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Research paper

ECOURBARCHITECTURAL HOUSES FROM PRINTED MATERIALS

Nikola Cekić[1]

Abstract

The rapid development of digital technologies of 3D printers and the introduction of construction robotised machines in the construction of houses, at the beginning of this century, brought a completely new conceptual strategy in the ecourbarchitectural design of functional residential-office, industrial, economic, tourist and other horizontal and vertical volumes. Incredible revolutionary urban planning changes have occurred in cultural-historical inherited artifactual and natural physical structures in space. Instead of the recent forty or more working hours for the traditional construction of one square meter of usable area in the building, when building materials and bricks were exchanged, today it takes only five minutes! With the introduction of robotic digital machines for printing walls and structural parts of buildings made of mud, concrete, plastic and long-specific materials, a new historical page of the future in the construction industry has been opened, when the amount of waste is zero and when the exact amount of required material is known in advance. An extremely high speed was achieved in the innovative construction of printed houses immediately ready for use. Examples from the world, in this work, show that buildings made of printed material provide users with absolute security since tests have confirmed their static resistance to earthquakes, winds and other disasters.

Key words: *3D printer, digital technologies, robotisation, eco-urban architecture, cultural and historical heritage*

[1] Academician, PhD., Full Eng. Architect. The Faculty of Civil Engineering and Architecture of the University of Niš, SERBIA - 18000 NIŠ, Aleksandra Medvedeva st. 14/111, email: ncekic@yahoo.com, ORCID 0000-0002-7607-3367

1. INTRODUCTION

Dramatic changes are visible not only in the high speed of construction, but also in the considerably reduced prices of usable built-up surface areas. In the world, digital-technical-technological 3D printers are being improved every day, with which even more effective buildings results can be achieved. Thus, in 2014, the Chinese company "WinSun New Materials" started using a huge 3D printer in the process of building houses, which allowed it to completely build as many as 10 houses in one day![2] This 3D printer, 6.6 meters high, 10 meters wide, and 150 meters long, used a material obtained from a mixture of cement and glass fibers for printing. It is predicted that in the future, old building materials will be used in order to raise recycling and environmental protection to a higher level. A very fast and cheap way of building buildings with a price lower than 1000 euros, from rice waste, local mud and straw, which is offered on the world market by many companies, among others WASP[3] from Italy, has an extremely promising character for the million people on the planet who live today in slums, suburbia and favelas.

2. EXAMPLES OF EXPLORED ECORURBARCHITECTURAL HOUSES MADE OF PRINTED MATERIAL

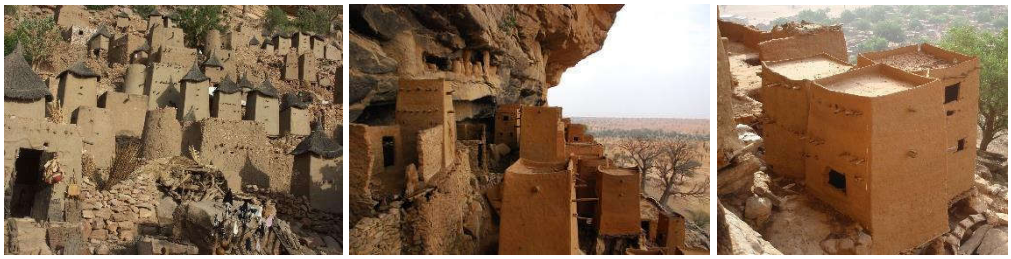


Figure 1. Bandiagara cliff in Mali. The land of the Dogons is a huge cultural landscape covering 400.000 ha and including 289 villages [1]

The Dogon are an ethnic group indigenous to the central highlands of Mali, West Africa, south of the Niger Bend, near the city of Bandiagara, and in Burkina Faso. The population is between 400,000 and 800,000 people. Since the twentieth century, there have been significant changes in the social organization, material culture and beliefs of the Dogon, in part because the Dogon country is one of Mali's main tourist attractions. The Dogon are best known in the world for their settlements and ground structures made of local indigenous materials [2], mud and wattle, wooden masks and sculptures. Colorful and harmoniously shaped houses made of mud could have been an inspiration for the design and construction of new cheap, more modern eco-architectural forms with 3D printers with a concept of space remodeling in poor neighborhoods.

