Challenging Glass 2 – Conference on Architectural and Structural Applications of Glass,
Bos, Louter, Veer (Eds.), TU Delft, May 2010.

Opportunistic Glass

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The proliferation of glass elements in building assemblies yields an endless array of fabricated components that are by nature glass-composites, resultants of myriad material techniques and processes. Every component parameter is an opportunity for detailed material definition in the service of a specific Architecture. Front designs and deploys glass technologies through creative and pragmatic collaboration seeking with our partners to opportunistically engage such materials in appropriate and specific ways so as to realize a broad set of Architectural intentions. The following are a series of illustrative projects using both conventional and specialized techniques in the service of a distinct set of project requirements and ambitions.

Keywords: Glass, Opportunity, Architecture, Values, Ideals, Collaboration

1. Seattle Public Library, USA

The building, designed by the OMA/LMN Joint venture and open to the public in 2005, is enclosed with a complex, faceted, glass and aluminum curtain wall covering 16,000m2.

Figure 1a, b, c: Seattle Library Exterior, Mesh Glass Detail, Metal Mesh 1st Mock-Up.

The building surfaces were mapped according to the required G-Value which is optimized for and varies with surface orientation. In order to perform better than code requirements, G-Value targets ranging from 0.14 through 0.29 were established for the glass panels. The basic requirements for panels facing north, east and that are self-shaded; the 0.29 glass target was adopted and achieved with a laminated and insulated glass panel using a high-performance low-e coating from Interpane Germany with final panel assembly by Okalux employing argon-filled cavities with polysulfide and stainless steel edge seals. This achieves a visible light transmission better than 50% and with a high color rendering index. However for the remaining half of the building enclosure that is facing south, west, or upwards towards the sun, was to achieve the 0.14 target.

Studies were made for available glass options yielding only tinted and highly reflective substrate and coating options that performed poorly for visible light transmission and color rendering index. Full scale mock-ups were commissioned and it was agreed that alternative approaches were required. Exterior passive shading devices were ruled out for maintenance and architectural reasons. It was proposed that a micro-sunshade integrated into the pre-fabricated glass assembly was desirable. Mill-finish aluminum was selected for color, brightness and color-neutral reflectivity. Expanded metal mesh was selected for its attributes as directional opaque sunshade and effective light-shelf.

Figure 2a, b, c, d: Mesh-Glass Samples, Production Panel, Performance Mock-Up, Installed Mesh Glass.

Two approaches were investigated: The first included laminating the expanded metal mesh between glasses as developed with Isoclima. The mesh required cleaning in a cold-drawn acid bath and subsequent lamination between 8 layers (4 each side) of very thin PVB foil sheets. The pliability of the PVB allowed for full encapsulation of the metal with no risk of future migration to the surface of oils from micro-fissures in the stretched metal. The second approach included encapsulating the expanded metal mesh between glasses within a 2mm air space. The essential technology here was the ability to reliably apply a consistent 2mm wide x 15mm deep polysulfide edge seal. Okalux was able to demonstrate this ability. The major risk in this approach was the potential heat-build up in the cavity and applied stresses at the edge seals. In this regard, the high reflectivity and low heat absorption of the mill finish aluminum combined with the low volume of the 2mm cavity and the relatively small panel size, was key to viable performance of the encapsulated material. The final decision was then based on cost allowing the encapsulation option to prevail over the laminated option.

The final resultant for the glass with a 0.14 target employed a combination of the encapsulated micro-mesh along with the same Interpane low-e coating. This allowed for a uniformity of color rendering and light intensity throughout the entire building. Additionally the depth, density and two-directionality of the interior façade support steel-work provided significant interior shading and glare control thus precluding the need for expensive and geometrically complex interior blind systems. The building design achieves a fully passive and fully optimized enclosure system that is harmonized with the building mechanical systems based on displacement cooling.

2. Louis Vuitton Paradise, Osaka, Japan

The project is for the Osaka, Japan headquarters of LVMH. The design by Kengo Kuma Architects imagined an abstract glowing block of Persian Onyx. The system designed for the project deploys a semi-unitized curtain wall with a custom steel mullion, aluminum transoms and a pre-bonded aluminum cassette to the glass panel. The glass panel is four-side structurally-adhered to the cassette and has two-side secondary mechanical restraints along the vertical external edges. The glass panels consist of two families, the first is the laminated onyx and glass and the second are printed images of edited high-resolution onyx panel photographs on foil laminated between two lites.

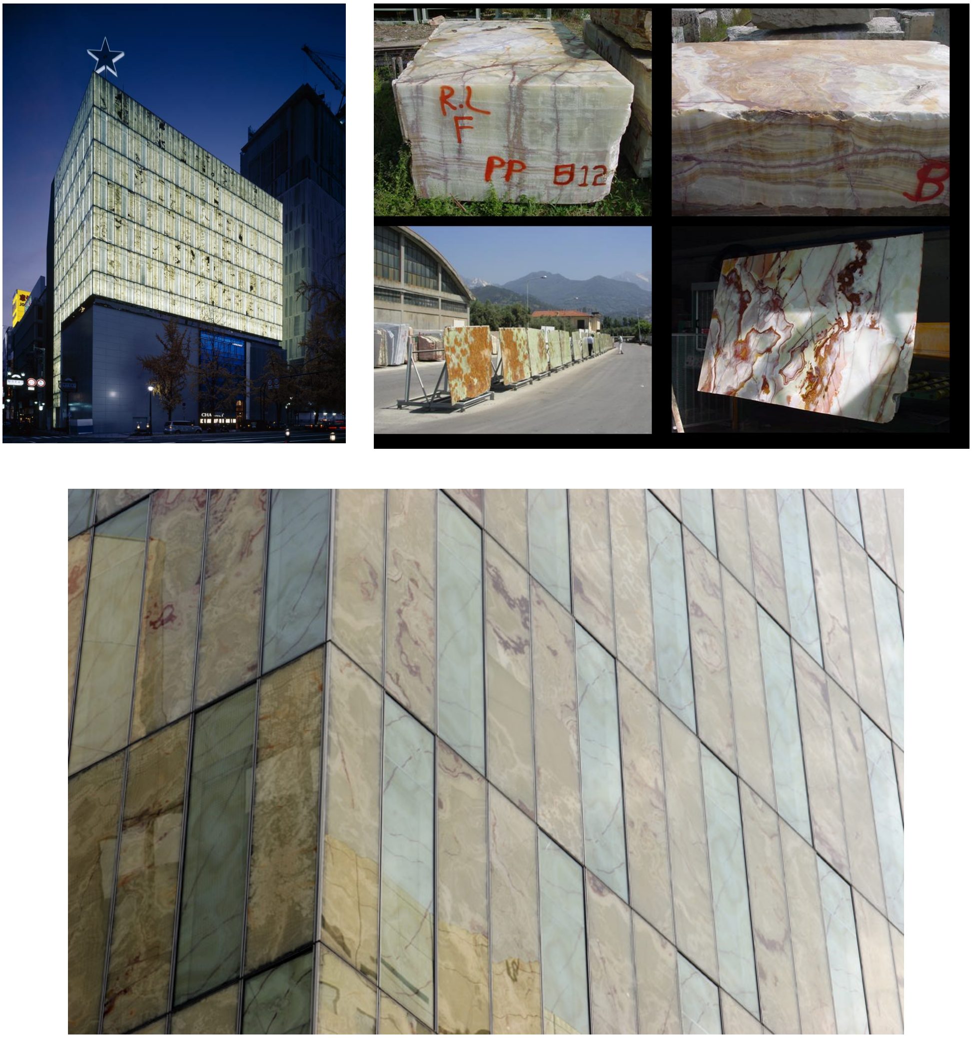


Figure 3a, b, c: LVMH Osaka Façade, Persian Green Onyx Blocks 7 Slabs, Façade Corner Detail.

