



LAYER BY LAYER
A cement mixture is deposited by the extruder of a 3D printer: the result will be a house, built in record time in Kenya.

Today, **3D printers** can build buildings in a short time, with **less emissions and materials**. Technology still has some limitations, but the revolution has begun. And **Italy** is in the front row.

by Vito Tartamella

I PRINT MY HOUSE

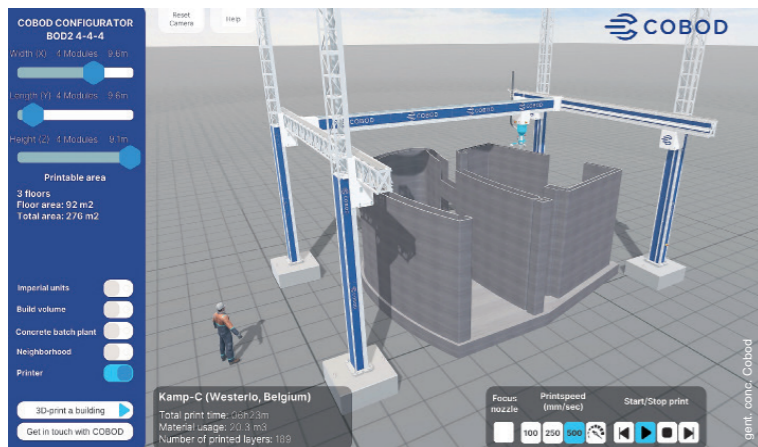
“**W**e accept reservations for 3D printed homes in Florida. Choose from one of the available designs or custom design your home. With our technology there are no limits to square footage, curved or shaped walls. Even two-story buildings can be printed with ease. You just need to provide a licensed land for construction. Places are limited: we only accept reservations until April 1, 2022”. The announcement is not an April Fool’s Joke. It is published on the website of Apis-Cor, a US company that produces printers for the building industry. It became famous for printing the world’s largest building in Dubai: 9.5 meters high, it covers an area of 640 m². This technology is similar to that of 3D printers, but on a much larger scale: a nozzle moves on a metal frame along the 3 orthogonal axes (width, length, height) depositing, like toothpaste on the toothbrush, a layer of cement mixture following the instructions of a three-dimensional project. The subsequent layers accumulate on top of each other, then solidifying into high and resistant masonry.

TRIPLED BUSINESS

The technology was born only 17 years ago but, according to the research firm MarketsandMarkets, it has already reached a global market of 12.6 billion dollars in 2021. By 2026 it should triple, rising to 34.8 billion. A bubble destined to deflate or has the era of architecture 4.0 begun? Will the new construction sites then be managed by ro- ▶

INSTRUCTIONS

On the right, the overhead crane with the printing nozzle in the center: it will deposit the layers of concrete on the foundation following the instructions of a 3D project (below, an example screenshot).



A New York company promises to build a 140 square foot house in 48 hours. And \$ 20,000 worth of material

botic arms under the gaze of a few workers holding a tablet instead of a bucket and trowel?

In the Middle East they believe it: the Dubai government has decided that in the coming years at least a quarter of the new buildings in the country will be 3D printed, and Saudi Arabia is betting on this technology to build 1.5 million homes by 2030. The potential is limitless: the Chinese company Winsun has built a 6-storey building by assembling pre-printed walls in 3D.

“We are in the midst of a technological and cultural revolution,” says Roberto Naboni, professor of computational design and digital fabrication at the University of Southern Denmark. “The technology is ripe for the market, but there is still no

established and widespread standard regarding the materials and procedures to be used, both in design and on construction sites. The next 10 years will be decisive in understanding in which directions this approach will be consolidated.”

THE COST OF ROBOTS. AND PROJECTS

The advantages of 3D printing in architecture are considerable: construction sites are less dangerous. Controlled cement deposition techniques reduce material waste (about 50% can be saved compared to traditional techniques), and more environmentally friendly compounds can be used.

The computer-controlled process makes it possible to create buildings with geometries of your choice, curved or perforated. And it takes less than half of the workers to build a house. The work can proceed even 24 hours a day. Therefore, you can build buildings quickly and with less money.