[2] https://www.archdaily.com/497836/chinese-firm-3d-prints-10-homes-in-24-hours>
[3] https://www.3dwasp.com/en/3d-printed-house-gaia/

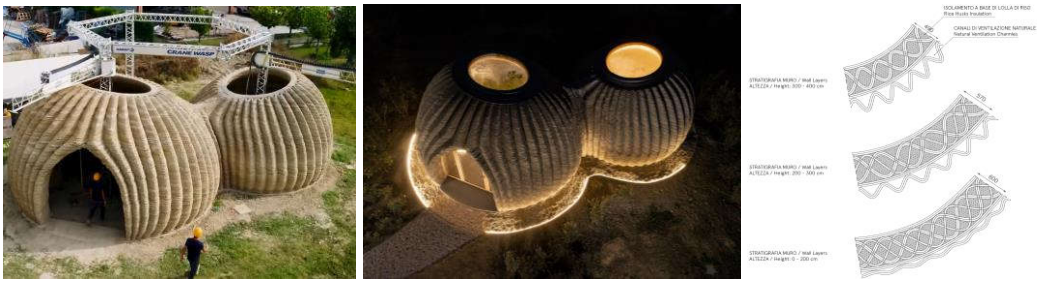


Figure 2. 3D-TECLA, first printed biomorphic mud cottage built in Ravenna, Italy [3]

Mario Cucinella, an Italian architect from Bologna, in collaboration with the company for 3D house printing - WASP [4], realized a pilot project in which he created a clay bioclimatic, low-carbon emission prototype house as a response to dramatic climate changes and the planetary housing crisis on the planet. The unusual physical structure of the "TECLA" house is designed with two interconnected solar domes through which natural light is introduced through the central skylight into the interior space. It was built from 350 layers of clay, 12 mm thick, of local origin from the nearby river bed, 150 km of extrusion and 60 m3 of natural materials. The size is 60m^2. The ecological house was built from organic, biomaterials in a time of 200 hours [4], while active printing with a homogeneous synthesized mixture of materials with 25% soil, 40% straw obtained from the rice stalks, 25% rice husk, 10% limestone and additives, mixed with a mixer took 72 hours. The designer says the challenge was to optimize "the thermal performance and living comfort of the building envelope". There is an opinion according to which this is the first derived 3D eco-architectural form in accordance with natural forms and biomorphic geometry. The house made of homogenized mud was built for only 1000 euros. WASP Company's ambitious goal is to print an attractive environmentally technologically sustainable village, which will be located in the Italian town of Massa Lombarda, Emilia Romagna, not far from Ravenna.

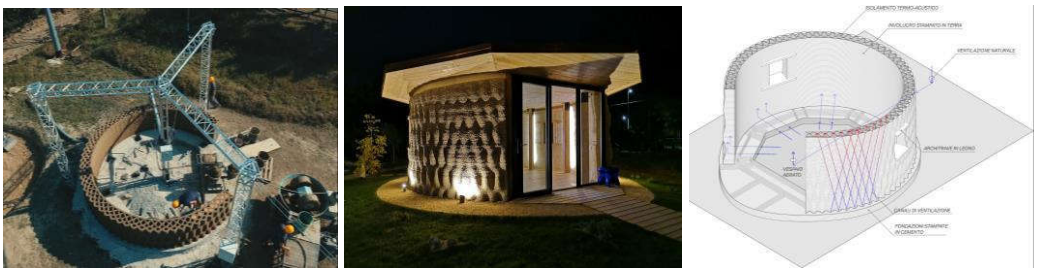


Figure 3. First 3D house printed with soil material, „Gaia“, 2018 [5]