The laminated onyx and glass technology was newly established in Europe with a few companies providing such panels for exterior applications; however the team had reservations about using relatively new techniques from small companies without significant financial depth. Working with Itochu, a large Japanese trading company, an agreement was reached with Saint-Gobain Glass to develop a version of the laminated onyx and glass utilizing their photo-voltaic factory in Germany, given its established expertise with resin laminating techniques. The stone selected at distribution yards in Italy was Persian Green Onyx with significant veining. The onyx blocks were saw-cut into 30mm thick slabs and delivered to a stone workshop in Germany. The stone panels are first cut to nominal sizes, surface calibrated and polished. The stone is then laminated both sides with pre-cut, heat strengthened glass panels.

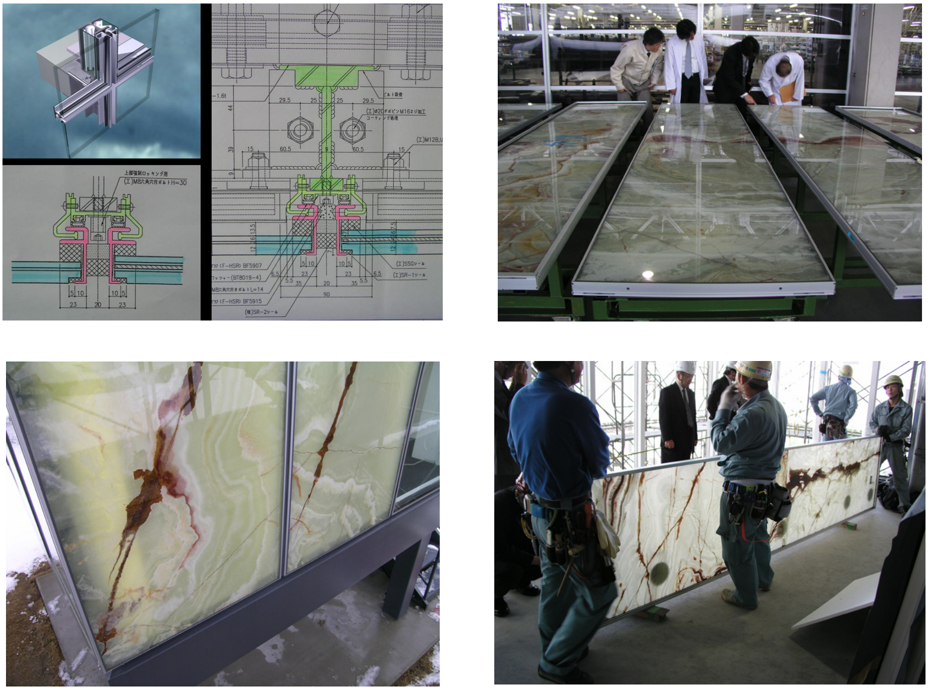


Figure 4a, b, c, d: System Details, Production Panels, Visual Mock-Up, Panel Installation.

A significant challenge for this project is that the glass panels are 900mm x 4000mm long, requiring the lamination of two onyx panels for every glass panel. After lamination, the full length panels are saw-cut down the middle to extract two separate panels. Each stone surface is then CNC calibrated and polished to precisely 4mm onyx thickness. Then each panel is laminated again with another piece of pre-cut heat-strengthened glass to fully encapsulate the two onyx panels forming one continuous seamless onyx/glass composite assembly. The exterior lite of glass is pre-routed out at the vertical edges allowing for the flush application of the secondary mechanical edge adapter. Extensive testing was done by Saint-Gobain Glass in Germany as well as in Japan at the Japan Weathering Test Center. Testing included accelerated UV, humidity and temperature cycling, and strength/integrity tests. Full scale performance mock-up testing was successfully conducted including air/water, pressure and seismic.

3. Lincoln Square Synagogue (LSS), New York, USA

Designed in collaboration with Cetra Ruddy Architects, Front Inc has assumed full design, engineering, testing and fabrication responsibility for this distinct façade. It consists of five spline-based ribbons of faceted glass panels. The geometry of the ribbons has been optimized to allow every panel to conform to a consistent 400m width with five differentiated heights per ribbon. The panels vary in height between 3000mm and 4700mm. All geometric differentiation is accommodated through unique framing elements, enabled through automated instantiation in a CATIA model environment. 3D CATIA Part files are extracted for all components and sent direct to manufacturers, including the glazed assemblies.

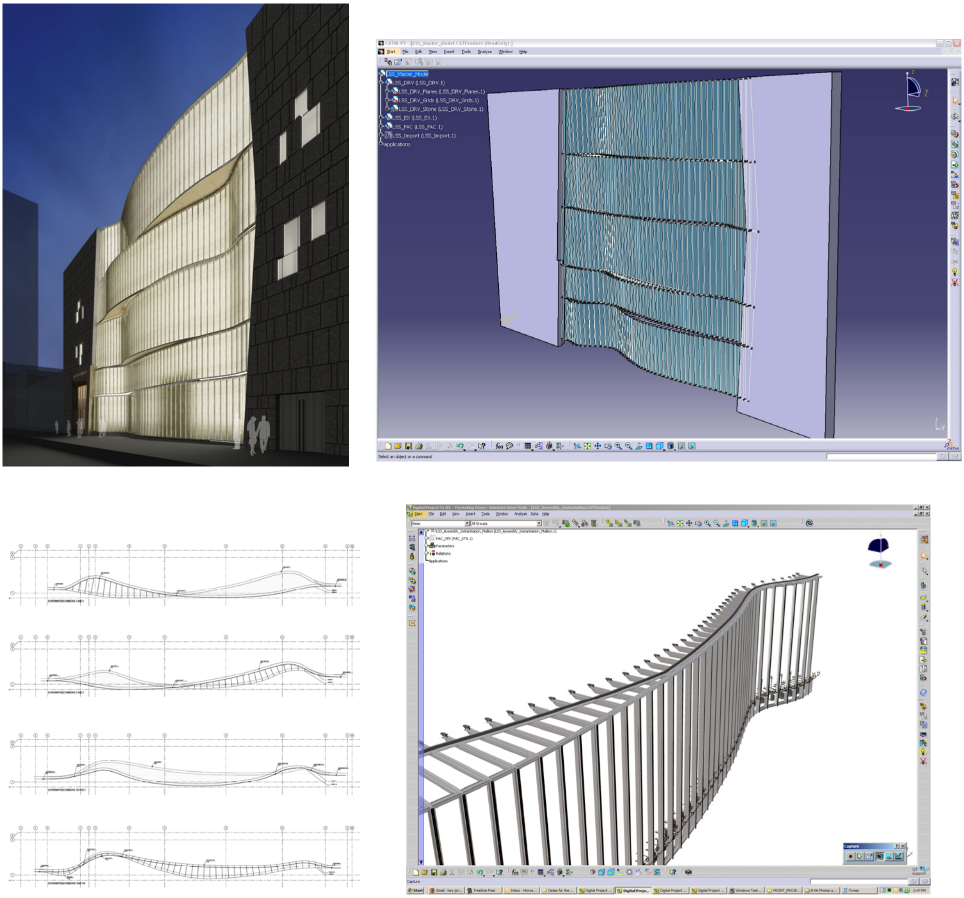


Figure 5a, b, c, d: LSS Rendering, CATIA Wireframe, Ribbon Geometry, CATIA Model Detail.

