BETABRAM - VISIT REPORT

With a small and dedicated team of enthusiasts headed by Joze Abram, the BetAbram project set a bold goal to bring 3D construction printing to everyone by selling extremely affordable printers. A functional prototype in place, but some financial and technical bumps along the way, the company is still slowly moving towards its goal.

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1. Technology overview

BetAbram is a technology based on 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. While there is no particular focus on the material at this stage, the company has been experimenting mostly with mortars and very fine concretes. This process 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 BetAbram is indeed very similar to its desktop counterparts in some aspects. It uses some of the same open source software, while it also aims at the very bottom level of the market, with an extremely affordable selection of printers that could be an easy investment for smaller construction contractors, or even 3D Printing enthusiasts.

The BetAbram printer (model P3)

2. Company and development

2.1 Company´s history and overview

The BetAbram is a project owned by Interelab, a company dealing with maintenance of large industrial machinery. While its parent company has been present for a longer time, BetAbram is fairly recent, having started with 3D Printers only in 2012. The name gained wide media attention in 2014, when the frame of its first and smallest model has been released to the public, along with some test prints, showing a working prototype. The company announced its following larger models that were missing adjustments of software. However, some financial issues followed, along with some technical issues regarding the extruder and material, which brought the project nearly to a halt. After resolving the financial issues, the project has been restarted in the middle of 2016. The company has redesigned its webpage and logo, and has been working with optimizing the printer models. They claim they have been working mostly on a new type of extruder, based on what has been learned with the first prototypes.

BetAbram's old logo (left) next to the newly designed one (right)

2.2 Company size and number of employees

The current number of employees and the sheer size of the company are not clear at this stage, but it is still quite small (less than 10 employees). The project is led by its founder, Joze Abram, mostly alone, while Rene Ribič has been a mentioned as a sales manager in the past. Other workers and experts are hired ad hoc, when larger work on the printer is necessary.

2.3 Targeted market

The company aims exclusively at selling printers and offering technical support and maintenance of the machines. The printers are currently built on demand, which translates to waiting times of about 6 months.

2.4 Past, current & future projects

Apart from some tests prints and prototypes on behalf of the company, there are no publicly known project involving BetAbram up to date.

2.5 Development stage of printers

BetAbram has 3 machines at the moment, one for each of their models (P1, P2 and P3), which are in a development phase. During the visit (December 2016), the largest model has been shown in a prototype stage, where the gantry movement structure was fully operational, but the extrusion head was missing, which was said being under maintenance and further development. The company has also published several footage showing the mentioned model fully operational in the past. The company is now working on a new type of extrusion head.

2.6 Development stage of printed materials and largest print to date

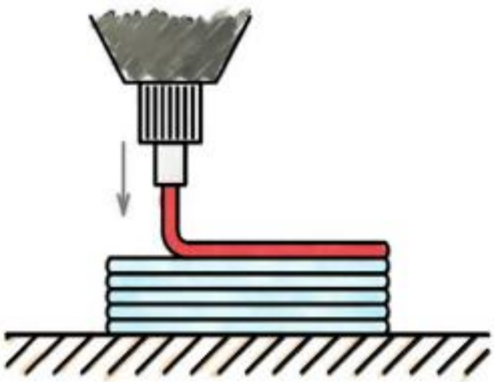
The company has hit some issues with the first models of printers, mostly with optimizing the material to be both fluid enough when passing through the nozzle, and hardening quickly enough once deposited. However, there have been several test prints done with this prototype material. The largest one is a small spiral staircase, showcasing the possibilities of the printer. The dimensions are approximately 1,5 x 1,5 x 1,5 meters (see picture below).

