XTREEE - REPORT

The picture can't be displayed.

A young and promising french startup trying to establish its name in 3D Construction Printing. With impressively strong industry partners, the company has quickly gained traction by delivering the first 3D printed structural element installed in a public building.

Company: XtreeE
Technology: D-Shape
Report issue date:

Issued by: 3D Printhuset A/S
Visit date:
Visited by:

Contents

Author: Anes Jakupovic, 3DPrinthuset

1. Technology overview

Xtree is a young startup focused specifically on 3D Construction Printing. The technology is based on a material layered extrusion process, where a concrete-like material is pushed through a nozzle that moves around the printable surface and deposits a continuous line of material in several layers, until the whole height of the object has been printed. This process, also called Material Extrusion, is seen in most 3D Construction printing technologies, and it is essentially a large scale implementation of the Fused Deposition Modeling (FDM), a very common technology seen in personal desktop 3D Printers.

The XtreeE company is well-rounded, as it covers all aspects within 3D Construction printing, from software, through printer and material, all the way to consulting, either on their own or through their numerous partners.

The Xtree printing technology in action

2. Company and development

2.1 Company´s history and overview

The company is a young french startup dating back to July 2015, with its first steps dating back to Democrite, a university project focused on large-scale additive manufacturing. It has quickly attracted strong industry partners in construction, cement, robotics and software, merging together all the important aspects necessary for a 3D printed construction project. Although still focused extensively on developing their technology, the company has managed to output an organically shaped pavilion, and the first 3d printed structure installed in a public building.

The company is guided by architect Philippe Morel, and a heterogeneous team of experts of various fields such as civil and mechanical engineering, computer science, management, material science, and architecture, the latter being the predominant field of most of its founders and current employees.

Apart from the 3D Printers, Xtree boasts a very technologically advanced design and consulting office, with all the most up-to-date technologies in use, such as Virtual Reality equipment, free-hand 3D design software, touch sensitive displays and drawing pads, and many more.

The XtreeE director, Phillipe Morel

2.2 Company size and number of employees

It has 10+ employees at the moment, with a strong will and plans to grow in the years to come. The company has mentioned the plan to move to larger facilities in 2017.

2.3 Partners

One of XtreeE's strongest assets is the partnership with many well known private companies from various industries related to 3D Printing in one way or another. Most of them from French origin, they are actively helping develop their project. Currently, there is no other technology that boast so many strong names as partners. A few of the main ones, are listed as follows:

- **Vinci** - a strong global player in civil engineering and the largest one in the world by revenue, with more than 183,000 employees in 100 countries. It deals with anything labeled construction, and specializes in large civil projects. Apart from being a partner, the company has also acquired a stake in XtreeE.

- **LaFarge - Holcim** - one of the largest concrete and building material providers in the world, working in 90 countries with 115,000 employees. It provides XtreeE with its expertise on creating the right mix to be used within 3D Construction printing.
- **ABB** - one of the largest engineering conglomerates that focuses on robotic systems, working in 100 countries with approximately 132,000 employees. It provides XtreeE with the necessary robotics.
- **Dassault Systemes** - a well-known software corporation focusing on 3D modeling and design, owner of extensively used software within mechanical engineering, such as Catia and SolidWorks. It provides XtreeE with all the software expertise and design programs necessary.

The company has also a wide variety of public partners, such as European Commission and many more.

Some of the main partners and clients of XtreeE

2.4 Targeted market

The company is targeting three separate sectors within 3D Construction printing, with its three separated categories of services:

- **XtreeE - Access** - providing consulting services within 3D Construction printing, that helps the client measure and quantify the costs and benefits of employing such technology
- **XtreeE - Core** - providing rental services of large-scale 3D printers

- **XtreeE - Platform** - providing supervision of projects that use large-scale 3D printers

2.5 Past, current & future projects

The young company has only a few projects and studies which have been released to the public. Although just a few, these projects are all very different, and represent each a small milestone within this developing industry. Some of the main ones include:

- **The first structural 3D printed part installed in a public building** - 4m-high post with a complex truss shape, which supports the playground roof of a school in Aix-en-Provence, France. The 3D printed part is actually the stay-in-place formwork of the structural concrete poured inside. However, it is still remains a very important milestone in the developing 3D Construction printing industry. It has been developed in partnership with LaFarge-Holcim, who provided the material expertise.
- **The first 3D printed pavilion in Europe**, with a strongly organical shape, made using generative design software. Commissioned by the Ile-de-France regional authority, it is a collaborative project bringing together XtreeE, Dassault Systèmes, ABB and LaFarge-Holcim.
- **Pillars for YRYS, a concept house** from Groupe Maisons France Confort (MFC), a showcase project for some of the most advanced and sustainable technologies in housing.
- **First 3D Printed student accommodation**, in partnership with organizations Habitat 76 and CROUS, a project still in design phase that will bring 3D printed housing to students of the University of Rouen's Mont-Saint-Aignan. Planned for 2018.
- **A 3D Printed drainage overflow shaft** for SADE, for the municipality of La Madeleine in Lille, also the first of its kind.

A complex-shaped column, the first 3d printed structure installed at a public school

The first 3D printed pavilion in Europe

The pillars for the YRYS Concept house from MGC

A sewage over-flow shaft, installed in Lille province, France.

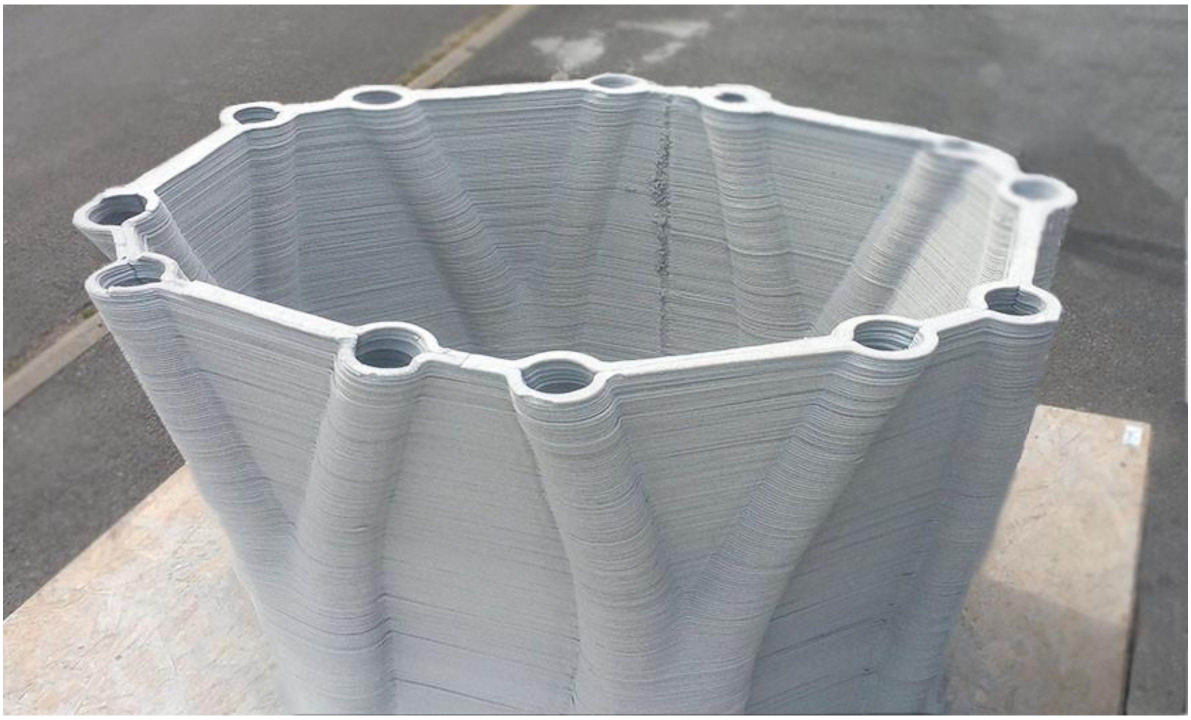
2.6 Development stage of printers

XtreeE has currently two printers in their facilities, which still under constant development and optimization. They have recently added a new nozzle system. The printers are fully functional and have been extensively used for various projects and prototypes.

