

# Revolutionizing Structural Glass Design and Construction: A Study on the Remodelling of a Glass Drum

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## Abstract

This paper presents the remodelling of a retail store in Shanghai, where an existing glazed drum of 10 m diameter and 12 m height, originally composed of glass fins and beams with infill panels, was transformed into a minimally supported structural glass enclosure while retaining the original architectural proportions. The paper first outlines the project background and the design intent to replace a conventionally framed system with a shape-driven glass structure. It then discusses the key design principles, the structural concept, and the load path developed through the interaction of drum geometry, domed roof geometry, bearings, silicone bonding, and glass stiffness. Particular attention is given to the behaviour of the system under different load conditions, including dead load, maintenance load, and fluctuating wind actions, with emphasis on the sensitivity of the slender roof structure beyond peak design values alone. The numerical design approach is presented together with the validation strategy, comprising full-scale testing of the roof and a full drum mock-up performed in parallel in two countries for both robustness and compliance. The paper further addresses fabrication tolerances, local expertise, and installation-related constraints as essential factors in the successful realization of the project. The study demonstrates how geometry-led design, targeted validation, and close interdisciplinary collaboration can enable a lean and robust all-glass system for demanding architectural applications.

## Keywords

Drum Structure, Structural Glass, Remodelling, Case Study, Retail

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## 1. Introduction

Historical dome structures such as the Pantheon in Rome and Brunelleschi's dome in Florence demonstrate how geometry itself can become a governing structural principle. Their ability to achieve stability and spatial clarity through form, rather than through an excess of secondary elements, provided an important source of inspiration for the remodelling concept presented in this paper. The project translates these principles into a contemporary all-glass application in Shanghai, where an existing glazed drum entrance was redeveloped into a more visually reduced and structurally integrated enclosure.

The project was developed through close collaboration between Eckersley O'Callaghan (EOC) and seele. EOC focused on the redevelopment of the structural concept, the key design principles, and the numerical assessment of system behaviour under different load conditions.

seele contributed from the façade engineering and construction side, including testing strategy, coordination with local experts, fabrication engineering, and installation planning. Beyond its architectural ambition, the remodelling also had to satisfy demanding requirements in terms of structural robustness, compliance, fabrication tolerances, and buildability. The resulting design seeks to combine maximum transparency with a clear structural logic, demonstrating how historical structural ideas can inform a highly refined contemporary glass system.



Fig. 1: Concept – Glass Cylinder with Domed Glass Structure ©EOC.

## 2. Structural Design

### 2.1. Design Intent

The original Pudong drum stood at the entrance of a retail store for more than ten years. When completed in 2009, it pioneered the use of curved glass in structural applications. It used the largest glass panels available at the time, forming a skin supported by a structural glass frame connected with mechanical fixings. The drum stood 12m tall and 10m in diameter. From the entrance, visitors descended to the store below via a glass staircase, engineered concurrently.



Fig. 2: Pudong Drum - Glass Frame and Mechanical Fixings visible ©EOC.

The brief called for a remodel of the drum to current standards, taking advantage of advances in fabrication, while fitting within the same envelope as the existing structure and retaining the existing glass staircase. This required the new drum panelisation to follow the existing configuration, so that joints would align with the staircase below. With no fixed architectural intent, the engineering team was free to explore various options. From the outset, the goal was set to reduce the number of mechanical fixings — and it quickly became clear that the glass fins could be removed entirely, allowing for a skin-only system.

The roof presented a distinct challenge: a single 10m-diameter glass panel was not feasible, so the roof would need to be panelised. A flat configuration would have required glass beams underneath for structural support, and several arrangements of this type were studied.

In parallel, the idea of a domed roof emerged. This initially seemed unfeasible, as there was uncertainty over whether the joints between panels could provide the necessary restraint. Deeper research into the behaviour of domes and the development of internal forces revealed that the type of forces crossing a joint could be controlled through the choice of panelisation. This insight led to the roof being divided into twelve pizza-like segments.

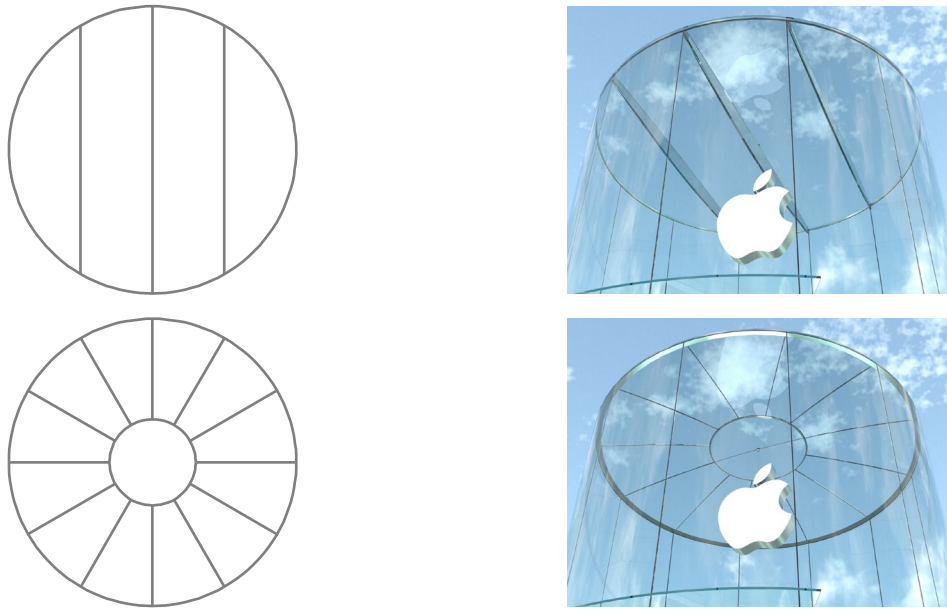


Fig. 3: Option Flat glass supported on Glass Beams vs. Final Design Option ©EOC.

The final design challenge was how to suspend the brand logo from the roof. With a skin-only system, a single central panel was needed to carry the full weight through an opening. This led to the introduction of a central oculus panel — itself a dome, 3m in diameter — completing the final configuration.

### 3. Structural Principles

#### 3.1. Key Elements

The system is divided into a number of elements based on their location and function.

