Versarien®

3DCP Design & Print Guidance

DECEMBER 2023

ABOUT VERSARIEN

Versarien plc (AIM: VRS) is an IP-led advanced engineering materials group that utilises proprietary technology to create innovative engineering solutions. Versarien holds more than 130 patents covering areas including the manufacture and use of graphene and related materials (GRMs) in diverse applications. We develop and manufacture advanced materials and products globally through a number of subsidiaries and have the widest portfolio of high-quality verified products.

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VERSARIEN 3DCP FACILITY

3D concrete printing (3DCP) corresponds to a technology that uses computer-controlled placement of materials to build a component without formwork. The most common placement process in 3DCP relies on extrusion of cement-based composites – whether this is a mortar with fine aggregates or concrete with large aggregates. 3DCP promises to enable the production of complex geometries in a fully-automated setup while delivering advantages such as material and labour savings, speed of production as well as production of non-planar and complex geometry and shapes.

Hardware

There are many different hardware solutions when it comes to 3d concrete printings. For the purpose of this document, we will look at the equipment that Versarien utilises, the robotic arm.
The robotic arm printer is built with a number of components

- A wet mix station where dry mortar materials are mixed with wet additives
- A pump to move the wet mix to the print nozzle at the correct flow rate
- A computer controlled robot that moves based on the the required design
- A print area where the element will be printed

Versarien's robotic arm for 3D concrete printing.

Material

The mortar used in Versarien printed elements has been selected for its combination of strength and cure rate. The printing process requires that printed layers are sufficiently cured (hard) to provide structural support to the layers printed above, but also sufficiently uncured so they adhere to contacting layers/features. The exact combination of mortar powder and liquid additive(s) varies from job-to-job, day-to-day, batch-to-batch; the 'printable' material is accessed as acceptable by a skilled operator prior to the commencement of every print.
There is no toxicological information at hand for the material, however the same mortar material has been approved for use in French subsea projects (an artificial reef) as well as in the USA (a living seawall).

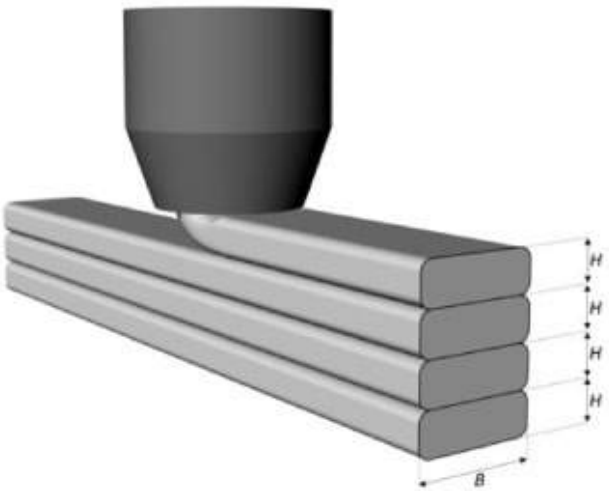
Software

Versarien uses Rhino3D software to create 3D computer models which will eventually be printed. This allows us to visualise the design and work out any engineering problems prior to print. This model is converted to an electronic file which the robot interprets as movements around the toolpath.
We can in some instances use other software to pull, push, stretch or enhance the model depending on the requirement of the customer and/or application, an example of this is adding embossed text or surface details that would be difficult to model using traditional 3D modelling software.

CONSTRUCTION

Basics of layer building

The extrusion nozzle both extrudes the wet mix and flattens the layers as the robot moves around the tool path. The flattening action pushes the material into the lower layers resulting in a near homogeneous solid cross section. Here the management of cure rates (as highlighted previously) is important for overall structural strength.



Extruded material laid upon each each other.

