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NEW TECHNOLOGIES IN THE FIELD OF CONSTRUCTION. USING 3D PRINTERS

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Technological processes in all branches of production are maximally automated in the world, this also applies to construction. The main driver of automation of construction processes is 3D-printing technology. The first driver was the invention of stereo lithography technology, which was discovered in 1986 by American engineer Chuck Hull. The article describes the process of 3D printing technology, using different materials and printing principles. The main 3D printing includes the application of material in layers at high temperature (for small plastic products) and layer by layer of concrete mix and geopolymer concrete when printing houses. The first to start using 3D printers in construction was the Chinese company Winsun. Also considered are building structures (buildings and structures) that were built using 3D printers, compared to their technical and economic indicators. The positive and negative aspects of the use of 3D printers in construction are studied. In the future it is planned to study plastics of ABS and PLA brands to create structural building elements with the subsequent use of these elements in construction.

Key words: 3D printers, stereolithography, laser sintering of powders, gluing of powders, 3D printing, building elements.

Statement of the problem in general.

Today, the world's fourth industrial revolution (Industry 4.0) is taking place in the field of production, at a time when construction has stopped at the second stage. (Kozyk, 2020 & Fabian Schmidt, 2013). The problem is that many construction processes are non-automated, especially on construction sites. This is due to the fact that in the organization of labor in industrial production jobs are “stationary”, and objects of labor move along established lines of production, while in construction production crews and means of labor (crane, bulldozers) move around the workplace, performing certain construction and installation work, and the objects of labor remain stationary. That is, stationary jobs in industry are easier to automate, namely to organize an automated workplace instead of an employee. It is problematic to do so in construction.

Analysis of publications.

At the moment, 3D printers are gaining popularity in the world. Their use reduces human labor costs and increases the speed of production for both light industry and construction. According to RoboTrends, one of the main manufacturers of 3D printers is WinSun in China and Apis Cor in the United States. Printers of these companies perform the construction of houses and buildings with both traditional materials and mixtures of waste from the construction itself, including glass, steel and cement.

The purpose of research.

The purpose of the study is to determine the feasibility of using 3D printers at different stages of construction, or when creating individual building structures (columns, trusses, crossbars, etc.), review technologies for erection of both small and large buildings, and materials that can be used.

Theoretical part.

3D printing technology was invented in 1986 by American engineer Chuck Hull and was originally called stereolithography. This technology consisted in the fact that the curing of the polymeric substance used in the stereolithographic technology of laser 3D printing took place under the action of an ultraviolet laser forming parts from layers. To build each of the layers, the laser passed through the cross section of the part on the surface of this polymeric substance. After the layer was built, the movable platform was raised to a distance equal to the thickness of the previous layer and it repeated this process until the end of printing of the part. After receiving the part was immersed into a chemical bath to be cleaned from excess resin, and the curing process was finished in ultraviolet furnaces.

With the development of this technology today, in addition to the process of stereolithography, there are three other technologies of 3D printing (Slyusar, 2007 & Fabricator, 2019):

1. *Laser sintering of powders.* The powder itself is delivered to the printer by means of a rotating shaft and is evenly distributed over the entire surface for printing. The 3D printer removes excess material, but later uses it again to apply the next layer. It should be noted that the high accuracy of this method provides the immobility of the parts. But there is one significant disadvantage in this way – low quality (non-smoothness) of the surface of the object, which requires mandatory refinement.

2. *Bonding of powders.* This principle of operation is as simple as possible – starch-cellulose powder, together with water-based glue, come on the needle of an inkjet printer. The glue binds the powder and forms the contours of the model, and to give the product strength, its cavities are filled with liquid wax. (COLOR Brand design. 2013).

3. *Inkjet simulation* (in this case, the printer uses two types of materials – supporting and modeling). Wax is most often used as a supporting material, but the list of modeling materials is quite long. Basically, these materials are similar in their properties and features to structural thermoplastics. The process consists in the simultaneous application of supporting and modeling material, followed by photopolymerization, and then – mechanical alignment. This method allows you to create both hard and soft products. In the second case, there is a similarity of the material of the product with rubber.(Zelenko, 2013). China was the first to use 3D printing in construction during the construction of the Vulcan pavilion (Fig. 1).

Fig. 1. Pavilion "Volcano" (China)

The 8.08 m long and 2.88 m high pavilion was printed more than once, it was assembled from +1023 parts which were printed on a 3D printer and gradually assembled during the construction of the pavilion. This pavilion become one of the wonders of the "Guinness Book of Records". This work revealed some shortcomings of 3D printing, as well as a rather limited scope. To create a small house, the 3D printer must be giant or have guide rails to move on them during printing. The need for large 3D printer and toosmall print elements showed that 3D printing was at an early stage of development.