The New York company SQ4D guarantees to be able to print a 140 m² housing in 48 hours, with only 20 thousand dollars of building material.

But it seems like an exception: the houses advertised on the Apis-Cor website cost from 330 thousand dollars for 160 m² to 470 thousand dollars for a 214 m² villa. So where is the vaunted convenience of 3D printing?

“So far, fewer than 100 homes have been printed worldwide: there is no consolidated experience to refer to, even for costs,” replies Vytautas Naslenas, global sales director of Cobod, one of the world leaders in the sector. “In addition, the cost of labor, materials and finishes varies greatly from country to country.” To all this, then, we must add the price of innovation: the special cement mixtures to print a building cost 3-4 times more than normal cements; and building robots cost from 100 to 500 thousand euros each.

“The design costs are also higher because you have to plan in detail all the printing phases,” says Massimo Moretti, founder of Wasp, a Romagna-based company that produces printers sold all over the world. “But if the same project is replicated several times, the costs are reduced.”



THE SECRETS OF THE MIXTURE

In addition to the economic limits there are technical ones. “The cement mixture is a key aspect of building printing,” adds Naboni. “It must be moldable but also able to consolidate quickly to support the weight of the subsequent layers. The adhesion capacity between the layers influences the final behavior of the structures depending on the efforts in the various directions.

Last year, Italcementi’s research center in Bergamo, the world’s fifth largest cement producer, developed a cement mixture, “I.tech 3D”, designed for 3D printers: its components guarantee the mortar to self-sustain during printing, maintaining the shape provided by the 3D model, and ensure workability and resistance.

But the difficulties to be overcome are still many, point out the engineers who followed the printing site of a single-family villa in Beckum (Germany). In a study published this year in the journal Construction Robotics they admit that “the preparations for printing took a long time and regular adjustments to the model were necessary to level the windowsills. This can be avoided in the future by using laser scanning during the printing process.” The work needed constant adjustments, because “the printed layers allow a very reduced tolerance to be visually pleasing”.

VERTICAL STRUCTURES

Today the “contour crafting” technique is widespread all over the world. A crane or a robotic arm draws the perimeter walls of a building by extruding a cement paste that accumulates layer by layer. The technology was born by applying the parameters of 3D printing (born in 1996) on a building scale. Instead of metal powders or polymers, printers extrude a cement paste containing crushed stone (pebbles) up to 4 mm thick. The process, intuited by some researchers already at the end of the 90s, was patented only in 2005 by Behrokh Khoshnevis, an engineer at the Institute of Computer Science at the University of Southern California. ▶

TROWEL? NO, TABLET

Left and below, Dubai: the construction site of the largest 3D printed building to date, an administrative office. The workers control the printing phases with the help of a tablet: the processing must be followed in every step.



SO, WE WILL PRINT SHELTERS ALSO ON MARS

The last frontier on Mars? Marsha, an egg-shaped habitat. It was printed by a New York company, AI Space Factory, mixing the basalt fiber of the rocks of the red planet with a bioplastic, polylactic acid, obtained from plants. A recyclable mixture capable of protecting against space radiation: it was found to be 3 times stronger than concrete in the tests carried out by NASA, which in 2019 rewarded the project with half a million dollars.

In space, 3D printing will be the only technology to build habitats using the resources present: regolith, fragments of lunar or Martian rocks. The European Space Agency had already imagined this solution in 2013. Thanks to the volcanic Enrico Dini, who proposed to print a habitat using the lunar regolith. “I discovered, in a disused pozzolan quarry near Lake Bolsena, a crushed stone similar for 99.8% to lunar regolith in chemical composition. Since the lunar simulants all have a 3-letter acronym, we called it Dna-1, or regolith “de noatri”, of the rest of us. With these rocks we printed a one-and-a-half-ton block with a hollow closed-cell structure, similar to bird bones, to give a good combination of strength and weight.”

Now, NASA and ESA are studying a process to avoid transporting the binding material into space: liquefying regolith using low-power microwave energy, to obtain a solid block similar to ceramics.

MILESTONES

Below, the first 3D printed house in the world: built by Enrico Dini, it was exhibited at the Milan Triennale in 2010. On the right, the first printed villa in Beckum (Germany).