A spiral staircase, the largest printed object by BetAbram

3. Technology

3.1 Additive manufacturing technology

The BetAbram additive manufacturing process falls under the category of Layered Material Extrusion. This is an 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 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 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 a 3D model being sliced into layers by a layering software such as Simplify3D, Slic3r or similar. The print is sliced according to the properties of the material, or more specifically how much it will settle down when extruded, which is approximately 10-20mm layers. The software then translates each layer into 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. It is usally 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-like 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. Therefore it is necessary to stop or slow down the printing process, to allow the first layers to harden enough. The BetAbram process can print up to 25 centimeters in one go, but then it is necessary to wait for 5-6 hours in order to have the layers harden enough for the next batch. Once the last layer of the object has been printed, the process is finished. The printed object is then left to harden completely (process known as curing).

The BetAbram printing process

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 only 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 the 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 as an example.. There is a high risk of the whole structure collapsing after many layers have been printed, losing a day's work. BetAbram has currently shown only vertically extruded objects and has not experimented with overhanging structures, probably due to the issues with the material described above.

The staircase printed by BetAbram is an example of an object with 2.5D freedom

3.4 Fabrication location and approach

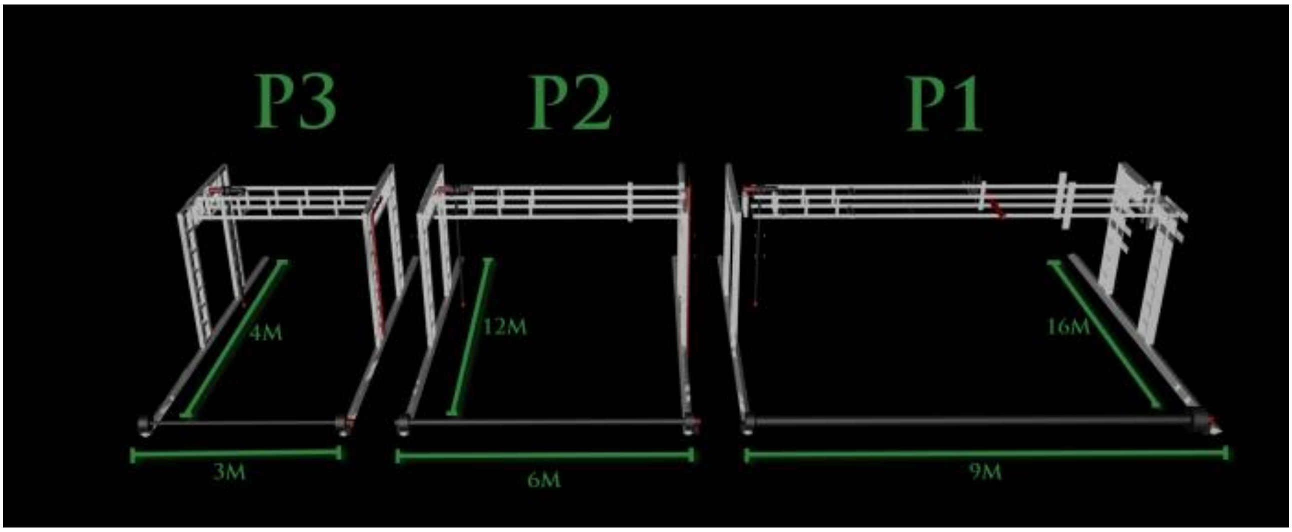
The printer requires a firm and straight support for its rails, and it would be best to make a small concrete foundation for the printer, to prevent any collapsing during the use. The printer also needs a fairly flat surface for its printable area, that needs to support to be able to support the weight of the print. Every bump or uneven spot on will deform the layer, which will follow its shape and create a bump into every next layer.

The printing process can be compromised with some considerable atmospheric agents, such as heavy wind or rain. However, it should be able to sustain some very light rain or wind without any substantial damage. Optimally, the printer should be covered by a tent or a similar lightweight structure. Also, the hardening process depending on temperature, and exposure to very warm temperatures or very strong direct sunlight can compromise the printing, create cracks, make the material harden too quickly and similar.

The BetAbram printer in outdoor conditions

4. Printer

The BetAbram 3D Printers come in three models, with the main difference in the size of the printable area. The P3 is the entry level printer with a smaller area of 4 x 3 square meters, and is intended for 3D Printing enthusiasts. The P2 is a middle level 12 x 6 square meters printer, and is intended for semi-professional use. The last and largest printer is the P3 model, which is said to be designed for construction companies. The different printers will be described jointly, since most of the printers are very similar structure and functioning.



