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UHPFRC CLADDING FOR THE QATAR NATIONAL MUSEUM

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Abstract

The Qatar National Museum (QNM) under construction in Doha is composed of various lens disposed in order to reproduce a giant gypsum flower as proposed by the Ateliers Jean Nouvel in Paris. The lenses which compose the shape of the structure are covered with precast UHPFRC cladding panels over an area of 120’000 m^2.

The use of UHPFRC allows reducing the thickness of the cladding to 40 mm without using passive reinforcement even thought the panels are large and the wind and temperature variation are extreme. The use of UHPFRC allows fulfilling all the requirements over the durability of the panel.

The project of the cladding system with UHPFRC panels is described in this paper.

Résumé

Le musée national du Qatar en construction à Doha est composé d’une multitude de lentilles disposées aléatoirement afin de créer une gigantesque rose des sables comme proposé par les Ateliers Jean Nouvel à Paris. Les lentilles qui génèrent la forme de la structure sont recouvertes de panneaux préfabriqués en UHPFRC sur une surface de 120'000 m^2.

L’utilisation de UHPFRC a permis de réduire l’épaisseur des panneaux à 40 mm sans utiliser d’armature passive bien que la taille des panneaux est importante et que les sollicitations dues au vent et aux variations de température soient extrêmes. L’utilisation de UHPFRC a également permis de satisfaire toutes les exigences au niveau de la durabilité.

Le projet de la facade en panneau UHPFRC est décrit dans cet article.

1. INTRODUCTION

The Qatar National Museum (QNM) in construction in Doha is composed of various lens disposed in order to reproduce a giant gypsum flower. The client of the project is Qatar National Museum and Qatar Petroleum. The lead consultant and architect is Ateliers Jean Nouvel (AJN) in Paris. Sub-consultant is Arup in London for the engineer and INGPHI SA in Lausanne for the engineer of the concrete cladding.

The QNM is made of different parts. They are illustrated in Figure 1 based on the BIM model developed by AJN.

