Prototypical opaque cladding systems
A mutilayered approach

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Abstract

This article concerns the development of prototypical, opaque cladding systems, and, in particular, how the design concept can impact energy performance.

As always, the success of a project depends on its details, but this is particularly critical in the case of complex geometries. Each component of the system must be carefully considered and its characteristics understood. The performance of the system (be it weathertightness, acoustical, fire) is limited by its weakest link and geometrical research cannot be restricted to the architectural finish. The viability and functioning of the envelope depends on details that are practical to fabricate and, above all, facilitate assembly on site.

Four cladding systems, of varying complexity, are described, and, in each case, the principal issues which influenced their design are set out.

1. Introduction

Over the last ten years TESS has been at involved in the development of a number of prototypical cladding systems, and, in particular, opaque systems covering large surface areas. Typically, these have evolved in response to a specific set of architectural demands, such as the desire for an innovative material finish, or a complex project geometry. Often these questions are coupled with additional constraints such as variable support conditions generated by atypical spaces, or configurations that transition from vertical to roof requiring particularly robust waterproofing. Access for maintenance can be limited and owners habitually seek highly durable solutions.

These challenges can overwhelm the design and execution process. Innovation takes time to mature, inevitably bringing late changes, which are frequently incompatible with the schedule of the project.

The first area to suffer is often the performance of the system. In such projects architectural imperatives dominate, and the external geometry may not be optimally coherent with the functional components of the systems, such as insulation or membranes. Boundary interfaces are often complex, and multiple "accidental" conditions can be generated as different systems come together.

This can have a particularly heavy impact on the energy performance of an opaque system, whose critical functions are insulation, and minimizing permeability. Both are highly dependent on the weak links in the system such as thermal bridges, intermediate movement joints, and interfaces – exactly the areas which can be the most difficult to resolve, and are often left till last. This can lead to awkward details and these can have a significant impact on performance, particularly if the result is a drop in quality of construction on site.

Optimizing performance can only be achieved if a clear technical design concept is put in place and rigorously seen through to the end of construction. This paper presents the strategies followed and systems developed for four projects of varying degrees of complexity.

2. Typical components of system

Evidently there are many different technologies that can be employed for opaque cladding systems, and the approach adopted will depend on the project context. In the four cases illustrated in this paper, a common theme is that all the systems must adapt to cover geometries with inclinations ranging from vertical “façade” to horizontal “roof” configurations. In each of the projects the opaque cladding systems may be split into two principal sub-systems – a weathering envelope and an architectural finishing skin.

The classic approach to the weathering sub-system in Europe is (from inside to outside) :

- Support
- Vapour barrier
- Insulation
- Waterproofing

The architectural skin sub system typically comprises of (from inside to outside) :

- A structural support framework, fixed back through the weathering system to the primary support
- Finishing panels to define the external appearance and often provide some degree of rainscreen protection

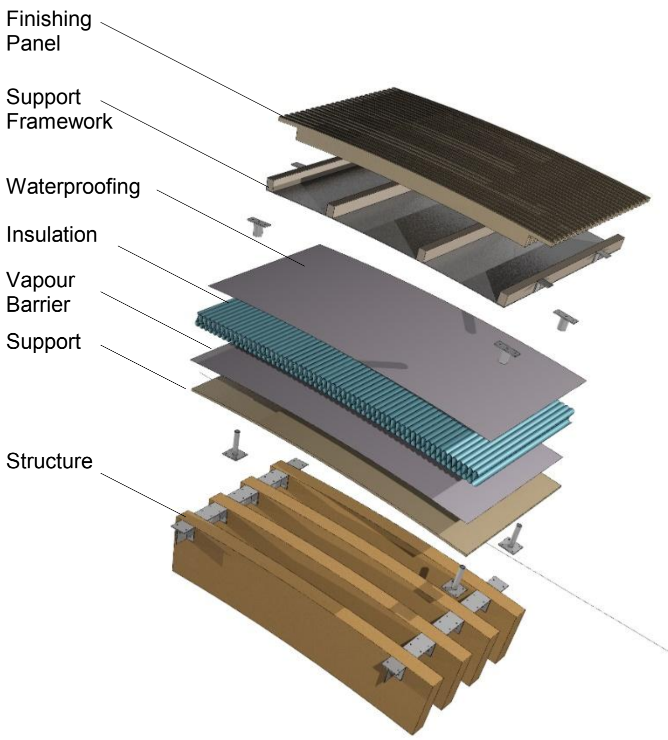

Figure 1: Typical components of system

3. Conception drivers

Each project generates its own imperatives, but certain themes remain constant.