The Italian company WASP-World's Advanced Saving Project produced a 3D infinite digitized printer with which a new model of an ecologically sustainable bioclimatic house was made in just ten days. 25% of the soil from the site (30% clay, 40% silt and 30% sand) was used as the main binder in the composition of the mixture, composed of 40% chopped rice straw, 25% rice husk and 10% hydraulic lime [6]. The resulting homogeneous mixed compound is made of natural waste materials, which originate from the rice production chain and which were used for the efficient, healthy bioclimatic construction of the new GAIA eco-sustainable house model. The foundation of the housing is continuously printed from concrete on site, with an extruder nozzle from the crane structure, while the 40 cm thick walls

[4] „World's Advanced Saving Project“. Italy’s pioneering specialists in 3D printing

are made by precisely stacking layers of combined mixed mud material with long plant fibers. In the central part, the walls are designed with digital precision and printed monolithically in the form of a braid. They considerably affect the static stability of the walls as well as the strength of the ecourbarchitectural structural assembly. The entire length of the hollowed-out fields of the wall, having 30m^2, have the function of solving vertical ventilation and thermoacoustic insulation of the house. The price of the materials used in the first house built of natural materials, for the wall structure, was €900.

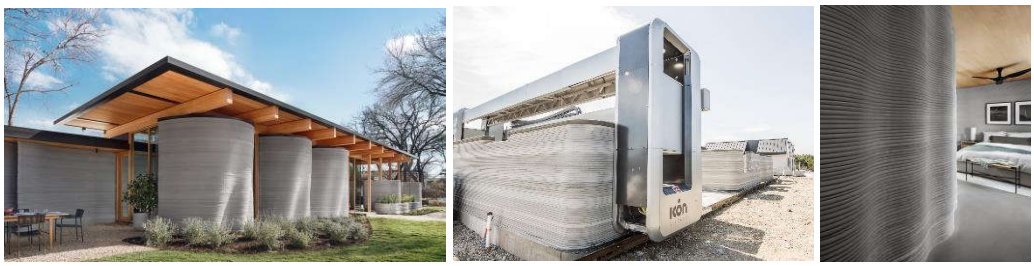


Figure 4. Companies ICON and LAKE FLATO built a 3D prented house Zero in Austin, Texas, 2022 [7]

For the construction of the house Zero in the eastern part of Austin, Texas, 3D printing technology was used - the "Vulcan" construction system, from the American company ICON in cooperation with the Lake Flato architectural studio from San Antonio. 186m^2 of walls were constructed by printing in ten days, by mechanically applying layers of material according to a computer program. The ICON company says that: " House Zero is ground zero for the emergence of entirely new design languages and architectural vernaculars that will use robotic construction to deliver the things we need most from our housing: comfort, beauty, dignity, sustainability, attainability, and hope,". The walls of the house are made of "Lavacrete" 3d printed, the original ICON's proprietary material, similar to cement that does not transmit air and has excellent insulating thermoacoustic properties [8]. Apart from the new construction method, the soft curved surfaces of the exterior walls reinforced with steel sections are characteristic, while most of the interior walls are made of wood in order to make the interior space of the family house more attractive, comfortable and organically connected to the natural structures in the environment. The company ICON intends to continue working actively on improving and presenting the future of house construction with 3D printed material. They also plan to create a 3D printed community in Latin America, and with NASA to build structures on the moon.