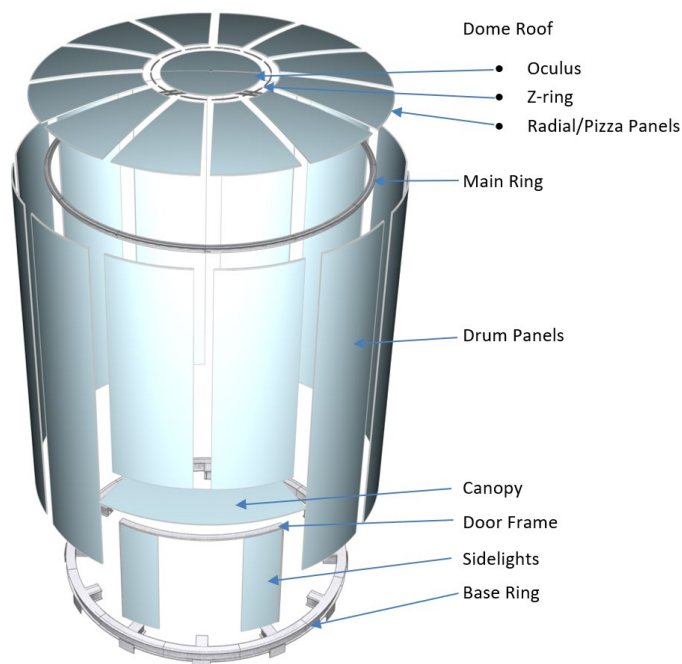


Fig. 4: Key Elements ©EOC.

The domed roof is the most challenging aspect of the design, as it consists of doubly-curved glass panels that need to fit together tightly. The radial panels together with the oculus and ring form a stable and rigid system which is then loaded on top of the drum panels.

The main ring is also required to close the “cylinder” structure of the drum. It is the most critical element of the system, as it serves both the stability of the drum and that of the dome. It mechanically links together all the drum panels.

The door frame relies on an arching system to support the two short panels above it. In this case, it poses some additional challenges in terms of design, as the panels are curved, meaning the arching forces generated in the system are not all in the same plane. The sidelights are utilized to provide support to the door frame to help reduce movements.

At the base, a ring serves as the interface between the super- and sub-structures. The ring is not fully locked on the slab, meaning it acts as a spring between substructure deflections and the glass structure above it.

### 3.2. Domed Roof

The domed roof consists of two primary elements: the radial (pizza) panels and the oculus. The primary structural system is formed by the radial panels supported on the main ring. A primary compression ring forms near the top opening between all the radial panels and a secondary nearer to the bottom. The forces from the two rings cancel each other out in tangential directions, but add up in the radial direction, counteracting the moment created by the gravity loads. This is the primary load path in the dome.

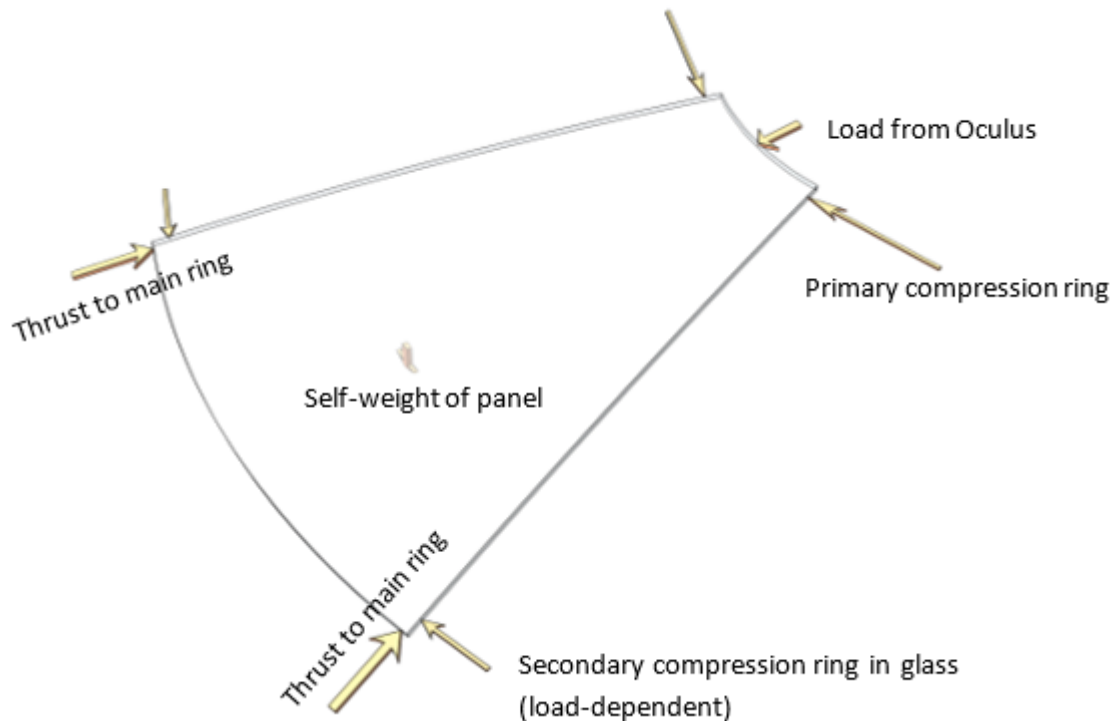


Fig. 5: Force Equilibrium ©EOC.

The addition of the oculus means that the ring compression forces are augmented by the thrust of the oculus. That contribution relieves some of the pressure on the ring and adds to the overall stiffness of the system. This effect is in fact a three-dimensional arching effect, but it should be made clear, it is a secondary effect and not a requirement for stability.