The three models of the printer with respective printable areas

4.1 Movement

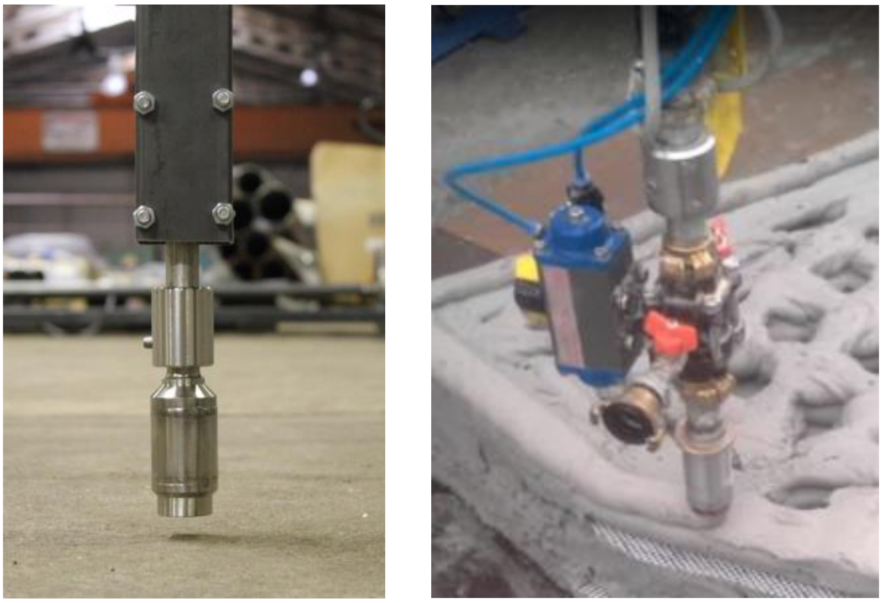
The BetAbram printer moves with a cartesian gantry system within a printable volume. The height of the printable volume is 2,5 meters, while the printable area varies according to the model (see paragraph and table above). Each of the three axes of movement are driven independently, with their own motors.

The printer is mounted on top of two parallel rails that are fixed to the ground before erecting the printer. Two columns on wheels sit on top of the each rail. All fours columns move together along the rails, dragged by a system of metal wire ropes and pulleys that is powered by electromotors placed on one end of the rails. This is the first axis of movement of the printer in the horizontal direction. Between the two pairs of columns there is a large middle beam that stands perpendicular to the rails and is fixed to the two pairs in the top. Finally, there is a vertical steel tube profile that has the nozzle mounted on its bottom end. This steel tube is mounted on the large middle beam and can move along it in the second horizontal axis direction. At the same time the steel profile can also be raised along its own vertical axis, moving the nozzle up or down. This way all three dimensions are covered, allowing the printer to cover every point within the printing volume.

The three axial movements of the machine:
-first horizontal movement along the rails (1)
-second horizontal movement along the middle beam (2)
- vertical movement along the steel tube (3)

4.2 Material deposition system

The deposition system is a single nozzle with a cylindrical shape. The nozzle is attached to a rubber hose, that connects it directly to the pump that delivers the concrete through pressure.. On some versions, the nozzle is also shown equipped with an electronic controller that allows to regulate or open/close the flow of concrete. The nozzle controller is also equipped with two water pipe connectors, one on each side, that allow to mix additional liquid materials into the mix right before extrusion. How this controller relates to the pressure created by the pump on the other end or if there is a connected system between them is currently not known.



View of the two versions of the nozzle, one with a visible controller (left)

4.3 Material feeding

The material is fed through a mobile screw pump, readily available on the marked (see example picture below). This pump consists of a feeding bucket in which the material is placed. The fluid material is so pushed down by gravity into a screw placed on the bottom of the bucket that rotates through the help of an electromotor and feeds the concrete into a pipe. This pipe is connected to a rubber hose, through which the concrete is delivered under pressure. This rubber hose is then connected to the nozzle of the BetAbram printer.