3.1 Geometry of external skin

A key generator of the solution is the compatibility of the external envelope geometry with weathering system components, which are typically constrained to relatively simple geometric forms. If the external geometry can be rationalized towards simple forms (for example developable surfaces) then it is more likely that an integrated solution can be developed.

If the architectural finish geometry is not compatible then typically each layer will be defined with a different geometry. This evidently requires a strategy to combine the two elements together, which raises questions of how to control the finished geometry and where to introduce adjustment into the system.

3.2 Degree of prefabrication

The degree of prefabrication in the project is critical. Clearly work in the shop can be completed in more favourable conditions, and isolated from the time pressures of site work, leading to a higher level of quality control, which may also be accompanied by testing. The conception of a system can be fundamentally configured by this choice, as it relates to where and how adjustment is integrated.

3.3 Weak links in the system

The advantages of minimizing the weak links in the system are evident. How this is done is rarely obvious. Much of the energy of conception goes into this effort, and solutions can have a significant impact on the development of the system.

4. Project 1 : Creteil Cathedral, Paris

Figure 2: Timber shell system

An example of a relatively simple system can be seen in the timber shell construction for the newly reconstructed cathedral at Creteil, Paris, designed by Architecture Studios. The shell covers the 700m² nave of the cathedral, spanning 25m in one direction and 38m in the other, and rising to a height of 21m. The total surface area of the external cladding is around 1,000m².

The structure is formed by two linked shells, each stiffened by a series of parallel ribs in glulam timber. Both shells are spherical, one with a radius of around 24m, the other 19m.

50mmx50mm curved, timber laths, set out in parallel and spaced at around 100mm, were adopted as the external cladding treatment. These follow a perfect offset of the structural timber shell.

The simplicity of the geometry and external finish meant that the weathering system could be a traditional "warm roof" construction built up directly on site from relatively small-scale components. The geometry is first defined by prefabricated glulam ribs. Onto this is laid a shell surface, made up of traditional tongue and groove planks, following a conic geometry between ribs. A vapour barrier membrane is fixed directly onto the timber support surface, and on top of this 200mm of rockwool insulation was placed, with timber studs providing lateral support. The envelope system is finished with a PVC membrane.

Structural considerations called for a full shell structure, thus eliminating the need for intermediate movement joints. The geometry of interfaces is regular and repetitive. In this instance, the principal concern from an energy standpoint is the cold bridging created by fixing of the timber laths to the support shell.

In order to manage this interface, a galvanized steel support panel was created for the timber laths. The panels ranged in size with the largest being approximately 2.5m x 5m. The laths were prefixed to the panels on the ground, and then lifted and bolted to a prefixed grid of anchor points on the shell. Geometry of the laths was controlled by the precision of prefabricated frame, which was then adjusted at the anchors to assure a clean, visually continuous external surface.

The anchor points were steel tube sections with preformed waterproofing sleeve bolted directly to the timber spacer studs. The impact of the thermal bridge was controlled firstly by the low density of the anchor grid, and secondly by the insulation provided by the timber subframe. An overall U value of 0.25 W/m²/k was achieved. This was complimented by a relatively low level of permeability due to the absence of complex movement joints, and the simplicity of the geometry of the interface details.

In this case the simplicity of concept allows for relatively rustic, traditional, site applied solutions with only limited impact on performance.

5. Project 2 : Montecarlo Pavilions, Monaco

Figure 3: Montecarlo Pavilions

Montecarlo Pavilions, designed by architect Affine Design, are a series of five pavilions ranging from 250m² to 750m² in floor area, and serving as high end commercial shopping space. The total area of opaque cladding of around 4,000m², is covered by more than 5,100 panels. Each pavilion is completely column free to maximize the flexibility of the spaces, and the entire project had to be completed in 20 months from the start of the design process to handover.

The architectural quality of the internal spaces and the external image were expressed by sculptural, double curved forms, emphasized by the panel joint layout. The architect was searching for a metal panel finish with a relatively high density of joints with average panel sizes of around 1m².

A triangulated geometry was developed to respond to the double curvature, with the tiling layout of panels driven by the constructive logic of the system. A series of vertical planes serve as the generator for both the triangular mesh and the support system. The mesh density of the triangular discretization is adapted as a function of the curvature to achieve a regular "smoothness". The panels themselves are folded diamonds to eliminate a third direction of joints, greatly enhancing the visual flow of the joints on the surface.