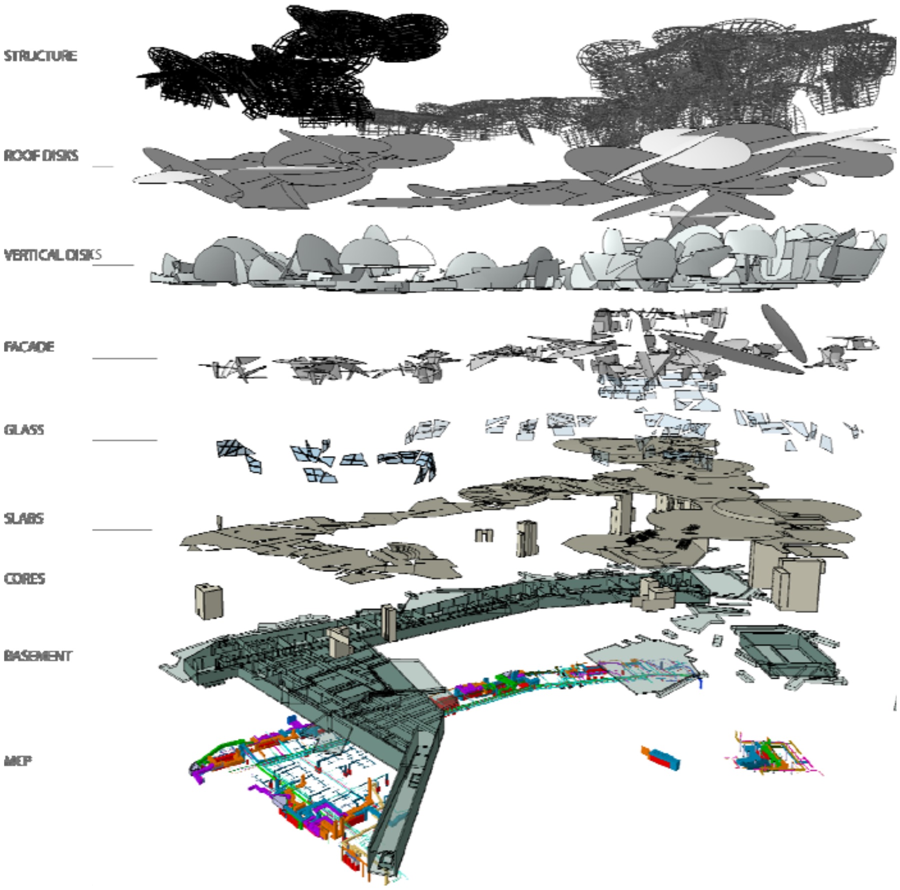


Figure 1 : Topology of the QNM taken from the BIM model (Ateliers Jean Nouvel)

A total of 130 lenses are used to create the roofs, slabs and walls of the museum. The lens radius varies from 10 to 43 m. Two different lenses typologies are designed: roof lenses and vertical lenses. Furthermore, the lens system is adapted for sun breakers and bottom surface of the slabs with interconnected beams.

For all these typologies, the concrete cladding is similar: same geometry, same material, same color and same texture over the 120'000 m^2. Various solutions were developed such as concrete cladding casted in situ, precast concrete panel, concrete cladding with shot concrete and plaster cladding. The solution with precast concrete panels was preferred but due to the size of the panel, the use of UHPFRC was necessary.

2. USAGE OF THE CLADDING SYSTEM

The concrete cladding is used to cover and protect the museum. Since the museum is located in a sea area, these environmental effects have to be considered. The design life of the museum is 60 years. The design life of the cladding is differentiated as follows:

• precast UHPFRC panels	60 years
• waterproofing and insulation	30 to 40 years
• sand barrier and joints	15 years

The purpose of the architects on the cladding is to obtain a smooth, uniform and regular curved surface. Mineral, massive and heavy appearance of the concrete panel is also required. No visible mechanical fixing parts (bolts, plates, lifting hooks) anywhere also thought the joints are allowed. The color has to be white with smooth surface under dry and wet conditions. The dilatation joint has to be minimal and regular opening.

The precast concrete panels must sustain permanent loads, loads for cleaning and maintenance on the roof, wind pressure determined on a wind canal test [1] which varies between + 1.9 kN/m^2 to -2.1 kN/m^2 (positive pressure acts inward) as well as extreme temperature variation from +10° to 85°C.

3. COMPOSITION OF THE CLADDING SYSTEM

The cladding system is composed of the following layers as illustrated in Figure 2:

- Ribdeck fixed on the primary steel structure
- Insulation and waterproofing membrane supported by the ribdeck
- Studs welded on the primary steel structure
- Secondary steel structure supported by the studs
- Concrete cladding fixed on the secondary steel structure

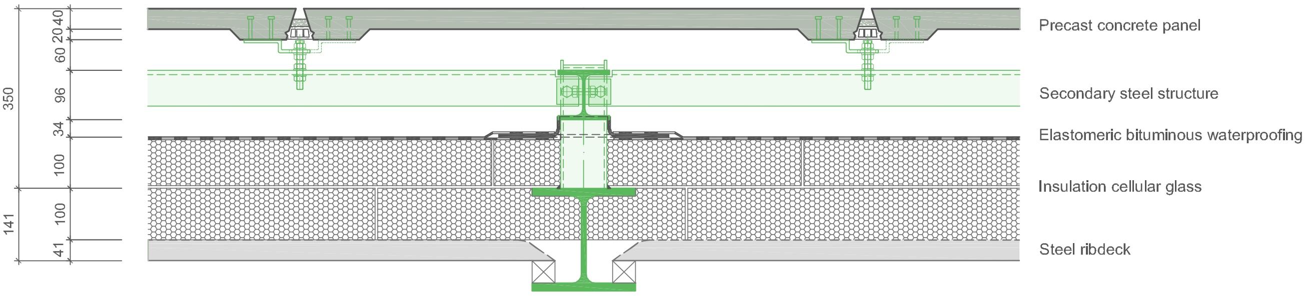


Figure 2 : General cross-section of the cladding system

The carrying structure is made with a steel construction called the primary steel structure. The link between the primary and the secondary steel structure which supports the cladding is insured by studs. These studs control the curved geometry of the lens. It has a circular cross-section with an external metric thread in order to receive the ring with the corresponding internal thread.