A screw pump for mortar or concrete, readily available on the market

4.4 Printer electronics and software

The printer is operated through a set of programmable logic controllers and sensors, which are connected to a personal computer. The software used to create the machine instruction is open source, while the communication between the computer and the machine is said to be done on a modified CNC software, which was optimized to be used for the BetAbram printers by the company itself.

BetAbram software in use

4.5 Printer speed

The printer speed is hard to define at this point, since there are no official statements from the company. However, at the current state, with the current size of the nozzle, the printing speed can be estimated to not more than 0.5m3/hour.

4.6 Printer accuracy

Similar to the speed, the accuracy of the printer is hard to define, since there are no official values given by the company and there have not been extensive print trials. The accuracy is also depending on the material mix that is used. Currently there is no specifically designed material, so it is not possible to define its properties. The accuracy is also influenced by the movement system, which in this case is partially made of metal wire ropes. These ropes have a certain degree of elasticity, which makes the movements of the printer oscillate and more prone to error. Judging by what has been seen in operation, the accuracy is estimated to approximately less than 50mm.

4.7 Printer operation, handling and assembly

Ideally, two persons should be operating the whole printing procedure. Given the sensitive nature of concrete materials, one person should be dedicated only to mixing and loading the material. The other person is dedicated to operating and controlling the printing process.

4.8 Printer specifications (all three models)

Printer size (assembled): 9m x 16m x 3.5m (Width x Length x Height - largest model P3)
6m x 12m x 3,5m (middle model P2)
3m x 4m x 3,5m (smallest model P1)

Printer size (stored): Not available

Print volume: 8m x 14m x 2,5m (Width x Length x Height - largest model P3)
5m x 10m x 2,5m (middle model P2)
2m x 3m x 2,5m (smallest model P1)

Printing speed (estimated): Approx. 0.5m3/hour

Layer thickness: 10-20mm

Accuracy (estimated): <50mm

Deposition head: Single nozzle (pressure extrusion)

Structure: Aluminum and steel gantry

Movement: 3 electromotors (1 vertical, 1 horizontal through pulleys, 1 horizontal along beam)

Shape freedom: 2.5D

Weight: 520 Kg (largest model P1), 400kg (middle model P2), 250kg (smallest model P3)

Energy consumption: 4kW (models P1 and P2), 3kW (smallest model P3)

Required personnel: 1-2 persons

Price per unit: 32.000 € (largest model P1), 20.000 € (middle model P2), 12.000€ (smallest model P3)

5. Material

5.1 General description

BetAbram uses a concrete-like mix for its material. The mix is essentially a mortar made of the same components as a shotcrete mix, a very common type of concrete material that is sprayed onto surfaces. This allows for interesting combinations that allow it the material to harden quickly, while being very workable at the same time.

5.2 Shotcrete properties

Shotcrete is a very common material in the construction industry. It is essentially a concrete material that is pumped into a hose and then projected onto a surface, where it solidifies quickly (it is also known as sprayed concrete). The technology has been invented in 1914, as a dry mixed version, also called gunite, where cement, aggregates (such as sand and fine gravel) are pushed through a hose in dry form, and then mixed with water and right at the end nozzle, before being projected on the surface. The sprayed concrete then quickly solidifies right after reaching the surface allowing to apply as many layers as necessary and quickly stabilizing the structure.

Since its inception shotcrete has played a major role in various segments of construction, mostly where it is necessary to quickly stabilize large surfaces. The technology is widely used in tunnel works, ground stabilization (when excavating trenches, as an example), concrete repairs, sealing of leaks, etc.

Today shotcrete comes not only in dry-mix version (gunite as above), but also as a wet-mix, called simply shotcrete. In this case the components are pumped together - cement, aggregates and also water, along with some additives called plasticizers that improve the pumpability. Finally, the shotcrete is mixed with some liquid additives called accelerators right at the end of the nozzle, that speed up the hardening process, and allow the material to quickly solidify when reaching the targeted surface.

