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Design of 3D printers analysis for construction and architecture

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As an advanced method of green construction, concrete 3D printing has the advantages of saving materials, energy and time. However, this technology still cannot meet the practical requirements of large-scale production in the construction industry, and it requires further equipment, materials, and software research. In this paper, the classification of 3D printing in the field of construction, the status of research, and acquaintance with existing equipment for concrete 3D printing are considered.

Keywords: additive manufacturing, 3D printing, green construction, robotic printer, concrete printing.

Аналіз конструкцій принтерів для 3D-друку в будівництві та архітектурі

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У статті виконано огляд принтерів для 3D друку в будівництві як цілих будинків, так і окремих їх частин. Проаналізовано основні недоліки і переваги різних конструкцій принтерів для 3D друку та визначено, у яких технологічних схемах їх використання є найбільш доцільним. Починаючи з 2005 року 3D друк став доступний для загального використання, але вартість виготовлених виробів за допомогою технології друку перевищувала вартість виробництва аналогічних виробів в декілька разів. У будівництві в більшості випадків технологія 3D друку використовується для створення ексклюзивних, індивідуальних, виставкових будівель, але науковці з кожним роком все більш пристосовують технологію для серійного виробництва будівельних конструкцій та будівель в цілому за типовими проектами, що дозволить зменшити витрати на будівництво. Підчас розгляду технології 3D друку встановлено, що принтер здатний працювати з безліччю різних матеріалів, включаючи глину, невелику кількість хімічних добавок, а також цемент. Стандартний будівельний 3D-принтер функціонує дуже подібно до стандартного принтера FDM, в першу чергу, тому, що обидві технології засновані на екструзії матеріалу. Тому їхні процеси дуже схожі один на одного: спочатку створюється цифрова 3D-модель за допомогою програмного забезпечення для 3D-моделювання. Потім модель розрізається і перекладається в G-код. G-Code потім направляє друкувальну головку, яка шарами укладає матеріал, що подається з бетонозмішувача, доки не буде виготовлений останній елемент. Залежно від типу бетонного 3D-принтера його конструкція, можливості та процес варіюються. Кожен з них має певні переваги та недоліки в залежності від бажаного застосування. Обсяг зони друку, точність друку, практичність та ефективність конкретного 3D-принтера будуть відрізнятися залежно від його системи, технології, виробника та передбачуваного застосування. Таким чином 3D технології все ширше використовуються у нашому повсякденному житті і в різних галузях техніки, що дозволяє пришвидшити будівництво, автоматизувати та здешевити його.

Ключові слова: адитивне виробництво; 3D друк; зелене будівництво, роботизований принтер, друк бетонним розчином.

Introduction

Nowadays the major difference between modern construction machines and technologies is the application of IT technologies, robotics, and automation. The technology of 3D printing is among the construction technologies that fully meet these criteria.

3D printing is a technology that applies plastic concrete layer by layer with an extruder.

The history of 3D printing technology dates back to the 1980s, but due to the high cost, the complexity of computers, and the lack of computer power, it has not been widely used. Since the 2000s, the development of computers has increased rapidly, which has made it possible to use 3D printing in medicine, mechanical engineering, and aircraft manufacturing. Since 2005, 3D printing has become available for general use, but the cost of additive manufactured products has exceeded the cost of common production of similar products several times. In most construction cases, 3D printing technology is used to create exclusive, individual, exhibition buildings, but every year scientists are adapting the technology for mass production of buildings in general on standard projects, which will reduce construction costs. The 3D printer is capable of working with many different materials, including clay and concrete [2].

Definition of unsolved aspects of the problem

The equipment for concrete 3D printing has a wide range of designs and printing technologies, which causes problems in choosing both the equipment and technological parameters of the printing process.

Problem statement

The goal of the work is to review the concrete 3D printers and to analyze the technologies in which their use is most appropriate.

