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3D-PRINTING OF BUILD OBJECTS

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Summary. ***Raising of problem.*** Today, in all spheres of our life we can constate the permanent search for new, modern methods and technologies that meet the principles of sustainable development. New approaches need to be, on the one hand more effective in terms of conservation of exhaustible resources of our planet, have minimal impact on the environment and on the other hand to ensure a higher quality of the final product. Construction is not exception. One of the new promising technology is the technology of 3D -printing of individual structures and buildings in general. 3D-printing - is the process of real object recreating on the model of 3D. Unlike conventional printer which prints information on a sheet of paper, 3D-printer allows you to display three-dimensional information, i.e. creates certain physical objects. Currently, 3D-printer finds its application in many areas of production: machine building elements, a variety of layouts, interior elements, various items. But due to the fact that this technology is fairly new, it requires the creation of detailed and accurate technologies, efficient equipment and materials, and development of common vocabulary and regulatory framework in this field. ***Research Aim***. The analysis of existing methods of creating physical objects using 3D-printing and the improvement of technology and equipment for the printing of buildings and structures. ***Conclusion***. 3D-printers building is a new generation of equipment for the construction of buildings, structures, and structural elements. A variety of building printing technics opens up wide range of opportunities in the construction industry. At this stage, printers design allows to create low-rise buildings of different configurations with different mortars. ***The scientific novelty*** of this work is to develop proposals to improve the thermal insulation properties of constructed 3D-printing objects and technological equipment. The list of key terms and notions of construction by 3D-printing and 3D-modeling. ***Practical value.*** Developed in this work equipment and materials allows in the nearest future to move from theory to practice and implement such effective method of construction as the technology 3D-printing.

Keywords: *3D-printing, printer, printing head, extruder, energy-efficient materials, building*

3D-ПЕЧАТЬ СТРОИТЕЛЬНЫХ ОБЪЕКТОВ

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Аннотация. ***Постановка проблемы.*** На сегодняшний день во всех сферах нашей жизни идет перманентный поиск новых, более современных методов и технологий, отвечающих принципам устойчивого развития. Новые подходы должны быть с одной стороны более эффективными с точки зрения сохранения небезграничных ресурсов нашей планеты, иметь минимальное влияние на окружающую среду, а с другой стороны обеспечивать более высокое финальное качество продукции. Строительство не является исключением. Одной из новых перспективных технологий является технология 3D–печати как отдельных конструкций, так и зданий и сооружений в целом. 3D-печать – это процесс воссоздания реального объекта по образцу 3D-модели. В отличие от обычного принтера, который выводит информацию на лист бумаги, 3D-принтер позволяет выводить трёхмерную информацию, т.е. создавать определённые физические объекты. На данный момент 3D-

принтер находит свое применение во многих сферах производства: элементы машиностроения, разнообразные макеты, элементы интерьера, различные детали. Но в связи с тем, что эта технология достаточно новая, она требует создания точных и детально проработанных технологий, эффективного оборудования и материалов, а также разработки общепринятой лексики и нормативной базы данной сферы. ***Цель.*** Анализ существующих методов создания физических объектов 3D-печатанием и усовершенствование технологии и оборудования для печати зданий и сооружений. ***Вывод.*** Строительные 3D-принтеры – это оборудование нового поколения для возведения зданий и сооружений, а также элементов конструкций. Разнообразие строительной печатной техники открывает широкие возможности в строительной индустрии. На данном этапе конструкции принтеров позволяют создавать малоэтажные постройки различных конфигураций с применением разных строительных смесей. ***Научная новизна*** данной работы состоит в разработке предложения по повышению теплоизоляционных свойств возводимых 3D-печатанием объектов и усовершенствованию технологического оборудования. Предложен перечень основных терминов и понятий строительной 3D-печати и 3D-моделирования. ***Практическая значимость***. Разработанное в рамках данной работы оборудование и материалы позволят уже в ближайшем будущем перейти от теории к практике и внедрить такой эффективный метод строительства, как технология 3D –печати.

