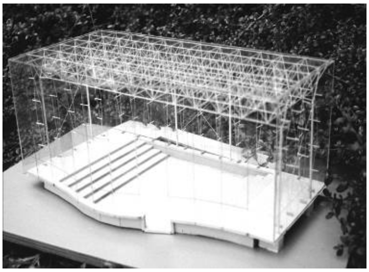


Figure 6 Model of Glass music hall, Amsterdam.

It was not the floor, but the roof structure that gave the greatest worries. Parallel to the Glass flower shop in Rotterdam, the first idea was to make a tubular structure in the ribs, but the fire brigade officer did not allow for a structural glass roof, without abundant experiences or self-confidence proven or engineered. They were right, one could add later. So the roof structure was taken as an ordinary space frame structure, stiff, supported on six columns only, stabilised with wind bracings and covered with laminated glass panels. Opened in 1990, it was the first structural glass building in the Netherlands. All glass panels were suspended vertically form one another. So the highest glass panels, 8 mm thin and fully tempered, carried the dead weight of the lower panels and the vertical trusses of 8 mm rods stabilised the facades horizontally, against leaning architects, as there was not much wind to be analysed, apart form the overpressure of the air-conditioning. That was the invention. It was a giant step forward. A book was written about this adventure [Ref.3: Product Development in Glass Structures].

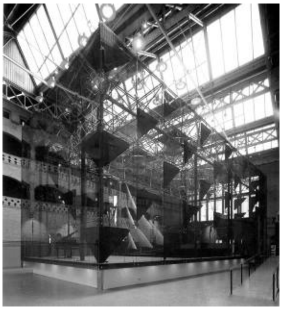
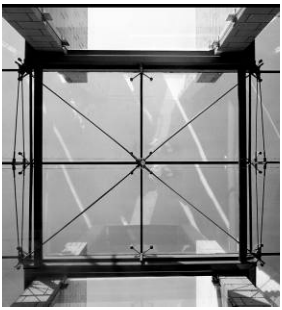


Figure 7: Glass music hall, Amsterdam.

Figure 8: Interior view.

5. Glass Roof on Brick Cubes in Hulst NL

However, the roof, built as a conventional space frame, was a source of annoyance.
A few months after the design was approved by the fire brigade a young Belgian / Dutch architect, Walter Lockefeer came to Octatube to co-design a glass roof in a double cubical pavilion with dimensions, derived from the golden rule: 6.870 x 6.870 x 6.870m. The walls, in his architectural philosophy, were overruling and the roof was unimportant. So the roof had to be invisible and made of glass, preferably without any steel. So he stimulated the development of the first glass panel roof, stabilised as a bicycle wheel with vertical compression studs and tensile cables underneath the glass panels. The first Dutch tensile stabilised roof had been realised. The roof was composed of double glass panels with laminated lower panes. All glass plates were fully tempered. The stainless steel connectors on the lower side of the roof panels were glued between roof panel and connector. In this case the deadweight was more than the eventual uplift, so even a glued connector without glue would have worked, as the panels were fixed horizontally between the roof edges. This experiment gave us enough confidence that a tensile under-spanned structure would work, even if a surrounding steel tubular steel frame balanced the tensile cables. The second profit was the glued experiment. It was just a project invention, nothing more. The pavilion was published in colour and attracted much interests [Ref.3]. The roof leaked for a number of years, but the cause was in the surrounding brickwork. The silicone sealant worked quite satisfactorily for a roof with a pitch of only one single degree (fig.8,9).



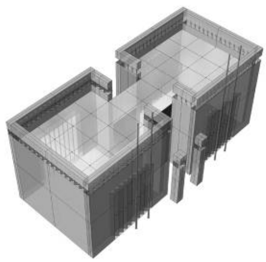


Figure 9 and 10: Flower shop in Hulst.

6. Prinsenhof Glass Museum Hall in Delft

The next step was, of course, to make a completely chemically bonded system. The glued connection was developed initially for roofs, where the tangential loads were restricted and uplift could be avoided by choosing thicker and heavier glass panels, the first one in a Court of Justice in Maastricht, 1995. (Fig.12)

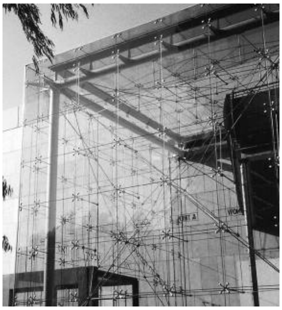
Figure 11: Court of Justice in Maastricht.

Figure 12: Prinsenhof Glass Museum hall in Delft

The first frameless façade was built in the Prinsenhof Glass Museum hall in Delft one year later, in 1996. The extra problems structurally for the glued connections were the vertical deadweight of the glass panels and the quite large distances between the panels and the Quattro nodes. In first instance the distance were too large, causing large bending moments in the connection bolts. A number of panels broke during the initial installation. Soon enough it was discovered that the cause of breakage was mainly in the diagonally stressed wind bracings, as a result of which the Quattro nodes were not accurately positioned. It was mid winter, her majesty the Queen came for the inauguration and the installation was too hastily done. For security reason the deadweight of the glass saddles, fixed on the Quattro nodes, carried the panels. In other vertical facades, the distance s between the glass panels ant the Quattro nodes were held as short as possible. Glass panels in their glued connections can take as large an amount of compression as (roughly) as tension and shear, but glass panels are only capable of carrying 10% of these forces in bending (fig.13).