The glass panels are double-laminated and insulated. All lites are low-iron substrates. The exterior laminated panel consists of two lites of heat strengthened glass with a custom synthetic fabric encapsulated between two Sentry Glas Plus interlayers. The fabric is open weave manufactured in France and the lamination process is being carried out in China. Samples were produced and extensively tested at Bodycote in Toronto, Canada and at Architectural Testing in York, Pennsylvania. Testing included thermal cycling for heat and humidity, boil test, bake test, accelerated UV test, structural integrity testing and energy/daylight testing per NFRC rules. A Glaverbel low-e coated glass is incorporated. The interior laminated panel employs a conventional PVB layer and has a custom white color ceramic silk-screen dot pattern over the complete area of the panel. Anodized aluminum spacers are employed with grey color butyl and structural silicone. The exterior laminated lite extends past the interior panel using a silicone smear to the visible face of the panel (in lieu of frit). The panels are two-side continuously supported on the vertical edges with field-applied structural silicone.

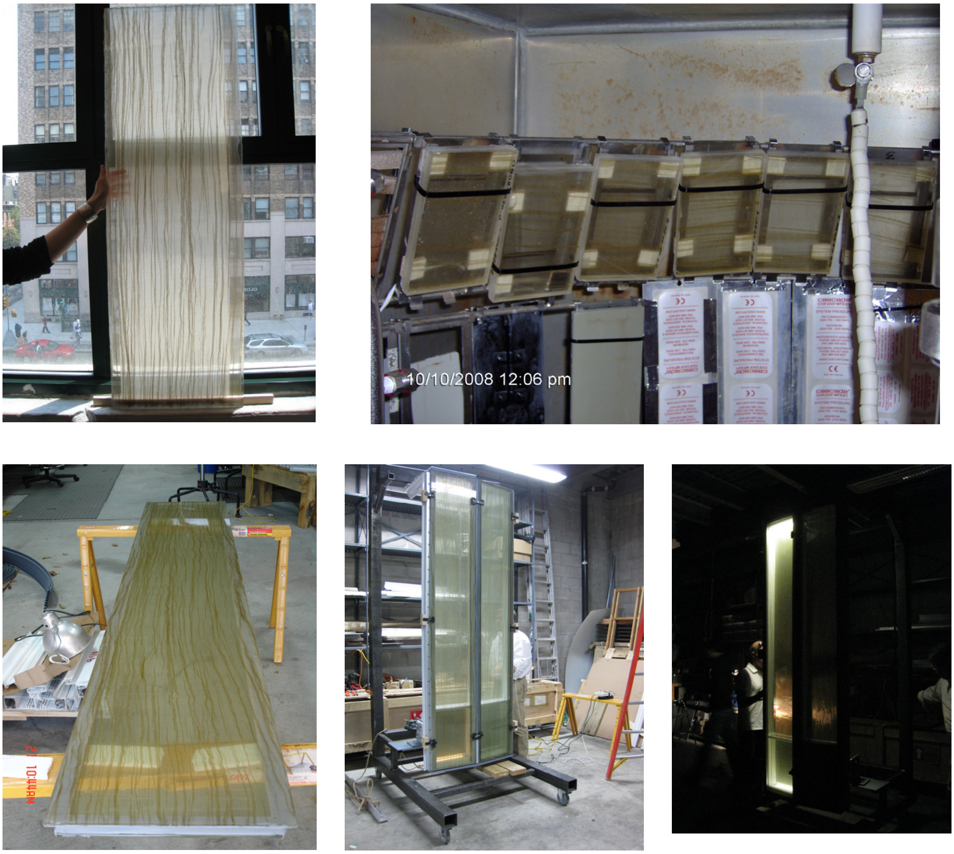


Figure 6a, b, c, d: Visual Mock-Up, Test Samples, Production Panel, Assembly Mock-Up with Lighting.

The curtain wall system has 250 vertical glass panels each of which is illuminated both top and bottom with one 300mm linear LED fixture per panel, for a total of 500 fixtures. These are all wired through the curtain wall system, controlled in logical groups on variable dimmers through the centralized BMS. The low-angle illumination strikes the interior fritted surface with a graduated intensity and provides a glowing back-lighting to every panel. Through the use of visual mock-ups the color of the fabric and the density of the frit have all been established to balance the need for visibility from the interior, privacy from the exterior and subdued illumination from dusk to dawn.

4. Dee and Charles Wyly Theater, Dallas, USA

The Wyly Theater project was recently opened to the public in 2009 and was designed by REX/OMA in collaboration with Kendall Heaton Associates. The unique diagram for this multi-form theater was organized with the public lobby at the lowest level located just below the main theater volume that includes the fly-tower and flexible seating equipment. Above this are nested a series of rehearsal, administrative and reception spaces.

Figure 7a, b, c: Wyly Theater, Glass Wall Detail, Theater Interior.

The theater volume was conceived as an all-glass enclosed space that allowed for complete black-out, sunshade and full day-lighting depending on the specific use of the space. Most significantly the glass wall was to achieve an STC rating of 50 due to adjacent road traffic and overhead cargo-plane traffic. For cost and maintenance reasons it was preferred not to built an acoustically sealed double-wall assembly. After considerable research and acoustical testing it was determined that the STC 50 target could be achieved in a single double laminated, insulated glass assembly. Furthermore, given the long 9m clear span of the wall, a simple off-the-shelf W8 steel section was used at 1.5m centers. The glass panel, using four sheets of 8mm glass, was capable of clear spanning the 1.5m horizontal distance and so no transoms were required. The exterior laminated panel consists of two lites of 8mm heat strengthened glass laminated together with a high performance acoustic interlayer assembly, and a low-e/solar coating. The air space is 25mm deep. The interior laminated lite is the same thickness as the exterior and also employs an acoustic interlayer assembly. The combination of the 32mm of glass mass, two acoustic interlayers and a 25mm air space achieves the required acoustic target. This was verified in laboratory testing conducted at Riverbank Acoustical Laboratories in Geneva, Illinois and through post-completion field testing. The resultant is an elegant long-span vertical wall with 1.5 x 3m high performance acoustic panels that are corner supported and self-spanning horizontally in order to emphasize the desired verticality of the system.

Figure 8a, b, c: Theater Night Views – Entry Wall, Theater Wall, Operable Wall (3m x 9m – STC 50).

There are two large wall panels, 3m wide x 9m tall each that are automated central pivoting doors used during and between theatrical events and concerts. The glass panels are incorporated into this large steel frame that is visible indistinguishable from the typical system. At the edges of the large panel frame is a double-bank of custom pneumatic gaskets that can be inflated during events in order to maintain the required acoustic separation.