Commercial space was a priority, so it was imperative to optimize the thickness of the structure and envelope complex and a steel shell structure was chosen to maximize structural efficiency.

The tight time schedule for the project was further complicated by the lack of storage on site and the very limited window available for the actual construction. The technological solution developed was to integrate the weathering envelope and structural shell into a prefabricated panel construction. The shell was broken down into large, transportable, modules, which were

Figure 4: Shop front

pre-fitted with a “warm roof” weathering system, comprising of (from inside to outside):

- Steel shell surface serving as the vapour barrier
- 150 mm of mineral wool insulation, supported by timber joists fixed to shell
- TPO (thermoplastic olefin) membrane on an OSB support plate

The approach allowed for extensive offsite quality control and testing, to verify the integrity of the construction. Panels were then re-tested once installed to make sure that no damage to the weathering system had occurred in transit. Any minor damage on the TPO membrane was easy to repair as membrane seams are simply heat welded.

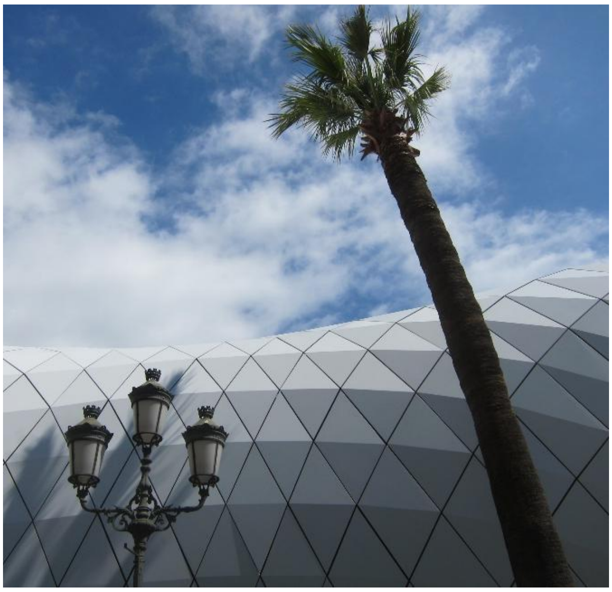

Figure 5: Folded diamond finishing panels

The geometry of the shell is discretized in a trapezoidal simplification of the external geometry. Internal stiffeners were curved to follow a pure offset of double curved geometry, and this was left as the exposed architectural finish of the interiors.

As with the Cathedral de Creteil, the integrated structural shell concept avoided any complex movement joints in the envelope system. Site joints between transportable modules are drained and ventilated cavities, following a simple, continuous, planar geometry.

The difference between the geometry of the external finishing panels and weathering panels of the steel shell was taken up in a secondary support structure for the finishing panels.

This structure is composed of primary elements arranged in the same vertical planes that serve to generate the tiling pattern of the finishing panels. These elements were braced together and preassembled in transportable subframes of up to 6mx2m. The subframes were then bolted on site to preadjusted horizontal ring beams, which were connected to the steel shell at anchor points on a grid of around 6mx3m. The density of anchor points was set to minimize thermal bridges, while also limiting the dimensions of the support structure.

The global performance U value achieved was 0.35 W/(Km²), benefiting from the low density of thermal bridging the lack of internal movement joints. The high proportion of prefabrication enabled precise geometric control and fast installation, combined with enhanced quality control and testing for