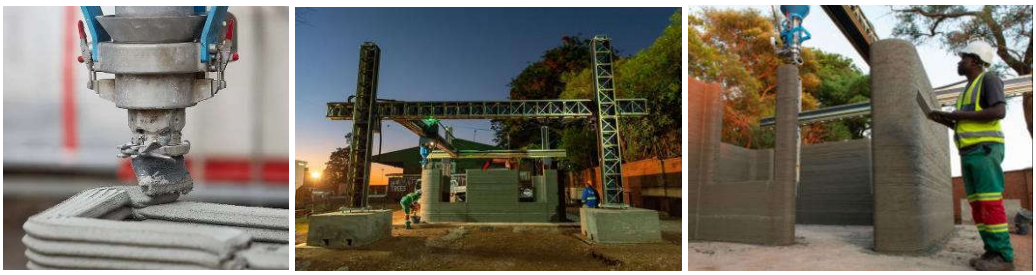


Figure 5. First African 3D printed schools and dorimitories opened in Malawi [9]

As a result of the chronic lack of school infrastructure in Malawi, in the southeastern part of Africa, and thanks to the financial support of the Swiss manufacturer of construction materials, Lafarge Holcim, and the help of the development financial institution CDC Group

of the United Kingdom Government, the first school was built with innovative digital technology, 3D wall printing [10]. Malawi has a shortage of 36,000 classrooms and in the near future, due to a similar situation, the wave of this kind of construction will continue in Kenya and Zimbabwe. If the construction problems were to be solved in a traditional, conventional way, 70 years of work would be needed. With the 3D digital technology of printing buildings, the time is shortened by 7-8 times, and the investment costs are reduced multiple times. It took 18 hours to build the school building in Salima using digitized 3D printing technology. The "Vulcan" 3D printer, 4m high and 8m wide, was used for the realization, which is considered to be one of the best in the world. This 3D printer has the ability to lay 7 inches of homogeneously mixed concrete building material in one second.

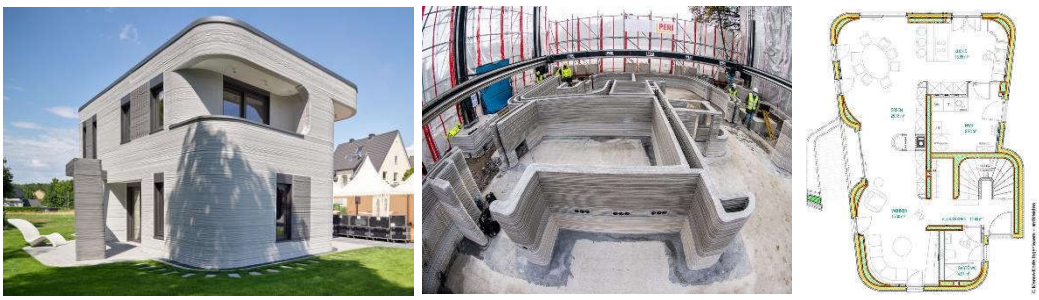


Figure 6. Beckum, Germany, features the first 3D printed two-storey building, 2021 [11]

The first house in Germany was built using an automated digitized 3D printer, in Beckum, North Rhine-Westphalia, as part of the "Innovative Construction" funding program. The two-story family house contains about 160 m2 of living space, and was created in about 100 hours of printing with a 3D printer for concrete material from the company PERI, with a special nozzle that can cover a surface of one square meter in five minutes, concrete layers were applied, so that the masons and other workers were not needed. It is commissioned for use on 26th of July 2021. According to the state ministry, the first residential building in Germany was built as a pilot project and if the experience is positive and the printer's work is financially profitable, it will serve as a model, an example for the entire construction industry [12]. There are already buildings made with a 3D printer in the world. This house is a big challenge for ecourbarchitecture. In 2021, the 3D concrete house construction process received the cross-industrial "German Innovation Award."