2.7 Development stage of printed materials and largest print to date

The material know-how is handled externally, by one of the strongest names in the concrete production industry, LaFarge-Holcim. They have selected and fine-tuned some of their products to meet the required specifications of the 3D Printing process.

The area on which the technology is capable of printing depends mostly on the robot used, which is approximately a radius of 4 meters. Most projects are printed in components and then connected on site. Some of the largest one include the 4 meter tall column, which was made of four components, or the 3D printed pavilion.

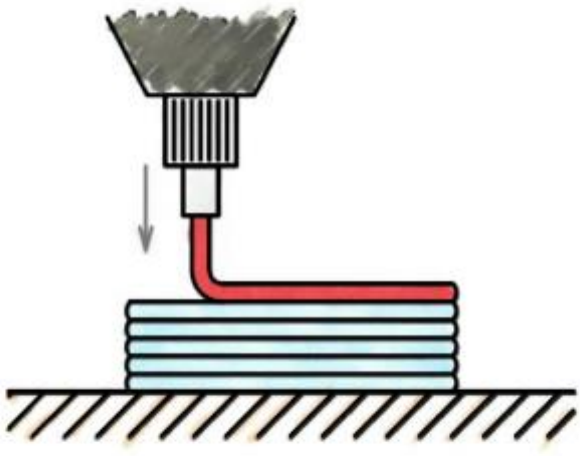


One of the components of the 4 meter tall column, the 1st 3D printed structural component in a public building

3. Technology

3.1 Additive manufacturing technology

The XtreeE additive manufacturing process falls under the category of Layered Material Extrusion. This is a construction-scaled *Fused Deposition Modeling (FDM)* process, a very known desktop printer process, where a material in fluid form is extruded through a small nozzle as a continuous stream or filament. The material is then solidified on the printing surface, ready for the next layer to printed on top. While its desktop counterpart uses molten plastic, that melts when going through a hot nozzle and then solidifies by cooling down, the construction scale process is quite the opposite. Here a cement-based material, usually with properties and aggregates similar to a mortar, is mixed right before being fed into the machine. While still fluid, the material is extruded through a simple nozzle, which only helps to shape and channel the material, very similar to adding frosting to a cake. When the material reaches the printing surface it starts to solidify by itself in a chemical reaction with air, which is also known as hardening (first hours) or curing (long term, several days). This process has a considerable level of sensitivity, since material needs to be fresh enough to flow through the machine. When reaching the printable surface the hardening should not be completed entirely before the next layer has been printed, in order to ensure a good bond between the layers, but it should also be sufficient enough to sustain the weight of the following layer (or layers).



Materiale Extrusion (layered)

3.2 Printing procedure

The printing procedure starts with the 3D model being sliced into layers according to the desired thickness, within the machine range. Xtree uses fine layers of around 3mm in thickness. Each layer is then translated into the instruction code for the movement of the nozzle around the printable area, using a programming language called G-code. Depending on the needs of the print, the machine can be instructed to:

- **Print only the outlines of the object:** This approach is the most typical and the most suitable one for formwork and walls, since it allows to print the outer walls of the object, and then fill in manually the space in between.
- **Fill the object completely as a solid:** this mostly done when a part needs to be heavy or structural (a solid is usually more resistant than a hollow material)
- **Partially fill by creating a specific pattern/geometry:** this type of filling is used mostly to reduce the quantity of material, the weight of the object, to reduce deformations that are induced from the material warping (less material, less warping usually), or similar reasons, while maintaining good strengths. It is usually done as a square mesh, but it can also be done in various specific shapes, if necessary.

