CONSTRUCTION & STRUCTURAL 3D PRINTING

Construction & structural 3D Printing are technologies that use 3D printing as a core method to fabricate buildings or construction components. Large scale Additive Manufacturing (LSAM), Freeform construction (FC) and 3D Concrete are alternative terms are also used to refer to concrete extrusion technologies.

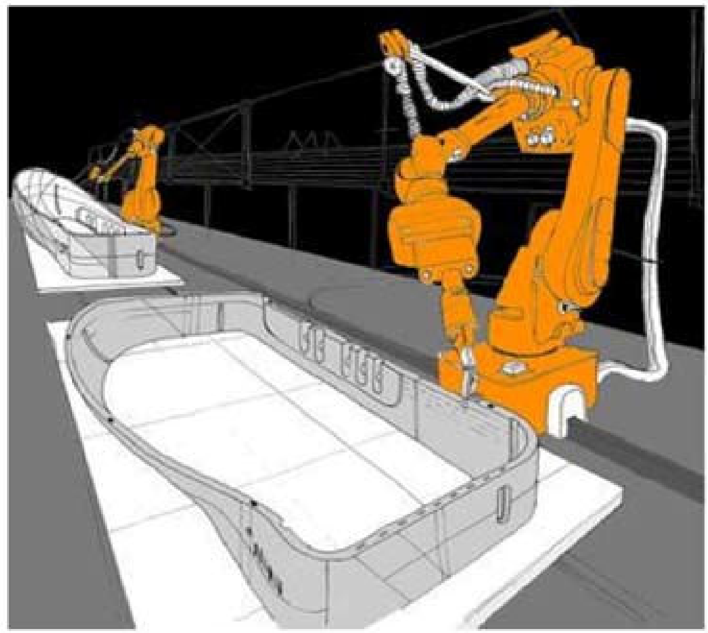
There are a variety of 3D printing methods used at construction scale, these include the following main methods: extrusion (concrete/cement, wax, foam, polymers), powder bonding (polymer bond, reactive bond, sintering) and additive welding. 3D printing at a construction scale will have a wide variety of applications within the private, commercial, industrial and public sectors. Potential advantages of these technologies include faster construction, lower labor costs, increased complexity and/or accuracy, greater integration of function and less waste produced.

A number of different approaches have been demonstrated to date which include on-site and off-site fabrication of buildings and construction components, using industrial robots, gantry systems and tethered autonomous vehicles.

Demonstrations of construction 3D printing technologies to date have included fabrication of housing, construction components (cladding and structural panels and columns), bridges and civil infrastructure, artificial reefs, follies and sculptures.

The technology has seen a significant increase in popularity in recent years with many new companies, including some backed up by prominent names from the construction industry and academia. This led to several important milestones, such as the first 3D printed building, the first 3D printed bridge the first 3D printed part in a public building, the first living 3D printed building in Europe and CIS, the first 3D printed building in Europe fully approved by the authorities (COBOD International), among many others.

Architect James Bruce Gardiner pioneered architectural design for Construction 3D Printing with Villa Roccia. The Villa Roccia took this pioneering work a step further with the a design for a Villa at Porto Rotondo, Sardinia, Italy in collaboration with D-Shape. The design for the

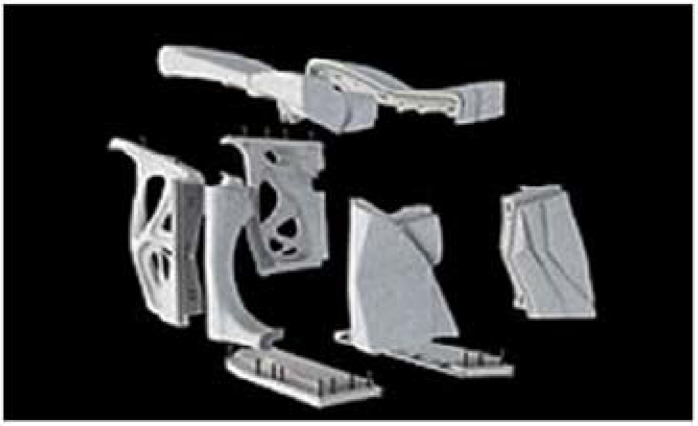


Robotic production line of monocoque shells

Villa focused on the development of a site specific architectural language influenced by the rock formations on the site and along the coast of Sardinia, while also taking into account the use of a panelized prefabricated 3D printing process. The project , however, went through prototyping and didn't proceed to full construction.

3D printed bridges

In Spain, the first pedestrian bridge printed in 3D in the world (3DBRIDGE) was inaugurated 14th of December of 2016 in the urban park of Castilla-La Mancha in Alcobendas, Madrid. The 3DBUILD technology used was developed by ACCIONA, who was in charge of the structural design, material development and manufacturing of 3D printed elements. The bridge has a total length of 12 meters and a width of 1.75 meters and is printed in micro-reinforced concrete. Architectural design was done by Institute of Advanced Architecture of Catalonia.



(shown above detailed design exploded view of the Villa Roccia.

3D printed bridge with the D-Shape technology. The first structure of this type in the world

The 3D printer used to build the footbridge was manufactured by D-Shape. The 3D printed bridge reflects the complexities of nature's forms and was developed through parametric design and computational design, which allows to optimize the distribution of materials and allows to maximize the structural performance, being able to dispose the material only where it is needed, with total freedom of forms. The 3D printed footbridge of Alcobendas represented a milestone for the construction sector at international level, as large scale 3D printing technology has been applied in this project for the first time in the field of civil engineering in a public space.

3D printed architectural forms

In August 2018 in Palekh (old town in Russia) was the world's first application of additive technology for creating the fountain. The fountain "Snop" (Sheaf) was originally created in the middle of the 20th century by famous sculptor Nikolai Dydykin. Nowadays, during the restoration of the fountain, it was changed from a rectangular to a round shape. The backlight system has also been updated. The restored fountain is 26 meters in diameter and 2.2 meters deep.

Concrete printing

Large-scale, cement-based 3D printing disposes the need for conventional molding by precisely placing, or solidifying, specific volumes of material in sequential layers by a computer controlled positioning process. This 3D printing approach consist of three general stages: data preparation, concrete preparation and component printing. For path and data generation, a variety of methods are implemented for the generation of robotic building paths. A general approach is to slice a 3D shape into flat thin layers with a constant thickness which can be stacked up onto each other. In this method, each layer consists of a contour line and a filling pattern which can be implemented as honeycomb structures or space-filling curves. Another method is the tangential continuity method which produces 3-dimensional building paths with locally varying thicknesses. This method results in creating constant contact surfaces between two layers, therefore, the geometrical gaps between two layers which often limits the 3D printing process will be avoided. The material preparation stage includes mixing and placing the concrete into the container. Once the fresh concrete has been placed into the container, it can be conveyed through the pump–pipe– nozzle system to print out self-compacting concrete filaments, which can build layer-by-layer structural components.

In the printing step, a control system is required to execute the printing process. These systems can be generally split into two categories: gantry systems and robotic arm systems. The gantry system drives a manipulator mounted onto an overhead to locate the print nozzle in XYZ Cartesian coordinates while robotic arms offer additional degrees of freedom to the nozzle, allowing more accurate printing workflows such as printing with tangential continuity method. Moreover, multiple 3D printing robotic arms can be programmed to run simultaneously resulting in decreased construction time. Finally, automated post-processing procedures can also be applied in

scenarios which require the removal of support structures or any surface finishing.