To achieve this goal, it is necessary to solve the following tasks:

– inspect the most common designs of construction 3D printers;

– analyze their advantages and disadvantages;

– to evaluate the possibilities of different construction 3D printers for quick readjustment depending on the change in the production program.

Basic material and results

Designs of construction 3D-printer are no different from the design of 3D printers used in other industries. The frame, extruder, and drives that move the extruder in a given direction are the main elements of a construction 3D printer.

The size of the printer will mainly depend on the object being built. The classification of printers is divided according to the spatial method of work, objects of printing, and mobility.

According to the spatial method of work is divided into portal printers, delta printers, and robotic manipulators.

In portal printers, printing is carried out on the X, Y, and Z axes has become the most common due to the simplicity of design. The drawbacks of such printers are the limitation of the dimensions of the building under construction.

An example of a portal printer is the BOD2 printer from COBOD (Figure 1-2) [3, 4]. The construction of a two-storey house in Belgium on 90 m^2 took 15 days.

Figure 1 – 3D-printer BOD2

Figure 2 – Two-storey building printed by BOD2

The Ukrainian manufacturer of portal printers is Voltaro - the Kharkiv plant of CNC machines. Printers manufactured at the factory can be used for the construction of buildings, gazebos, fences, and one-piece formwork. It can be built in the shop and on the construction site (Figure 3) [5].

The pros of portal 3D printers are:

– simplicity and reliability of construction;

– minimal maintenance.

The cons are:

– limited size of the 3D printing area used mainly for the low-rise buildings;

– non-mobile design of the 3D printer;

– high requirements for the preparation of the construction site.

Figure 3 – 3D-printer Voltaro

Delta printers in which the axes are located parallel on three frame supports, which can also be guides for the axle carriages. The frame shape is a triangle with angles of 120 °. It looks like the Latin letter Δ - delta. The advantage of delta printers is the ability to print complex objects compared to portal printers. Disadvantages of delta printers are inaccurate printing and low reliability. The largest concrete 3D printer is the Big Delta. Big Delta is a development of the Italian company WASP. The printing area on the construction site is 6 meters in diameter and 12 meters high (Fig. 4-5) [6].

Figure 4 – 3D-printer Big Delta from WASP, Italy

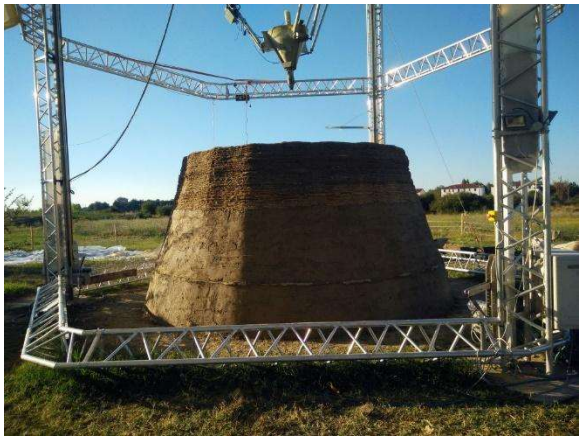

Figure 5 – Exhibition building printed by Big Delta

The advantages of construction delta printers are:
– large building field;
– modular design of the printer which is easily mounted;
- the ability to serve low-skilled staff.

The disadvantages of delta printers are:
– the impossibility of using heavy extruders;
– the inaccuracy of 3D-printing in XY direction;

Robotic manipulator printers can print designs of any shape in any direction at the distance of the manipulator length.

According to their design, robotic manipulator printers have different types: tower crane printers and robotic "arm" manipulators.

Apis Cor printer (Figure 6) is a nice example in the niche of robotic manipulator printers [7]. The company develops manipulators that allow you to print buildings under the supervision of only two operators. Due to the compact design, the printer can be easily transported with a trailer, which will increase its competitiveness in the market for construction 3D printing.