Once the software has prepared a file with all the necessary machine instructions, the printing process can start. The concrete material is mixed in smaller batches, to prevent it from hardening too soon and blocking the machine (cement-based materials are usually workable for a few hours). The first batch is loaded into the pump, which pushes it to the nozzle and deposits it on a flat surface. Once the first layer has been printed, the next one can be printed on top. With each following layer there is some weight added to the structure, which will squeeze the first layers, making the whole print slightly shorter. XtreeE uses very fine layers, so this makes the problem less significant.

Once all the layers of the print have been completed, the process is finished and the object can be left to cure completely.

The XtreeE printer - printing of a layer

3.3 Form freedom

Since each layer needs to be printed on top of the previous one, the freedom of this additive manufacturing technology is more limited than others. The printer can create any shape in the horizontal plane, but once that shape has been chosen, it can essentially create vertical extrusions of this shape on top of it, or at least something contained within the shape itself, since it is impossible to start a next layer in midair. This type of printing freedom is not considered three dimensional, and it is often referred to as 2.5D freedom.

There is however a possibility to print each layer slightly leaning towards the outside compared to the previous one, slightly hanging over the edge. This allows to create mildly arched structures. While this approach is very common in desktop 3D Printing, where the sizes are very small and the materials are very light, it is much more complicated to achieve the same with a heavy and fluid material such as concrete, especially on a construction scale. It has a very unpredictable behaviour that depends a lot on the quantities that have been mixed, how long has the material been hardening, and many other external factors, such as wind. There is a high risk of the whole structure collapsing after many layers have been printed, losing a day's work.

There is also a third approach, where a sacrificial support structure is printed and then removed after the hardening is complete, by using mechanical tools. The advantage is a higher degree of form freedom, but the cost of the extra work and material necessary can be a limiting factor in some cases, so each print has to be studied carefully to choose the best solution.

XtreeE has successfully printed in all three different approaches: vertically extruded objects, slightly overhanging structures with a gradual change in their geometry through their height, as well as supported objects with sacrificial material that was removed afterwards.

3.4 Fabrication location and approach

The printer requires a foundation for the robotic arm to be installed, and a flat surface to print on top of. The printing process has currently been used mostly in indoor and controlled environments, for prefabrication of components that were later installed on site.

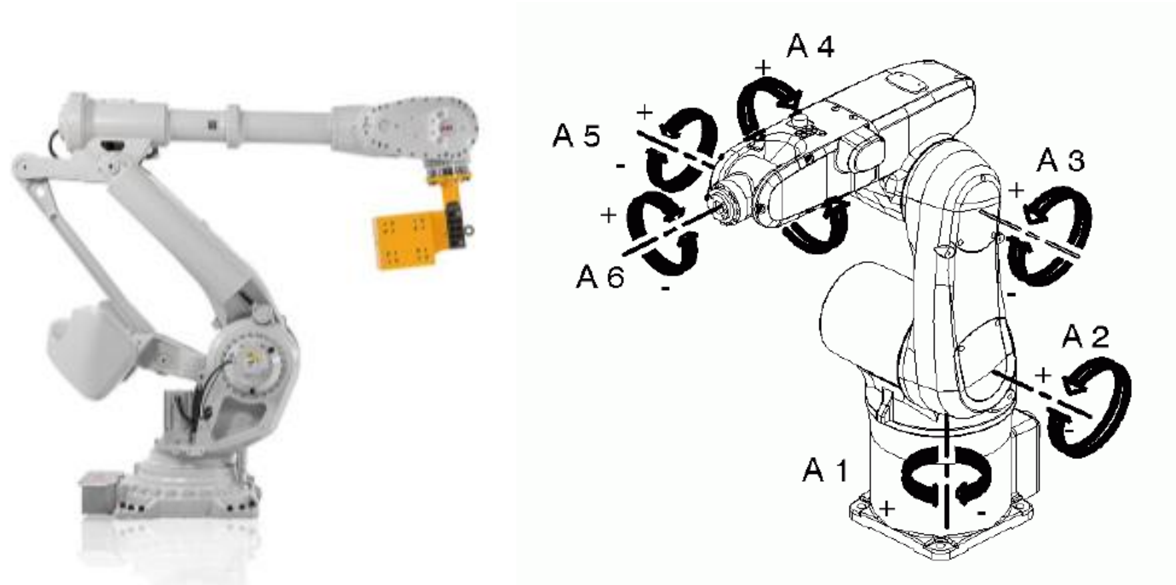
3D Printed components made by XtreeE on a flat printable surface

4. Printer

There are currently two machines that XtreeE is using, both based on a robotic arm system with an attached nozzle.