The secondary steel structure is composed of steel profiles. They are curved so that the fixings of the concrete panel which is axially symmetric are also axially symmetric. The secondary steel structure is composed of simply supported beams with a maximum span of 3.0 m. They are fixed with bolts at extremities, one with normal hole and one with oblong hole. Therefore, force transfer between the secondary and primary structure due to thermal movement is limited.

Insulation is composed of cellular glass in order to insure the required design life of 30 to 40 years. No vapor barrier is required since it is impermeable to water and water-vapor. The coefficient of linear expansion of cellular glass, concrete, and steel are similar, allowing normal thermal movement without damage. The insulation is 200 mm thick in order to reach the recommended U value of 0.2 W/m^2K. The cellular glass panels are glued with bitumen so that holes are also fulfilled with bitumen.

Water and sand will be stopped by the cladding line created by the precast concrete panel. This cladding line creates an efficient front line although the real waterproofing line is created by the waterproofing membrane. The waterproofing membrane is differentiated according to the sun and rain exposition. A membrane of various layers bituminous SBS membrane is placed on exposed roof lens, one layer of SBS membrane is placed on soffit of roof lens and vertical lens which are not exposed. Self adhesive membrane is placed on areas which are not easily reachable.

A cold façade is realized so that he air is ventilated internally between the outer layer that offers protection against the weather and the thermal insulation layer.

4. UHPFRC CLADDING PANELS

The surface of the concrete cladding is made up with precast concrete panels. Due to the extreme temperature variation, the precast concrete panels are separated by expansion joints at least every 4 m. A movement joint is placed between the concrete panels at each lens intersection as shown in Figure 9 and dilatation joints are placed between different parts of the building.

The precast concrete panels have to be curved in both directions such that the radiuses of curvature of the panel are equal to the radius of curvature of the lens. There are 31 different lens geometries which cover the roof lenses, vertical lenses and slabs. The concept of tessellation of one lens is illustrated in Figure 3 with a radius of 31 m. The panels are arranged such that a limited number of around 20 different panel elements and two nose elements cover the entire area of the lens with a simple rotation. In order to cover the entire surface of the museum, there are around 150 different panels according to the lens curvature. This system was chosen in order to limit the number of mould for the panel fabrication.

The concrete color is white. Therefore, white aggregates, white cement and white pigment have to be used.