5. Yas Island Marina Formula One Racetrack Hotel, Abu Dhabi, UAE

The project, designed by Asymptote, and executed from concept design through completion in 22 months, employs a unique glass and steel lattice-work with integrated dynamic lighting while serving a macro-environmental function enhancing overall building comfort.

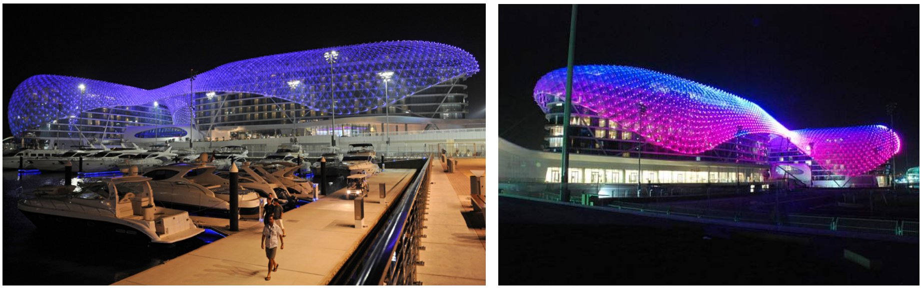


Figure 9a, b: Yas Island Marina Formula One Racetrack Hotel.

The exterior lattice-work was an intensively collaborative effort led by Asymptote and bringing together partners including Front, Schlaich-Bergerman, Arup Lighting, RED, Gehry Technologies, Waagner-Buro, Al Futtaim-Carillion, Tilke, the University of Vienna, and others. This was an intense simultaneous collaboration deploying every design and analysis software resulting in one of the most integrated design to delivery BIM-enabled projects. However, each team member utilized tools appropriate to and optimized for their own work and in pragmatic fashion worked through inter-operability issues as required to realize the project. This process of engaging the realities of each organization's required inputs and outputs was essential. There was no singular model used for every aspect of the project.

The geometry of the lattice-work resulted in over 5000 individual glass panels each of unique geometry. All field panels are unique quadrilaterals and all edge panels are unique triangles; however with all panels having corners of consistent radius, and with all angles forced to conform to an integer. Glass panels were harmonized to a consistent thickness, all heat strengthened for consistency of detailing purposes. The glass panels have a gradient white frit on surface two that ranges from 70% coverage to 30% coverage. The frit was studied extensively in visual lighting mock-ups to transform the glass panels into individually addressable pixels within the overall lighting array. The glass panels have a four-sided uniform offset between the laminated glass panels. This was done to allow for the profiled aluminum frame to mechanically capture all glass panels while achieving a flush appearance. This was considered essential in order to mitigate wind-borne sand accumulation and for weathering during occasional precipitation. The exterior lite of glass is restrained only by the uniformly distributed adhesion provided by the PVB interlayer.

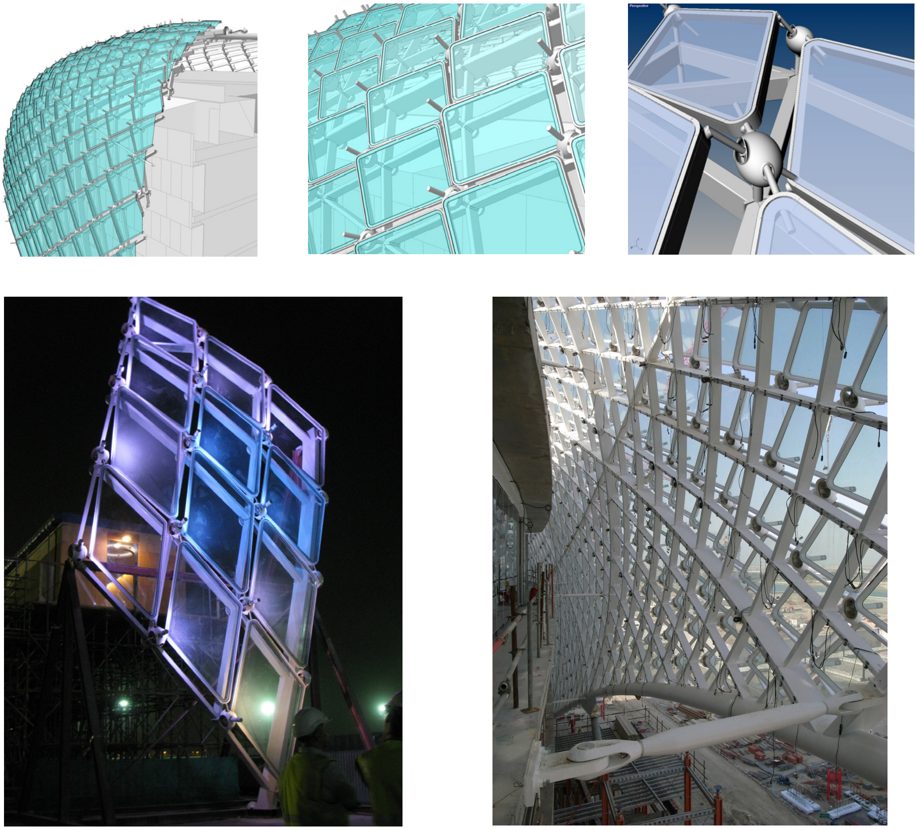


Figure 10a, b, c, d, e: CATIA Global Model (30, 31, 32), Visual Mock-Up, Installation View.

The aluminum frames are composed of aluminum extrusions (straight segments) all unique and cut to precise length, aluminum forgings (radius segments) all standard as circular elements CNC cut into four unique sections that comprise the four corners of any given panel, and the stainless steel struts. The forged aluminum corner elements are five-axis CNC milled to thread the drilled holes that receive the stainless steel struts and to anticipate the backing material required for welding the forgings and extrusions. All elements of a unique frame are jigged in the workshop and elements are all welded and ground smooth. The final continuous assembly is shop painted. This assembly technique and finishing process was adopted to provide corrosion protection to the glazing frames.

The definition of the exact system assembly and its unique geometry was enabled not only through extensive digital definition and optimization but equally through the intensive and regular collaboration of a highly qualified design and delivery team. The result is an iconic building that fulfills the expectations associated with a premiere Formula One Racetrack Venue, indeed the circuit runs through the building.

6. Glass Pavilion, Toledo Museum of Art, Ohio, USA

The Glass Pavilion, home to one of the world's most significant collections of glass artifacts and built by a city that is the home of America's glass industry. The architects

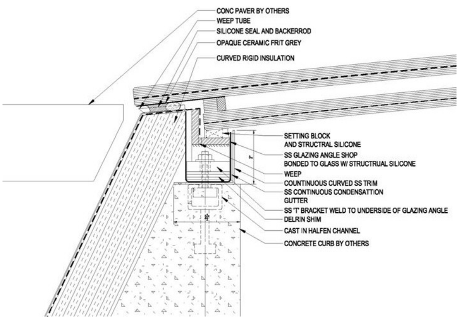
SANAA with Kendall-Heaton Associates designed a one storey seamless ribbon of glass, sited in a green field surrounded by trees, to house the glass collection and to accommodate two glass-blowing hot-shops, open storage and multi-function public spaces.