As can be deduced from the above, shotcrete is a highly specialised and complex type of concrete, where all the ingredients need to tightly controlled. Shotcrete is essentially a science on its own, a niche in the construction market. These are some major differences when shotcrete is compared with normal concrete:

- **the material hardens very quickly** - compared to traditional concrete that takes hours to harden, shotcrete is cured in a few minutes.
- **the material is very adhesive** - the material needs to be sticky to allow it to be applied in many layer also on overhanging structures
- **the water/cement ratio is usually very low** - this means that the content of cement is much higher than traditional concrete, which allows the concrete to harden quicker and makes the concrete more pumpable
- **the aggregates are generally smaller** - most shotcrete mixtures have a consistency of a mortar, with mostly fine and medium sized aggregates (sand and fine gravels). They are typically around 4mm size. They can also be larger up to 8mm and also 16mm in some cases, but the larger the

aggregate the hard it is to work with the material.

- **the components of the mix are extremely delicate** - especially aggregates, where small differences in percentage can change a shotcrete from extremely workable to impossible to pump.
- **additives play an extremely important role** - accelerators added in the end allow the concrete to harden very quickly, while plasticizers allow it to flow better and reduce shrinking, that would make it crack during hardening.

For additional information about shotcrete materials, see the sprayed concrete handbook in the links section below.

Shotcrete for stabilizing ground (notice also the addition of a reinforcement steel mesh in the top part of the surface)

5.2.1 Curing process / Chemical reaction

Apart from different ratios of components and additives, and a different approach, from the chemical point of view shotcrete is essentially a traditional portland cement concrete, which is comprised of various calcium silicates that react with water to form a cement paste, that glues together the aggregates. This paste is formed through the chemical reaction called hydration. With time, the reaction bonds the aggregate particles into a solid mass called concrete. The hydration is a very complex process, with various reactions taking place, but they can be roughly summarized in the reaction below:

$$Ca_3SiO_5 + H_2O \rightarrow (CaO)\cdot(SiO_2)\cdot(H_2O)(gel) + Ca(OH)_2$$

As for shotcrete, due to a presence of accelerators and the large surface of exposure, the hydration process can be much quicker than traditional concrete. A slow process that takes hours and days, is here translated into minutes or seconds.

5.2.2 Raw materials ratios

It is hard to find a typical shotcrete mixture, as each mix is specifically made for each case and application. However, as a general guideline the following ratios can be used:

- **Cement** 450kg/m3 (or 150l/m3)
- **Water** 150kg/m3 (or 150l/m3)
- **Voids** 4,5% (or 45l/m3)
- **Aggregate** 0-4mm 1000kg/m3 or 360 l/m3 (sand)
- **Aggregate** 4-8mm 800kg/m3 290 l/m3 (gravel)
- **Additives** 1-2%

All raw materials are easily available on the market. Approximate prices of raw materials are:

- **Cement** 1500dkk /m^3
- **Aggregate 0-4mm** (sand) 1000dkk/m^3
- **Aggregate 4-8mm** (gravel) 800dkk/m^3

Additives play a major role in the price and are depending largely on the mix. They are usually around 200-600dkk per cubic meter of concrete. Average prices for a ready-mixed shotcrete from a batching plant are around 1500-2000dkk/m^3.

5.3 BetAbram 3DPrinted concrete properties

The BetAbram material is a cement-based material that could generally be considered a mortar, based on the aggregate composition. The aggregates appear very fine, mostly sand approximately up to 2mm in size. According to the company the mix ratios are very close to shotcrete mixtures, which means high cement content and very small aggregates. This makes the material a very fluid paste that is easy to spread and shape on the printing surface. At the same time, the fluidity makes the material more prone to deforming under the weight of the consecutive layers, or when very angled or curvy shapes are being printed. When printed, the material appears smudged and irregular on the edges, and also presents a horizontally layered surface, typical for this type of technologies.