7. Glass Cube of Museon in Tel Aviv

In this short history of incremental product development successively the material glass, single panels and laminated and double panels, the Quattro nodes, welded and later stainless steel, the tensile trusses form 8 mm in Amsterdam to a heavily typhoon loaded project in Hongkong 2x 30mm, the glued connections and the architectural detailing were developed to the current level of design perfection. The entrance cube of the Museum of Modern Art of Tel Aviv offered the opportunity to make single span cube with only the tubular compression frame elements in the corners. The size is roughly 12x12x12m3. The system worked, be it here in single laminated glazing and a little building physical problem with the abundant solar radiation coming into the building part, in the Israeli desert climate. (fig.14,15).



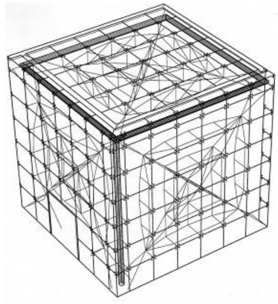


Figure 13 and 14: Entrance cube of the Museum of Modern Art of Tel Aviv

8. Glass Cube Hall of the Synagoge, The Hague NL

The synagogue of the Liberal Jewish Community in The Hague was built in the midst of the 18th century and is regarded as a monument. The synagogue complex needed an extension between the street front ‘gracht’house and the hidden synagogue with a glass hall for social gatherings and festivities. Mick Eekhout was invited as the architect and he designed a cubical glass construction with an apex almost as high as the existing synagogue monument. The structure is a tubular structure, covered with a glass roof and 4 glass façades. The 4 legs stand alone in the ground floor level, connected to the walls and of the premises by an acoustically perforated flat metal roof. The glass cube embraces, as it were, the front part of the synagoge monument. The new technology embracing the classical building with respect.

Figure 15: Interior of the Glass Cubical Hall for the synagogue in The Hague

9. The Santander Glass Cube of Madrid

The apotheosis of this contribution, and its main subject is the cubical glass building serving as the entrance building for the Santander ‘Bancopolis’ in Boadilla del Monte, near Madrid. The Bank town has been designed by 85 years old Kevin Roche from New York, Pritzker Architectural Award winner 1982. In 2003 a 30 m diameter circular glass roof was deigned by his office and detailed and realised by Octatube. The structure was post-stressed 36 pieces of bicycle wheel principle with multiple compression studs and stainless steel tensile rods of 30 mm diameter. It opened the eye of the client for lightweight tender structures. Some years later he issued an order for a cubical glass building as the entrance cathedral for the bang premises as a maximally glass building.

Madrid architect Alfonso Millanes was the architect who developed the cube, much in the line of the above-described know-how with the engineering office of Typsa and Octatube. The predominant features of this building are: overall size 30x30m floor plan, 21,4m height; large insulation glass units (IGU), 2,5x2,5m2; large custom designed Quattro® nodes 350x350mm; compression tube grid of 5x5m; integrated wind braces-glass supporting structure; mechanical connection of glass to nodes through the inner plate of each IGU; twisted roof panels; insulated glass roof gutter; integrated water drainage system.

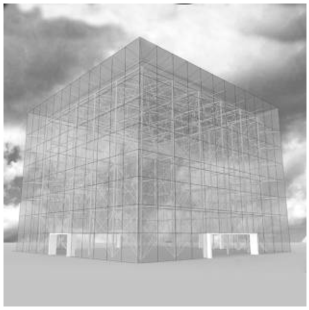


Figure 16 and 17: Design of the Glass Cube by architect Millanes and engineers Typsa and Octatube.

Integration of several functions into the components comprising the structure of this particular cube was imperative to reach the accomplished transparency level. For instance, the wind bracings of the main structure not only serve to stabilize the structure against horizontal external forces, but are also designed to support the glass panels of the façade.

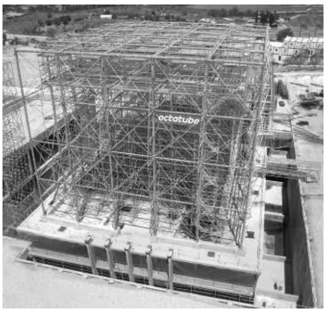


Figure 18: Installation of the Glass Cube

The roof has also a unique feature: a completely flat roof can only exist in theory; when put into practice, rainwater needs to be drained to prevent stains on the glass, or even worse, excessive accumulation of water on the surface of the roof. The roof is designed to drain water to the gutter running on all four sides, thus raising the central point. The glass panels of the roof are twisted to avoid the use of triangular glass panels. The glass gutter is positioned directly above one of the compression tubes of the main steel structure. This not only disguises the gutter, but also leaves the corner of the roof-façade connection to be very transparent as well; no structure other than a mechanical glass-on-glass connection is used to support this corner. The vertical corners of the cube are designed in a similar fashion; the main difference being a vertical corner profile is used to support the weight of the glass panels (another example of integration of functions). Although here the profile has a different function, it can be compared with the corner profile of the 600x600x600mm glass cubes in Goor described earlier.