The vertical walls are either glass or painted steel and there is only one skylight, a 3m diameter oculus located flush at the base of an open courtyard, providing light to the conservation workshops located below. The vertical walls are consistently laminated low-iron annealed glass only. No coatings, no silkscreen prints, no insulated glass units. The panels are 3m wide x 4m tall and are all frameless, spanning vertically. There are no glass corners in the project, all panels resolve in curved panels of varying radii. The exterior glass panels are two sheets of 10mm annealed with a PVB interlayer and the interior glass panels are two sheets of 8mm annealed with a PVB interlayer. All corner panels have a small extended segment of flat glass allowing for compatibility of deflection between frameless curved corner panels that have inherently greater stiffness and the adjacent frameless flat panels that allow for greater deflection under wind loads. This technique, perfected through multiple trials, is difficult to control geometrically so as to minimize optical distortion at the point of inflection from straight to curve segments within the same panel. The resultant is architecturally significant as the presence of the corners is dematerialized in part through the deferment of the vertical joint.

Figure 11a, b: Exterior View, Interior View.

Annealed glass was selected for its optical clarity and flatness which was essential to guarantee that adjacent panels would be perfectly aligned panel. The vertical joints between glass panels were occupied with a translucent extruded silicone feather gasket that served as a backer rod for a site applied translucent wet-applied silicone sealant. This provided material compatibility between gasket and wet seal while preventing silicone to PVB interlayer contact, useful in avoiding edge blushing of the interlayer. A feature of the interior glass is the special support condition. The ground level concrete slab has long spans over a heavily utilized basement workshop space. The short and long-term deflections and creep within the concrete yielded deflection profiles such that the interior glass panels, at 3m width, would experience significant racking resulting in unacceptably large glass joints. To solve this issue, a machined steel rocker was incorporated at the base. The rocker is sufficiently long to provide setting blocks that do not overstress the glass under self-weight, while allowing the complete glass panel self-weight to resolve onto a single point at the center line of the panel. The resultant is that when the concrete below deflects the panels displace vertically but not laterally, allowing the interior silicone joints to be designed for vertical shear instead of in-plane expansion and contraction. The resultant joints are approximately one third of their original value. The exterior panels are supported conventionally at corner points as they bear onto a solid 4.5m deep perimeter basement wall.

The courtyard skylight panel was originally conceived as rectangular in plan and completely flush with the adjacent floor pavers. Given the large scale of this element, it was not considered viable as flat since the long unsupported span combined with the self-weight of the glass would generate permanent deflections that would collect water. It was proposed that the skylight could be circular and could possibly be double-curved into a part section of a sphere, similar to a contact lens. The desired span is 3m clear and the glass would need to be insulated, have a low-e coating, would require interior and exterior laminated lites for safety and would need to be heat strengthened for integrity. After multiple trials a prototype panel was successfully developed. Structural analysis of the panel demonstrated that the rise of the shell would need be only around 50mm to provide the stiffness required to prevent deflection under self-weight. Additionally, the geometry allowed all lites of glass to be only 6mm, so total thickness is 24mm of glass, two PVB interlayers of 4.5mm total and a 12mm air space, yielding a panel of 40.5mm. The panel is pre-bonded with structural silicone to a curved steel angle in the workshop and was installed by setting the glass panel onto a series of inflated air-bags that were deflated in a controlled fashion allowing the glass panel to settle precisely into its designated location.



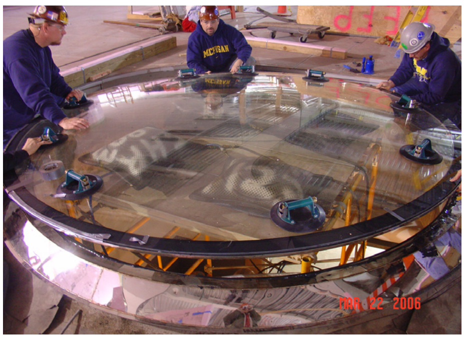


Figure 12a, b, c, d: Oculus Skylight, Context View, Section Detail, Installation Procedure.

The exterior walls of the Glass Pavilion are all double-walls with a temperature controlled and ventilated 800mm air space. Within the cavity, which is accessible for maintenance and cleaning, are suspended custom designed heat reflective sputter-coated fabric curtains. These elements reflect the sun’s heat and capture it within the cavity which is in turn ventilated from below and cooled with ceiling mounted cooling coils. The resultant building is a seamless high-performance tour-de-force that achieves the full synthesis of the Architectural ambition without compromise.

7. Holt Renfrew Flagship Store, Vancouver, Canada

Holt Renfrew, a high-end fashion retailer in Canada commissioned Janson Goldstein Architects of New York to design a new flagship department store for Vancouver. The project is a renovation of an existing commercial complex and required significant ingenuity to completely re-present the building as a new architecture. There are certain constraints that informed the design including a relatively small available area of vision glass, a requirement to significantly improve the net thermal performance of the building, and to comply with maximum power consumption per unit area for the project that precluded the use of external façade illumination. These factors yielded an interesting approach that called for a translucent, reflective and specular surface that would be activated visually by the presence of ambient light both at night and during the day.

Key precedents include Pierre Chareau’s Maison de Verre and RPBW’s Hermes Ginza, as they provide clear illustrations of the potential of specular reflections on glass surfaces. For this project however we were interested in the potential seamlessness of slumped annealed resin laminated glass. Working with Nathan Allan Studios in Vancouver, techniques were developed to slump glass over a slightly irregular grid of arised steel blades allowing pillows of glass to deform naturally under gravity for several seconds once achieving the softening temperature. The process is quenched and the deformation is arrested. Multiple trials were developed eventually resulting in a pillow with 10mm of deformation with overall dimensions of 150mm x 225mm, with a full panel size of 2m wide x 3.3m tall. The geometry of the glass precluded the use of sheet laminate products so a stiff UV-stable urethane based resin was used to bond the panels. The glass geometry also precluded heat treating of the glass so a laminated assembly was requires for safety and for stiffness. The panels are structurally adhered two sides on the short horizontal dimension and spanning clear vertically.

Detailed analysis was carried out to ascertain the stresses at the pillow fold lines under wind deflection. This was cause for concern as we clearly needed to avoid stress fractures due to wind or thermal effects at these locations. This analysis determined that two sheets of 12mm glass would suffice. Additionally, groups of three adjacent panels were studied to understand any collateral benefit from the dampening effect of adjacent panels generated by the continuous structural silicone joint between the panels in the vertical axis. This demonstrated that due to wind patterning effects, the glass deflections would be lower than if modeled as a single one-way spanning panel. This was not used to justify any reduction in panel thickness but instead to generate more comfort in the design. Extensive testing was carried out including thermal and humidity cycling tests, radiant heat with partial shadowing tests, accelerated UV tests, complete structural testing and also full scale destructive testing to ascertain final mode and period of failure in the case of full panel breakage.