Ключевые слова: *3D-печать, принтер, печатная головка, экструдер, энергоэффективные материалы, здание*

3D-ДРУК БУДІВЕЛЬНИХ ОБ'ЄКТІВ

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Анотація. ***Постановка проблеми.*** На сьогоднішній день у всіх сферах нашого життя йде перманентний пошук нових, більш сучасних методів і технологій, що відповідають принципам сталого розвитку. Нові підходи повинні бути з одного боку більш ефективними з точки зору збереження небезмежних ресурсів нашої планети, мати мінімальний вплив на навколишнє середовище, а з іншого боку забезпечувати вищу кінцеву якість продукції. Будівництво не є винятком. Однією з нових перспективних технологій є технологія 3D-друку як окремих конструкцій, так і будівель і споруд в цілому. 3D-друк - це процес відтворення реального об'єкта за зразком 3D-моделі. На відміну від звичайного принтера, який виводить інформацію на аркуш паперу, 3D-принтер дозволяє виводити тривимірну інформацію, тобто створювати певні фізичні об'єкти. На даний момент 3D-принтер знаходить своє застосування в багатьох сферах виробництва: елементи машинобудування, різноманітні макети, елементи інтер'єру, різні деталі. Але в зв'язку з тим, що ця технологія досить нова, вона вимагає створення точних та детально опрацьованих технологій, ефективного обладнання і матеріалів, а також розробки загальноприйнятої лексики і нормативної бази даної сфери. ***Мета.*** Аналіз існуючих методів створення фізичних об'єктів 3D-друкуванням та удосконалення технології та обладнання для друку будівель і споруд. ***Висновок.*** Будівельні 3D-принтери - це обладнання нового покоління для зведення будівель і споруд, а також елементів конструкцій. Різноманітність будівельної друкарської техніки відкриває широкі можливості в будівельній індустрії. На даному етапі конструкції принтерів дозволяють створювати малоповерхові будівлі різних конфігурацій із застосуванням різних будівельних сумішей. ***Наукова новизна*** даної роботи полягає в розробці пропозиції щодо підвищення теплоізоляційних властивостей зводяться 3D-друком об'єктів і вдосконалення технологічного обладнання. Запропоновано перелік основних термінів і понять будівельного 3D-друку і 3D-моделювання. ***Практична значимість***. Розроблене в рамках даної роботи обладнання і матеріали дозволять вже в найближчому майбутньому перейти від теорії до практики і запровадити такий ефективний метод будівництва, як технологія 3D-друк.

Ключові слова: *3D-друкування, принтер, головка для друкування, екструдер, енергоефективні матеріали, будівля*

Introduction. Today, in all spheres of our life we can constate the permanent search for new, moderner methods and technologies that meet the principles of sustainable development. New approaches need to be, on the one hand more effective in terms of conservation of exhaustible resources of our planet, have minimal impact on the environment and on the other

hand to ensure a higher quality of the final product. Construction is not exception. One of the new promising technology is the technology of 3D -printing of individual structures and buildings in general. 3D-printing - is the process of real object recreating on the model of 3D. Unlike conventional printer which prints information on a sheet of paper, 3D-printer allows you to display three-dimensional information, i.e. creates certain physical objects. Currently, 3D-printer finds its application in many areas of production: machine building elements, a variety of layouts, interior elements, various items. But due to the fact that this technology is fairly new, it requires the creation of detailed and accurate technologies, efficient equipment and materials, and development of common vocabulary and regulatory framework in this field. These objectives and the focus of this work.