4.1 Movement

The XtreeE printer uses a six-axis robotic arm from AAB, one of its partners. The machine is capable of moving in every direction with its reach, by a combination of movements of its six different rotational joints. The complex joint movements are coordinated through a specific programming software. The current models are used as fixed onto a foundation, and are best suitable for indoor use. The company has expressed an intent to make future models mobile versions, that can be used also outdoors.



An IRB8700 robot from AAB (left), along with a sketch of the the six-axis of rotation (right)

4.2 Material deposition system

Most of the details on the deposition system are proprietary and not released to the public. The deposition system is a single nozzle with a cylindrical shape. The nozzle is equipped with an electric motor that is used to fine control and push the material through it, probably through an auger coil inside the nozzle itself. The nozzle is attached to a rubber hose, that delivers the concrete through pressure. Between the attachment of the rubber hose, and the nozzle there is an additional controller with a small plastic tube attached to it. The latter is probably used to deliver some additives to the mix right before being extruded. The company has mentioned a use of additives that change the rheological properties of the material right before being extruded, and changes its viscosity. The delivery system is also shown occasionally equipped with air heaters, to facilitate the hardening of the extruded material.

The material deposition system of an XtreeE printer

The company has recently shown one of its printers equipped with a new nozzle. The latter is now encased in a plastic cover, so the interior components cannot be seen. No details on the improvements made to the nozzle have been disclosed.

The new nozzle system of the XtreeE printers

The nozzle has been seen with various diameters. The most recent versions are shown with very small, 5-

10mm diameters, suitable for very thin layers of material (3 millimeters),, while older versions have been seen with much larger 30-50mm diameters capable of extruding larger quantities in less time. It seems that the company is focusing more and more on creating a precise print, as opposed to a fast print.

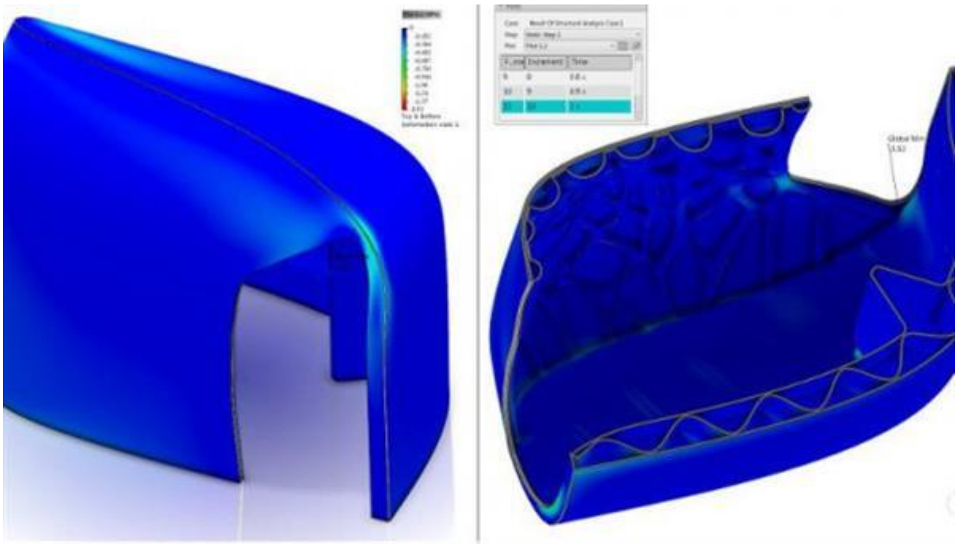
4.3 Material feeding

The material feeding components have not been disclosed to the public, although it is most probably an auger or piston pump feeding the nozzle through the rubber hose. These pumps are readily available on the market. The concrete is prepared separately with a standard mortar mixer, and then fed into the pump.