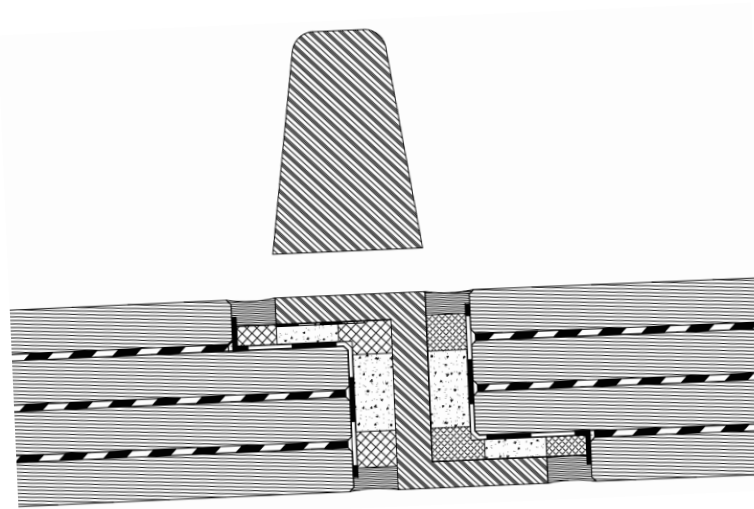


Fig. 6: Load transfer between oculus and radial panels. ©seele.

A Z-ring is introduced between the edges of the radial panels and the oculus; the key functional requirements are the following:

1. Maintain vertical alignment between panels during installation
2. Reduce the bearing block width in the joint, thereby making the system stiffer
3. Provide an alternative load path (redundancy), where the ring is seated on the radial panels and the oculus is seated on the ring.

### 3.3. Oculus

The oculus forms a secondary part of the structural system of the roof. To integrate the oculus panel with the rest of the system, bearing blocks are used to generate thrust loads on the surface of the radial panels. The advantage of this arrangement is that the stresses generated are primarily in compression and the oculus can contribute to the overall system stiffness.

The oculus also needs to support the pendant logo of the client with the following requirements:

1. Weight of 410kg
2. A symmetric conduit

The conduit is embedded in the oculus build-up so that it is more discreet and avoid splitting the panel on the outermost surfaces; the second ply (counting from outside) is instead split in two. This allows the conduit to pass and then everything is sandwiched together in the lamination process creating one uniform, stiff panel.

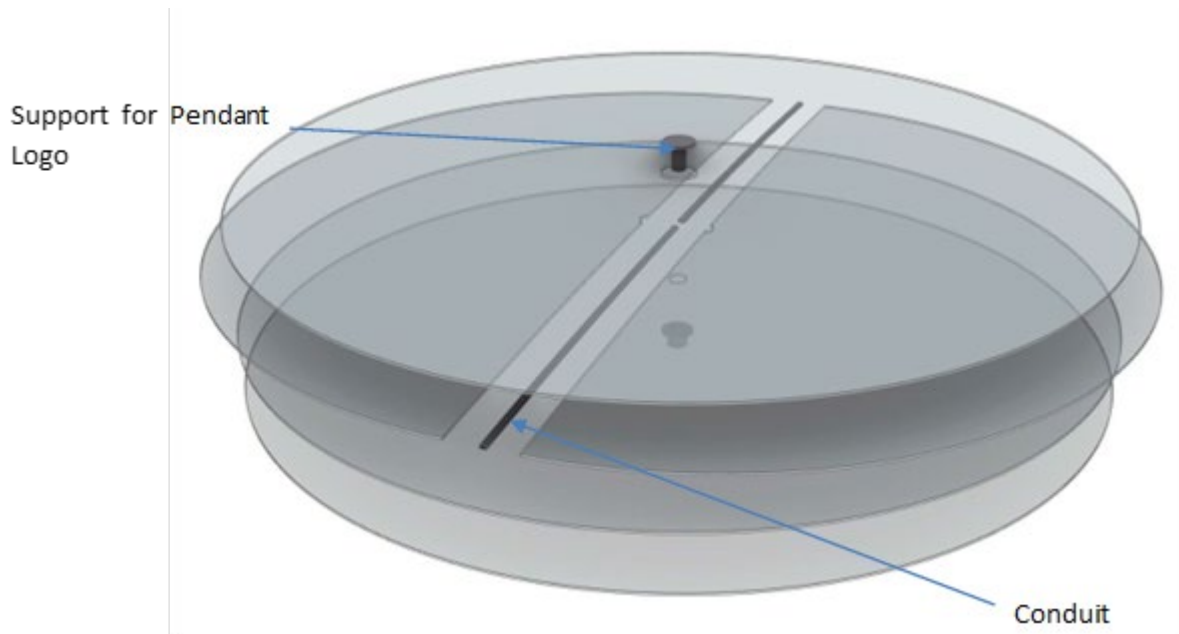


Fig 7: Oculus Panel - Exploded Views ©EOC.

### 3.4. Load transfer mechanism

For vertical loads, the path is straightforward: thrust is generated on the roof, which is locked in by the main ring. The ring then transfers the load to the drum panels which are then connected to the base ring and from there to the substructure. Over the entrance door, the door short drum panels form a three-pin arch system and transfer the load onto the door frame, close to the columns of the frame. This reduces the span of the load and helps keep the frame size minimal.

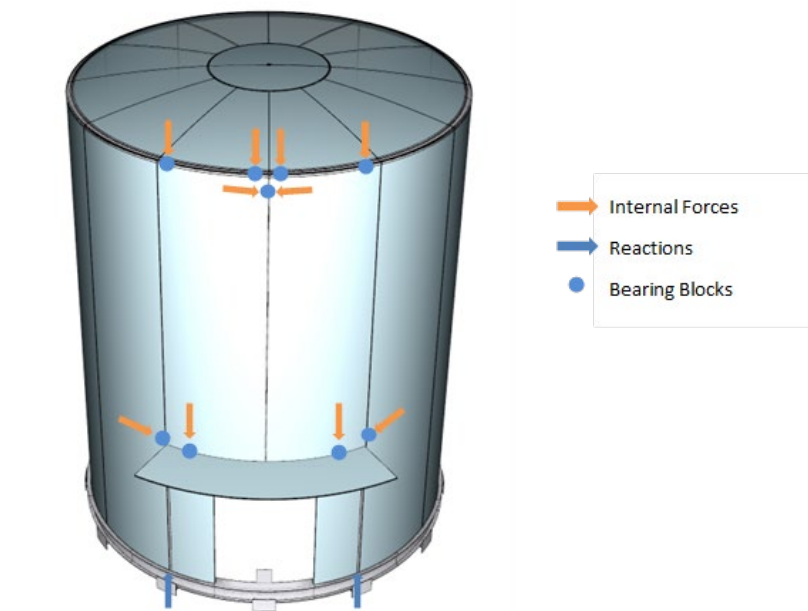


Fig 8: Load Transfer over the Entrance Door ©EOC.