Apart from the standard concrete components (water, cement and aggregate), the material is mixed with additives provided by KEM, a local chemical and sand aggregate production company from Slovenia. The following additives are mentioned are added to the mix:

- **Kema Expand** - a powder additive that makes the concrete swell, compensating the shrinkage of the material. It also functions as a plasticizer, which reduces the amount of water necessary in a mix, and therefore reduce shrinkage caused by water evaporation, while also improving the workability.

- **Kema Non-Shrink** - a liquid additive used to reduce shrinkage which acts as a plasticizer, reducing the water ratio, and therefore the evaporation. It acts also as a retarder, postponing the hardening process, and improves the workability.

- **Kemament Hiper X** - a liquid additive used to reduce shrinkage - it is a superrplasticizer, essentially a more powerful plasticizer that has a stronger effect both on reducing shrinkage and improving workability. Also, the retarding effect is less pronounced.
- **Kema Latex** - a product that is used usually for the reparation of the tunnels, as it helps bond the new layer of sprayed concrete. It can also have a plasticizing function within the mix (reducing the amount of water necessary and improving workability).

The plasticizers and superplasticizers are usually added in a 1-2% ratio. The use of accelerating additives once the last end of the nozzle is a very typical approach of shotcrete. Although it seems to be possible to do it on BetAbram printer through the controller on the nozzle, this has not been seen in use.

Once hardened, the material appears having a good bond between the layers, without visible laminations. However, the material seems prone to cracking ad breaking and presents some weak and brittle spots, probably due to a very fine aggregate content, a large exposed surface, and some printing errors, all of which are typical for this type of technologies.These negative aspects are also heavily influenced by atmospheric conditions, so it is hard to define all the causes that create them. The material generally appears more porous than traditional concrete. Due to no official testing performed on the material, it is hard to define more thoroughly the current properties of the material compared to traditional concrete in a more specific way. Further research and optimization is necessary to make this material more reliable for construction use.

A sample of printed material with the distinctive layered surface, along with some errors and porous areas

A cross section of the material showing a good bond between layers

5.4 Material possibilities

Shotcrete is a good starting point for a 3D Printed material, as it uses a lot of different additives that quickly modify the properties of the base concrete material. These can be used both upfront, when mixing the material, as well as on the last moment, before extruding the material through the nozzle. This widens the possibilities considerably and allows to tweak the material on the go. Furthermore, there is an extensive body of research and a very well consolidated technology that can be used as a support. Shotcrete has been present on the market for more than a 100 years, and has been improved considerably over the years, widening its range of application. It is only a matter of optimizing this knowledge and machinery to the new use.

Currently, the company is making a new extrusion head, and it has mentioned the plan to use a larger nozzle to allow the use traditional concrete with larger aggregates, up to 40mm. Not much has been disclosed on whether they will be also develop the material, or use what is already known, but there is a clear departure from the previous direction, aiming at shotcrete materials. However, there was mention of the use of a controller/dispenser for accelerators at the end of the nozzle, to be able to control the hardening process similarly to wet-mixed shotcrete. This is probably the aspect that is most compatible with 3D Printing, as it allows to better control the process where it is actually necessary, right on the front end, where the extrusion begins.

5.5 Material pre- or post-treatment

There are currently no pre-treatments or post-treatment that the company has introduced to the process. But as any other concrete, this material allows for a wide array of products available on the market that can be applied to enhance its properties, such as primers or anti-evaporation coatings to name a few.

6. Useful links and sources

Official website:
http://betabram.com/

Youtube channels:
https://www.youtube.com/channel/UCdXUokLxlUEKMjkfTdnsJtg
https://www.youtube.com/channel/UCcSM8A3FiGaC8seIXSH2tMQ

Media articles on the technology:
http://www.3ders.org/articles/20140526-betabram-to-release-3d-house-printer-in-july-august-2014.html
https://3dprintingindustry.com/news/betabram-set-to-3d-print-two-story-house-this-summer-50826/

Shotcrete handbook by Sika:
https://www.sika.com/content/dam/Corporate/Microsite_Shotcrete/pdf/sika_sprayed_concrete_handbook_2011_GB_low.pdf