Winsun, has printed several concrete houses in China. One of its projects is often cited as an example when it comes to 3D printing in construction. Representatives of the company claim significant savings. Thus, compared to traditional construction, printing a new house requires 60 % less materials, 70 % less time and 80 % less labor. The device is 150 meters long and 10 meters wide and can print a house up to 6 meters high in just a few hours. WinSun 3D construction printer uses fiberglass-reinforced cement mortar as "ink".

The first ten houses, which were printed in 2014, cost a little more than 105.000 hryvnias. (3000 €). Over time, Winsun improved its printing technology and produced several buildings of different sizes and designs for the exhibition in an industrial park in the Chinese province of Jiangsu (Fig. 2). The tallest of the buildings had 5 floors. The price of these houses started from UAH 3.500.000 (€ 100.000). (Biolog-center, 2018 & DOMINANT, 2017. & Pro 3D, 2019).

Fig. 2. 5-storey building (China)

In Europe, the first to use a 3D construction printer in construction were Amsterdam specialists from DUSArchitects, who "printed" a house called Canal House. The project was completed in 2017.

One of the main competitors of the Chinese company Winsun is the American company Apis Cor. In January 2016, a residential building was printed in Stupino in cooperation with American and Russian companies. Printing of load-bearing walls, partitions and enclosing structures of the house took 24 hours, and the area of the printed building was 38 square meters. The building was printed using additive technology, layer by layer. To demonstrate the capabilities of the 3D printer, a non-standard look of the house was designed, and construction was carried out in the winter. The 3D printer withstood frosts down to -35 degrees, but the use of concrete mixtures was possible only at temperatures not lower than +5 degrees, so the construction was carried out under a canopy in which the desired temperature was maintained. The used printer by its design reminded the miniature crane which was capable to print both outside and inside the house (Fig. 3).

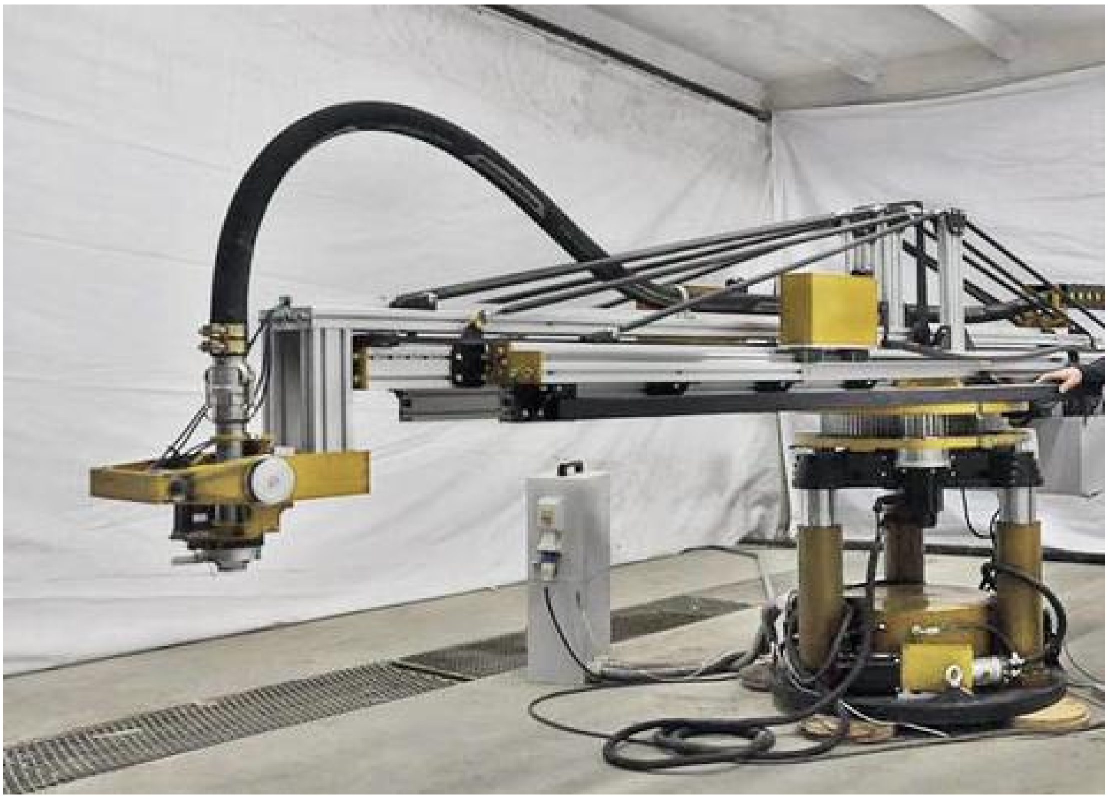

Fig. 3. 3D printer, 2016 (Russia)

The small size of the printer did not cause problems with transportation. It also did not require additional training to get started because one of the features of the 3D printer was a built-in automatic vertical alignment system and stabilization system.