Figure 6 – Exhibition building by Apis Cor

Anna Chen-iun-tai, CEO and Co-founder of Apis Cor, says, “3D printing technology allows us to reduce the amount of construction waste. Additive manufacturing is the opposite of the subtractive manufacturing process where you need to cut out extra material to build a needed shape. In the case of 3D printing, you add as much material as you need to create a shape.” This makes it a more efficient and sustainable process [7].

Apis Cor has a unique solution - tracked chassis. This allows movement freely around the building site (Figure 7) [8].

There is one of the oldest techniques – building with earth, dating back thousands of years. Not surprisingly, it's being combined with modern digital fabrication techniques such as 3D printing, in order to create eco-friendly, low-carbon structures that are also affordable.

Italian company WASP (World’s Advanced Saving Project) is one of these modern-primitive pioneers in the field of 3D printing with mud (as seen previously), creating large delta-style 3D printers that can manufacture habitable homes out of the mud. Their latest project is Gaia, an affordable tiny home that's been printed out of mud using the company's modular printing system which uses a new “infinity 3D printer”, dubbed the Crane Wasp. (Figure 8) [9].

Figure 7 – 3D-printer by Apis Cor with tracked chassis

Figure 8 – 3D printer by Crane Wasp

The advantages of robotic 3D printer manipulators are:
– small dimensions and weight;
– easy transportation - mobility;
– easy preparation on construction site;
– the ability to move around the site while working if the printer has a mobile platform or move with the help of auxiliary equipment
– versatility and possibility of construction of complex buildings due to replaceable nozzles of an extruder;
– automated laying of reinforcing and insulation, surface finishing, and painting.

The main disadvantages of using robotic 3D printers-manipulators in additive construction are:
– the high cost of equipment;
-- the complexity of maintenance, which requires professional and highly qualified staff;
- the limited height of the building under construction.

One of the specifications that have been established is that the printer needs to be mobile so that it can be moved to the building site where the building is to be built. This led to the idea of the printer being integrated into the trailer of an articulated lorry, such as the one shown in Figure 9 [3], and sliding out from one side of the lorry to produce the build area. This means that some of the components of the printer could be integrated into the trailer of the lorry itself. Also, the lorry trailer could be attached to the support structure of the printer to increase the stability or be used to replace part of the support.

However, this means the size of the printer would be restricted by the trailer of the lorry, which is predetermined from the maximum allowed size according to the regulations of the road. This meant the maximum size of the lorry trailer could be 12 meters long, 3 meters wide, and 4.95 meters in height. It also means that there would be a weight restriction on the printer of 44 tonnes. Additionally, this means that the printer will not be limited to one building site and therefore saves time in setting up the printer as it can be transported almost completely assembled.

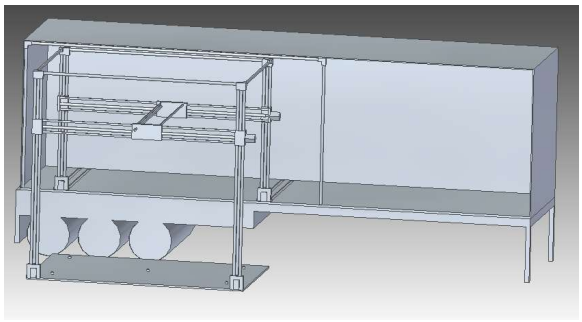

Figure 9 – Car trailer 3D concrete printing

Due to some of the printer components being integrated into the truck or attached to the support structure, there would be some vibration that could either cause the printed part to subside or cause the print head to move and cause inaccuracies in the printing.

Therefore the vibration would have to be kept to the minimum by the use of rubber dampers underneath the components which cause vibration or on the bars which have moving parts on them.

The components that are to be mounted in the trailer itself which will cause vibration can be mounted on a rubber mat which damps the vibration and stops the machinery from getting damaged. These rubber mats are commonly used in construction for reducing the effect of vibration caused by heavy static generators, compressors, engine test beds, etc [3].

All the described printers work according to the following algorithm:
– Data preparation;
– Preparation of concrete mix;
– 3D printing.