Maximum print sizes

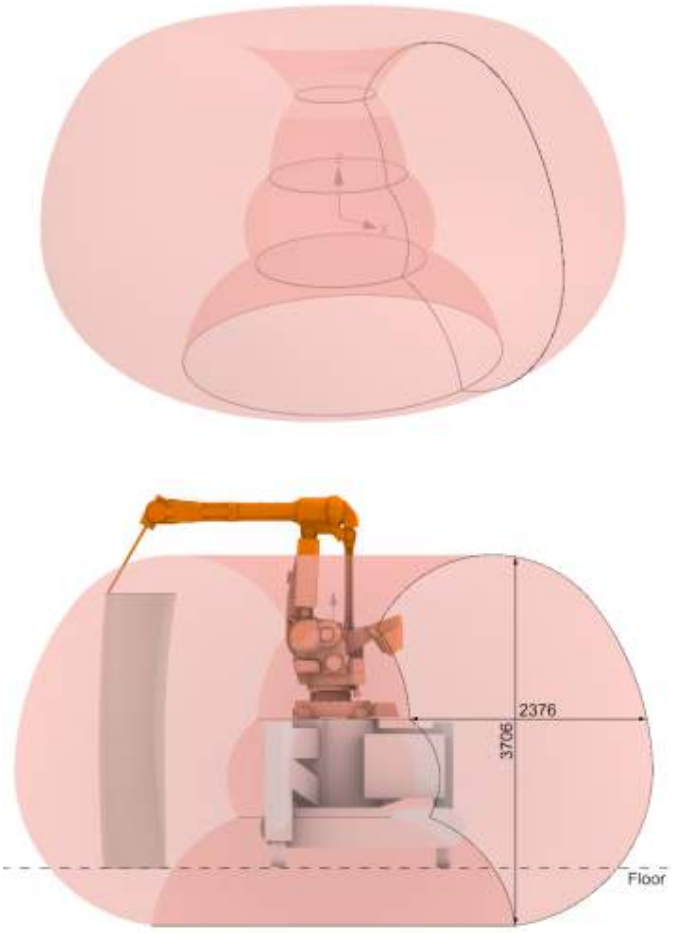
The shape of the printer's range is based on the reach of the robotic arm. The general shape of the range is donut-like. As a result, there is not a singular maximum height x width x length of a printed element; the height, width, length and shape of an element will determine how the element fits within the volume of the printer's range.
As a general rule, Versarien's robot can print elements 3m wide or 2m deep or 4m high.

Wall thickness

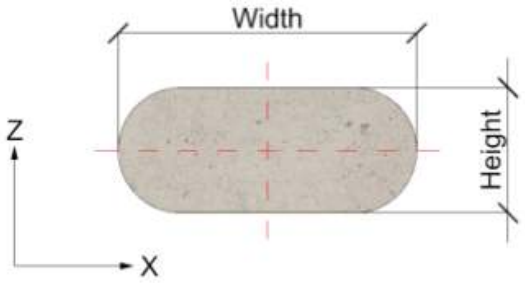
The wall thickness is related to the profile of the bead of mortar that is deposited as the robot moves around the tool path. The dimensions and theoretical profile of the bead are below. This translates to a bead profile that is approximately 40mm wide and 12.5mm high. Due to gravity, the bead slumps a little on the sides.

Dimensional tolerance of final print

Accuracy of the final print is better than +/-10mm on overall dimensions. It should be noted that the robot is accurate to better than +/-1mm, but holding a tight tolerance on the extruded mortar is less accurate.



Indication of printer's range, volume and dimensions (Credit: CyBe Construction).



Printed mortar bead dimensions approximately 40mm wide by 12.5mm high (Credit: CyBe Construction).

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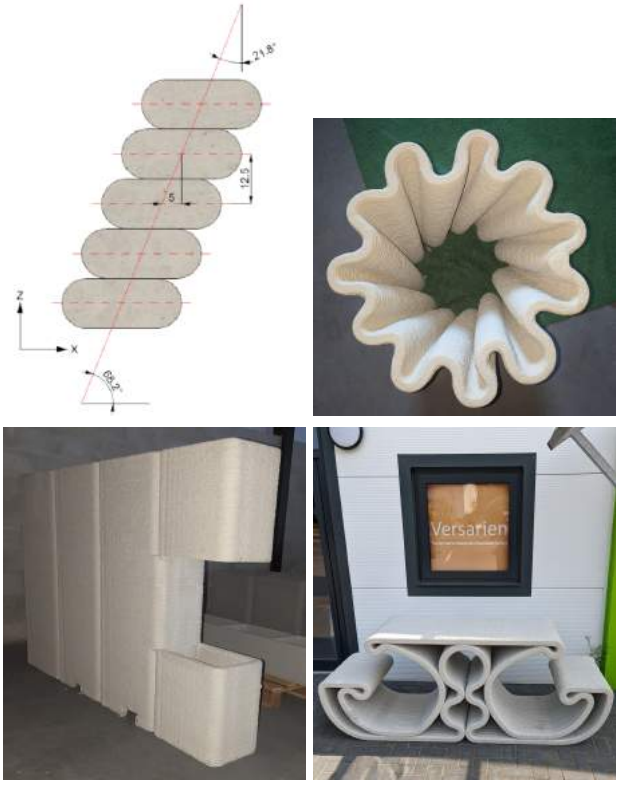
Maximum inclination of print