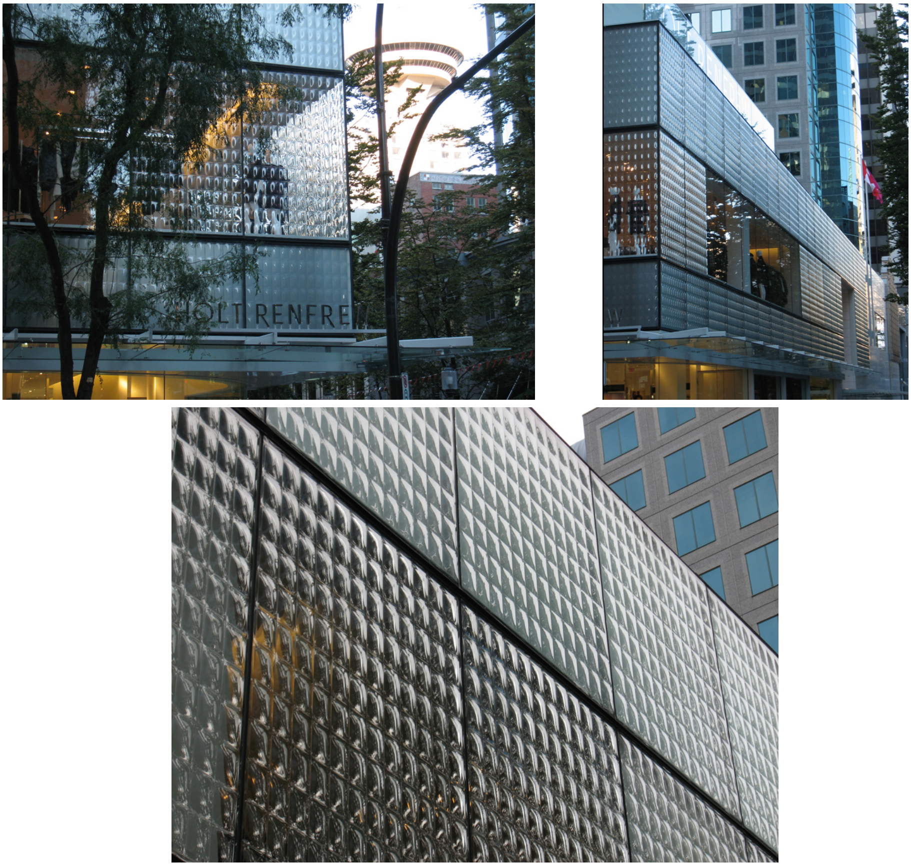


Figure 13a, b, c: Façade Corner View, Long View, Detail View.

The final configuration allowed for the interlacing of frameless pillowed vision panels with smooth optically clear surfacing with frameless textured pillowed spandrel panels with a reflective backing-glass to assist and enhance the complex play and reflection of ambient light. The resultant is a striking new façade that despite being over 80% opaque spandrel glass and without external illumination delivers a vibrant iconic presence for Holt Renfrew in Vancouver throughout the day and seasons.

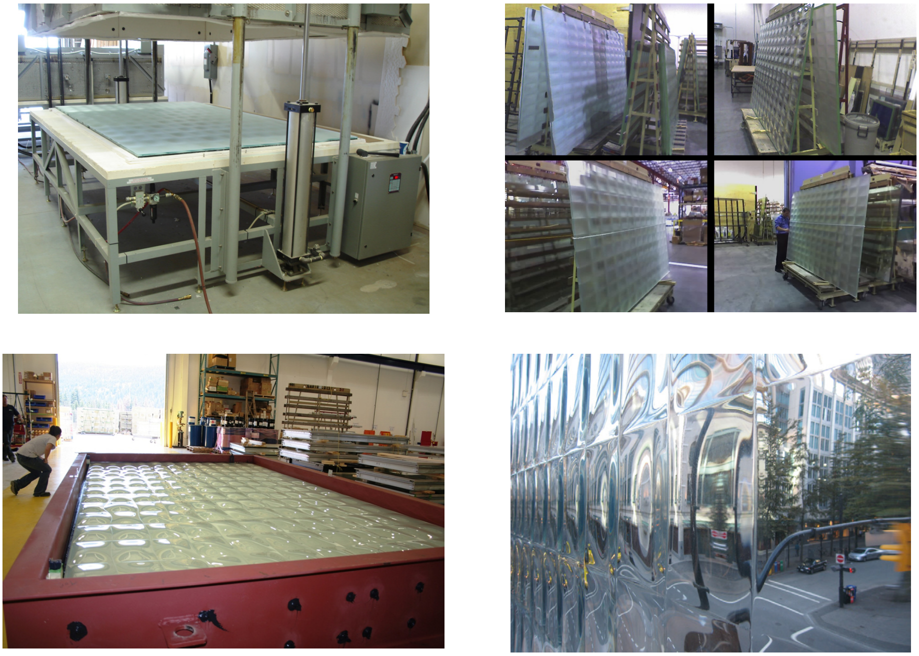


Figure 14 a, b, c, d: Slumping Oven, Production Panels, Thermal Test Rig, Detail View Completed.

8. Vakko Headquarters, Istanbul, Turkey

Vakko, a major Turkish fashion retailer and its sister company Power, a large media group; approached Ramus Ella Architects (REX) of New York to design a new iconic headquarters for their combined group. The project is located in Istanbul and was to be built onto the site of an abandoned incomplete hotel structure. The project has multiple façade systems however for this article we present only the slumped glass “X” façade.

REX and Front discussed the previously presented Holt Renfrew project and the potential of the techniques deployed. It was agreed that the glass panels would be insulated assemblies with low-e/solar coatings, that the panels would be graphically expressive through reflected light, and that the deformed geometry should be structurally advantageous as opposed to being a liability. It was determined that the high performance coatings would be destroyed through the heat-slumping process and that the interior layer for technical, practical and cost reasons would be specified as a flat panel. The interior lite is also laminated and has countersunk integrated fittings for attachment back to the primary building structure.

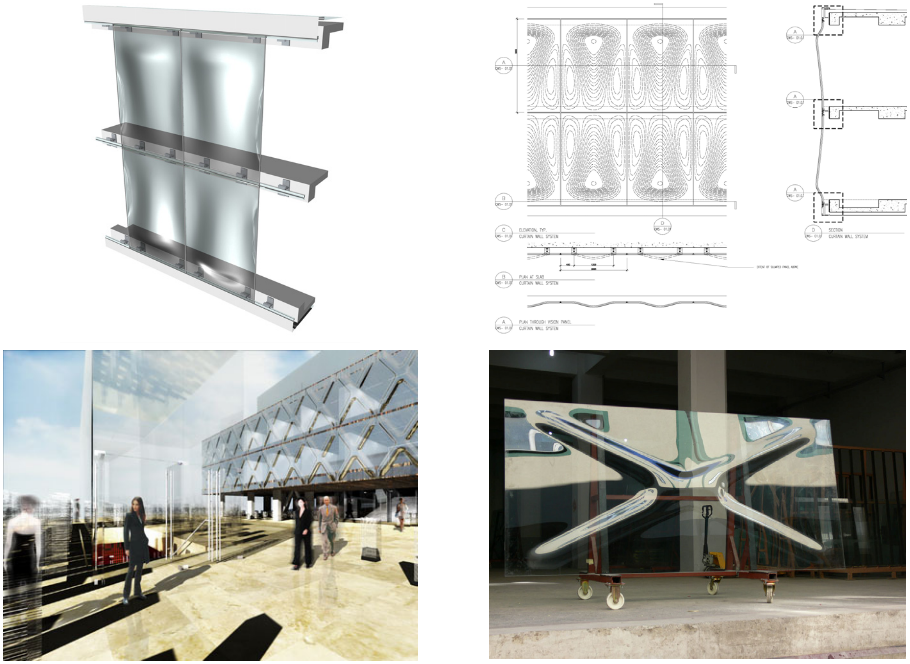


Figure 15a, b, c, d: Preliminary 3D Studies, 2D Studies, Rendering, Trial Test Panel.