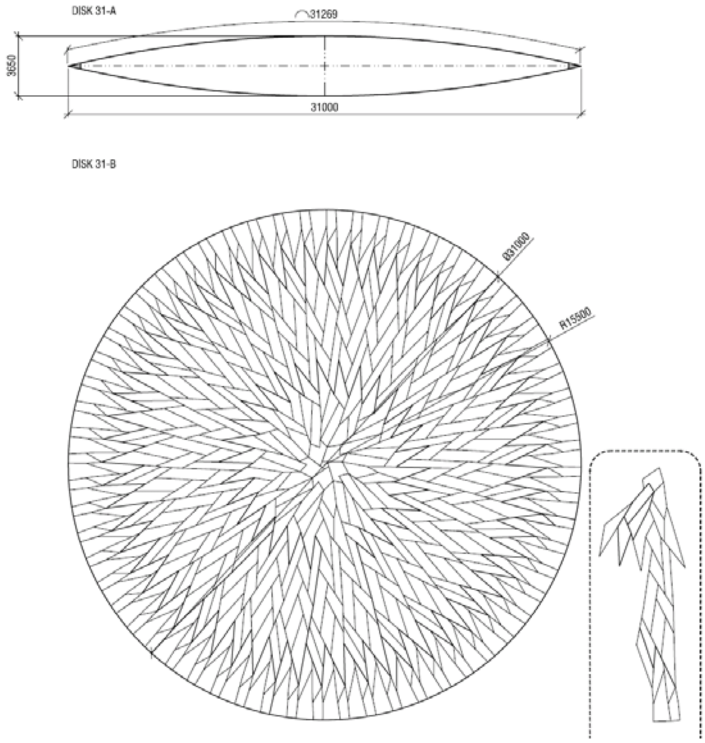


Figure 3 : Concept of tessellation of one lens in precast concrete panels

The concrete used for the precast concrete panel is UHPFRC with exceptional characteristics in terms of mechanical resistance, durability, abrasion resistance, and resistance against chemical and environmental attack. The main purpose of using UHPFRC is to minimize the thickness and therefore the weight of the panel even thought the panel size is large. The minimum requirements for the concrete are presented in Table 1.

Thickness	mm	40 – 60
Compressive strength	MPa	100
Tensile strength	MPa	15
Ductility in traction: ratio of rupture displacement / elastic displacement		Min. 10
Middle Young’s modulus	MPa	35’000
Density	kN/m^3	24
Exposure classes (EN 206-1)		XC4, XS1
Shear strength of one fixing point (in all direction)	kN	5
Water permeability	g/(m^{2}h)	10
Specialty		White color

Table 1 : Minimum requirements for the UHPFRC

The content of fiber and the type of fibers are not specified even though the use of steel fibers is necessary to achieve the required strength and ductility.

The design of the UHPFRC panel was performed according to the AFGC-SETRA interim recommendation [2]. Thanks to the use of UHPFRC, the thickness of the precast concrete panel is reduced to 40 mm. The finite element analysis of one rectangular panel with the computer program ANSYS [3] using shell element shows that the maximal stress σ_x over the fixation points reaches 3 N/mm^2. UHPFRC will sustain this stress without any passive reinforcement.

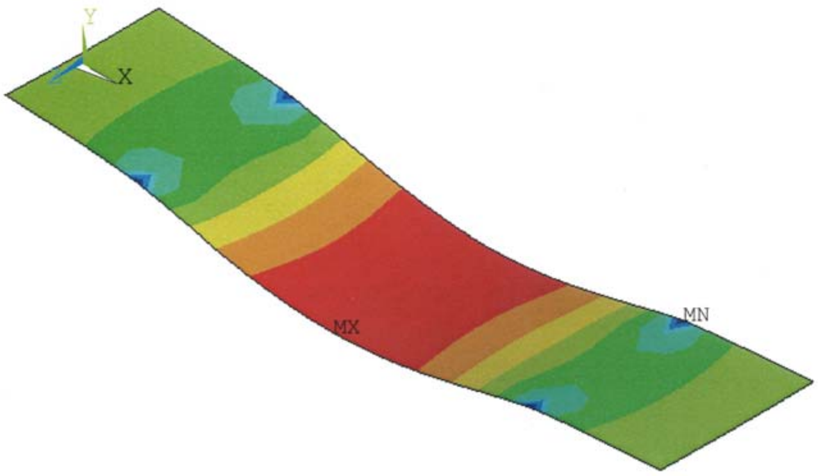


Figure 4 : Stress σ_x under wind load plotted on the deformed mesh (blue: 3 N/mm^2)

The size of the precast concrete panel was limited to 2 m^2 due to his weight. Furthermore, the width of the panel was limited to 0.40 m due to the torsion strength and the maximum span between two fixing points is 1.50 m and the cantilever was limited to 0.60 m, both due to bending strength.

5. DETAILING OF THE UHPRFC PANEL

The thickness of the panel is increased around the periphery to 60 mm in order to place the fixing anchorage and to insure the shear strength of the fixing point. The precast concrete panel is fixed to the secondary steel structure with a Z-steel plate anchored with four studs. All Z-plates of the concrete panels are fixed to the secondary steel structure with threaded rods. The design of the fixing elements is not straightforward so that it has to be confirmed with experimental tests in order to guarantee that each fixing point must sustain a load of 5 kN in all direction.