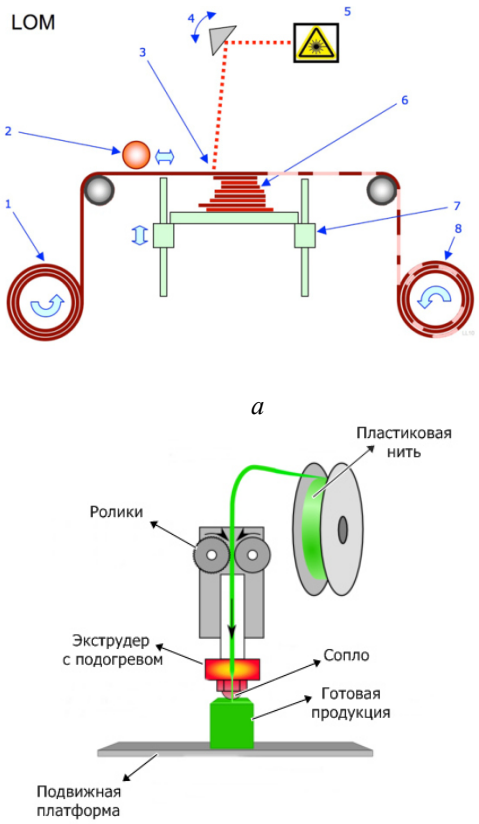
Findings. Key technologies of 3D-printing are [1-3]:

- *Layer Object Manufacturing, LOM.* The main idea is to cut the sheet of various materials with a laser beam (paper, laminates, metal foil, ceramic), and then heated rollers glue the layers between each other (Fig. 1a). The disadvantages are: a rough surface products, the possibility of bundling and mistaking if sheet is not completely cuted (damaged layers are needed to be removed, and done again);

- *Fused Deposition Modeling, FDM* — This is three-dimensional printing technology, in which the object is created of the melting the plastic thread it fed through the extruder on a work surface and is hardened there later. After the first layer, the working platform is lowered and the process continues again (Fig. 1b). It is the only technology of «cultivation» 3D-objects using industrial thermoplastics which can withstand high temperatures and mechanical loads. Layering allows to receive parts of complex geometry. The method has such disadvantages: plastic melts and spreads in all directions, so the models have pronounced relief surface, so the object precision is lost;

- *laser stereolithography, SLA* - this is three-dimensional printing technique in which liquid photopolymer under the action of laser light changes its physical properties and solidifies. The three-dimensional object is grown layer by layer, the thickness of layer in an average is 0.1 mm, which ensures high print quality. The disadvantages of the technology is high cost of equipment and low printing speed (a few millimeters per hour);

- *selective laser sintering, SLS,* is like the previous technology, but the basic material is powdered thermoplastic, sintering with laser beam.



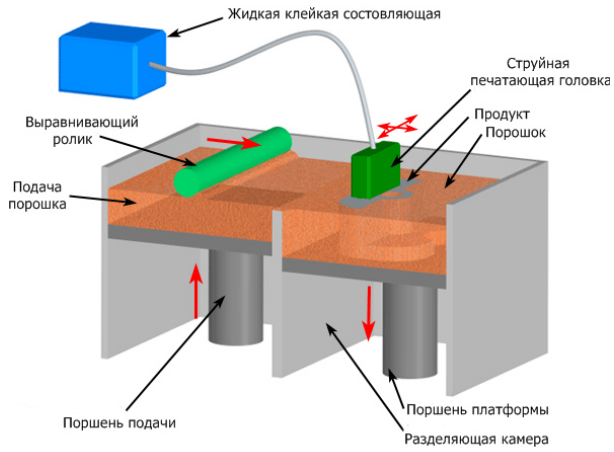
а

б

Fig. 1. 3D-printers with print technology [3]:
а – production of object by layers: 1 – foil; 2 – heated roller; 3 – laser beam; 4 – scanning prism; 5 – laser device; 6 – layers; 7 – mobile platform; 8 – remains;
б – modeling by melting method

The powder in the chamber is heated till the nearly melting point temperature, than it is leveled and the laser beam draws the required contour on it. At the point of contact of the beam and powder the particles melt and sinter with each another and with the previous layer. Then the platform is lowered a new layer of the powder is poured in the chamber, it is leveled, and the process is repeated. The technology is characterized by high speedy printing (up to 35 mm / hour), but it requires a lot of time to prepare to heat the powder and stabilize the tem-

perature while resulting models have rough and porous structure.



