PRIMENA TEHNOLOGIJE 3D ŠTAMPE BETONA U REPUBLICI SRBIJI

APPLICATION OF 3D CONCRETE PRINTING TECHNOLOGY IN SERBIA

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Apstract

Tehnologija 3D štampe betona predstavlja inovativan postupak izrade betonskih konstrukcija. Korišćenjem računarskih sistema i robotske tehnologije, omogućava se optimizacija i automatizacija procesa u savremenoj građevinskoj industriji. Ovaj rad pruža pregled principa 3D štampe betona, informacije o prednostima, ograničenjima i budućim pravcima razvoja ove tehnologije. Prikazana je dosadašnja primena kroz nekoliko izvedenih objekata. Takođe, rad prikazuje trenutno stanje naučno-istraživačkog rada u oblasti tehnologije 3D štampe betona u Srbiji.

Ključne reči: *3D štampa; beton; aditivna (postepena) proizvodnja; tehnologija*

Abstract

3D concrete printing technology represents a novel method for construction of concrete structures. By utilizing computer systems and robotic technology, it enables optimization and automation in construction industry. This paper provides an overview of the principles of 3D concrete printing, giving information on advantages, obstacles, and directions for future development. The previous applications of this technology are presented through several completed objects. Additionally, the paper describes the current state of scientific research in the field of 3D concrete printing technology in Serbia.

Key words: *3D printing; concrete; additive manufacturing; technology*

1 Introduction

3D printing technology was developed in the 1980s as a novel method to produce different elements based on the ideas of Charles Hull. This method, which is also called "Additive Manufacturing" (AM), includes the layering of material over a chosen path in order to produce complex-shaped elements based on a 3D computer model. The technology immediately found use in many of industries after being initially applied to metals, polymers, ceramics, textiles, and other composite materials [1]–[3].

Behrokh Khoshnevis from the University of Southern California through his own technique, Contour Crafting (CC), started the use of concrete as a printing material in 3D printing technology. [1], [3]. In addition to the CC method, it is successfully used the Fused Deposition Modeling technology (FDM) in which material is extruded in layers based on G-code generated from a CAD model of the element (Figure 1) [2], [4]. Also, another applied technique is called Shotcrete 3D Printing (SC3DP), which involves continuously spraying concrete with a robotic arm without using clear layers and with the possibility of adding reinforcement (Figure 2) [3], [5]. The company D-Shape successfully developed and deployed the ink printing method, which involves spraying a binder into layers of material intended for printing (Figure 3) [1], [6].

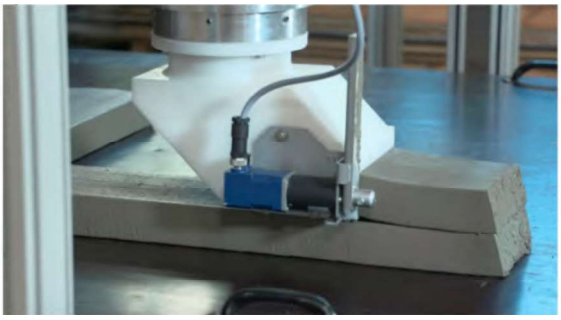

Figure 1. FDM technology for 3D printing of concrete (TU Dresden). [4]

Figure 2. 3D concrete printing using the spraying method (SC3DP). [5]

Figure 3. Application of ink printin method by D-Shape. [1]

Faster construction without formwork, material savings, increased safety, and the potential for sustainable development are all benefits of 3D concrete printing. However, disadvantages include higher starting prices, the need for trained labor, doubts about the quality of the materials, and a lack of standards for design and construction [1], [4], [7]. The development of 3D printing technology in the construction sector has been impressive. Numerous structures, including residential homes (Figure 4), multi-story buildings, and pedestrian bridges (Figures 50 and 6), have been built using this technology with success. Additionally, individual parts such as walls and columns obtained by 3D printing concrete were successfully used. Beyond structural applications, 3D printed concrete has also been used to create non-structural components including sculptures, planters, urban furniture, and other ornamental things (Figure 7) [1], [7].