The expansion joint which is also the sand barrier is build between each precast concrete panels. The expansion due to thermal variation by considering $\alpha = 1.1\ 10^{5}\ °C^{-1}$ with a maximum temperature variation of 75°C represents around 4 mm for a 4 m panel. Considering a safety factor of 1.5 on this expansion, the joint opening should be at least 12 mm. The opening of the expansion joint is increased up to 15 mm in order to insure enough room for construction.

The expansion joint is closed to create a sand barrier with an elastomer EPDM joint over which a silicone joint is placed as illustrated in Figure 5. The silicon joint is white. After silicon application, fine quartz sand is powdered over the surface of the joint.

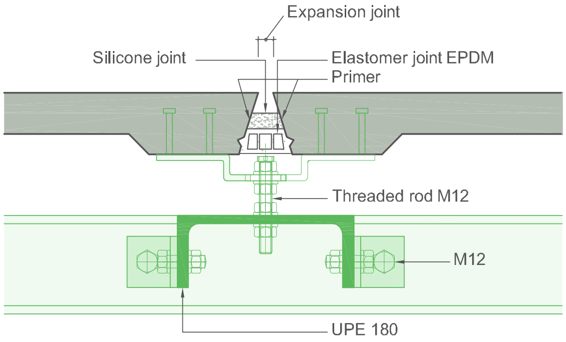


Figure 5 : Expansion joint between the UHPFRC panels

The nose element is made in one piece. The nose element is fixed to the nose beam (being part of the primary steel structure). The geometry of the nose element depends on the lens curvature; the cantilever from the nose beam up to it extremity can vary from 0.90 m to 1.50 m. The wide of the nose element is 1.0 m. The nose element is fixed with a pair of stainless steel rod ϕ =16 mm every 1.0 m as illustrated in Figure 6. The geometry of the nose element is adjusted with one cons nut and one nut.

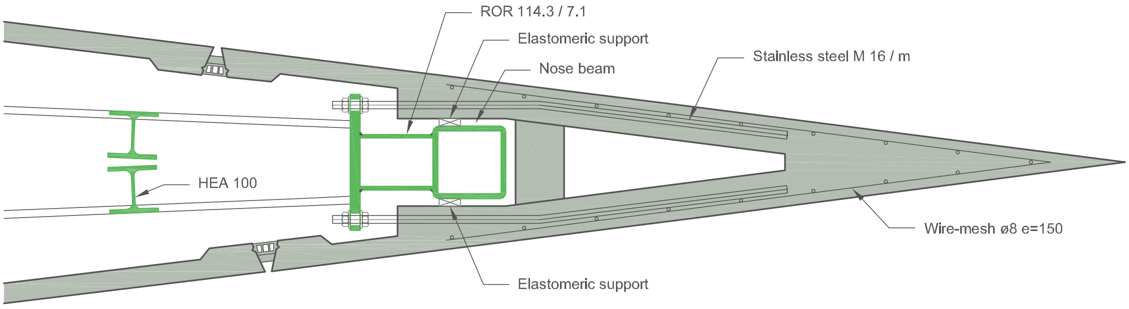


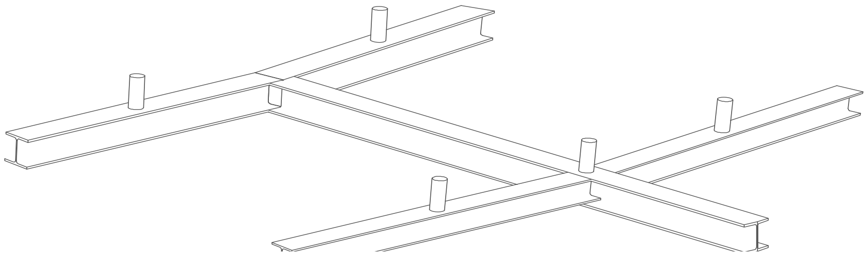
Figure 6 : Detail of nose element

The nose element in UHPFRC is built in one stage by pouring it vertically so that the acute angle can be as sharp as possible. The internal stiffener inside is poured in a second stage as they are not visible.