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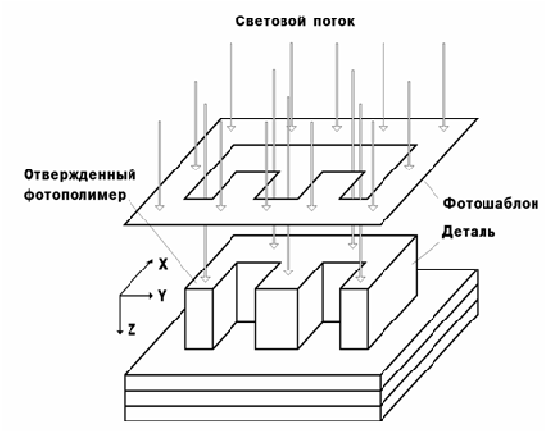

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Fig. 2. 3D-printers with print technology [3]: а – stereoscopic printing; б – photopolymer sintering

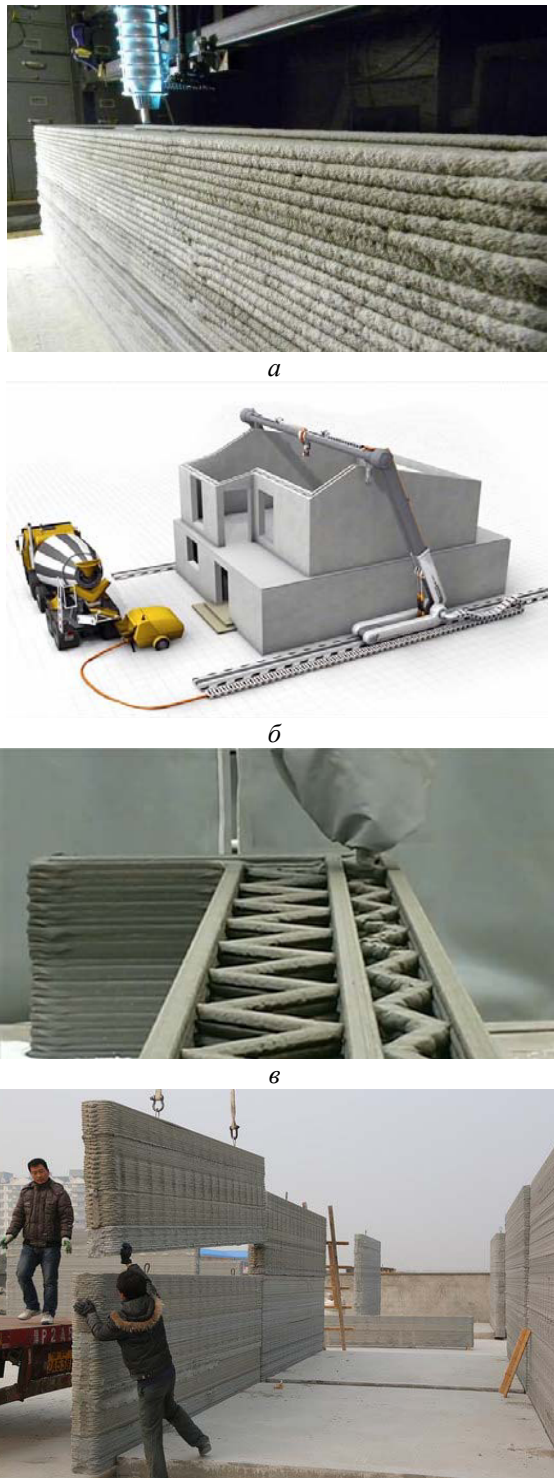
- *Three-Dimensional Printing, 3DP,* is based on inkjet technology. This kind of printers is provided with two ingredients powdered mass and liquid binder. The working chamber of each printer consists of two parts (Figure 2, a.): The first part is a powder feed chamber (model material is loaded), and the second part is the construction chamber where necessary 3D-model is grown. Initially, the material is distributed uniformly on the entire surface of chamber construction. Then, on the first thin layer special binder is applied that glues all the particles of the material together. After the platform is displaced. The supply chamber platform is lifted up, and the construction field platform is lowered down. Dislocation must be made on the same height. After this, immediately the offset printing head again begins to move, building up the model.