Exploring the incorporation of reinforcement into the printing process, improving the connections between printed pieces, and solving problems like cold joints could lead to further developments in 3D concrete printing technology [1], [3], [7], [8]. These problems can be resolved, allowing 3D printing technology to become more widely used in current construction technologies. Additionally, the sector of prefabricated construction represents a feasible approach for the future development of 3D printing technology. The ability to create various prefabricated printed components using various printers has the potential to revolutionize the construction sector by bringing faster, more effective, and environmentally friendly building solutions [9].

Figure 4. First-ever 3D printed concrete house in Germany (Beckum House) [8]

Figure 5. Striatus Brodge in the atrium of ETH Zurich [8]

Figure 6. Pedestrian bridge over the Peelse Loop canal [10]

Figure 7. Horizontal panel manufactured by Loughborough University, UK [7]

This paper provides an overview of the current state of scientific research and the practical application of 3D concrete printing technology in Serbia. Constructed objects with descriptions of companies that use 3D concrete printing technology has been shown. The paper also gives a review of scientific research on this topic at the universities in the Republic of Serbia.

2 3D Concrete printing technology in Serbia

2.1 Practical application

The practical application of 3D concrete printing in Serbia started with the company NaturaECO in 2019. NaturaECO is a young startup company made under the patronage of Science Technology Park Čačak. The company's primary task is the development and production of 3D printers and concrete mixtures for 3D concrete printing [11].

In December 2021, NaturaECO completed the first-ever printed house "PROTO-DOM" (Figures 8 and 9) in Eastern Europe, using its own mixture and 3D printer. The “PROTO-DOM” house with area of 24 m^2 was made for 21 hours using a 3D printer called “D.L.L. 1.2” (Figure 10) and the mixture “NEconcrete” [11]. The "D.L.L.D. 1.2." printer has dimensions of 350x350x370 cm, with printing area of 2000x2000x2500 mm and a printing speed in the range of 15-30 cm/s [11]. The „NEconcrete" mixture is an eco-friendly ready-to-use premix with a low cement content and a maximum compressive strength of 60 MPa [11].

NaturaECO used FDM technology for making the house, where the fresh mixture was pumped through the hose and deposited from the nozzle in layers to make the element (Figure 4). The house was made from single elements without any horizontal or vertical connection between them. Also, single elements only have horizontal reinforcement using the single bars between the walls without vertical reinforcement (Figure 11). A finished house has a wood roof, furniture, windows and doors like a traditional house. Also, openings between the element’s walls provided a lot of space for the installation of different types of installations in the house.

Figure 8. PROTO-DOM House [11]

Figure 9. Interior of PROTO-DOM House [11]

Figure 10. The 3D printer "D.L.L. 1.2"

Figure 11. The printing process of single element

2.2 Scientific-research work

The fundamental step for wider application of any new technology is extensive scientific research. On the topic of 3D concrete printing technology, extensive work started in 2020. A research group from the University of Novi SAD published a review paper [12] about the fresh properties of extrusion-based 3D printed concrete. At the same time, a research group was formed at the University of Belgrade, Niš and the Institute for Testing of Materials in Belgrade.

In 2022, the Faculty of Civil Engineering at the University of Belgrade has been finished construction of the first academic 3D printer for concrete in Republic of Serbia (Figure 5) [9], [13]. The maximum size of the specimens the printer can produce is 600x400x2500 mm. With movement along all three axes (X, Y, and Z) and a maximum speed of 6000 mm/min, the printer head includes a rectangular nozzle with dimensions of 40x15 mm. The freshly mixed concrete is added to the loading hopper of the pump after mixing, and the hose is then used to transport it to the printer nozzle. The PFT Swing-M pump was utilized for this purpose [9].

