DESIGN AND PRODUCTION OF UHPFRC RAISED FLOOR TILES

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Abstract

High-rise buildings renovation generally demands to replace existing false floor with new incombustible, strong and as thin as possible tiles. Gypsum based products are widely used for this application; however their weight and thickness are major disadvantages. UHPFRC raised floor tiles (CIMBURO) have been developed by Bonna Sabla to offer improved thickness (14,5 mm), significant lightening (13 kg instead of 25 kg - making them safely handle-able) and incombustibility (M0 degree). UHPFRC grey premix, was tested with different dosage of metallic fibers to provide the performance required by NF EN 12825. Cost-effectiveness of the solution was achieved among others with the implementation of a fully automatic line of production integrated with adapted UHFRPC facilities. 5 000 m² of 600x600x14,5 mm UHPFRC raised floor tiles have successfully contributed to the renovation in 2016 of the "Tour Hachette" in Paris (IGAPE, Roland Castro architect) newly-named "Tour Greenelle".

Résumé

Les rénovations entreprises sur les immeubles de grandes hauteurs nécessitent généralement de remplacer les faux-planchers existants par de nouvelles dalles incombustibles, mécaniquement performantes et aussi fines que possible. Les produits en plâtre sont largement utilisés pour cette application bien que leur poids élevés et leurs épaisseurs importantes soient des inconvénients majeurs. Bonna Sabla a développé récemment un système de faux-plancher en BFUP (CIMBURO) offrant des dalles d'épaisseurs réduites (14,5 mm), significativement plus légères (13 kg au lieu de 25 kg donc manuportables) et incombustibles (M0). Le prémix a été testé avec différents dosages de fibres métalliques afin d'obtenir les performances mécaniques requises par la norme NF EN 12825. La mise en place d'une ligne de production totalement automatisée intégrant du matériel adapté à la fabrication des BFUP contribue à l'efficacité économique de cette solution. 5000 m² de dalles de faux planchers (600x600x14,5 mm) en BFUP ont contribué en 2016 au succès de la rénovation de la « Tour Hachette » à Paris (IGAPE, Roland Castro architecte) rebaptisée « Tour Greenelle ».

1. RAISED ACCESS FLOORS MARKET AND SOLUTIONS

Raised access floors have been revolutionising office layouts for the past 50 years. This is why the office planners have adopted this solution in order to improve workspace modularity. Currently, most solutions focus on the use of chipboard tiles in combination with a metal frame. A more "up-market" solution consisting of gypsum tiles is also proposed. This range targets high-rise buildings and those open to the public in order to guarantee fire-resistant behaviour. Finally a more "architectural and marginal" solution adopts ceramic or concrete tiles left exposed. Pressures on real estate in large cities, and environmental criteria have imposed the need for building renovation for several years. This is why a number of high rise office blocks and real estate units are undergoing or pending renovation. In addition, changes to fire regulations making them more stringent has forced renovations to comply with the use of floor boards compatible with fire resistance criteria.

Office developments give priority to a significant clearance under the ceiling for comfort, while having to cope with the passage of building systems (ventilation, electricity, etc.) leading to a reduction in void thickness (in the ceiling or in the floor). A final criterion is related to the difficulty of tile laying operations. A tile must indeed remain movable by hand and thus the unit weight per slab must not exceed 25 kg.

In light of all these points, Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC) has appeared as a response to these restrictions.

2. THE CIMBURO SOLUTION AND UHPFRC

CIMBURO flooring is a raised access floor made of Ultra-High Performance Fibre-Reinforced Concrete tiles laid on fixed height pedestals positioned on the structural support. These floors, compliant with the NF EN 12825 standard, are designed for use in office blocks, buildings open to the public and high-rise buildings to enable electrical, IT and telephone wires to pass into the void created.

In light of the preceding criteria, the solution is constituted of the following components (geometric details in the figures 1 below):

- UHPRC prefabricated tiles with plane dimensions 600×600 mm² and 14.5 mm in thickness. Portable, as they only weigh 13 kg. The tiles are in M0 material (incombustible) and will resist considerable punching forces, despite their low thickness.
- V0 plastic pedestals, standard height 38 mm, fitted with integrated adjustment shims and two M1 material cable inlets/outlets.