The inclination of a printed feature is limited by the strength of the below layers of mortar. As a rule the maximum inclination is 22□ off vertical (5mm horizontal shift for every 12.5mm layer) however this can be increased if the shape of the tool path offers support in the localised area of the inclination. We have seen the inclination angle exceeded when printing ribbon like features which fold back onto itself creating a self support feature.
With external structural supports (i.e. formwork) it is possible to print horizontal features. This is useful when printing overhanging features for windows or doors. Overhangs can also be created by printing the element flat on the ground then rotating the part after it has cured.



(Top L-Bottom R) Maximum inclination of printed material (without supports) (Credit: CyBe Construction), ribbon like features, overhand created using formwork allowing a lintel to be created, printed table rotated 90° to print orientation.

Strengthening ribs

Strengthening ribs are required to secure two printed features together, typically two wall-like features. It is possible to use non-mortar materials during the print to act like rib (i.e. wall ties or rebar).
As a general rule, rib-like features are included every 600mm. This distance may be reduced where extra strength is required.

Internal ribs showing the tying of two different walls.

Surface finishes

The as-printed finish of the printed element has layered horizontal lines. To some people this finish is part of the charm and story of 3d concrete printed elements.
During the curing process the printed element can be wet sponged over the surface to smooth the ridges to give a smooth like finish. This is not glassy smooth like a rendered wall due to the exposure of small pieces of aggregate.
Other surface coatings can be used to change the colour of the material. We have previously included pigment into the mix as well as painting on-top of the as-printed surface.

As printed finish

Wet sponge finish

Painted finish

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INSTALLATION

The 3D concrete printed elements can be heavy, typically 300 kg - 2,000 kg per part. The design process requires us to consider how we will move them once complete. Previously we have included:

- Rebar put through holes
- Lifting eyelets
- Lift from cutout features in hidden places (i.e. internal ribs)
- Create fork tyne slots in the external of the part, that will be hidden later

Methods of connection between pieces

Short items, or items under no sideways load, typically do not require a physical connection between adjacent parts. When the risk due to a toppling printed object is high, a physical connection between adjacent parts can be created using traditional bolted arrangements or tongue and groove features.

Connection to concrete slab and foundations

To permanently fix 3D elements to a concrete slab or similar, it is preferred to lower the elements over vertical rebar protruding from the slab, then backfill the element with a small amount of concrete to fix the element in place.

Ensuring components are level

Versarien's 3DCP robot has internal levelling. This enables it to print layers of material horizontally layer upon layer. Issues arise when printing in one location then moving the printed element somewhere else. If the datum (ground) is uneven or not level, this can cause the printed element to lean when placed in another location where the ground isn't identical in flatness, gradient etc. To overcome this Versarien has come up with several solutions

- Survey the print location and print on a perfectly flat and level surface,
- Print on a engineered platform that can be adjusted to be flat and level,
- During the installation process, use supports and packers to hold the 3DCP structure in position (vertical and level) and back fill with materials to hold this position.

Holes in element(s)

Cured mortar is hard and brittle. It is easier to create holes in the part during the printing process. If a hole is required after the mortar has cured, Versarien recommends using diamond/tungsten tip concrete cutters and the drill setting on the drill. Do not use impact/hammer mode on drill/sds as this will create cracks in the element.

Drilled hole for rebar

Lifting from internal ribs

Embedded lifting eyelets

External fork slots

Tongue and groove connection

Print platform to ensure level and even print surface

Connection of wall elements to concrete slab (Credit: QOROX Ltd.).

Holding wall in vertical position while it is set in place (Credit: QOROX Ltd.).