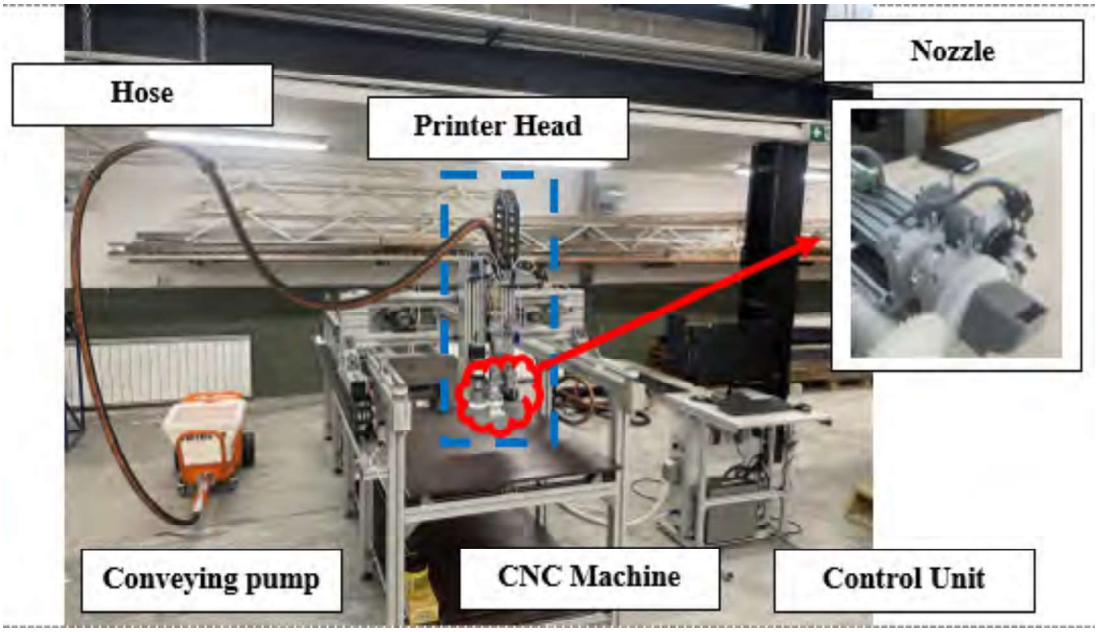

Figure 5. The 3D concrete printer at Faculty of Civil Engineering University of Belgrade taken from [9]

Following the installation of the printer, a research group from the University of Belgrade continued extensive work on the topic of 3D printing concrete. First, it published a literary review about the structural applications, advantages and obstacles of this technology [13]. In the following research, an experimental part was conducted, which included testing the fresh and hardened properties

of the mixture for 3D printing [14]. Bulk density, setting time, consistency, and compressive and flexural strength are analyzed (Figure 6.). Investigation of these properties is the main step in checking whether the mixture is adequate for the 3D printing process.

Figure 6. Determining setting time and consistency using flow table test: a) sample before testing, b) measurement of diameter [14]

The last research provided information about the hardened properties of 3D printed concrete [9]. The physical and mechanical characteristics, such as its bulk density, compressive strength, flexural strength, and interlayer bond strength (Figures 7 and 8), were the objectives of this research. It was used for two types of specimens: full-notch removal and printed samples. Furthermore, samples with four or six layers were investigated. Beside this, research groups from the University of Belgrade, Novi Sad, Niš and the Institute for Testing Materials have submitted project proposals in 2020 and 2022 (Programs IDEAS and PRISMA) under the patronage of the Science Fund of the Republic of Serbia.

Figure 6. Fracture of sample from series 1 in compressive strength test [9]

Figure 7. Fracture of sample from series 2 in axial tension test [9]

3 Conclusion

The technology of 3D concrete printing as an innovative method gives more opportunities for optimization and automation of the construction process. It will provide a lot of advantages, like faster construction, better quality control, reducing costs, and saving materials. The construction sector has recognized the potential of this technology through several finished objects, like one-story houses, multi-story houses, and pedestrian bridges. Beside advantages and application, this technology has some obstacles and open questions that are recognized by scientific research organizations. It can be noted that there has been an increase in the number of organizations and projects on the topic of 3D concrete printing.

A lack of standards and regulations for quality control of material and printing process, structural design of 3D printed structures with incorporation of reinforcement, and investigating connections between single elements made from 3D concrete printing are the main directions of research. Additionally, the RILEM organization's active engagement in two technical committees (TC PFC and TC ADC) will provide standards and regulations for the manufacture and use of 3D concrete printing structures in the near future.

The development and application of 3D concrete printing are present in the Republic of Serbia. The appearance of companies and research organizations at universities has popularized 3D concrete printing technology. In the near future, it is expected that more research will be done at universities

through national and European projects. The results of research have provided for eliminating obstacles and increasing the number of companies that use 3D concrete printing technology.

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