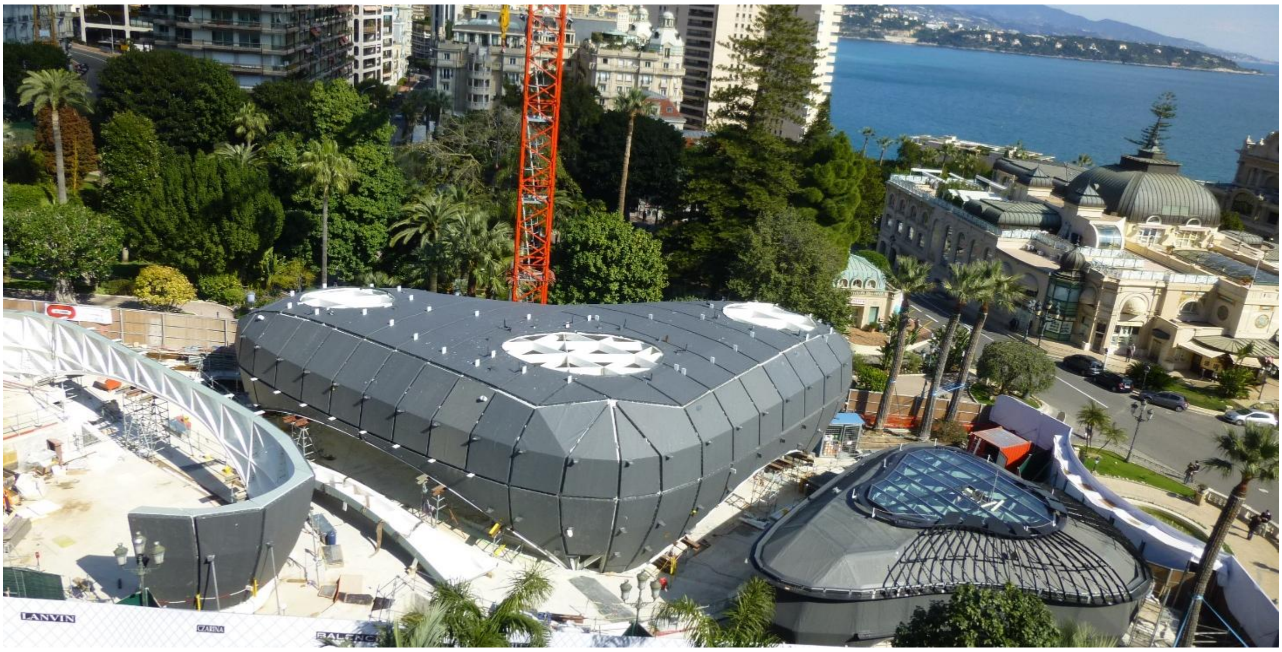

Figure 6: Weathering panel shell system and secondary structure during installation off site work.

6. Project 3 : Iceberg Cladding for the Fondation Louis Vuitton, Paris

The Fondation Louis Vuitton, design by Frank Gehry, is a contemporary art gallery with around 3,500m² of gallery space and incorporating a 350 seat auditorium. The external weathering skin comprises of around 9,000m² of opaque, white cladding, known as the Iceberg, which is interspersed with glazed breaks.

The Iceberg takes on a myriad of forms, each with a chiselled, sculptural geometry composed of intersecting, curved, developable surfaces. The inclination of the surfaces ranges from horizontal through vertical to negative inclinations.

The system had to be designed with a very high degree of robustness, with a desired design life of 100 years. This was further emphasized by the fact that, in many cases, the internal skin would be hidden by an interior sculpted plaster finish, preventing the early detection of problems.

*Figure 7: Iceberg cladding at entrance*Primary

The finish for the Iceberg was the subject of a lengthy process of development, covering a diverse range of options, including plaster, aluminium shells, and sprayed concrete. The option finally chosen was a cast panel solution, fabricated with high performance fibre reinforced cement (Ductal) [1]. Panels were around, 0.5m² in area, requiring a total of over 19,000 panels, the majority of which had its own, unique geometry.

The technology for manufacturing the panels had to be entirely developed from scratch, and involved casting each panel in a flexible silicone mould, that was placed on a machined polystyrene form to generate the required curvature. The system had to be developed to accommodate a very wide range of structural spans and support conditions.

As with the Pavilions at Monaco, a warm roof system with steel support panel was developed to respond to the structural demands and geometrical precision required. The build-up of the weathering system from inside to outside started with the steel shell surface serving as the vapour barrier, on which was placed 180mm of rockwool insulation, with steel z section brackets acting as spacers and supports. The panel was then sealed, in the factory with an EPDM membrane covering on an aluminium support plate.

Central to the conception for the system was the desire to minimize the number of internal movement joints. These would clearly create weak links to the system, from both a waterproofing robustness and energy performance standpoint. As with the Pavilions at Monaco, this was achieved by creating large structural shell surfaces, made up of rigidly connecting a series of transportable 12mx3m panels together.