A standard construction 3D printer works very similarly to a standard FDM printer. This is primarily because both technologies are based on the extrusion of the material. Therefore, their processes are very similar: first, a digital 3D model is created using 3D modeling software. Then the model is sliced and translated into G-code. The G-Code then drives the extruder, which lays the material layer by layer until the last element is extruded. Construction 3D printers are designed to make parts by extruding material from the print head (extruder), which is attached to a portal system or a robotic arm system similar to a crane. Depending on the type of concrete 3D printer, capabilities and processes

can vary. Each of them has certain pros and cons depending on the desired application. The size of the printing area, printing accuracy, practicality, and efficiency of a particular 3D printer can vary depending on its system, technology, manufacturer, and intended use.

The most important process is the preparation of concrete mix. While preparing the concrete mix, the following parameters must be taken into account: the speed of laying, the height of the mix, and the time between two layers.

The supply of concrete to the extruder can be constant or cyclic.

During 3D printing, the concrete mixture is extruded from the printer through a nozzle.

Extrusion of the concrete mixture and laying in layers is provided through the nozzle of the printer in a given way (Figure 10), programmed by the user. This path is programmed accordingly, so the printer extrudes concrete in layers, forming a real three-dimensional object in a digital model form. At this stage, it is necessary to control the time of delivery of concrete to prevent rapid hardening and as a consequence clogging the printer.

Figure 10 – Concrete extruding layer by layer

The scheme of feeding the concrete mixture into the printing area includes two stages: preparation of the mixture and its subsequent injection through the feed hoses to the extruder (Figure 11).

3D printing technology allows the creation of a variety of building structures of any strength and different designs. These are structures in which the possibility of adding heat-insulating material (Figure 12) or additional reinforcement, adaptation to the landscape, and special climatic conditions.

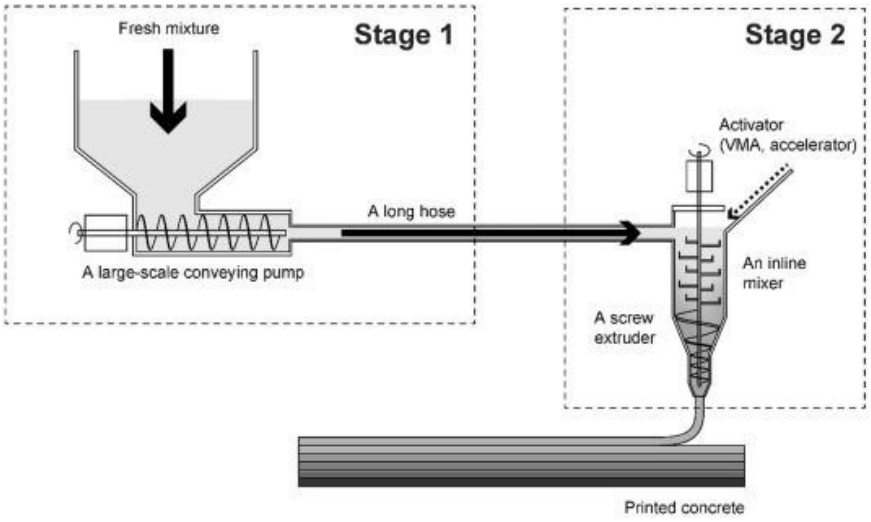

Figure 11 – The scheme of feeding the concrete mixture into the printing area

Figure 12 – Adding heat-insulating material or additional reinforcement

Conclusions

As a result of the analysis performed in the paper, the main designs of concrete 3D printers and their individual elements are determined. Their disadvantages and advantages in terms of logistically efficient organization of production are considered. It is determined that at the moment the designs of existing printers allow the creation of low-rise buildings of different configurations with the use of different construction mixtures. The main ways of feeding the mixture to the printer extruder, ways to improve the performance of construction printers, and their further possible improvement are analyzed.

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