The horizontal load transfer is more complex in nature, as it involves different functional systems. Drum panels subjected to wind pressure, span closer in nature to four-side supported panels. The support along the vertical results from the curvature. On the bottom side, the loads go directly into

the base ring and then into the substructure. On the top, the combined ring and dome act rigid infill element and pick the load from the top of the drum panels. The side drum panels then in turn provide the reaction to that load through the ring. To enable this path the ring is equipped with hidden shear keys in the joints between the drum panels. As a result, the side drum panels are loaded with a moment perpendicular to their plane. This moment is then resolved at the base of the active drum panels through a push-pull system on the two pins supporting each panel.

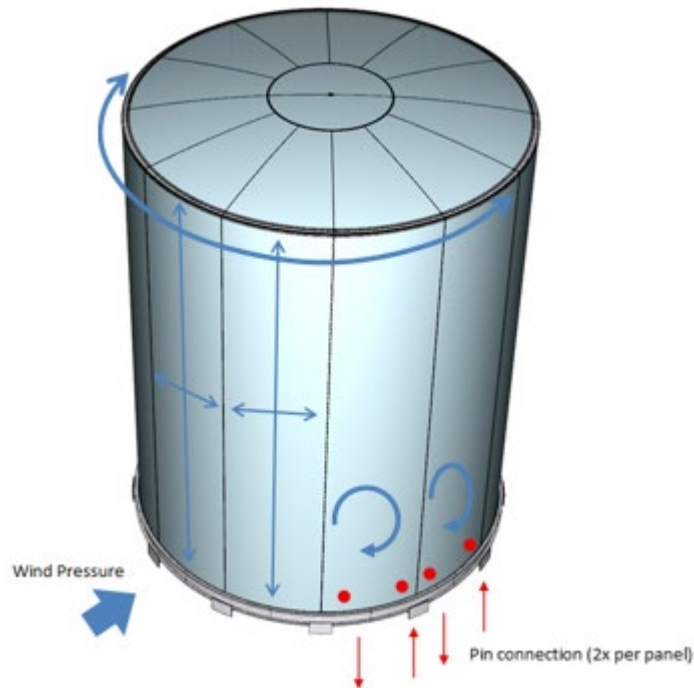


Fig. 9: Load transfer with wind pressure ©EOC.

The load transfer mechanism for suction is similar; however the drum panels act more like top/bottom supported panels with structure silicone acting as a stiffening element controlling deflections.

#### 4. Numerical Modelling

Several numerical models were developed using Strand7 and RFEM software. The glass was modelled as plate elements, the remaining elements as beams. Different models were used to simulate the behaviour in conditions beyond the standard load assumptions, especially the stability of the roof. Due to the complex load transfer mechanisms, separating the elements for testing purposes made it easier to understand how the elements interact with one another. A global model served as the basis for the design.

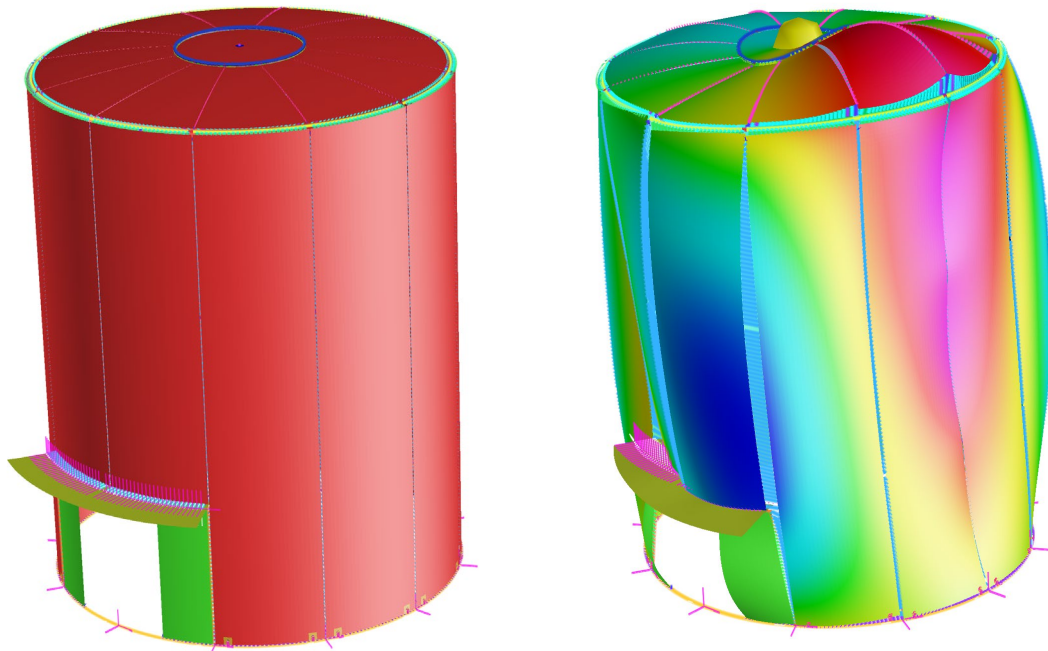


Fig. 10: Global Model – Undeformed (left) vs. deformed (right) wind loads ©EOC.

## 5. Standards, Testing and Local approval

Shanghai provides a particularly relevant setting for the assessment of wind-sensitive glass structures, as the city has built up a substantial body of experience in wind engineering, aerodynamic assessment, and the technical evaluation of complex high-rise buildings. In the immediate surroundings of the project are some of the most prominent structures in the Lujiazui skyline, including the IFC North and South Towers at 250 m respectively, the Oriental Pearl Tower the Jin Mao Tower the Shanghai World Financial Center exceeding > 400 m architectural height, and the Shanghai Tower at 632 m. This dense concentration of landmark towers illustrates not only the architectural significance of the location, but also the existence of an established local framework for wind studies, code interpretation, and expert review procedures.

### 5.1. Interpretation Local Codes vs. Wind Tunnel Test (WTT)

The local standard DG/TJ 08-56-2019 subdivides the city into different wind regions, which form the basis for the corresponding performance test requirements.

A comparison of the results shows that there are clear differences between a purely code-based interpretation and the wind pressures derived from wind tunnel testing, both in an isolated condition and with the surrounding buildings included.

