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OSNOVNI PRINCIPI 3D ŠTAMPE BETONA U SVETLU ODRŽIVOG RAZVOJA

BASIC PRINCIPLES OF 3D CONCRETE PRINTING IN THE LIGHT OF SUSTAINABLE DEVELOPMENT

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Iako konzervativna, građevinska industrija se mora transformisati u skladu sa novim tehnologijama. Usvajanje koncepta 3d štampe može dati pregršt prednosti u pogledu kreativnosti, fleksibilnosti, manjeg generisanja otpada, efikasnijeg utroška energije kao i niže emisije ugljen-dioksida. Cilj ovog rada je da sumira osnovne principe 3d štampe betona, diskutujući glavne ciljeve i nedostatke koji se moraju sagledati i rešiti pre šire primene. Takođe, biće dat osvrt na tehnologiju proizvodnje i materijale koji se koriste, kao i održivost građevinskih objekata izgrađenih primenom koncepta 3d štampe.

Ključne reči: *energija; beton; 3d štampa; materijali; zahtevi; primena;*

Although conservative, the construction industry must be transformed in line with new technologies. Adopting the concept of 3D printing can provide a handful of benefits in terms of creativity, flexibility, less waste generation, more efficient energy consumption as well as lower carbon emissions. The aim of this paper is to summarize the basic principles of 3d concrete printing, discussing the main goals and shortcomings that must be considered and resolved before wider application. Also, a review will be given on the production technology and materials used, as well as the sustainability of buildings built using the concept of 3d printing.

Key words: *energy; concrete; 3d printing; materials; requirements; application;*

1 Introduction

In the light of the technological advances designed to make human life easier, energy crises and greenhouse gas emissions have been identified as a global concern. Today, at the beginning of the 21st century, the world is searching for the environmentally friendly solutions that need less energy, effort and time, in order to prevent the negative effects that are being predicted.

Additive production, known as layered or fast production, is a new technology that many manufacturers are considering and adopting [1]. It is presented as a low-impact 3D printing process that saves time, costs and labor. The concept of this process is to transform an existing digital design into a real structure by adding materials in layers, one above the other. The scale of the application varies from the printing of micro-functional parts to the printing of large structures and buildings. In such applications, the concrete printing systems mainly consist of: a concrete tank (1), a pumping mechanism (2), a printing nozzle (3) and a motion control system (4), schematically shown on Fig. 1.

As the construction sector has a very high demand for energy, it is inevitable that energy consumption before, during and after any construction process can also be considered as a primary global concern. Therefore, the introduction of various strategies to reduce energy consumption during the construction of buildings leads to a reduction in environmental impact [2]. The only question is whether the concept of 3D printing can contribute to the sustainable development in the construction sector. Certainly, the successful implementation of the principles of 3D printing in this sector would

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contribute to the further optimization of the production process, and to converge to the sustainable development, but there are lot of aspects of construction that, due to their complexity, prevent full automation.

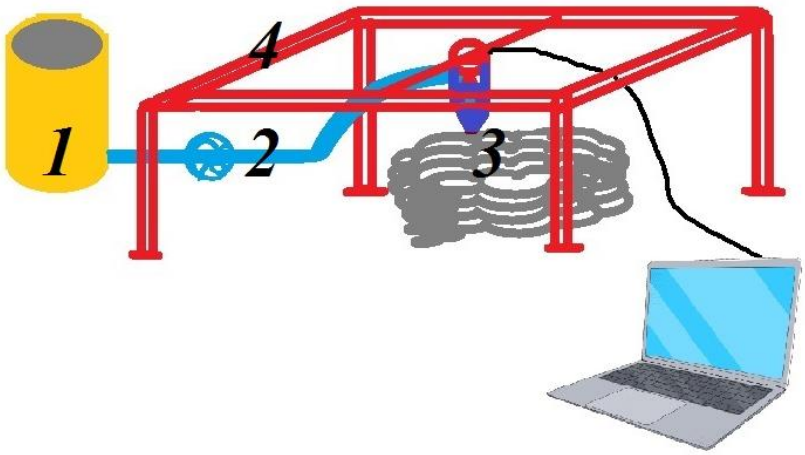

Figure 1 – Schematically presented concrete 3D printing system: a concrete tank (1), a pumping mechanism (2), a printing nozzle (3) and a motion control system (4)

This is evident from the state of affairs in the sector of concrete industry, given that previous attempts to introduce prefabrication of concrete remained at a very low level, and related mostly to the production and assembly of elements (pillars, beams, plates) while other construction activities remained far from the factory production. At the same time, it should be noted that such systems, although widely present and accepted today, have remained applicable only in the domain of a narrow set of structures.

2 Key advantages and disadvantages of the concrete 3d printing concept

For civil engineers, 3D printed buildings represent one of the most significant trends in construction and design. Constructional applications of 3D printing are diverse, this technique is meant to make buildings of all types and different levels of complexity, from the residential to multi-storey office buildings, or bridges. It is important to note how easy it is for the civil engineers to adapt or modify a model using software, and 3D printing technology can accurately reflect these changes. This allows on-demand adjustment, as production can be modified in a very short time. In addition, the technology ensures the optimized use of the material. In addition, the nature of the material provides the possibility of recycling and reuse, which largely solves the ubiquitous problem of construction waste disposal. In the best-case scenario there is no waste, because the printer can precisely manage the construction material according to the design. All this contributes to a smaller footprint and a lower environmental impact, compared to the traditional construction techniques. At the same time, the technology reduces the need for formwork and scaffolding systems, so less human power is needed to build the structure, which contributes to solving the problem of labor shortage, without jeopardizing the business. Besides the fact that the 3D printing approach has long been supported as a potential solution to the housing crisis, a note has to be made that this is considered to be only the tip of the iceberg of what technology is capable of. The ability to quickly and cost-effectively create models, samples, and products has already proven useful in the timely response to the unexpected disasters (making ventilation valves for hospitals, protective equipment for health care workers etc.).