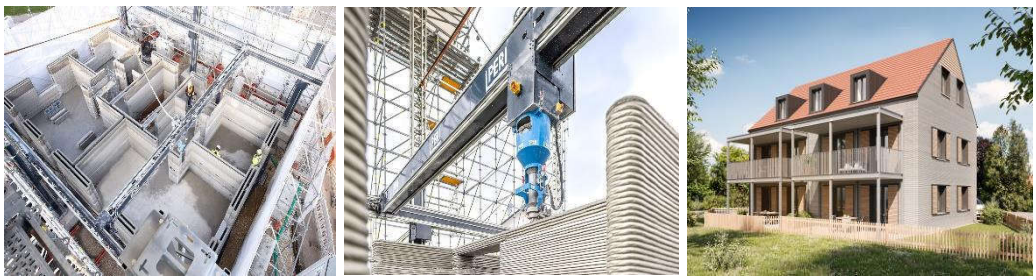
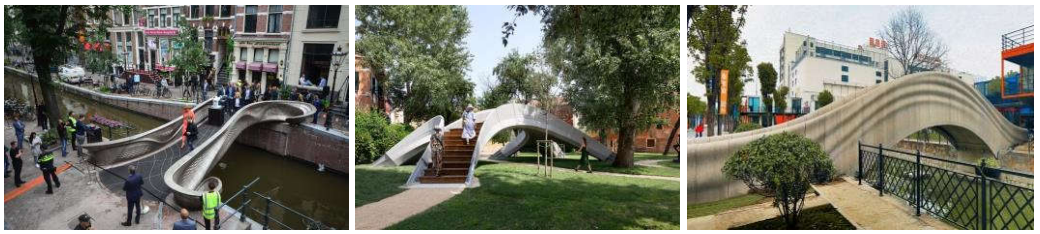


Figure 7. BOD2 3D printer by COBOD company was used for the construction of building in Wallenhausen [13]

A three-story residential building in Wallenhausen, Bavaria, with five residential units and a usable area of 380m2, was built in just a few weeks after the unveiling of a two-story 3D-printed building in Beckum. A modular digitized BOD2 3D printer from the COBOD company,

measuring 12.50x20.00x7.50 meters, was used in the construction. The printer is flexible and can be expanded in all directions in a module of 2.50 meters to meet the requirements of all customers, and it took less than five minutes to cover a two-layer wall of 1m2. The company PERI used this printer to build the largest printed building in Wallenhausen, but also in Europe, at a maximum speed of 1m/sec or pouring 10 tons of concrete per hour. Only two workers participated in the work. It was completed in six weeks. Henrik Lund-Nielsen, founder and CEO of COBOD, commented: "We are incredibly excited to start seeing the fruits of the many automated 3D construction printers sold." Thomas Imbacher, head of innovation and marketing at PERI GmbH, said: "We are very confident that 3D construction printing will become more important in certain market segments in the coming years and that it has significant potential [14]. By printing the first residential building on site, we show that even large residential units can be printed with this new technology. When it comes to 3D construction printing, we are opening up additional areas of application on a whole new level."



a) b) c)

Figure 8. Examples of realized physical structures built by 3D printing technology:
a) World's first 3D printed steel bridge installed in Amsterdam, 2018 [15],
b) Phoenix - A New Reinforcement-Free 3D Printed Concrete Bridge - Lion France [16],
c) World's longest 3D-printed concrete bridge opens across canal in Shanghai [17]

In addition to printing buildings with 3D digital-robotized technology, the same is used for the realization of other physical structures in public space. Thus, the world's first stainless steel bridge, 12 meters long and weighing 4.5 tons, was cast with a robotic printer and placed across the canal in Amsterdam in 2018. The bridge was assembled in two parts, off-site, by welding. For six months, four digitized robots worked to pour the 1,100-meter-long layers (Figure: A). The Holcim company built the 3D-printed concrete bridge PHOENIX, for Lyon, France, designed with 10 tons of recycled material in collaboration with Zaha Hadid - Architects Computation and Design Group, Block Research Group at ETH Zurich and incremental 3D. The so-called circular construction, by integrating computer design and 3D printing, which facilitates a possible reduction of up to 50% in the use of materials without compromising performance was implemented. The bridge was designed on advanced "Ekocycle®" circular technology, relying only on compression, without reinforcement, using blocks that can be easily dismantled and recycled (Figure: B). On February 5th, 2019, the world's longest concrete-printed pedestrian bridge, 26.30 meters long and 3.60 meters wide, was opened in Shanghai over a canal in Shanghai's Baoshan District [18]. The arch bridge is built from 176 concrete units made using two 3D robotic printing systems. All components were printed within 450 hours (Figure: C).