The technical characteristics are given below. (RoboTrends, 2017):

– own software;
– for control of work and giving of material 2 people are required;
– printing zone – 132 sq.m. m;
– printing material – fiber concrete, or geopolymers;
– dimensional dimensions – 4×1.6×1.5 m;
– weight – 2 tons;
– energy consumption – 8 kW * h;
– the maximum height of rise from one point – 3100 mm;
– productivity – 100 sq.m of usable area per day;
– working speed – 1–10 m/min;
– idle speed X/Y – 20.000 mm/min;
– positioning accuracy – ± 0.5 mm;
– accuracy of repeated positioning – 0.1–0.2 mm;
– drive on the X/Y/Z axes;
– servo drive;
– linear guides on the X/Y axes;
– precision profile;
– accuracy along the Z axis – 0.1–0.2 mm;
– automatic stabilization on the horizon – high-precision inclinometer 0.0001 degrees;

– reverse switches – contactless on all axes;
– tracking the location of the head in space – gyroscope and laser rangefinder;
– stabilization in space;
– UNDER the regulator.

Since 3D printers have opened up many opportunities for creativity, the range of products can be very diverse. Currently in Ukraine there are no large 3D printers with which you can print large houses, but there are printers with which you can make small parts and individual structures and the main material for such printing can be plastic.

The most common materials for 3D printing are standard and exotic. (Table 1, 2). These materials can contain nylon, polycarbonate, polypropylene and more. There are materials that conduct electricity and glow in the dark. (3DiY, 2017. & 3DPrintStory, 2015)

Table 1

Standard materials. Comparative table

Material	Ease of use	Physical properties (maximum 4)		
		Strength	Flexibility	Durability
PLA	So	2	1	2
ABS		2	2	3
PETG (PET, PETT)		2	2	3
Nylon		3	3	4
TPE, TPU, TPC (flexible)		1	4	3

Table 2

Exotic materials. comparative characteristic

Material	Ease of use	Features
Wood	So	It looks like a tree
Metal	So	Looks like metal
Biodegradable (bioFila)	So	Biodegradable
Conductive	So	Conducts current
Glow-in-the-Dark	So	Glows in the dark
Magnetic		Ferromagnetic
Color-Changing	So	Changes color depending on temperatures

The most common standard printing plastics are PLA and ABS plastics.

PLA plastic – is one of the best in terms of home printing. It is often compared to ABS – the second most popular – but still PLA significantly outstrips ABS. And there are reasons for that:

– first (most important) – PLA plastic is easy to print. The temperature for printing PLA plastic is lower than for ABS plastic and it does not come off the stand so easily, ie it is not necessary to use a heated table (although it will definitely help).
– second – PLA plastic does not smell bad during printing. In general, it is believed to be odorless, but in fact evaporation is present.
– third is an environmentally friendly material made from renewable resources, such as corn.

The main characteristics of PLA plastic for 3D printing:

• strength: high;
• flexibility: low;
• durability: average;
• difficulty of use: Low;
• printing temperature: 180–230 °C;
• table temperature for printing: 20–60 °C (optional);
• shrinkage / deformation during cooling: minimal;

• soluble: No;
• environmentally friendly: Depends on the manufacturer.

Scope of use. Unlike other materials, PLA is fragile, so do not use it if the product is to be bent, pressed or dropped often. For example, it should not be used to make phone cases or tool holders. It should also not be used for models that will be exposed to high temperatures, as models with PLA begin to lose shape at 60 °C or more. For all other cases, PLA plastic is an excellent choice, for example, for models, prototype parts and mechanisms.

ABS *plastic* is the second most popular, after PLA plastic. By its properties, ABS is a kind of improvement of PLA, although it is much more difficult to print. Due to its physical properties, ABS plastics are actively used in production. This material is used to make, for example, LEGO bricks and helmets for motorcycles. Products made of ABS plastic have a long service life, can withstand high temperatures, but for 3D printing a high temperature must be maintained, plastic has the ability to shrink when cooled. Evaporation when printing ABS plastic is harmful to the body. ABS plastic should be printed using a heated table in a well-ventilated room.

The main characteristics of ABS plastic for 3D printing:
• strength: high;
• flexibility: medium;
• durability: high;
• difficulty of use: average;
• printing temperature: 210–250 °C;
• table temperature for printing: 80–110 °C;
• shrinkage / deformation during cooling: tolerable;
• solvent: acetone and its analogues;
• environmentally friendly: no.

Scope of use. These characteristics make ABS plastic a versatile material. Its main advantages are manifested in products that are often mounted / dismounted, can be rapidly decreased or heated. For example, ABS plastics are perfect for printing phone cases, cases for electrical appliances. You can print plain bearings.