Although 3D printing provides civil engineers with numerous opportunities, it also faces challenges, preventing it from the broader application nowadays. One long-standing concern with buildings with 3D printing is that technology alone is not enough to make a building habitable. Namely, while the printer is capable of making walls and frames, other elements such as carpentry, plumbing and electrical systems must be installed manually, which decreases the positive effect of the printing phase, and illustrates the fact that the technology improvement of the technology is needed. An even more serious drawback is that 3D printed structures, when tested, usually prove to be less strong and

robust in comparison to the conventional buildings. This is because the material used often tends to degrade and lose some of its structural integrity over time. There has been some success in solving this problem by purifying existing concrete and semi-polymer mixtures and incorporating biodegradable materials.

The concept of the principle advantages and disadvantages of the 3D printing in the construction sector are summarized in the Table 1.

Table 1 – The principle advantages and disadvantages of the 3D printing in the construction sector

Advantages	*Disadvantages*
wide range of construction types and complexities optimized use of materials reduction in formwork, scaffold and labor fast adjustment (modification) recycle and reuse friendly minimizes waste as well as CO2 releases energy efficiency	materials must be of high and constant quality less strength and robustness then conventional 3D presents just one segment in construction

3 Materials and technology of the concrete 3d printing concept with respect to the energy efficiency

Materials play a key role in the construction of 3D printing. The material used has to be of an optimum composition, and to possess the appropriate consistency and workability [3]. For construction purposes, the most common method involves a mixture of materials consisting of cement, fibers, aggregates and additives.

The exact combination of the used materials depends on the application, purpose and the type of the 3D printer itself. Firstly, these different raw materials are thoroughly mixed in a large tank and, after that, they can be introduced into the extrusion apparatus and combined into the computer aided designed shapes and patterns. There have also been cases where houses are printed from completely biodegradable materials, including mud, earth, straw and rice husks. A good example for the diversity of the materials used in this process is the WASP Italian start-up, which uses a mixture based on natural materials [4].

In order to create a successful construction product, some properties of the materials itself, related to the extrusion process, must be met. The material to be used in the process must be pumped, which means that it must be able to move easily through the pipelines. It must also have the ability to be formed by printing as precisely as possible, which indicates that the material must be easily deposited through the nozzle (the end of the pipeline). It must also have the necessary strength to withstand the required loads, to resist deformations and to meet the required structural behavior during all phases - printing, hardening and in the exploitation.

With respect to the technology, there are many ways to perform 3D printing of a structure. They all share the main components and concepts. They can primarily be classified into two techniques (methods): jet bonding and material application method (MDM). The basic principle of both of these techniques is to build any complex structure by adding small layers of material over each other. A short description of the two methods is following.

In the jet bonding procedure, a layer of dry powder material is applied by the jet, and then sprayed with a bonding liquid. This process is repeated until the product is completely printed. Unbound material is sucked out of the printing house and recycled for reuse. Unless certain protection is applied, this technique is not suitable for the construction site itself, because it is very sensitive to weather conditions. It is suitable for relatively small parts of structures that can be transported to the site. Sand and stone fillers bound with an inorganic binder, dry concrete mix and many other materials can be used in this process, but carefully selected.

The Material Application Method (MDM) process works by gradually pouring a layer over a layer of material, until a given model is completed using a computer. In order to obtain the desired

quality of the product without any deformation, the mixture must withstand its own weight and the weight of subsequent layers.

It is a common knowledge that the design of the building itself and its elements have a great influence on the energy consumption. Therefore, a special attention must be paid at the earliest stage of design in order to construct buildings with low energy consumption. If designed properly, buildings can passively achieve thermal comfort. The flexibility of 3D printing execution gives designers the opportunity to create the appropriate elements for each project, preventing later treatments for the energy consumption reduction.

For instance, according to the climatic conditions, building elements must be designed in such a manner to achieve a certain value of thermal transmittance, and in order to achieve thermal comfort of the inhabitants. In most construction techniques, this is usually achieved by introducing air gaps or layers of insulation within or between the structural components of the building elements. 3D printing provides the opportunity for designers to create a print layout with air cavities that meets both thermal and structural requirements. Different arrangement of cavities affects the value of thermal transmittance. In addition, the ratio between the dimensions of the extruded concrete and the air gaps are an essential aspect of designing printing walls that meet the required structural behavior. In order to achieve structurally stable geometries without additional external reinforcements, the realistic presentation of the structures made by 3d printing have to be comprehended. In the cases when it is not possible to provide the required values of thermal transmittance only through the arrangement of cavities, experts recommend the use of materials for filling cavities (dry sand, polystyrene and polyurethane) instead of adding insulating layers. Nevertheless, in such a way the concept of 3D printing itself loses its meaning.

4 Conclusion

It is estimated that about 30-40% of the total energy consumption in the world takes place in the buildings, because most of the energy demanding human activities take place in them. Also, most of the contemporary research is focused on the adoption of energy efficiency strategies and other solutions to overcome and mitigate greenhouse gas emissions.

As the world turns towards the green, sustainable and energy efficient solutions, the concept of 3D printing offers a high potential of green construction. In comparison to the current methods, this method offers to eliminate a large amount of CO_2 emission, and to reduce the energy consumed in the construction process. The 3D printing of civil engineering structures clearly has a huge potential, however, the key challenges in this field lie in innovative materials and new techniques that must be studied and developed prior to the wider application of this process [5].

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