As with the system developed for Monaco, the weathering system for each panel was tested off-site to ensure that it was perfectly sealed, prior to leaving the factory, and once installed to make assure that no damage had occurred during transport or installation. The concept had an additional advantage that each

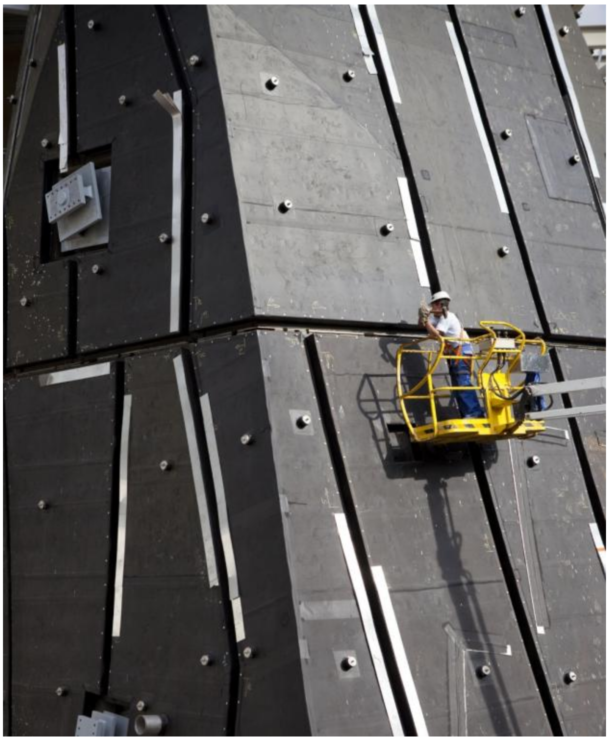

Figure 8: Iceberg weathering panel system

panel was effectively isolated from its neighbours, so that, in the event of an infiltration, the consequences would be contained in a restricted area.

The elimination of intermediate movement joints raised the question of structural interaction with the primary support frame, due to the very high in plane stiffness of the cladding shell system. Interaction was minimized by controlling the direction of forces transferred at anchor points for the shells. In plane force transfer was managed by employing releases at connections such that the system approached an isostatic support condition, limiting forces from differential temperature loads or movements. Out of plane forces were transferred at points in the shells which were relatively flexible (avoiding corners for example) allowing the system to "breath" and not compete with the stiffness of the primary structural frame.

The geometry of the external finish was based on developable surfaces, which is ideal for construction formed by bending of flat sheets. In most cases, the geometry of weathering system was developed as a direct offset of the external finish surface greatly simplifying the construction of sub-assemblies, and enabling the standardization of many elements such as anchor points for the external finishing support system.

The Ductal finishing panels required a high density of extremely precise, rigid supports. Options to fix the panels directly to the weathering system support panel were considered, but abandoned due to the risk posed by approximately 100,000 hidden penetrations of the waterproofing membrane.

The final solution adopted was to create an aluminium shell support surface. This was fabricated in panels of around 3mx3m dimension with a very high degree of geometric control, and then installed onto anchors and precisely adjusted on site. Final installation of the Ductal panels was rapid with minimal additional adjustment required.

The global U value achieved was around 0.3W/m²/K, benefitting from the low density of thermal bridging the and the elimination of internal movement joints. Permeability was extremely low due to the efficiency of the steel vapour barrier, the lack of internal movement joints, and the minimal degree of site work required to seal the system.

Figure 9: Aluminium support shell for Ductal panels

Figure 10: Ductal panels during installation

7. Project 4 : Block Façade of the LUMA Foundation, Arles

The LUMA Foundation, design by Frank Gehry, is a 55m high tower currently under construction in Arles, France. It acts as a gateway building to a cultural park, and incorporates a restaurant, café, event spaces, conference, archive, and artists' studios. The cladding comprises of the 4,500m² opaque Block Façade, precast facades totalling 8,000m², and around 5,500m² of glazed elements, with the glazed Drum atrium at its base.

The Block Façade references the stone architecture of the Romans, vestiges of which are scattered across the city, while also evoking the rock formations found in the Alpilles mountains of the region. The architect also wanted to generate a pixelated sparkle, inspired by the works of Van Gogh, who painted extensively in the city and surrounding countryside. This led to the choice of stainless steel as a finish material, and the development of the block forms from thin folded plate.

Figure 11: Block Façade during installation

The project posed many similar technical challenges to the Fondation Louis Vuitton. A diverse range of structural support and geometrical configurations had to be accommodated, combined with a high degree of robustness and 100 year design life. To this was added the requirements of high rise construction, which imposes supplementary performance and regulatory constraints, particularly in terms of permeability and fire.

The weathering system concept for the Fondation Louis Vuitton could have been adopted as a solution. However, the geometry of the blocks posed a new challenge, as their staggered layout does not follow a continuous surface. In effect, each block requires a specific support structure geometry.