The pedestal + tile unit has dimensions of 50 mm, which generally corresponds to the thickness of the screed (taking out the existing screed allows the use of a raised access floor) and gives a void clearance of 36 mm, which will accommodate power supplies (for junction boxes, there must be a minimum clearance of 30 mm).

The mechanical strength of the tiles is compliant with the specifications of the NF EN 12825 standard and is subjected periodically to certified tests (see §3).

UHPFRC tiles meet the loading and strength criteria for tiles under stress, specifically punching. Development of a specific UHPFRC formulation: cement matrix + fibres enabled these criteria to be met. This optimisation work is discussed through the next paragraph.

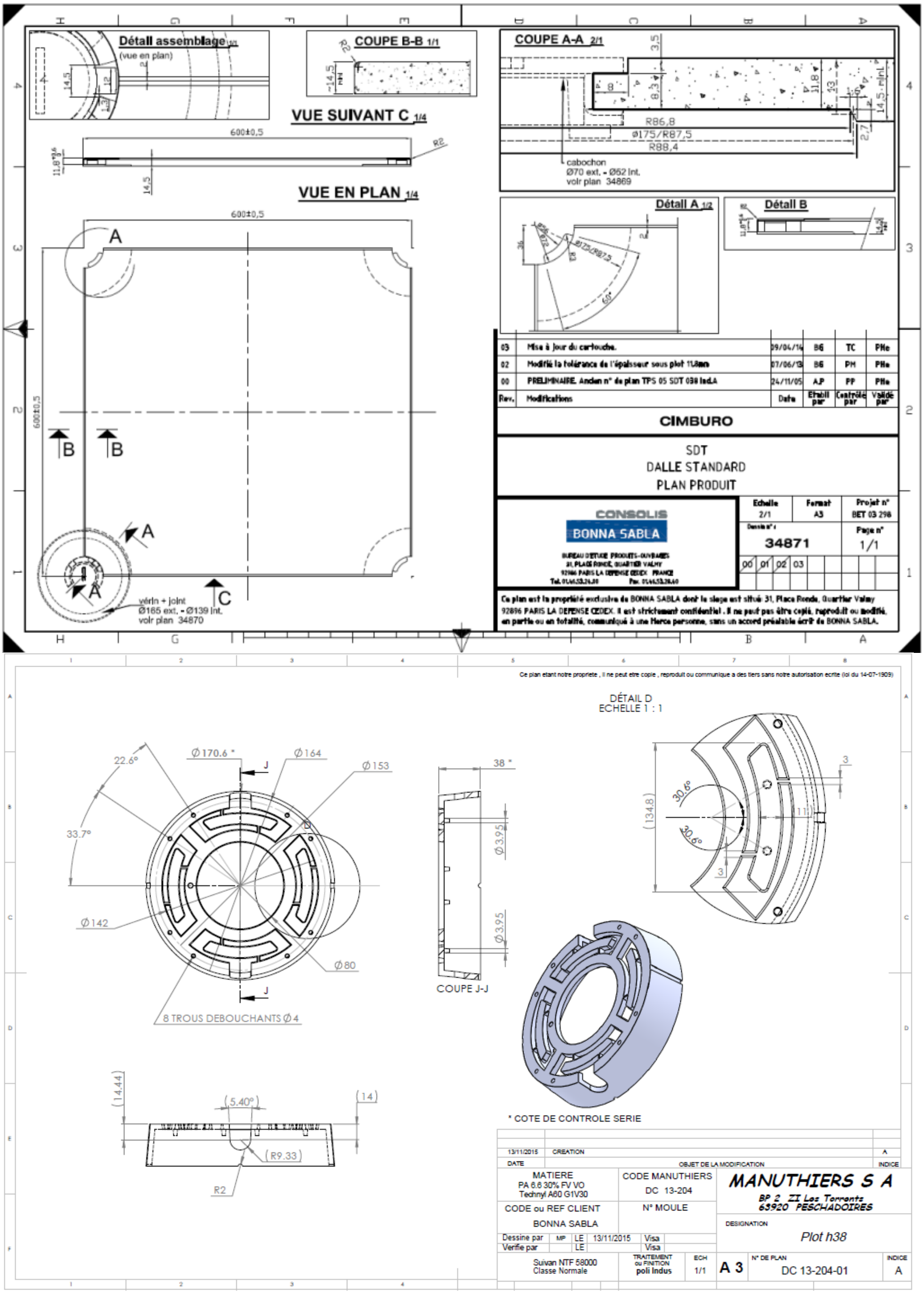

Figure 1: Description of CIMBURO Solution

3. SETTING UP AND CHARACTERISATION OF A UHPFRC TILE

3.1. NF EN 12825 standard – Raised access floors

The EN 12825 standard specifies the relevant characteristics and instructions applicable to freely accessible raised access floors, designed to be installed inside buildings and to offer total access to building system facilities located in the void. Raised access flooring is designed and manufactured to provide mechanical resistance and stability so that the intended operating load will not cause it to buckle or break.

The failure load is the main criteria used for rating. We apply a safety factor of 2 which, based on the breaking load, gives the permissible load for the raised access floors.

Deflection corresponds to the flexibility of the system. The most rigid system has a rating of A and the most flexible is rated C. Deflection is measured while loading the tile at the permissive load value. In accordance with the NF EN 12825 standard (Tables 1-2), the CIMBURO solution is rated 1A this means that the permissible load on the system is 2kN, that deflection has never exceeded 2.5 mm under 2 kN and that the breaking point is ≥ 4kN.

Tables 1 and 2: NF EN 1285 ratings

Rating	Failure load (kN)
1	≥ 4
2	≥ 6
3	≥ 8
4	≥ 9