Plastics, which are not so widely used due to the high price, but are not worse in their characteristics than popular plastics, are PETG, PET, PETT.

“Pure” PET is rarely used for 3D printing, but its first variety – PETG – is a fairly common material. “G” means “glycol-modified”, which makes the material cleaner, less brittle and, what is the most important, easier to use for 3D printing comparing to standard PET. PETG is often positioned as something in between PLA and ABS plastics – the two most common materials for 3D printing. PETG plastic is more ductile than PLA and ABS plastics so it is easier to print.

Three factors one should keep in mind when using this plastic:

1. PETG adsorbs moisture from the air, so this negatively affects the subsequent process of 3D printing. It should be stored in a cool, dry place.

2.PETG is impregnated during printing, so you need to be especially careful when printing the first layers.

3. Although PETG is not brittle, but it scratches harder than ABS.

Polyethylene coTrimethylene Terephthalate (PETT) is the second type of PET. This material is harder than PETG, but has gained popularity because it is transparent.

The main characteristics of PETG, PET, PETT plastic for 3D printing:
• strength: high;
• flexibility: medium;
• durability: high;
• difficulty of use: low;
• printing temperature: 220–250 °C;

• printing table temperature: 50–75 °C;
• shrinkage / deformation: minimal;
• soluble: no;
• environmentally friendly: depends on the manufacturer.

Scope of use. PET is a very versatile material with high rigidity and resistance to high temperatures. Thanks to this PETG will prove to be perfect for production of separate details for mechanisms, cars, the same 3D printer. It will also be ideal, for protective products and cases.

Conclusions

According to the results of the research, the following conclusions can be drawn:

1. From the conducted research it is possible to see that the technics used at manufacturing of details by means of 3D printers are similar and the principle of "spraying" the material is used everywhere.

2. The advantages of using a 3D printer when printing buildings with a concrete mixture are:

• Almost complete automation of the process (work with the printer requires 2–3 people who will monitor the operation of the printer and early submission of material);

• Opportunity to implement any architectural and design ideas that are not available using standard construction methods;

• Low energy consumption of equipment;

• Cost-effectiveness by means of reducing labor costs for workers;

• Complete absence of no construction waste at all;

•, Elimination of the human factor and reducetion of the likelihood of errors due to the process of automation;

3. The disadvantages include:

• Restrictions on printing dimensions;

• When printing at home, the printer prints everything except the roof and internal networks. Thus, the roof must be arranged by traditional methods.

4. Since this field in Ukraine is only developing and plastics are used for the manufacture of household parts, the idea is to test these plastics, namely PLA and ABS as building materials. In the future, the 3D printer will be used for producing and testing beams, columns and dome from these plastics. They also will be tested for strength and physical properties. Lviv Polytechnic National University has the opportunity a producing these building elements on a 3D printer with limited dimensions, namely 20×20 cm.

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НОВІ ТЕХНОЛОГІЇ В ГАЛУЗІ БУДІВНИЦТВА. ВИКОРИСТАННЯ 3D ПРИНТЕРІВ

У світі максимально автоматизують технологічні процеси у всіх галузях виробництва, це стосується і будівництва. Основним рушієм автоматизації процесів будівництва є технології 3D-друку. Першим рушієм стала поява технології стереолітографії, яку в 1986 р. винацшов американський інженер Чак Халл. У статті описано процес технології 3D-друкування з використанням різних матеріалів та принципів друку. В основну 3D-друкування входить нанесення матеріалу шарами за високої температури (для малогабаритних виробів з пластику) та пошаровим з бетонної суміші та геополімерного бетону в разі друку будинків. Першою почала використовувати 3D-принтери в будівництві китайська компанія Winsun. В Європі першими застосували 3D друк амстердамські фахівці, які “надрукували” будинок під назвою Canal House. Також розглянуто будівельні конструкції (житлові й промислові будівлі та споруди), побудовані за допомогою 3D-принтерів, порівняно їх техніко-економічні показники, зокрема павільйона “Вулкан” в Китаї, зібраного з 1023 частинок, які були надруковані на 3D-принтері, та інші одно- та багатоповерхові будівлі та споруди. В статті розглянуто перший 3D-принтер, який витримував морози до – 35 градусів та був використаний для друку за мінімальних температур, які дали змогу використовувати будівельну суміш, а саме +5 градусів. Досліджено позитивні та негативні аспекти використання 3D-принтерів у будівництві. Надалі заплановано досліджувати пластмаси марок ABS та PLA для створення конструктивних будівельних елементів з подальшим використанням цих елементів у будівництві

Ключові слова: 3D-принтери, стереолітографія, лазерне спікання порошків, склеювання порошків, 3D-друк, будівельні елементи.