Concrete and mortar pump, with feeding tank, readily available on the market

4.4 Printer electronics and software

XtreeE uses very technologically advanced design software and hardware provided by Dassault Systemes called 3D Experience Platform. The printer hardware and software has not been disclosed, although it is said to be made and optimized internally by the company itself, and is still in development phase.



Design software from the 3D Experience Platform, used to make the 3D printed pavilion

4.5 Printer speed

The speed of the system has not been disclosed, although XtreeE has mentioned printing a 2.5 meter wall in 5 hours. What can be seen from their nozzle in action is a speed of approximately 10-15 centimeters per second, which translates to approximately 0,02m^3/hour. This means that the system can print a 2.5 x 2.5 m^2 hollow wall with one face on each side in about 6-7 hours, which is not far from the stated. The XtreeE printer is on the lower end for speed, but the company seems more focused on the quality of the print.

4.6 Printer accuracy

The accuracy is hard to define at this point, as the printers are still in constant evolution. A trend towards the reduction of the nozzle and layer thickness size has been noticed, which indicates clearly that the company is focusing on creating a product that gives reliable and repetitive results. This can also be seen in the quality of their prints and the fine nature of the used material. The accuracy varies also depending on the shape of the print. A rough estimate would be around 5mm accuracy, which is on the higher end of the spectrum.

4.7 Printer operation, handling and assembly

Theoretically, a single operator can operate the whole printing procedure, but the process seems best handled with at least two, one in charge of the printing procedure, and one mixing the concrete. In the XtreeE printing demonstrations there are numerous workers helping with the printing procedure, some checking or repairing the print during production.

Since the printer is essentially used in-house by XtreeE only, there is currently no official information on the time required to assemble or remove the printer on site.

4.8 Printer specifications

Printer size (assembled): approx. 1.5m x 1.5m x 3.0m (Width x Length x Height)

Printer size (stored): Not available

Print volume: radial reach of 4.2 meters
(Note: the robot can print 360 degrees around itself)

Printing speed (estimated): 0,02m^3/hour

Layer thickness: 3mm

Accuracy (estimated): 5mm

Deposition head: Single nozzle

Structure: Robotic arm

Movement: 6-axis rotation

Shape freedom: 2.5D

Weight: Not available

Energy consumption: Not available

Required personnel: 1-2 persons

Price per unit: Not available

5. Material

5.1 Material overview

The XtreeE has a great advantage compared to its competitors as far as material goes, since it has a partnership with one of the largest concrete producers in the world, LaFarge-Holcim. This allows the company to tap into a great knowledge resource, and finely optimize the material for 3D Printing purposes for years to come. XtreeE is currently using one of LaFarge-Holcim's high-end products, called Ductal, a ultra-high performance concrete with some amazing properties. The mix ratios have been fine tuned by LaFarge-Holcim specifically for the use with the XtreeE printer.

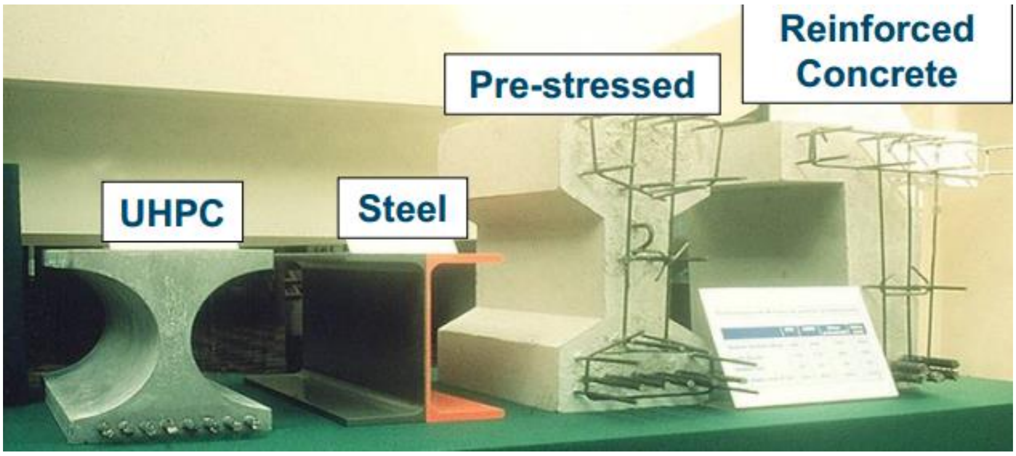
5.2 Ductal and ultra-high performance concrete properties