5	≥ 10
6	≥ 12

Rating	Maximum deflection (mm)
A	2,5
B	3,0
C	4,0

3.2. Test protocol

While developing the CIMBURO raised access floor solution, various trials were carried out with the UHPC premix. The objective of the tests was to determine the optimum metallic fibre dosage to achieve the mechanical strength performance required by the EN 12825 standard.

21 tiles with dimensions 600×600×14.5 mm were manufactured:

- 7 tiles containing 2.5 vol.% of metallic fibres (L_f : 12,7 mm / D_f 0,175 mm) – Ref. B0807
- 7 tiles containing 2.0 vol.% of metallic fibres (L_f : 12,7 mm / D_f 0,175 mm) – Ref. B0810
- 7 tiles containing 2.0 vol.% of metallic fibres (L_f : 20,0 mm / D_f : 0,30 mm) – Ref. B0812

These tiles were tested to determine breaking load as well as deflection. The forces were applied by means of an Enerpac BRD-46 hydraulic jack. The punching load was applied gradually increasing and following a straight line curve up to product breakage. The load was applied by means of a cubic punch with edges 25 ± 0.1 mm.

Tests were carried out by placing the punch: either in the centre of the weakest dimension of the tile, i.e. the centre of the edge; or in the centre of the tile. The test should have been carried out on the complete raised access floor system. In the case of CIMBURO, this system is formed by pedestals and tiles. As the prototype tiles do not support this configuration, they have been tested individually placed on 4 pedestals (figure 2).

Figure 2: Test material

A load-distortion curve at the jack is obtained on completion of these tests. The test is conducted with the load increasing, this being controlled by a hydraulic pump fitted with a pressure gauge. The bending is measured by a 0-25 mm range comparator, set as close to the punch as possible. A fresh tile is used for each test. The other elements are replaced as necessary according to the operator's assessment.

3.3. Results

The figures 3-4 summarise the experimental data obtained by punching in the middle of the edge, which is the most discriminant test for CIMBURO tiles.