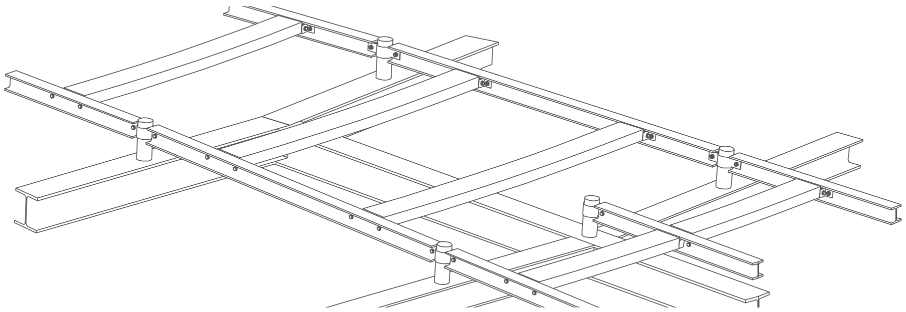
6. CONSTRUCTION PROCESS

The construction sequence is illustrated in Figure 7. The QNM involves around 130 lenses with a total cladding area of around 120’000 m^2. Under the assumption that one team can fix around 20 panels of 2 m^2 in one day which is around 40 m^2. It means that around 10 teams are required to fix the precast concrete panel of the entire museum in one year of around 300 days of work. The use of precast concrete panels is also justified by the size of the project.

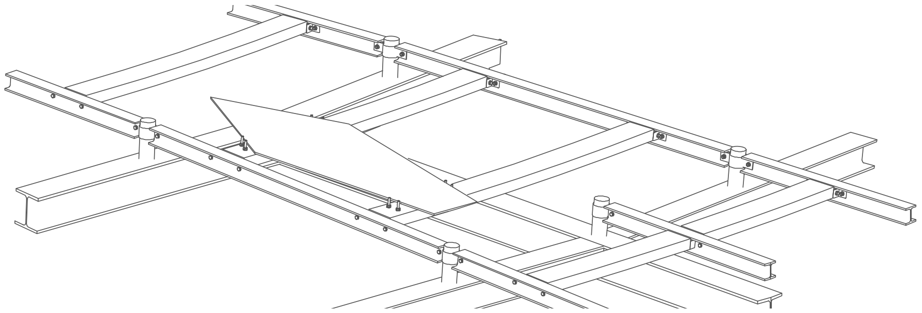
Primary steel structure with the studs



Secondary steel structure



Stencil of the concrete panel to adjust the threaded rods



Setting the concrete panel

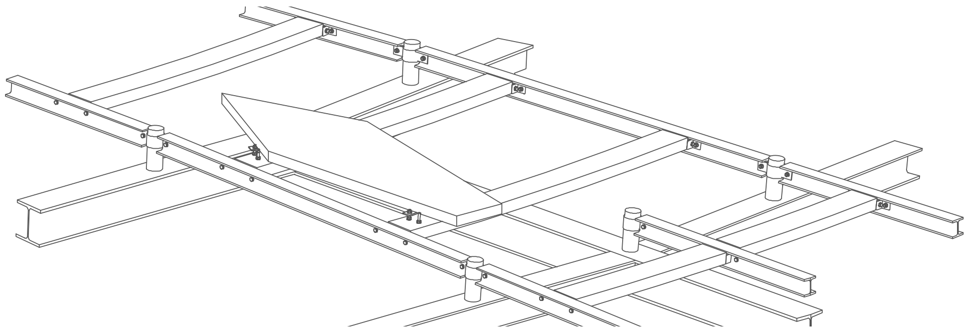


Figure 7 : Sequencing of the mounting of the concrete panel

The final geometry of the concrete cladding surface has to satisfy high requirement: ± 2 mm deviation of the theoretical line. The adjustment capabilities of the secondary steel structure and the fixing are summarized in Figure 8.