- *Solid Ground Curing, SGC,* is based on the fact that the special tonic creates the specific model template on a glass plate (Fig. 2b). Formed photomask is located over a thin layer of photopolymer situated on the desktop, further it should be exhibited by UV lamp. The layer corresponding photopolymer pattern hardens, and all liquid stocks are removed. In the next step all inside cavities must be filled with molten wax, solidifying enough quickly. Then the process is repeated again, but the template for the next section is already used. The advantage of the technology is that the process can be paused at any time and then be restarted from the same moment (this is important when you need to remove the defective layers or contamination). The printer creates the model with a moving component parts. A lot of noise, large weight and the constant presence of the operator are disadvantages of this type of printing.

Constructions 3D-printing is a new technology of building, which allows to build a house on an individual project using different materials in a short terms. Building 3D-printer uses extrusion technology, where each new layer of building material is squeezed out of the printer on the previous one. Construction printers are divided into two groups, printers, printing the entire building (Figure 3, b.), and printers, printing separate elements (Figure 3 in.). An example can serve models of buildings from the real building materials, elements of landscape design, etc.

Application of printers producing separate structural elements eliminates the seasonality of the construction, i.e., it is possible to print the buildings parts, to cure them in the warehouses till concrete sets necessary strength and then to assemble them into a building on the construction site (Fig. 3d).

Before start building mixture must be prepared in accordance with the requirements of the equipment. Accept the place for 3D-printer, it is also required to provide land for: mixture preparation, its supply to the printer printing head, pre-drying station, warehouses and loading site. To install the manufacturing equipment, the area or equipment room should have connection points to service lines (power, water supply).



а

б

в

г

Fig. 3. 3D-printing of constructions [11]:
а, б – building; в – printing of construction;
г – assembly of printed building structures

In the process of creating a ready-made objects at least two people are involved : the operator (directly controls the printer) and a worker (prepares a mixture, reinforces the products in the process of printing, prepares equipment for use at the beginning and the end of shift). The number of workers is up tothe equipment size and the complexity of the process, depending on design solutions manufactured object.

Printers for 3D-printing are of different dimensions and weight, for example, a printer format of 12 x 12 meters for printing elements of buildings, landscape items up to 3 meters high, is a large-size 120-ton structure (Figure 4a.). To print individual structures in the enclosed space we can use small-format printers with the capacity of the head storage device 18 ... 32 liters, dimensions of 4 x 6 meters and weight of 620 kg (Fig. 4b). At this stage, the design of printers allows to create low-rise buildings of different configurations using different construction mixtures.

It is reasonable to simulate the shape of the construction and verify the printing process of the object (3D-modeling) before the construction using technology of 3D-printing. This can be made by small format equipement using real building mixes, allowing to check the adopted architectural design and solutions. To print the building model plaster mixes are used, while cement mixture are used to create products designed for outdoor use. The process of horizontal and vertical reinforcement, installation of reinforcing skeletons inside wall cavities, laying of communications is worked out on models. An important aspect is that printed patterns are convenient for carrying out laboratory tests on various parameters.

Advantages of 3D-printing are:

the ability to create objects of any shape and complexity;

speed of building;

the use of different materials, including environmentally friendly materials;

wasteless production;

the simplicity of the process;

reduction of the human factor, and thus quality improvement and construction accuracy.

The disadvantages of this construction technology are:

lack of common terminology;

constructed facilities do not have an effective thermal insulation and have a high energy consumption;

tooling elements require further improvement.

а *б*

Fig. 4. Building printers [11]:
а – format 12 x 12 metres; б – format 4 x 6 metres

Research purpose. is to analyze the existing methods of creating physical objects by 3D-printing and the improvement of technology and equipment for the printing of buildings and structures.

Results of the study. Based on the analysis of publications and research, authors suggest, the following key terms and notions in the field of 3D-printing building.

3D-printing – the process of real object recreating based on the 3D-model.

Technology of 3D- printing – is based on the principle of layered growing (creation) of solid model.

3D-modelling – the process of construction object physical model creating.