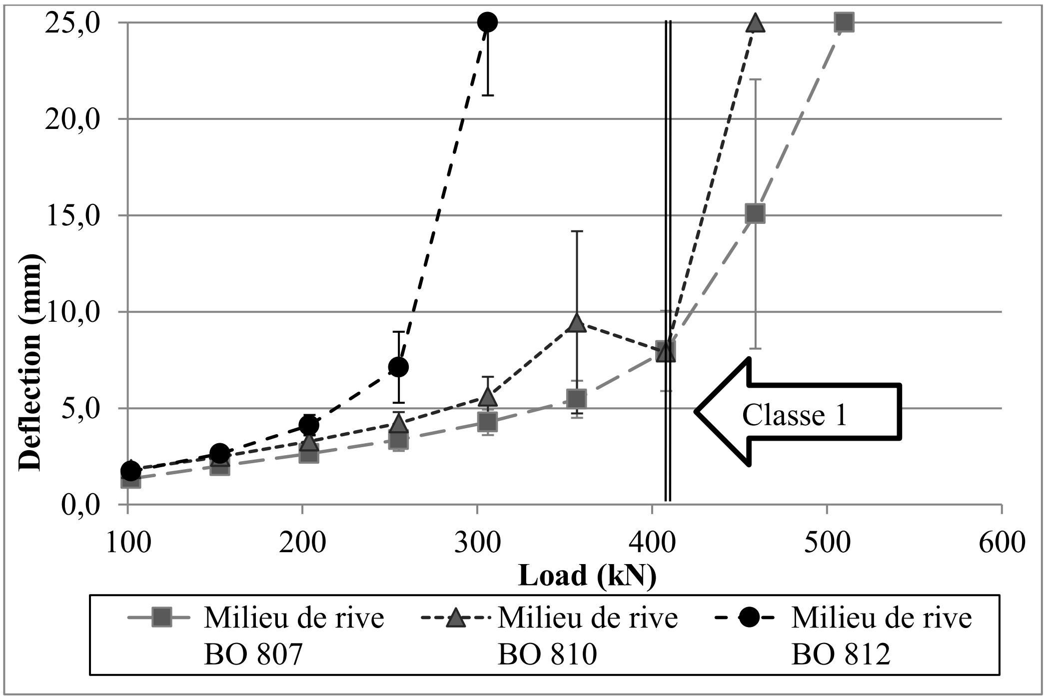

Figure 3: Breaking loads results (middle of the edge punching)

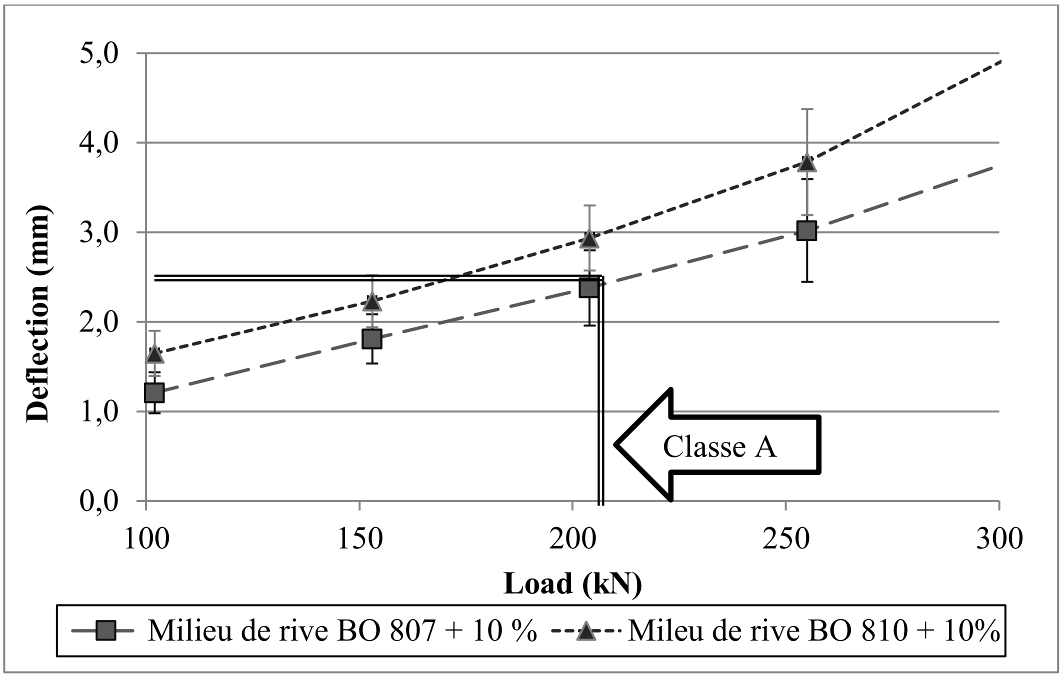

Figure 4: Deflection results (middle of the edge punching)