Table 1 summarises the respective wind pressures and their interpretation.

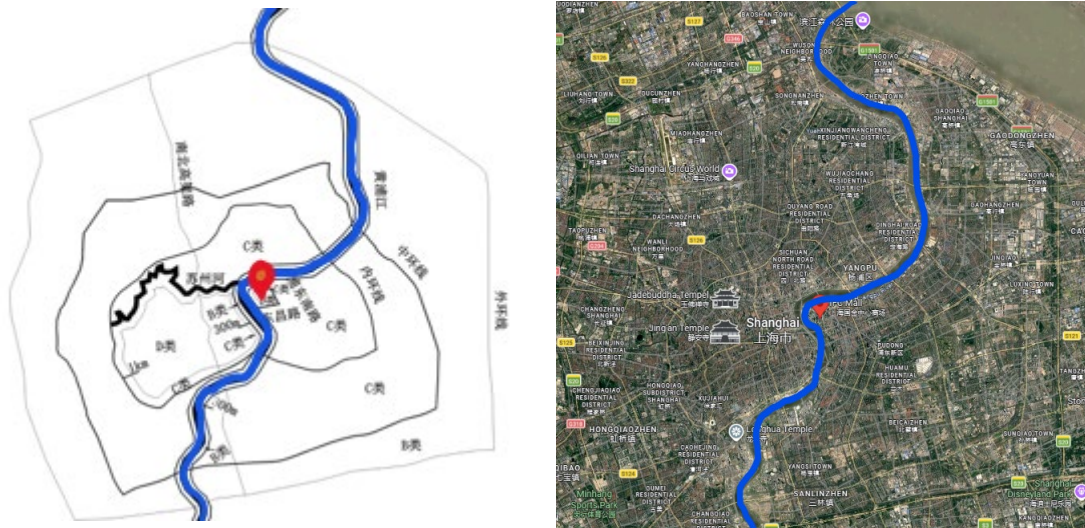


Fig.11: Local Wind Classification – as per code and satellite photo - left ©DG/TJ 08-56-2019; right ©Google Maps.

Table 1: Comparison of wind pressure on the roof.

Source	max. Wind suction [kN/m <sup>2</sup> ]	max. Wind pressure [kN/m <sup>2</sup> ]	Pull on Drum [kN]	Drag on Drum [kN]
WTT results	-1.62	+0.61	-61	+47
Local Standard – City Category “D”	-0.42	-	-34	+25

As discussed at the beginning of this chapter, the project is located within a dense high-rise environment in which local wind effects are strongly influenced by the immediate urban context. These conditions cannot be represented adequately by code provisions alone. Wind tunnel testing that incorporates the surrounding built environment is therefore the key to establishing more realistic design loads and to understanding the effects of different wind speeds and wind directions on the structure.

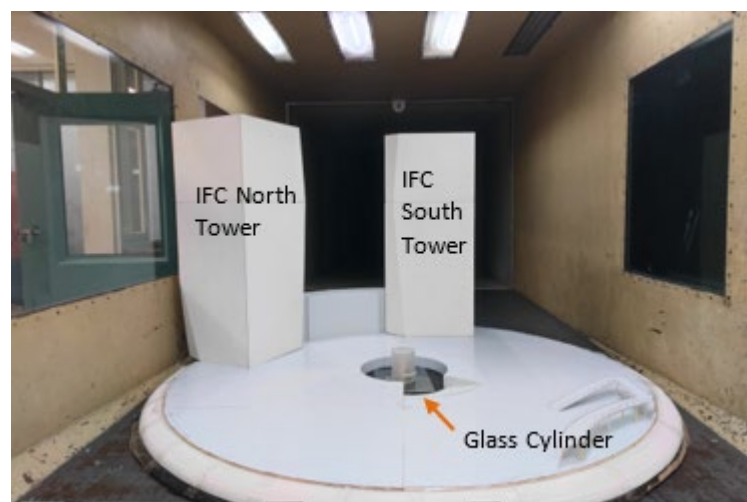


Fig. 12: Photo of Wind Tunnel Test ©Tongji University

The wind distribution on the roof, in particular, deviated significantly from code-prescribed values.

While the code-derived distribution is linear, testing revealed high suction at the windward tip that drops rapidly toward the center of the roof. These discrepancies proved critical for the design of the panelized roof system.

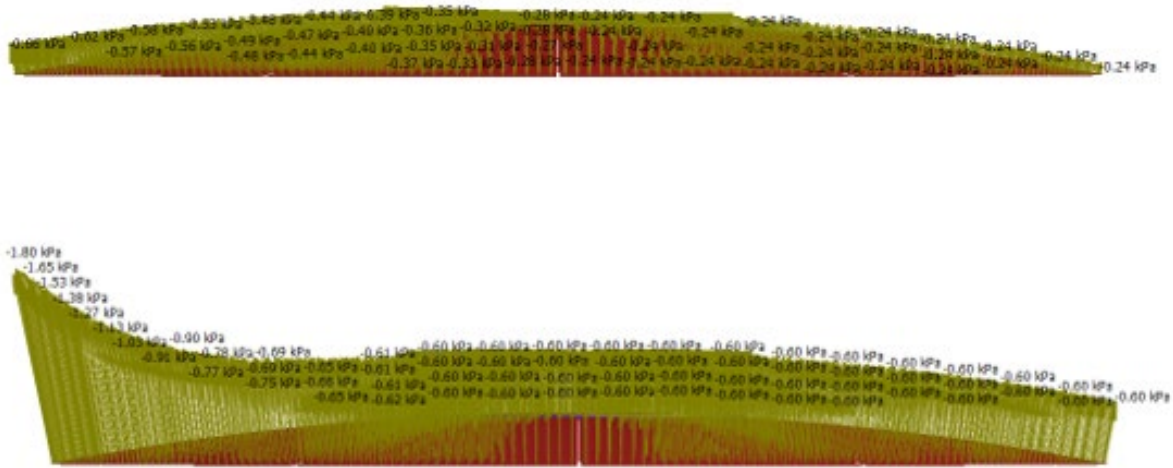


Fig. 13: Comparison of roof pressures code-derived (top) vs. WTT (bottom) ©EOC.