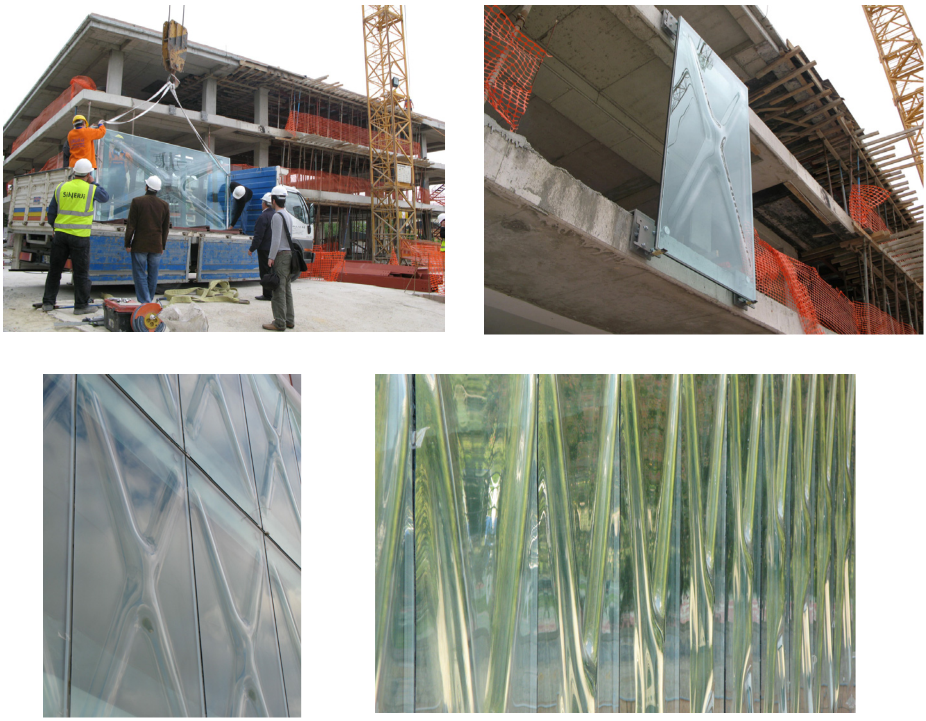


Figure 16a, b, c, d: First Panel Delivery, Install, Detail View, Oblique View.

The exterior glass was studied in many configurations to assess the optimal structurally beneficial geometry. We had decided that the four edges of the glass panels should be flat in order to maintain continuity of weather seals from panel to panel and to maintain the straightness of the conventional insulated spacer integrated into the edge of the glass panel. These constraints combined with the structural analysis to yield the “X” stiffener geometry, which was adopted for reasons of architectural and technical simplicity and elegance. A critical issue was identified in regard to the build-up of thermally induced stresses inside the air cavity and the associated potential failure of the glass edge seals. Analyses were carried out to model the variable temperature in the cavity and to ascertain in-plane stresses acting on the edge seals. The volume of the cavity had to be limited to guarantee minimal edge stresses. Two conflicting parameters were established: the desire to maximize the deformation of the panel for structural and architectural reasons and the imperative to limit the deformation of the panel for thermal build-up reasons. The final dimension was a compromise at 50mm maximum deformation between the interior flat low-e coated laminated glass and the exterior monolithic slumped glass.

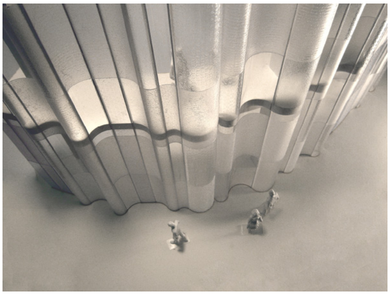
While being architecturally specific and highly acclaimed, for Front it represents a continuity of process where ideas and challenges experienced in prior projects manifest themselves iteratively through new project opportunities.

9. Louis Vuitton ION Global Store, Singapore

Front was invited by Louis Vuitton to participate in an invited design competition to propose a concept for a new Singapore Global Store at the ION Orchard commercial complex. The location is the busiest commercial corner in the city at Scott and Orchard Roads. We were interested in expressing the associations of artisanal quality embodied in the Louis Vuitton identity. It was proposed that this could be achieved through manipulation of a material surface and geometry instead of the established highly graphic approach utilized for most Louis Vuitton stores and buildings.

Figure 17a, b: Exterior View Day, Exterior Detail Night.

At the competition phase, using our awareness of international sources, we proposed specific suppliers as potential fabrication partners located throughout the world. Additionally the façade was largely pre-engineered and conceptually complete as a system. We focused on these industry factors as it was a requirement that the façade be complete and the store open within twelve months from the competition. The schedule was achieved in thirteen.



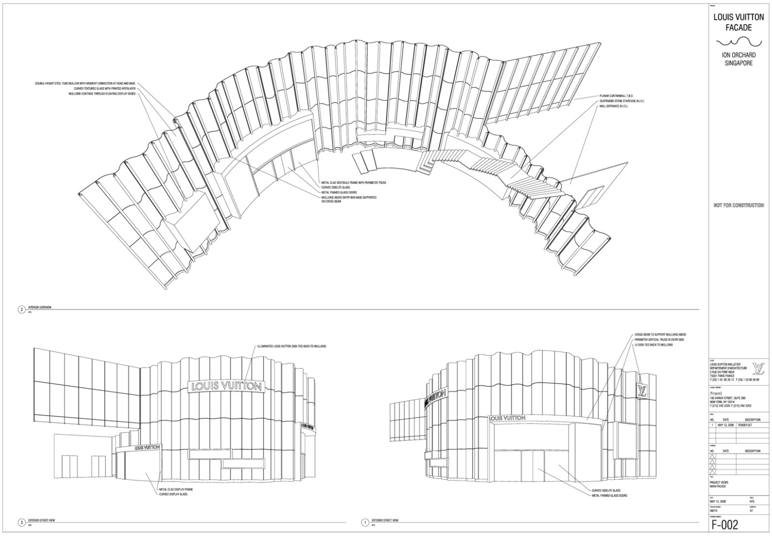


Figure 18a, b, c: Study Model, Perspective Views, Mullion to Glass Relationship.

The complete façade has a developed surface of 700m2 and includes both a double-height 11m tall exterior plaza façade and a single-storey 4.5m interior façade. The entire façade is suspended due to the presence of the local subway tunnel passing underneath. The mullions are 169mm diameter circular hollow sections, clad with mirror finished stainless steel, with a fixed end moment connection at the head and pin-slot connection at the base. The mullions are 990mm on center and are un-braced for the complete 11m span. All of the steel framed vitrines, illuminated displays and entrances including doors, are all suspended.