Relatively high standard deviation figures were obtained for loads close to the 4 kN limit, which might be explained by a more unequal distribution of the fibres in the edge of the tile. The BO 807 (and almost B810) formulation meets the breaking load of 4 kN.

Simulating the fixing of the tiles with the cabochon system represents a reduction by 10 % of the measured deflection. The graph below depicts the values which were obtained in this way. The BO 807 formulation meets the conditions imposed by the NF EN 12825 standard.

The punching at the centre of the tile resulted in 3 different breakage profile for the BO 807 formulation with 2.5% by weight of short fibres: "pure" punching, punching over a more extensive area and bending. The failure profiles observed during the punching test in the middle of the edge (Fig. 5) was similar for the 3 tests, with a crack starting at the punch and propagating at right angles to the stressed edge.

Figure 5: Failure pattern after punching tests (middle of tile)

3.4. UHPFRC FM full characterization

UHPFRC performances were fully characterized according to NF P 18-470 [2]. Tables 3-5 shows information extracted from the product identity card.

Table 3: UHPFRC mechanical performances

Characteristic strength in compression (f_{ck}) *(according to NF EN 12390-3)*	150 MPa
Characteristic value of the elasticity limit in traction ($f_{ctk,el}$) *(according to NF P 18-470)*	8.8 MPa
Characteristic value of the post-cracking strength in traction (f_{ctfk}) *(according to NF P 18-470)*	7.8 MPa
Mean value of Young's modulus (E_{cm}) *(according to NF EN 12390-13)*	44.0 GPa
Poisson's ratio	0.2

Table 4: UHPFRC durability performances

Water porosity at 90 days *(according to NF P 18-459)*	≤ 6,0 % *(Dp+ : improved porositiy)*
Chloride diffusion coefficient at 90 days *(according to NF P 18-462)*	$\leq 0{,}1.10^{-12}$ m².s^{-1} *(Dc+: improved resistance to the diffusion of chloride ions)*
Apparent permeability to gases at 90 days *(according to NF P 18-463)*	≤ 1.10-19 m² *(Dg+ : improved resistance to gaseous transfers)*
Abrasion index *(CNR testing protocol)*	1,1 *(RM1 – material resistant to "hydraulic" abrasion)*

Table 5: UHPFRC other performances

Coefficient of thermal expansion *(according to NF EN 1770)*	12 µm.m-1.°C-1
Total shrinkage amplitude at 90 days *(according to NF P 18-427)*	≤ 450 µm.m-1

4. UHPC RAISED FLOOR TILES PRODUCTION

Floor production fits into a vision of automated industrial production of standardised products. The Bonna Sabla plant, located in the suburbs of Lyon (France) is fitted with an automated UHPFRC tile production chain. The pedestals themselves are made by injection moulding at a specialist supplier. The production system (Fig. 6) is organised as follows:

- A mixing unit fed by silos for the premix and a bowl +conveyor for automatic fibre feed.
- A hopper for transferring the UHPFRC from the mixer to the moulds. This bus hopper is automated and fitted with a worm gear which deposits the desired amount of UHPFRC for each mould automatically.
- The moulds are arranged on an automatic carousel. The moulds are in groups of four and operate in the following sequence: pouring; oven storage for 24 hours; unmoulding; cleaning and moulding;

- Finally, the ovens will complement the installation in order to apply a thermal treatment to the tiles. These ovens may contain one week's production.