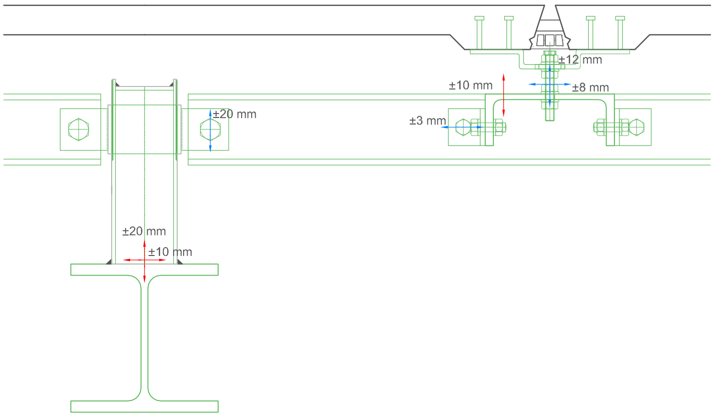


Figure 8 : Graphical summary of the adjustments capabilities

Lens intersections are illustrated in Figure 9. A movement joint is located at the intersection of the UHPFRC panel of each different lens. The UHPFRC panels are sawn on site to handle the geometry of the intersection.

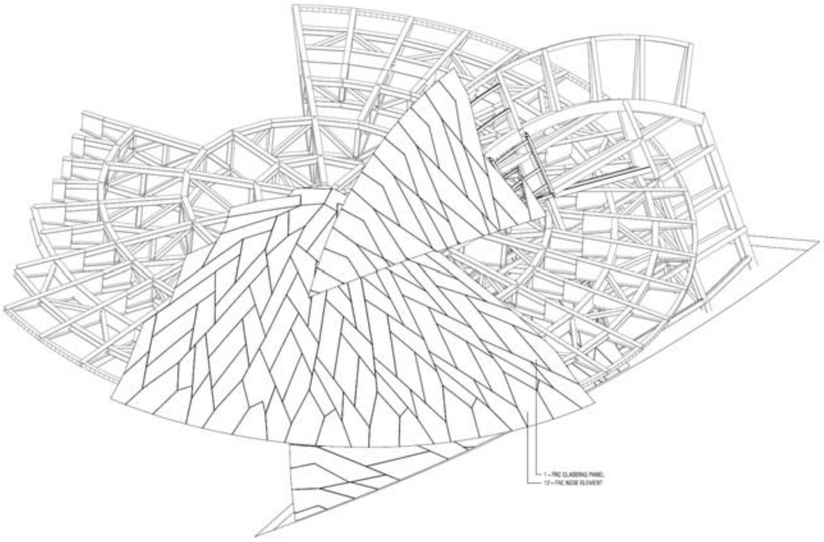


Figure 9 : Lens intersection

Quality controls are performed for every samples such as compressive strength, Young’s modulus, four point bending test of 1.5 m long specimens up to failure, shear tests of the fixing in the concrete panels at different angle, density and water absorption.

Some muck-up of the UHPFRC panels were constructs in order to finalize the design process as illustrated in Figure 10.

Figure 10 : Mock-up of the cladding panels

7. CONCLUSIONS

The project of the cladding of the Qatar National Museum (QNM) in construction in Doha has been described. The use of UHPFRC panels to cover an area of 120’000 m^2 has been shown to be an adequate solution as it allows reducing the thickness of the panels even thought the panel size is large, the wind and temperature variation are extreme and the requirements over durability are high.

It has to be mentioned, that the design of the shear strength of the fixing elements in UHPFRC panel was not possible so that experimental tests were required. This shows that further research in the area of shear strength of UHPFRC is necessary.

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Architects	Ateliers Jean Nouvel, Paris / Eric Maria, Geneva
Engineers	Arup, London
Engineers for the cladding	Ingphi SA, Lausanne
General Contractor	Hyundai Engineering & Construction co, Ltd, Seoul

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[2] Ultra High Performance Fiber-Reinforced Concrete, Interim Recommendations, Setra, 2002.
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