## 5.2. Local Expert Panel

Although the design of an all glass construction was not new at that location, the local approval process was challenging, especially in reviewing the design assumptions, structural design, and testing strategy. In this context, it is important to note that complex and unconventional projects are not dismissed by the authorities outright; rather, the review process is supported by a local expert panel with deep expertise in code interpretation, testing protocols, and construction practice. Independent specialists from academia and research, including experts from Tongji University, were also consulted as part of this process. In a series of coordinated discussions, design theses were challenged, engineering evidence was reviewed, and test procedures were aligned and refined. Without this expert panel, the project would likely not have progressed to execution in its proposed form. This review framework is therefore worthy of particular recognition, as it provided a constructive path for evaluating and advancing a highly complex design.

## 6. Design Features

The following section highlights key components that are fundamental to the structural design, yet remain largely concealed due to the system's highly reduced and transparent appearance.

### 6.1. Mainring Connection

The central interface between the cylindrical glass drum and the all-glass domed roof structure is the so-called main ring. This element performs two essential functions. First, it stabilises the cylindrically curved façade panels at their upper edge allowing the individual panels to function together as a drum. To enable load transfer in all directions, including in the transverse direction of the cylinder, shear keys are embedded on the main ring and hidden within the silicone joints between the panels. Second, the main ring acts as the tension ring of the dome. The glass panels forming the dome stabilise each other

through the geometry of the roof itself, and the resulting forces are transferred into the main ring, redistributed around the perimeter, and then channelled through the vertical façade panels into the supporting substructure.

Due to the high level of geometric accuracy required, and in order to realise the calculated details as precisely as possible during construction, the original idea of joining the ring segments on site by welding was abandoned. The heat input from welding would have caused significant distortion at the connection points, which could not have been corrected reliably on site. Such deformation would have compromised the required tolerances of the overall assembly. Instead, the main ring, with a diameter of approximately 10 m, was divided into individual segments. The connection between these segments had to allow for positive load transfer while also respecting the architectural constraints of the project, as at least one surface of the ring formed part of the finished visible interior surface. For this reason, a simple bolted connection was not considered suitable.

A long-established and proven construction principle was therefore adopted in the form of a dovetail connection between the ring segments. This approach allowed the structure to be fully assembled, tested, and surveyed prior to shipment, then dismantled for transport and reassembled on site while maintaining the same geometric quality. This repeatability was of critical importance to the successful realization of the project.

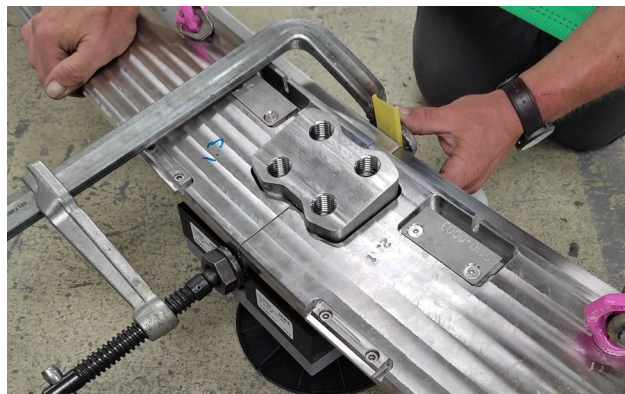


Fig. 14: Connection Detail – Main ring ©seele.

## 6.2. Lightning Arrestor

In accordance with applicable codes and statutory requirements, the building had to be equipped with conductive lightning protection measures. This requirement emerged at a relatively late stage in the design process and could not be reduced through further justification or engineering argument. As glass itself is not an electrically conductive material, the necessity of such measures was not initially obvious to all parties involved in the project. Nevertheless, an appropriate solution had to be developed that would satisfy the regulatory requirements without compromising the clarity of the architectural concept.

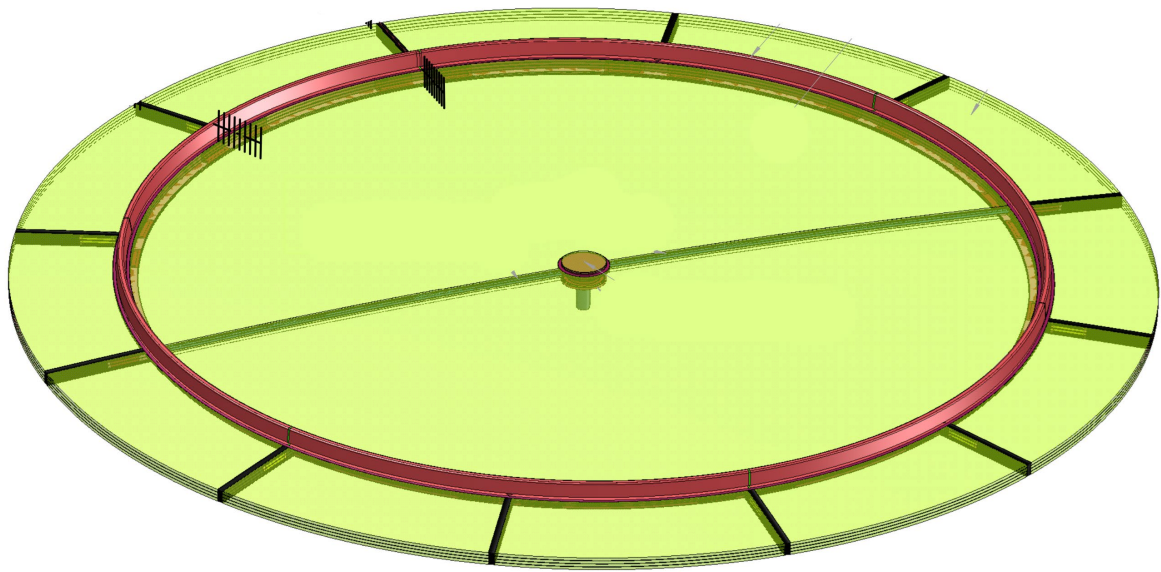


Fig. 15: Lightning arrester detail over Z-ring ©seele.