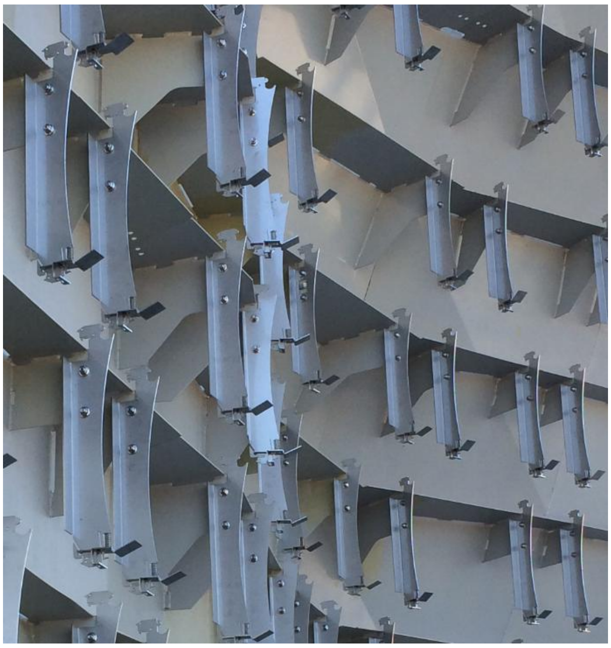

Figure 12: Support brackets for blocks

The contractor, Eiffage Construction Metalique, proposed a radical solution, inverting the logic of the steel shell system, and placing the support surface on the exterior, just behind the blocks. The multiple support brackets required for the blocks could then be fixed directly to the external shell, outside of the insulation envelope, with no thermal bridges.

One consequence of this strategy was that the shells were fabricated in stainless steel to provide the durability required without the need for regular maintenance.

The second was that the classic warm roof concept was no longer suitable for the system. The functioning of a classic warm roof is based on placing the least permeable vapour barrier on the inside face of the insulation, and adding a more permeable waterproofing membrane on the outside face. This means that any moisture built up in the envelope insulation can escape to the exterior through the more permeable external membrane.

If the external support surface for the insulation is a steel shell then it is virtually impermeable. It is very complex (and seems somewhat irrational) to actively increase the permeability of this external surface. Conversely it is practically impossible to achieve a near perfect barrier on the inside face of the insulation, which could compete with the steel surface.

The solution proposed by the contractor was to employ a cementitious sprayed insulation, applied directly to the inside face of the steel shell, allowing it to breath towards the interior. The insulation has a very high water content when applied and, as it cures and dries, it maintains its capacity to hold moisture. In effect the insulation acts like a sponge. The interior face of the insulation is typically exposed to a relatively low level of humidity in the building, and, due to the relatively dry climate in Arles, the insulation tends to continue drying over its lifetime.

Figure 13: Support shell during installation

During the testing and validation process it became clear that an internal vapour barrier tended to impede this drying process and so was eliminated further simplifying the construction.

The logic of minimizing intermediate movement joints to eliminate weak points in the system applied. As the weathering system is not exposed to view, detection of problems such as water infiltration is difficult and a highly robust system is desirable. A solution similar to the Fondation Louis Vuitton was developed, where transportable prefabricated panels were bolted together on site to form large scale shell elements. Once in the shells are installed and adjusted, the site joint is welded to provide a highly durable waterproof detail. The structural support scheme for the shells was developed to minimize interaction with the primary structural frame.

As the geometry of shells is disassociated from the blocks it was possible them to follow a simple triangulated discretization, optimized to suit the fabrication constraints imposed by stainless steel plate dimensions. Stiffeners for the shells were laser cut and employed as an eggcrate jig to define the geometry of the shells and to facilitate their fabrication.

Figure 14: Block Façade prototype

Globally the U value achieved was 0.25 W/m²/K, due to the minimization of cold bridges. The system has a very low level of permeability due to the steel shell surface and the low density of movement joints.

8. Conclusions

Prototypical façades typically arise in exceptional projects that often imply a significant degree of complexity. This can impose challenges that overwhelm the design process, leading to poorly conceived details, particularly at the awkward conditions at the edges of projects.

The impact can be significant on the energy performance of the system, which is highly dependent on its weakest links - thermal bridges, intermediate joints, and interfaces.

While the ambition is to create great architecture, the obligation is that it performs.

The battle to optimize performance, more often than not, is fought around eliminating weak links, and simplifying site work. This can only be achieved with a clear technical design concept, developed in the earliest phases and rigorously seen through to completion of construction.

9. References

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