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ARCHITECTONIC UHPFRC ELEMENTS IN BSI®

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Abstract

UHPFRC's extreme strength enables a wide range of applications, including architectural elements that would be too delicate for ordinary concrete. Thanks to its incredibly fine and dense microstructure, the cement matrix is virtually air and watertight and very durable. So are facades built with this concrete. UHPFRC's fineness and mechanical strength allows complex parts to be manufactured, with lots of details and intricate latticework, while maintaining low thickness. BSI® fits in perfectly with this approach. Many iconic buildings feature the use of BSI®'s white formula with synthetic fibres in their low-thickness, large-sized components, whether it be textured panel or mesh-like mashrabiyyas.

Résumé

L'extrême résistance des BFUP permet d'envisager une multitude d'applications dont la réalisation d'éléments architecturaux que les bétons « traditionnels » ne peuvent réaliser. Du fait d'une microstructure extrêmement dense, leur matrice cimentaire constitue un milieu quasi imperméable à l'air et à la pénétration des liquides, ce qui contribue à une amélioration significative de l'étanchéité des façades par l'extérieur. La finesse des BFUP, associée à une résistance élevée, autorise également la fabrication de pièces aux dessins plus complexes de résilles tout en conservant une épaisseur moindre. Le BSI® s'intègre parfaitement dans cette démarche. Plusieurs chantiers de bâtiment ont mis en avant l'utilisation du BSI® blanc à fibres synthétiques pour l'habillage de façades avec des éléments de grandes tailles en faibles épaisseurs ainsi que la réalisation de pièces fines ajourées de type résilles ou « moucharabieh ».

1. INTRODUCTION

UHPFRCs have many structural uses since it's what they were initially designed for. But such qualities as fineness, water tightness, high compressive strength and significant tensile strength, makes them good candidates for fine and elegant structurally autonomous elements. The great ability to mould that material brings it closer to architects who already recognized concrete as a durable and mineral material. Being able to go through time without aging neither in structure nor in appearance, justifies its use for aesthetic and architectural purpose. What would have been an overhead expense is in reality a saving considering no maintenance is needed at all over a virtually infinite lifetime.

BSI® is a patented kind of UHPFRC with different formulas available including one specifically engineered for architectural applications. (BSI® stands for Béton Spécial Industriel, Special Industrial Concrete). Through 5 iconic projects, this papers illustrates with how UHPFRC opens a new spectrum of architectural application.

2. CARCASSONNE SCHOOL OF ARTS

The Carcassonne's School of Arts, France, whose 1200 students study music, dance, plastic arts, dramatic arts (theatre and cinema), photography etc… boasts an impressive façade. Located in southwest Carcassonne, the building reflects the city and flows along the meanders of streets at the city's entrance. Its white concave façade wraps around an outdoor theatre.

Figure 1 : facade panels with Bamboo imprint

A total of 750 planar façade panels are juxtaposed to cover 1200 m² of the curved wall. These are prefabricated on a bamboo-like mould (called matrix), that gives a very fine degree of detail. Width is standard for all panels, 85 cm, while height is variable according to the layout, up to 2.60 m. Due to the pattern imprinted on the panel, its thickness varies but no less than 35 mm, which is the solid section validated by calculation (Fig. 1).

The prefabrication process is the same for all kind of flat elements. Concrete is poured into rigid polyurethane moulds featuring specific design and/or texture. These moulds are handmade, with the help sometimes of numerically controlled machines and/or pre-existing patterns.

All faces of the panel are in contact with the mould and produce a perfect finish. The top face which is not in contact is finely hand floated and usually is the non-visible one. Pegs or captive nuts are also inserted while the concrete is fresh, to be able to extract the panel from the mould and lift it until its final place. Extraction occurs 48 to 72 hours later. The pieces are then stored onto custom racks and immediately ready for delivery.

Given the panels' limited weight (less than 260 kg), a classic stone cladding technique (stapled stone) was chosen to attach the façade to the wall, consisting of a load bearing stainless support with restraining pins (Fig. 2). Those pins fit in matching grooves in the panels' top and bottom edges. While requiring exact positioning of the attachments according to the architectural layout, it offers great results because two successive panels can be attached with only one support ensuring continuous alignment. A rain screen and a thermal insulation were installed after the supports positioning, and before the panels' installation.