Ultra-high performance concrete (or UHPC) is a novel type of concrete first developed in the 1980s for applications where very high strength and durability are required.

UHPC is produced with common concrete materials, such as cement, silica fume, sand, superplasticizers and water. The Portland cement mixtures used are usually of very high strength, and there is also an addition of some unique materials like ground quartz and fibers, the latter usually made of steel. There are no large aggregates used, only fine grained sands.

Ultra-high performance concrete (UHPC), with visible steel fibers.

The properties of this concrete are exceptional. It has strengths of 150MPa, and can go as high as 250MPa, beating traditional Portland-based concrete by up to 6-8 times. Same goes for flexural strengths and tensions strengths, reaching up to 40MPa and 10MPa respectively. Given the presence of steel fibers, it is very ductile, and can withstand repeated stress cycles and deformations. It is also self compacting, due to the high content of superplasticizers and fines, which also gives it a very smooth and aesthetically pleasing surface with abrasion resistances comparable with natural rock. While being resistant to chemicals and damaging environmental factors, it is also resistant to cracking, shrinkage, thermal variations (freeze-thaw cycles), it is impermeable to water, and resists heavily chloride migration inside the concrete, that would consequentially corrode the steel inside.



Structural beams sections with equivalent strengths - UHPC has a comparable size to steel.

UHPC is extensively used in prefabrication for various elements, due to its aesthetic properties, abilities to conform to complex and detailed shapes, and a good resistance to environmental factors. It is also heavily used in large civil infrastructures and seismic areas for bridge decks, beams, windmill towers, columns, and many more, due to its great ductility, durability and high strengths.

Ductal is a very well-known brand of UHPC made by LaFarge-Holcim, with a well documented history of more than 25 years. This exceptional concrete comes also with a very high price, around 20 times more than traditional concrete.

Prefabricated facade elements made of UHPC

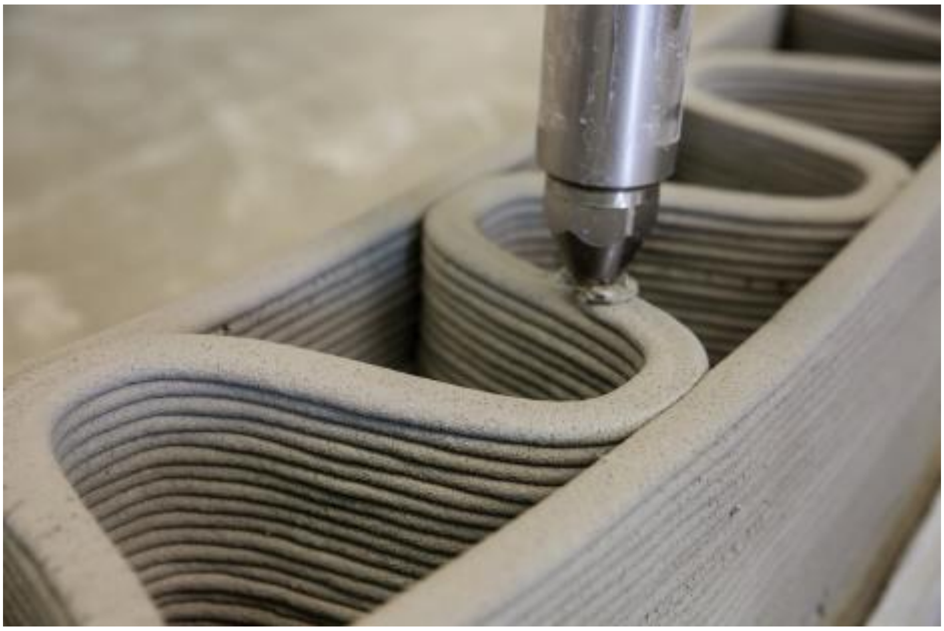
5.3 XtreeE 3D Printed concrete properties