CASE STUDIES

Versarien are pioneering innovative 3D concrete printing (3DCP) construction methods. Utilising our own robot printer we can offer 3D printing of structures for flood defences, garden offices, humanitarian shelters, and much bigger structures using our modular build program. This section highlights some of the types of products and projects we've delivered.

Lunar

In 2022, Versarien announced the launch of its 3D-printed lifestyle pods, designed with sustainability and innovation at the core. Versarien specialises in advanced engineering materials, and provides graphene-enhanced admixture, trademarked as Cementene™.
This milestone project, dubbed "Versarien Lunar", is the world's first 3D-printed product with a graphene-enhanced admixture, which enhances certain characteristics of concrete, such as strength, curing rates and water impermeability. It's a versatile garden space that can be used as an office, studio, gym or leisure room. Its unique wall design shows the level of detail, flexibility and precision that can be achieved with 3D-concrete printing.

Key benefits:

- Fast installation
- Increased structural strength from inclusion of graphene
- Potentially reduced carbon footprint when compared to traditional concrete manufacturing / construction 3D-printed structure can be recycled into new building material
- Modern and futuristic design
- Pioneering 3D-concrete printing technology
- Embedded Graphene enhanced technology
- Designed and manufactured in the UK

Specifications

Internal dimensions: W 3.5m x D 2.2m x H 2.3m
External dimensions: W 4.4m x D 2.8m x H 2.6m
Lighting 6 energy saving and long-life LED lighting
Heating Digitally controlled embedded heating system
Insulation Insulated for all year round use
Power 2x 240V double sockets with USB ports
Windows & door Full height triple-glazed doors & windows Modern aluminium frames
Flooring Carbon neutral flooring

Island Steps by Steuart Padwick (Design London)

Versarien have teamed up with British Artist and Designer Steuart Padwick to create a 3d printed installation using 100% cement free concrete reinforced with Graphene. Not only does 3D printing significantly reduce the volume of concrete needed, the special mortar being cement free also reduces the carbon footprint by over 70%.

The team wanted to highlight not only the beauty of this advanced material but also its green credentials both in composition as well as its 3D manufacturing. The volume of concrete needed is reduced significantly as the printed structure is hollow, and together with the fact it is cement free means it has an overall reduction of circa 85% compared to a conventional build with standard concrete. There is less waste and there has been no need for formers.

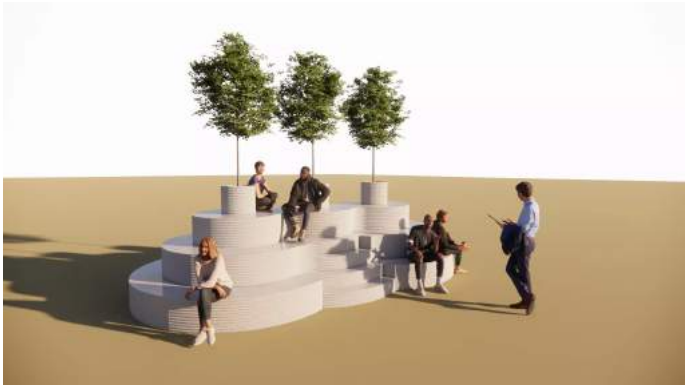
Steuart Padwick's Island Steps has been designed as a playful oasis and can be located both internally or in an outdoor environment. It will incorporate lighting within the 3D printed material.

For this project Padwick is collaborating with Ben Harries at Versarien, an architect and designer who is also passionate about sustainable design and believes that 3D printing technologies, aided by developments in material science, will transform the future of construction.

Versarien, who develop and manufacture advanced material technologies, with the purpose of improving the environment, have developed Cementene, a graphene enhanced concrete admixture which significantly increases the strength and durability of concrete thereby allowing less material to be used in construction.

Steuart Padwick is an artist and designer, best known for his furniture and lighting designs, who has in more recent years created a number of large-scale public sculptures often in support of Mental wellbeing and the environment. Most notable pieces include Head Above Water on London's South Bank, and last year's official COP26 legacy artwork - The Hope Sculpture Project, which was a series of 3 permanent public sculptures across Glasgow.

Find out more...
London Design Festival article
Graphene Flagship article



Mr & Mrs DIY

Click here to watch the print in process

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