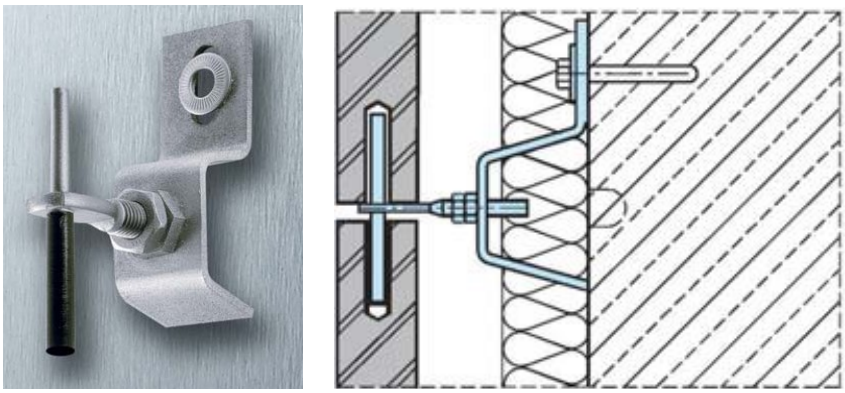

Figure 2: Fitting principle

Owner:	Communauté d'Agglomération du Carcassonnais
Client representative:	C.P. & O
Architect:	Atelier J. Ripault et D. Duhart
Technical inspection:	CETE Apave Sud Europe
Contractor:	Eiffage Construction Roussillon
Prefabrication plant:	Atelier Artistique du Béton - AAB
Key figures:	750 BSI® panels – 1190 m²

3. DIJON REGIONAL DEPARTMENT OF EDUCATION

Previously dispersed across five different locations, 600 employees of Dijon's Regional Department of Education, France, were brought together to the same place in an eight-storey building with a surface area of 11 000 m².

This tall building, which makes maximum use of the available building volume, is a sculptural block of white and luminous stone streaked with varying continuous glass banners in a zebra-like pattern (Figure 3). From the inside, it provides uninterrupted panoramic views to the offices. From an outside point of view, it's an intricate combination of custom made windows and tailored UHPFRC panels. Panels are cladded to the building using conventional techniques.

Almost 1100 elements, all 2.6 m wide, were produced to specific dimensions and geometries. This is a particularity, given that prefabrication is more used to produce strictly or mostly identical elements. Around 4000m² of façade are covered in this mineral material. Panel thickness grows with height. If it's less than 2.70 m high, thickness is only 35mm and it increases up to 70 mm for the tallest panel (5.20 m high). Special curved panels were manufactured to cover the building's external angles.

Figure 3: Dijon Regional Department of education (façade panels in white BSI®)

Highly specific engineering studies were conducted to justify this concrete cladding for a tall building. Positive and negative wind pressures were determining factors for the dimensions of these thin panels.

The panels were 3D modelled in a finite element calculation Software. These finite element models use a UHPFRC material, with linear behaviour, to validate thicknesses needed to withstand load cases, such as wind or punctual loads (Figure 4).

After theoretical calculations, physical tests are conducted at the Structures and Fire Safety Department of the CSTB research centre in Marne-la-Vallée, France.

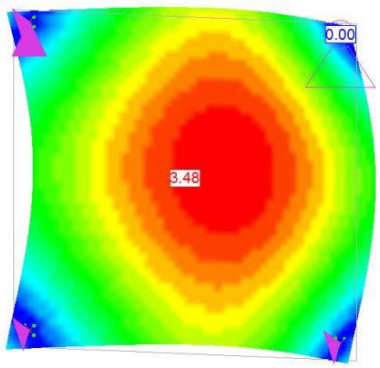

Figure 4 : Panel's 3D stress model

Wind resistance test is performed by the mean of a static distributed load of 68 daN/m² for positive pressure and -50 daN/m² for negative pressure. When 68 daN/m² are applied on a surface S = 6.24 m² it makes 425 kg supported by the 2.6 x 2.4 x 0.035 m panel which only deflects by 4mm at the centre (1.5/1000 deflection). The load is maintained for 10 minutes and the residual deformation measured one minute after load removal is less than 0.5 mm. Failure test is also required and performed by gradually increasing the distributed load up to 1086 kg, or 174 daN/m^2, which is 2.5 times the normal load.