The adopted solution was to integrate a stainless-steel crown at the highest point of the structure, designed to blend into the overall appearance as discreetly as possible. From this point, the lightning current had to be safely conducted through all structural levels down to the grounding system. In order to preserve the visual clarity of the enclosure, the lightning protection conductors were carefully integrated into the joints of the construction. To minimise differential thermal movement between the glass, the structural silicone, and the conductive element itself, these components were manufactured entirely from titanium. In order to achieve the required conductor cross-section, the detail was arranged in parallel within two opposite joints of the drum.

### 6.3. Logo Fitting

The logo fitting consists of a machined stainless-steel part that houses an axial bearing that allows the logo to work as pendulum in all directions. The metallic housing posed a particular issue when it came to lightning protection, as it could not be connected to the grounding system due to its location. To protect this component, a glass plate was bonded above the metal fitting to act as an insulating element. This is a project-specific solution developed to reconcile lightning protection requirements with the architectural and structural constraints of the design.

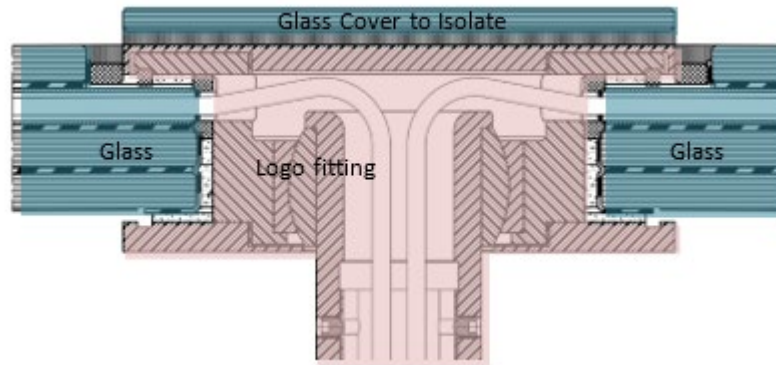


Fig. 16: Glass cover to isolate the metal logo fitting ©seele.

## 7. Testing

From the outset, testing formed a rigorous and integral part of the project. In line with JGJ/T 139-2020, *Glass Curtain Wall Engineering Quality Inspection Standard*, an extensive verification programme was defined at an early stage. As the project progressed, however, it became clear that the final scope of testing would exceed the original expectations. Additional requirements raised by the expert panel had to be addressed during the ongoing programme, requiring the test strategy to be continuously adapted and refined. Testing therefore became an iterative process of verification, review, and adjustment, rather than a fixed and predefined compliance exercise.

### 7.1. PMU - Oculus panel

The first component to be tested in isolation was the circular and spherically shaped center glass, the oculus panel. The successful completion of this test series was a key prerequisite for the continuation of the overall design and construction process. The main objective of the component test was to verify the connection of the logo fitting, to perform load testing, and to assess the residual load-bearing capacity of the glass under damaged conditions. During testing, the panel was subjected to 1.4 times the actual service load of the suspended logo (410 kg). At the same time, the glass was intentionally pre-damaged by impact testing in order to evaluate its residual stability. All deformation of the panel was recorded in detail using displacement and measurement sensors to verify the post-breakage behaviour.

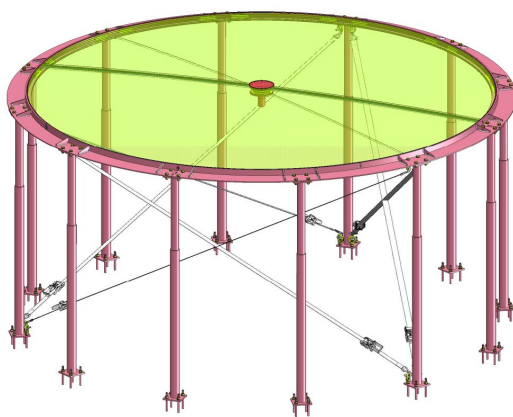


Fig. 17: Oculus Glass Test in Germany ©seele.

The construction successfully passed all the described tests, even after the inner laminates had been damaged and weakened. In order to also account for the influence of temperature, the complete assembly was heated for 24 hours by means of heat lamps to an average temperature of 60°C. In addition to confirming the viability of the design, the tests also provided important constructive findings, which were subsequently incorporated into the following mock-ups and later into the final series solution.

## 7.2. PMU Full-Scale Roof Test

The next stage of the testing programme focused on the performance testing of the roof structure. For this purpose, the complete roof assembly was constructed at full scale at seele in Germany. The primary objective was, of course, to verify the load-bearing performance of the structure under the various environmental actions to which it would be exposed in service.

At the same time, the test programme was also used to evaluate whether the intended construction and maintenance procedures could be carried out as planned. Particular attention was given to the installation of the bearing blocks and to the replacement of individual glass units within the bonded assembly. In this way, the mock-up served not only as a structural verification test, but also as a practical validation of buildability and maintainability.

Following the structural assembly, the entire roof construction was enclosed in an airtight chamber so that positive and negative pressure conditions could be simulated by means of a climate chamber. For the residual load-bearing tests, the complete roof surface was additionally heated to 50°C. This temperature was maintained over several days, after which impact tests were carried out in order to examine the behaviour of the deliberately weakened structure under continued thermal exposure.

Sensors installed on both the interior and exterior of the mock-up recorded all movements and deformations throughout the test programme. The measured displacements could then be directly compared with the predicted values from the structural calculations. Finally, watertightness was tested by means of a one-hour pressure-assisted water test. As the test chamber was not located outdoors, a temporary circular water supply system had to be installed in order to perform the test under indoor conditions. During the water test, alternating positive and negative pressure cycles of  $\pm 1500$  Pa were applied over a period of one hour. Across the entire roof area, this corresponded to alternating uplift from the interior and wind pressure from the exterior with a total force of approx. 12,000 kg acting on the construction.