No specific details have been disclosed about the characteristics of the XtreeE printed material. Judging by the size of the nozzle and layers (3mm), it seems less plausible that the steel fibers are used when extruding the material, rather only when the mould is made out of clay, and the concrete is cast inside of it. This reduces greatly the many exceptional properties of ultra-high performance concrete, mostly ductility, flexural/tensile strengths, and cracking resistance. Though substantially reduced, the material probably still maintains some good compression strength, abrasion resistance, and low shrinkage.

Since the printed material is made in layers, there is a reduced bonding between layers, which further decreases some of its properties. Namely, its tensile strength and impermeability are compromised, since a poor bonding can result in delamination between two layers.

Specimens printed by XtreeE, with a high quality surface appearance

The printed objects appear with a very fine layered surface, with a small amount of imperfections and errors in printing when compared to other technologies. The overall quality of the prints seems higher. The use of UHPC allows for superior mechanical properties, less shrinkage, and an overall more accurate, finely grained, and aesthetically pleasing appearance.



An XtreeE print, with very thin even layers, and a finely grained surface

5.4 Material pre- or post-treatment

The finished prints are often grinded or plastered to give them a more smooth surface.

5.5 Material possibilities

Ultra-high performance concrete is a great material with an ever expanding research and use within the construction industry. When used as a 3D printed material, some of its properties are inevitably lost.

XtreeE has opted for a more fine layer and nozzle configuration, which deprives UHPC of its fiber reinforced advantages. Even if a larger nozzle would be used, which would allow for fibers to be extruded as well, they would probably end up oriented in a specific direction, following the trajectory of the nozzle. This would allow for increased tensile strength in the horizontal plane. But the main issue with the poor bonding between layers, a characteristic of additive manufacturing technologies, rather than a problem related to XtreeE, would still remain unresolved.

However, the use of UHPC mixes within 3D Construction printing are still justifiable and recommended in many ways. First of all, the process itself is a very expensive and time consuming process, especially when focused on high quality fine-layered printing that XtreeE is aiming for. This justifies using a more expensive material, that delivers better results for the same, limited amount of volume that is being printed. Furthermore, the low content of water in UHPC makes it less prone to shrinkage, which is a major issue in 3D printed parts, where a large surface of the material is exposed to air and evaporation. This can cause objects to warp, deform and crack, or layers to delaminate before even being put into use. Finally, the presence of fines gives the material a more even finish, and allows the printed objects to be easily smoothed or polished for an improved quality.

Overall, when comparing UHPC to traditional concrete within 3D Construction printing, UHPC is more expensive, but a better choice if quality is crucial, since it delivers a product with less issues and far better properties.

6. Useful links and sources

XtreeE web page:

http://www.xtreee.eu

Dassault Systemes web page:
https://www.3ds.com/

Articles in media about XtreeE:

https://3dprint.com/164656/xtreee-vinci-construction-partner/

http://www.3ders.org/articles/20160921-french-startup-xtreee-is-developing-direct-3d-printing-for-construction-processes.html

http://www.3ders.org/articles/20160922-xtreee-dassault-abb-and-larfargeholcim-unveil-europes-first-3m-tall-3d-printed-pavilion.html

http://www.3ders.org/articles/20160921-lafargeholcim-and-xtreee-successfully-3d-print-europes-first-concrete-structural-element.html

https://www.sculpteo.com/blog/2016/12/07/interviewing-xtreee-3d-printing-concrete-to-push-the-limits-of-construction/

Ductal (UHPC) web page:
http://www.ductal.com/en