The manufacture of these panels is similar to Carcassonne ones since there is a fixed width flat mould with adjustable heights. Yet, there are some specificities: the top and bottom edges of the mould are adjustable in height and angle to fit the varying façade's lines. Given the panel's weight, pegs and rails are inserted in the concrete to serve to lift and hang the panel, instead of stapled stone grooves.

A hanging system is adopted. Two attachment points at the top and two anti-lift retention points are implemented. Attention should be focused on not rigidly fixing the panel in place and on allowing it to settle with its expansion and stresses. The system was designed by the installation contractor, according to the windows installed at the same time (Figure 5).

The inserts incorporated into the panels, whether sockets or rails, underwent lamination and shear testing at the CSTB, in order to validate these parts' stress resistance

Any type of attachment can be considered and assembled with our inserts, which means the panels can be installed in soffit positions. It's the case in some places on this Dijon project.

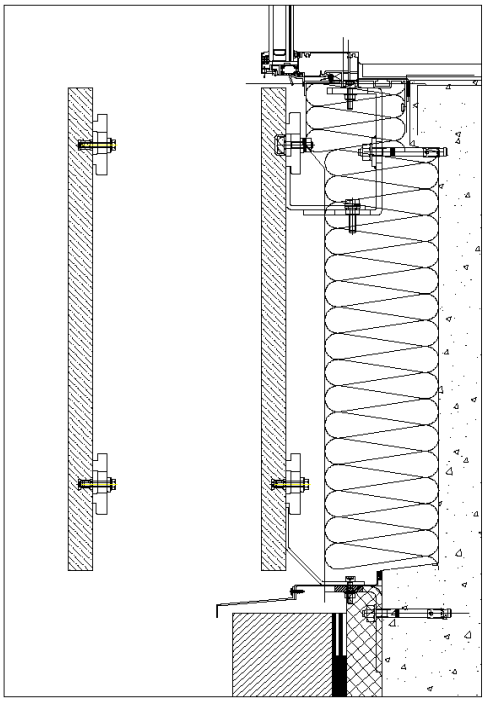

Figure 5 : Fitting detail

Owner :	Ministère de l'Education Nationale
Project manager :	DDT Côte-d'Or
Architect :	Rudy Ricciotti
Technical inspection :	Qualiconsult
Contractor :	Eiffage Construction Côte-d'Or
Prefabrication plant :	Atelier Artistique du Béton - AAB
Key figures :	1090 BSI® panels – 3870 m²

4. FRESNES SCHOOL

La Ceriseraie is a district in Fresnes, France, that needed new primary and pre-schools. 3800square meters of buildings and playgrounds had to be protected both physically and visually from public space and streets with a fence, hence the architect's choice of a fishnet-like interlaced fence, made of white UHPFRC with synthetics fibre. At first glance this mesh seems random, but on a closer look it reveals hundreds of animals.

The palisade is 300m long and made of 134 panels following a lace-like route. Each panel is 1.85-m wide and measures up to 3.20-m high (Figure 6). On the upper part voids are significant to see through the fence, and from top to bottom the density increases by increasing strands thickness to give better inertia to the barrier.

The complexity of such a design, with lots of interlocking strands, guided the choice of a silicone mould (Figure 7). It is way more flexible than a polyurethane mould and enables an easier release. However, silicone is more fragile and less durable than its late competitor which implies having more moulds, in that case 3 instead of one to cast all 134 elements. This could have been a problem in other circumstances, by increasing the cost for nothing. But in that case advantage was taken to improve the overall design making 3 unique moulds, used 45 times each, multiplying the diversity of the fence's elements.