Figure 9. NASA intends to build the astronaut habitats on the moon by 2040, using 3D printing [19]

NASA5 and ICON, an Austin, Texas-based construction company that uses a 3D printer to create low-rise buildings, have been planning to build a settlement on the moon by 2040. The plan calls for sending powerful robotic 3D printers that can build a housing unit in 48 hours and building materials to make lunar concrete composed of mineral fragments and dust from the moon's surface. Although it looks like a dream sequence, the NASA company is of the opinion that today is the key moment when the realization of the idea should be started. They believe in the possibility of successful realization of the ambitious plan for houses on the empty Moon, which would be used in the long term not only by astronauts but also by civilians. Work is being done to create new programs, functional machines and robotics for future space missions on the lunar surface that are still in the conceptual space exploration phase. There are obstacles in finding and forming localities for the construction of settlements [20]. The fine powder of moon dust is sharp and can cut like glass. It spreads easily and is toxic to inhale. In addition, the problem is that the temperatures are significantly higher than on Earth, and there is also harmful, adverse radiation.

a) *b)* *c)*

Figure 10. First 3D printed house in free scultputural form, by WATG company. Harbinger of future and advancement in the development of 3D printing technology of ecourbarchitectural structures is seen on newly designed eocurbarchitectonic sculptural forms formama [21]

WATG company, from Chicago, won the Freeform Home Design Challenge 2016 Design Award for the winning project "Curve Appeal" [22]. The Company says that this revolutionary solution should change the further development path in the construction of complex physical ecourbarchitectural forms (A). The 27-foot-tall archisculptural Phoenix House was built in Austin, Texas, using ICON's latest 3D digitized construction printer with which they think they will be building landing pads, roads, and NASA habitats on Mars in the near future (B). Architect Eduard Galkin, from Saint Petersburg, made a futuristic impressive project for an attractive one-story house with an archisculptural-biomorphic-organic form that would be realized with digital 3D printing technology (C).

[5] The National Aeronautics and Space Administration is an independent agency of the U.S.

3. CONCLUSIONS

A new advanced era of more effective technological, non-traditional processes of construction of buildings and application of modern materials has begun. In urban agglomerations, they contribute to a better and more sustainable life, save costs and enhance the time efficiency of construction, which favorably affects the opening of a new perspective in the field of social housing. Houses created with 3D printers offer many advantages. They are built much faster, in just a few weeks, in contrast to houses realized in the traditional way, where the works last several months and where the investment costs are noticeably increased. They are recyclable and energy efficient. With a small amount of energy to create synthetic material, reinforced with synthetic or plant long fibers, with straw and rice husk, with insulation and ventilation chambers in the wall envelope of the building, an excellent thermoacoustic protection of the interior space is achieved. The process of building a house begins by extruding homogenized material through a special extruding nozzle according to pre-made designs, layer by layer, so that the walls, partitions and structural parts of the building can be printed. The printer uses only the required amount of material mix for the constructions. The possibilities of architects, urban planners and planners have been increased resulting in freer and more creative thinking when designing physical structures, from the simplest to those with more complex spatial geometry. Same as the traditional construction, 3D printed houses meet all safety and quality standards. The construction of ecoarchitectural houses and settlements from printed materials with innovative 3D digitized-robotized technology has opened a new, revolutionary page of history in the construction industry. This short review shows great design-transformative and potential possibilities, with which, by redefining the way of thinking about construction, we can repair and make the existing world with an environmentally better concept.

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