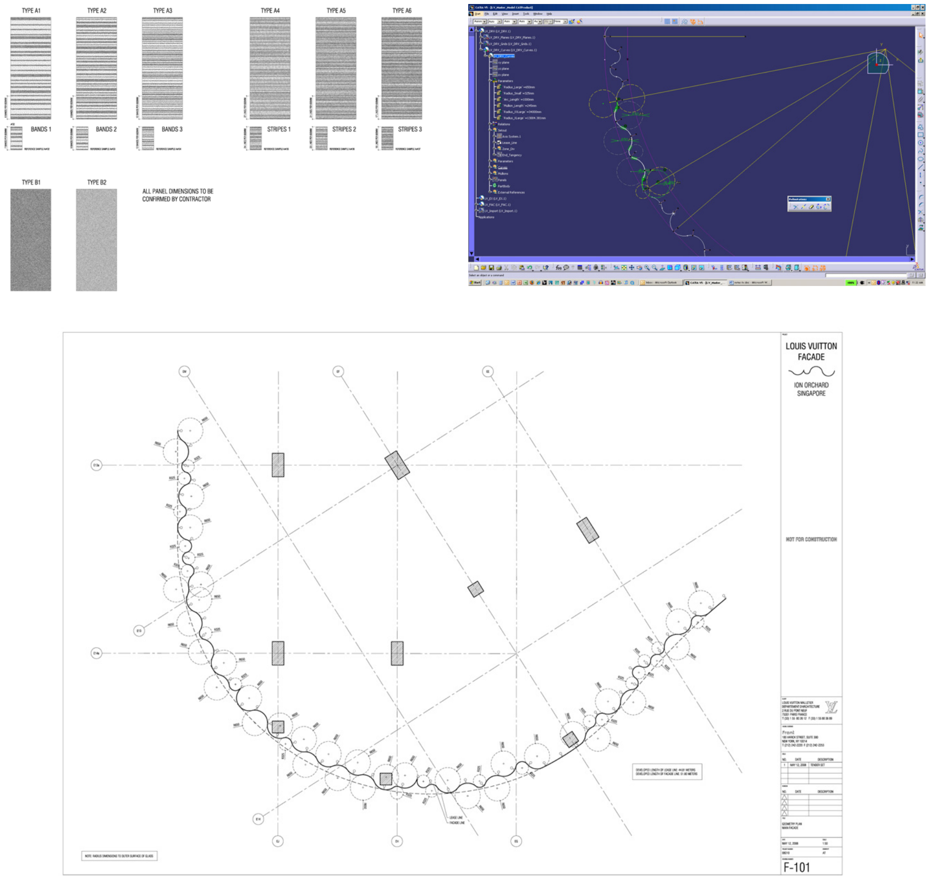


Figure 19a, b, c: Glass Texture Families, CATIA Tool for Geometry Management, General Arrangement Plan.

The glass itself is laminated annealed glass with 2 sheets of 8mm low-iron material. Each individual pair of panels is heat slump-textured in a sand-bed by Fusion Glass, London. The deformation is sufficiently significant that mating pairs of glass are required to be slumped simultaneously so that the geometrical offset between the two surfaces would be consistent for resin laminating. Subsequent to the slumping process that imparts one of six custom line textures, the panels are then, again as a mating pair, heat curved into “C” shapes, “S” shapes and double “S” shapes. Each segment of curvature along the façade is unique however the developed length of every panel is precisely 990mm and has only one of the six specified textures. However, in the end, each panel address is a unique combination of geometry and texture specification allowing for no repetition in the final product.

Figure 20a, b, c, d: Sand-bed Glass Texturing, Slumping Oven, Glass Samples, First Lighting Mock-up.

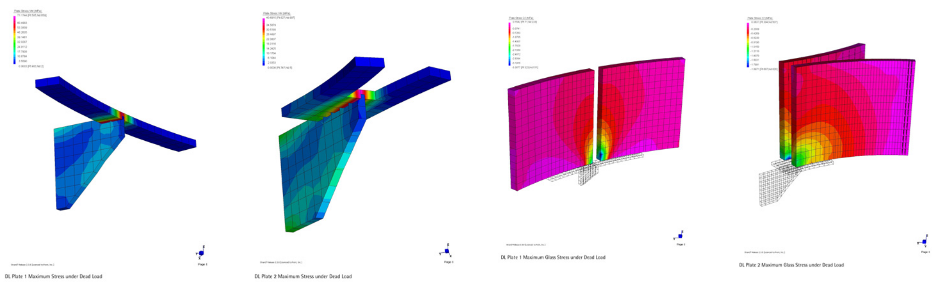


Figure 21a, b, c, d: Finite Element Analysis of Dead-load Support Cleats and Resultant Stresses in Glass.

The glass panels are supported by two-side structural silicone pre-bonded to aluminum glazing channels. The horizontal joints are frameless with glass panels being supported on custom engineered steel and EPDM bearing shelves, supported in turn directly off the mullion. These elements were profiled so that they followed the curvature of the glass at every location allowing them to be embedded in and concealed by the silicone sealant between joints.

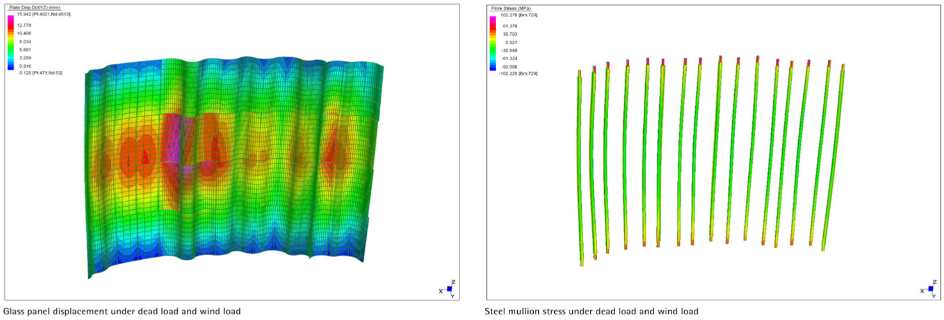


Figure 22a, b: Global Stress Analysis in Glass Panels, Stress Analysis in Suspended Mullions.

The process included the manufacture of a significant number of 600mm sample panels. This allowed for the production of four full-scale panels deployed in a first trial lighting mock-up at Fusion Glass' facility. Upon approval, the team, with Gartner Hong Kong on board as curtain wall contractor employing Fusion Glass as material supplier, proceeded to erect a full scale 5m x 11m working prototype of the façade and interior and now integrating signage and identity concepts as well as interior finshes. Significantly the mock-up was utilized as a full scale lighting mock-up, and for final client review. This mock-up allowed Louis Vuitton's management team to select the final glass textures. The panels were re-fabricated and included in a re-built mock-up for final verification and client endorsement. The fabrication progressed in China and the UK with final installation by Gartner's Singapore-based installation crew.

Figure 23a, b, c: Full Scale Prototype Night, Full Scale Prototype Day, Detail Night.

The resulting façade, a synthesis of expressive material exploration, inventive structural design, precise lighting, and proper execution, is a diaphanous linen-like membrane that delivers an unprecedented architectural form and experience.

Figure 24a, b: Completed Façade Exterior, Exterior Detail.

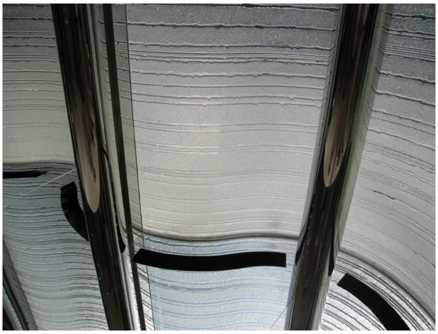


Figure 25a, b: Completed Façade Interior, Interior Detail.