Figure 6 : Fence elements in white BSI®

Figure 7 : Silicone Mould

5. LA MANTILLA - MONTPELLIER

La Mantilla owes its name to the white mantilla that envelopes its façade (Figure 8). This property development with seven buildings arranged around a central 2000 m² landscaped island, boasts 32,000 m² of floor area, 407 dwellings, almost 5900 m² of ground floor retail space and a 3500 m² building with three levels of underground parking. It is a sculptural and modern project thanks to the lacework that runs along the loggias and balconies.

The architect designed 3 different patterns with 4 void density each. This implies 12 different types of moulds. Given the tight schedule and the 1150 panels, for some 4000 m of balustrade, 16 heavy-duty polyurethane moulds were used (Figure 9). A white UHPFRC formula with synthetic fibres was implemented for its brightness and its safety regarding the contact with people. An interesting challenge was to fasten the balustrade to the balcony slab (Figure 10), given the openwork is only 5 cm thick. The principle adopted was to attach UHPFRC posts to the panel's back. The posts are 10 x 8 cm with an integrated plate for fastening to the balcony floor. This configuration can withstand applied stresses of 60 daN/ml at a standard height of 1.10 metres. Moreover, a swing bag test simulating a body impact was performed at the factory to check the compliance of the calculated structure to safety standards.

Finally, given the location and altitude, the wind pressure adopted for drag effects was 125 daN/m². The tests were conducted on the most open and therefore the "weakest" pattern with an evenly distributed load in an approved laboratory. It took almost nine months to produce and transport these balustrades to Montpellier.

Figure 8: Balustrades for "La Mantilla" project

Figure 9: Concreting a prefabricated element

Figure 10 : Test prototype

Owner :.....	BOUYGUES IMMOBILIER / PRAGMA / SOGEPROM
Architect and project manager :	Jacques Ferrier Architecte / A+ Architecture
Technical inspection :.....	Qualiconsult
Contractor :.....	Fondeville
Prefabrication plant :.....	Atelier Artistique du Béton - AAB
Key figures:.....	1153 BSI® panels – 5808 m²

6. EVA SALMON SCHOOL IN VITRY-SUR-SEINE

Eva Salmon School's rehabilitation was subject to high environmental requirements. The cladding latticework, with a 60 % void, impacts the visual comfort and energy performance. This lattice facade blends with the urban landscape evoking tree's branches (Figure 11).

Figure 11: Project overview

The architect wanted to materialise strong strands at the base of the façade and finer and more numerous strands upwards, like a tree. The intermeshed strands are 7 or 9 cm thick.

The 4.80 m wide by 8.65 m high pattern's recurrence is blended over 4 panels, 2 types on top and 2 types below, mimicking a homogeneous forest.

Four different moulds were made using a flexible material able to absorb the shrinkage of such large elements as the concrete sets. The release was the most critical phase in the panels' lives and had to be performed with care:

- The number of lift points was increased
- A spreader was systematically used
- Concrete's resistance for release had to be greater than 70 MPa.

The special BSI® white formula with synthetic fibres made it possible to pull the components from the mould after 20 hours of cure only, without any heat treatment. These 170 panels are

suspended from a secondary metal frame using two hangers and four spacers. Each panel has six attachment inserts that were tested for lamination and shear resistance in representative strands. The facade's curves were covered with vertically split panels (Figure 12).

Figure 12: Facade curved lines

Owner :	Ville de Vitry-sur-Seine
Architect and project manager :	Daquin et Ferrière Architecture
Technical inspection :	Socotec
Contractor :	Urbaine de Travaux
Prefabrication plant :	Atelier Artistique du Béton - AAB
Key figures :	170 BSI® panels – 1130 m²

7. CONCLUSION

Architectural boldness featured through these facades proclaims the BSI®'s and UHPFRC's new abilities compared with standard concrete. Not only it fulfils intricate and refined architectural and design needs but it also boasts its adequacy for long lasting self-supporting architectonic elements.

Large-scale, lightweight, thin, durable, rot proof, watertight…, are few of BSI®'s intrinsic qualities to which user purposely adds elaborate texture, well-chosen color, to play with mineral feel and visual aspects.

Ideally suited for structural projects, UHPFRC are now also proven architecturally relevant.

ACKNOWLEDGEMENT

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