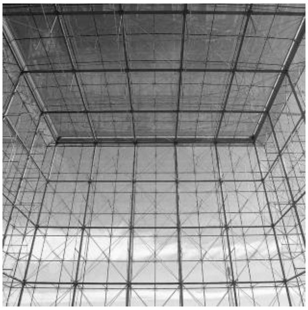


Figure 19: Inside view

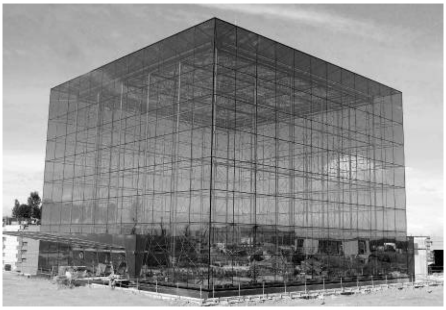


Figure 20: Glass Cube Santander Bank, Madrid

In true Octatube style, the structure is prefabricated to the maximum possible extent in the factory in Holland. This, together with the just-in-time arrival of components on the building site leads to a short and effective assembly. This also applies to the glass panels; freights of glass are called to arrive on site with little advance to minimize the risks of damage during storage on the building site. This approach results is the total assembly of all glass panels (516 in total) without any damage.

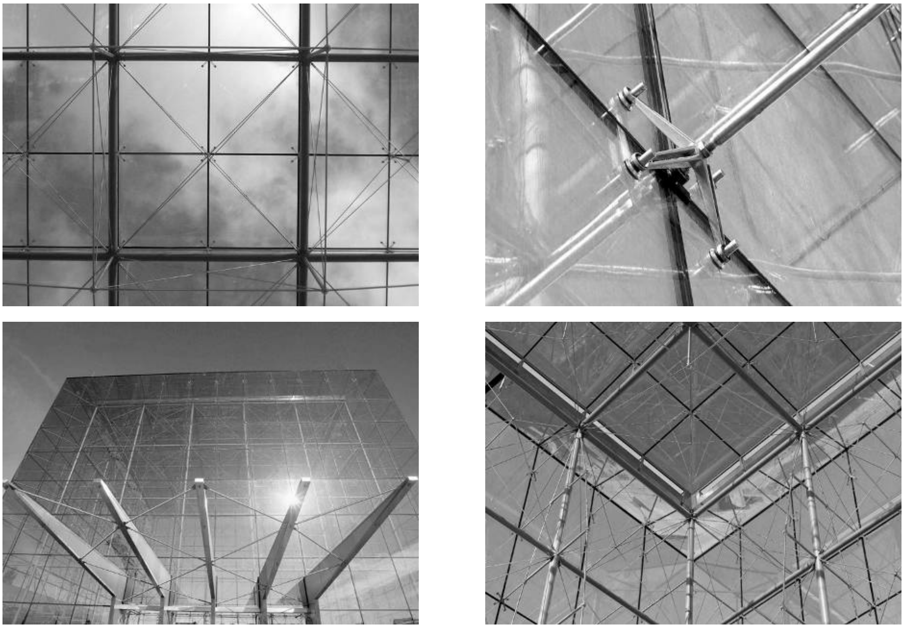


Figure 21-24: Details of the Glass Cube.

10. Conclusion

The Santander Glass Cube in Madrid is an example of high tech know-how on different levels that has been obtained grossly on a project-to-project base. This careful incremental approach took place on different scale levels:

- Glass and glass panels
- Connections glass to Quattro nodes
- Tensile structural systems
- Refinement of constructions
- Industrialisation/prefab components.

At the engineering department there is a general feeling that the resulting glass cube structure is the about lightest possible.

Next step could be to use glass panels also to function as shear force holders in the plane of the façade and the roof and or to have the glass panels provided with internal tubes so that vertical pre-stressed cables could be inserted through the panes to stabilize the façade against wind pressures.

It is yet a few steps from the ideals that are put by the Cubism of Pablo Picasso and the contemporary translations of painters' Cubism into architects' Cubism like Coop Himmelb(l)au. But ambitions show the direction to be followed.

11. References

[1] Eekhout, M., '*Stressed Glass, Zappi or Product Development for the Nai'*, NAi Publishers, 1990. ISBN:90- 72469-78-x.
[2] Westra, J.(eds.),'*Tussen traditie en experiment*', 010 Publisher, Rotterdam, 1990. ISBN:90-6450-096-7.
[3] Eekhout, M., *'Product Development in Glass Structures'*, 010 Publisher, Rotterdam, 1989. ISBN:90-6450-111-4.