Automation reduces labour costs, increases productivity and this means a maximum production of 200 tiles a day - in other words, 17,000 m²/year

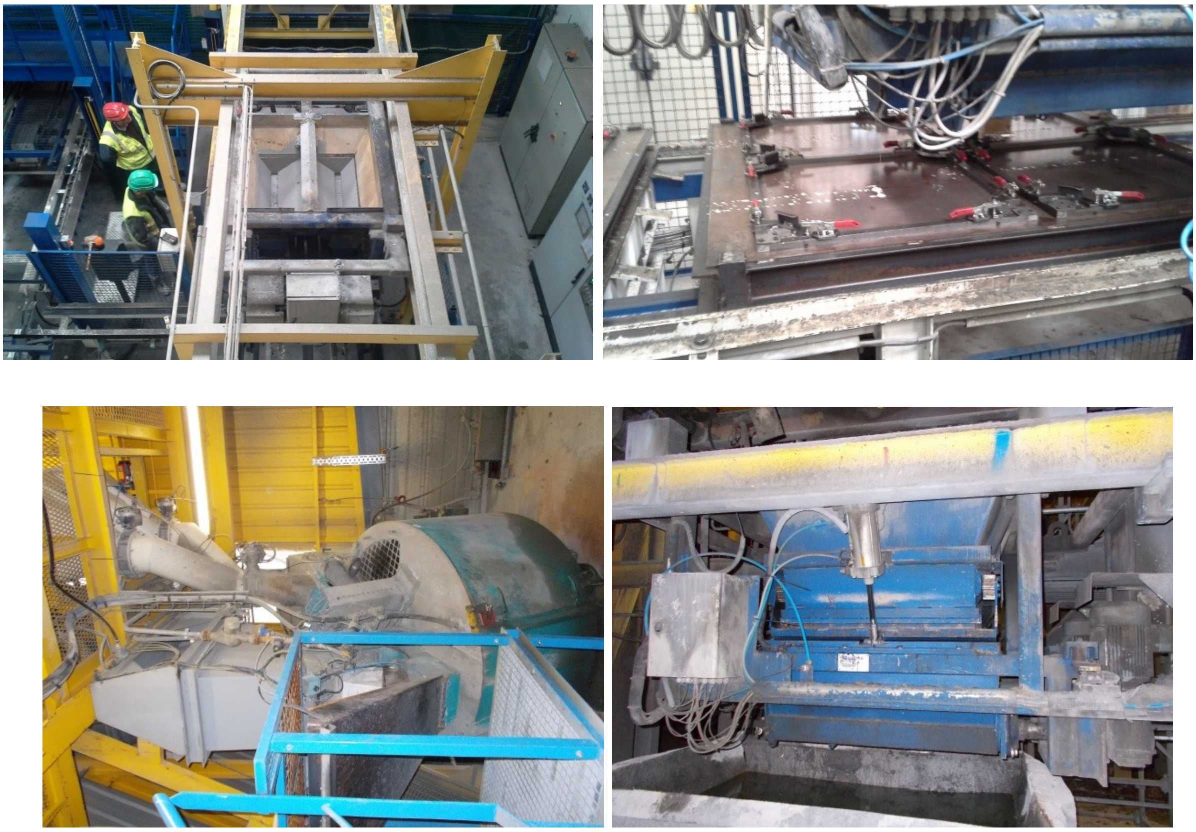

Figure 6: Photos of the production hall

5. CONCLUSION AND PERSPECTIVES

CIMBURO UHPFRC raised floor system offers a suitable and innovative alternative to competing solutions.

UHPC premix associated with 2,5% vol. of metallic fibres allows to reach the mechanical performance required by EN 12825 (raised floors standard).

Implementation of a fully automated production line and optimization of concrete fluidity enable to increase productivity, bringing CIMBURO price closer to competing solutions.

Future UHPFRC floor developments will focus, in addition to renovation, on an offer of raised access floors for industrial building capable of absorbing heavy loads by adjusting tile thickness if necessary.

REFERENCES

[1] AFNOR (2002) NF EN 12825, Planchers surélevés.
[2] AFNOR (2016) NF P 18-470, Ultra-high Performance fibre-reinforced concrete: Specification, performance, production and conformity.