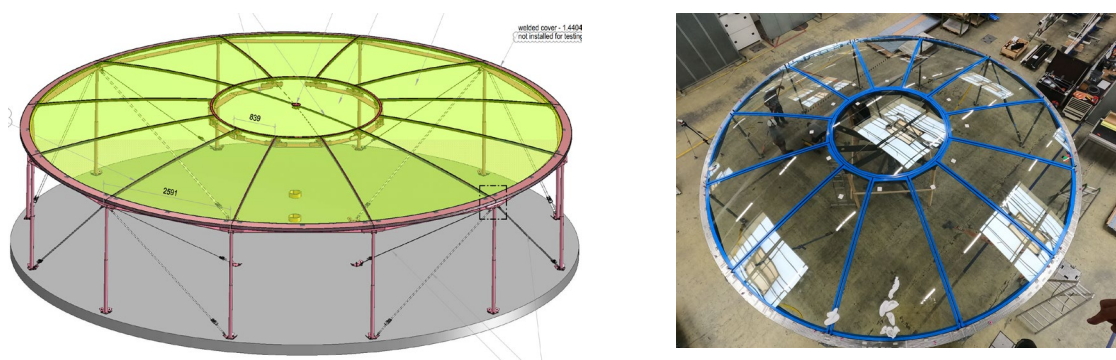


Fig. 18: Roof Testing in Germany ©seele.

### 7.3. PMU Full-Scale Façade Test (P.R. China)

In addition to the PMU testing carried out in Germany, the load-bearing vertical structure was also erected at full scale in China. The purpose of this mock-up was to verify the behaviour of the cylindrical façade structure under realistic test conditions and to assess its performance as part of the overall approval strategy.

By introducing temporary partition walls into the cylindrical mock-up, different zones of the structure could be subjected to positive and negative pressure conditions. At the same time, a roof structure was incorporated into the test assembly, which had to reproduce the same structural characteristics as the original roof construction previously tested in Germany. In this way, the interaction between the vertical drum and the roof-related boundary conditions could also be represented during the test programme.

In addition to the pressure tests, the entrance canopy area was subjected to a hurricane test. Larger movements and vibration effects had initially been expected in this zone; however, these did not materialise during the testing. The measured response of the system therefore confirmed a more stable behaviour than originally anticipated.

A particular challenge of the test setup was the introduction of the partition walls themselves, as these were freestanding and not connected to the actual building structure.



Figure 19: Façade Testing in China ©FarEast.

## 8. Conclusion

We began this project with the goal of creating a glass structure unlike any other: one that did not rely on hardware fittings for its structural integrity but rather leveraged the skin to its full potential. This enabled us to reclaim the transparency so often lost to complex connection interfaces. Reaching this level of technical execution required a rigorous effort from everyone involved. We owe a debt of gratitude to our collaborators and, most importantly, to our client, who shared our ambition and championed the concept from start to finish. The result truly speaks for itself.

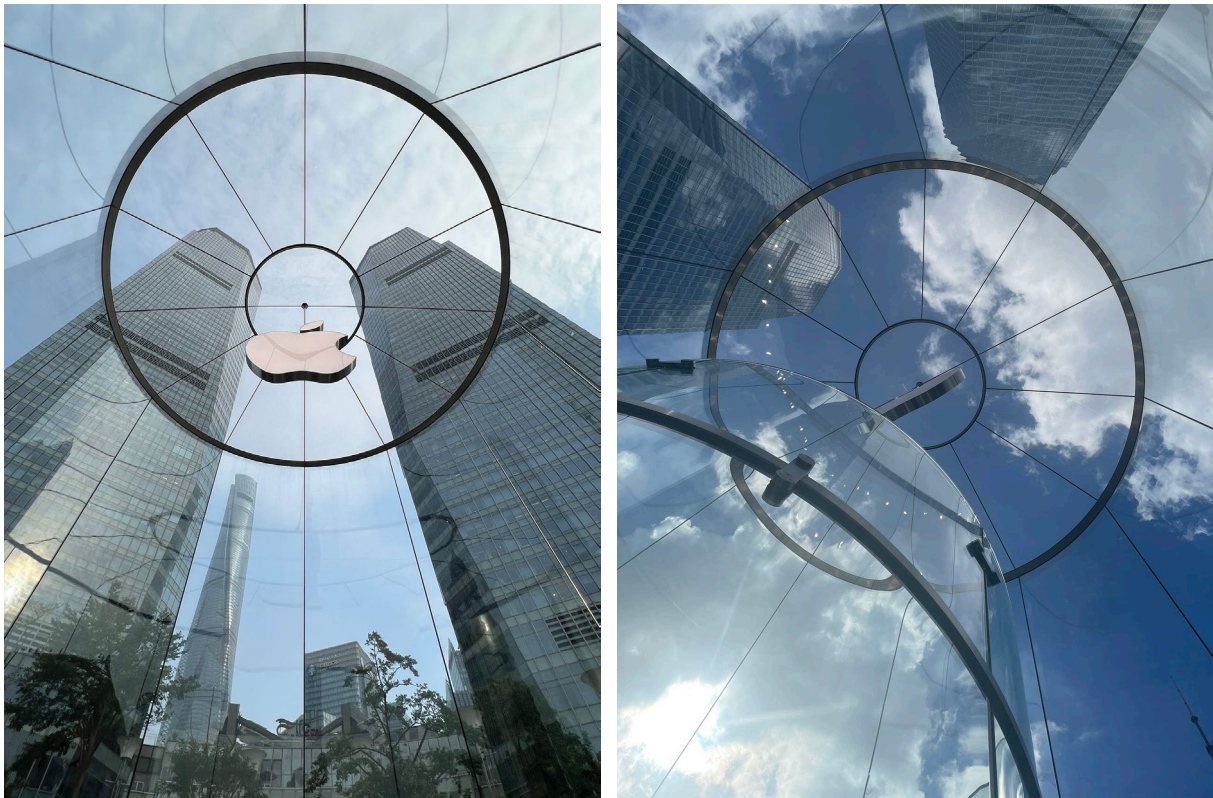


Fig. 20: Final Result - Fin- and Beamless Construction ©seele.

## Acknowledgements

The authors would like to express their sincere gratitude for having been entrusted, for the second time, with the realization of this remarkable structure. In its renewed form, the building conveys with great clarity the lightness, simplicity, and refinement originally intended by the client and the architectural team.

It is often said that change without improvement is deterioration. In the case of this project, it can be stated with confidence that the transformation represents a clear improvement. The redevelopment has not only preserved the essence of the original concept, but has elevated it through a more reduced, more integrated, and more technically advanced structural solution.

The authors also wish to acknowledge the valuable support provided by the international expert panel and the site-based construction management, whose commitment and practical assistance were essential throughout the project. Finally, this project stands as an example of what can be achieved when international teams collaborate closely, overcome boundaries, and combine their expertise toward a shared goal.

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