CHALLENGES

Left, a pavilion in Yaroslavl (Russia): 3D printing allows for unusual shapes. Under, the first school printed in Malawi: its walls were built in just 18 hours.



The new trend? Print houses using the land of the place. For a **zero km** building

“But with this technique you can only make the wall structures of a building,” comments Professor Naboni. “Our lab is also trying to make horizontal structures (floors) and roofs by combining 3D printing layers with steel reinforcements to resist bending.”

HABITABLE MONOLITH

Meanwhile, also in 2005, a few months before Khoshnevis someone had patented an alternative process, capable of printing an entire house: the “deposition on a bed of sand.” A layer of sand and magnesium oxide is spread on a plane, over which flows an overhead crane that deposits, from an arm equipped with dozens of diffusers, drops of magnesium chloride saline solution. The chemical reaction turns the compound into magnesium carbonate, a geopolymer 16 to 20 times stronger than cement.

At the rate of one layer at a time, 5-10 mm thick, a structure in the desired shapes and thicknesses is obtained, which comes to light once all the unused sand is removed. With this method you can print a house from the foundation to the roof, including stairs, partitions, ducts for water and electrical systems. A habitable monolith, ready to plaster.

The process was invented by a Pisan engineer, Enrico Dini, who produced footwear with robotic implants, using 3D printing to produce casts of the feet. “When I saw the first 3D printer, I immediately thought that this way you could print large structures,” he says. “Instead of cement, I chose geopolymers, popularized by the French chemist Joseph Davidovits: probably with this technique the ancient Egyptians obtained the

large stone blocks of the pyramids. We, however, today have the advantage of being able to shape these materials into the shapes we want». With his system, called D-Shape, Dini has reached a historic milestone: in 2010 he printed the first building in the world, the “one-piece house”, 3.5 meters high, 2.4 wide and 4 meters long, exhibited at the Triennale di Milano. An all-Italian record, which inspired all the constructions printed all over the world.

But so far the technology has not caught on. Dini does not give up and looks for a financier to build a machine 10 meters high and 12 meters wide, to print in one fell swoop a 3-storey building. Meanwhile, his method served to print a hundred artificial coral reefs for the port of Hong Kong: the openwork structures are used for the fish restocking of the bay and the breeding of oysters.

NATIVE MATERIALS

But why focus on innovative materials? For ecological reasons. Concrete production, in fact, produces 7% of global CO₂ emissions: targeted deposition through printing allows to limit cement waste. All the more so if you print porous walls that offer the same resistance with less material: the trabeculated structures, made from spongy slats intertwined on the anatomical model of the bones. “The bones are very resistant, although full of holes,” says Moretti. “3D printers can make structures that until a few years ago were difficult if not impossible.”

And in recent times a 100% ecological material has returned to the forefront, experimented with in the 70s, at the time of the energy crisis: raw earth. As Wasp did by creating in Massa Lombarda (Ravenna) Tecla, the first eco-sustainable house designed by the Bolognese architect Mario Cucinella: a 60 m² house formed by two domes built with zero emissions and km 0 using the local land, without concrete.

The masonry was obtained from clay taken on site, combined with silt, sand and a special fluidifying and thickening additive. All material that, if tomorrow the building were demolished, could be dispersed in the environment: earth that returns to the earth. Not to mention that the structure, in addition to



being fireproof and resistant, has a perfect thermoregulation: “The clay guarantees cool environments in summer and warm in winter. It keeps the humidity constant and purifies the air,” says Moretti.

An approach, that of exploiting the resources present on site, which has opened the possibility of building homes in disadvantaged locations: in Malawi the company 14Trees has built the first school in the world 3D printed, and aims to create several housing in Kenya.

In Mexico, the technique has been used to print homes for the homeless. The Logistics Agency of the US Ministry of Defense has opened a 3D printing section to set up housing quickly in the event of natural disasters. And so the bases will also be built in the most difficult to reach places, where it would be prohibitive to transport cranes and concrete: the Moon and Mars (see box on previous page). **F**

PIONEERS

Above, Tecla, an igloo-shaped house printed using local earth.

Right, Enrico Dini: he invented 3D printing of buildings in 2005, the same year that a Californian engineer, Behrokh Khoshnevis, patented a similar method.