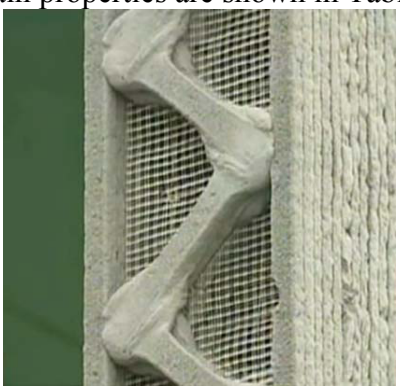
3D-printer - device to recreate real object per sample of 3D-model.

Printing head – a component of the printer, delivering the mixture to the object of construction.

Extruder – part of the printing head, forming a thick layer of extruded mortar.

Extrusion – technological process, when each new layer of building material is extruded from the printer over the previous.

During the construction of the building by any known at present method it is necessary to ensure high energy efficiency of building envelopes as well as the whole building. Alternative building wall structure created by 3D-printing, makes it necessary to search for alternative methods of energy efficiency. In this paper, we propose to increase the thermal insulation properties of objects created by 3D-printing, and reduce the overall energy losses of the building by laying energy-efficient thermal insulation of ecological materials in empty wall structures (Fig. 5) (on the basis of cut reed, pressed straw, hemp shives, adobe, lightweight adobe, lightweight concrete on the base of boon of hemp). All these materials have been created in our laboratory [9, 10] and passed preliminary tests. Their main properties are shown in Table 1.



а

б

Fig. 5. Building hollow structure [11]:
а – reinforced with fiber;б – reinforced by partitions

As for the technology, the printing process by different mortars basically differs by thickness of the printed layer and the total height of the product. The thickness of the extruded layer formes extruder. During the printing we can adjust the geometry of the extruded layer, change the speed of printing to obtain high-quality products.

Table 1

Characteristics of thermal insulation materials [10]

Material	Volume weight, kg/m^3	Thermal conductivity coefficient, Watt/(m*K)
Chop of jonk	400	0,12
	300	0,09
	260	0.078
	220	0,06
Pressed straw	150-250	0,09
	90-110	0.045
	73-85	0.04-0.05
	100	0.054-0.065
Boon of hemp	70-90	0.048-0.06
Adobe	1500	0,5
Lightweight adobe	1000	0.13
	900	0.114
	580	0.073
	420	0.071
Lightweight concrete on the base of boon of hemp	260	0,075
	360	0,079
	400	0,084

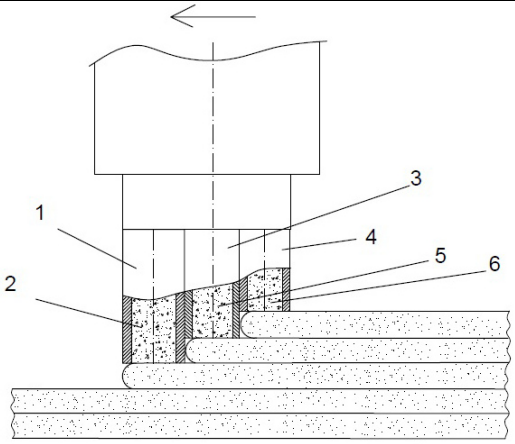


Fig. 6. Printing head with multiple extruders: 1, 3, 4 – extruders; 2, 5, 6 – cavity of mixture feed

To increase the efficiency of printing it is proposed to use printing head with several extruders set at different levels one after the another (Fig. 6).

Taking into account the properties of a stacked mixture the distance between extruders 1, 3 and 4 can regulated extending the possibilities of printing technology and capacity of construction projects.

Originality and Practical value. Developed in this work equipment and materials allows in the nearest future to move from theory to practice and implement such effective method of construction as the technology of 3D-printing and make the process of building fast, efficient and modern.

Conclusions.

1. Building 3D printers is a new generation of equipment for the construction of buildings structures, and structural elements. A variety of building printing technologies opens up wide range of opportunities in the construction industry. At this stage, printer design allows to create low-rise buildings of different configurations with different mortars.

2. The proposals for improvement of the thermal insulation properties of constructed 3D-printing objects and improvement of technological equipment are developed.

3. The list of key terms and notions of construction by 3D-printing and 3D-modeling technology are proposed.

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