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INNOVATIONS IN ARCHITECTURE OF UKRAINE: 3D-PRINTED HOUSES

Abstract. *The development of the latest technological trends in the 21st century which is justly called the age of information technologies, the strengthening of the role of innovations in the engineering sector lead to the revolution in architecture and the construction industry. It is 3D printing that has greatly influenced the field of architecture. Designers and engineers can easily create structural models based on their ideas. 3D printing allows architects to develop prototyping skills. This method is also used for producing add-ons to help them from conceptualization and iteration to actual construction. Exploring this area of technology in the laboratory of polymer materials of KNUTD, we aim to tell a wide audience about the possibilities of 3D printing in order to emphasize the attractiveness and advantages of this new technology for manufacturing companies of Ukraine.*

Keywords: *innovation technologies; architecture; design; 3D printed house; contour crafting.*

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ІННОВАЦІЇ В АРХІТЕКТУРІ УКРАЇНИ: 3D-ДРУКОВАНІ БУДИНКИ

Анотація. *Розвиток новітніх технологічних трендів 21 століття, який по праву називають століттям інформаційних технологій, підсилення ролі інновацій у інженерній практиці призводять до революційних процесів у архітектурі та будівельній промисловості. Саме 3D-друк надзвичайно вплинув на сферу архітектури. Дизайнери та інженери можуть легко створювати структурні моделі на основі своїх уявлень. 3D-друк дозволяє архітекторам розвивати навички створення прототипів. Цей метод також використовується для виробництва добавок для концептуалізації та здійснення ітерацій у фактичному будівництві. Досліджуючи цю сферу технологій в лабораторії полімерних матеріалів КНУТД, ми прагнемо проінформувати широку аудиторію фахівців про можливості 3D-друку та наголосити на привабливості та перевагах цієї новітньої технології для виробничих підприємств України.*

Ключові слова: *інноваційні технології; архітектура; дизайн; надрукований на 3D принтері будинок; контурне будівництво.*

Introduction. Architecture as we know has been shaped by countless cultures and civilizations existed before. It gives a great opportunity to appreciate all the structures and styles left by those cultures and civilizations behind the designs and construction techniques, and to apply them to modern works. 3D printing as an internet phenomenon has recently extended to wider sectors such as rapid prototyping in manufacturing, automobiles, firearms, construction, food, dental, and medical industries. 3D printing is hugely impacting the field of architecture, from concept models and custom designs to interior design and 3D printed houses.

Analysis of recent research and publications. The issues of current status and future prospects of 3D printing of buildings, the applicability and limitations of 3D printing for civil structures, the automated construction by contour crafting-related robotics and technologies have been the subject of many works by prominent researchers such as B. Khoshnevis, Q.M. Shakir, N. Nadarajan, M. Sakin, Y.C. Kiroglu, H. Lipson, M. Kurman, Joop de Boer, M. Savitsyi, S. Shatov, O. Ozhyshchenko and others.

The aim of the research is to analyze innovations in building which can be achieved with 3D printing and to emphasize the attractiveness and advantages of 3D printed houses with the prospect of development in Ukraine.

Results of the investigation. Understanding architecture's history is important because it gives us the basis to build and also to innovate. New to the stage, even 3D printing takes advantage of traditional methods and materials, bringing any idea into the physical world in an easier and cheaper way. From concept models to house construction 3D printing has a lot of useful applications for architects. Every architectural project needs a concept model that helps architects and clients to visualize the idea, but a lot of time and hard work is invested in the creation of a handmade concept model. It becomes even more difficult when the complex geometries are involved in the process. Nowadays 3D printing has been invented to simplify this process. A highly-detailed physical model can be produced in a CAD program, quite apart from the fact that designers can choose from a wide range of different materials and colors. This makes the work more efficient, allowing architects to make models faster while they're doing other tasks. If an interior designer proposes a special kind of wall tile that cannot be found anywhere else, it is possible to overcome this problem with the help of 3D printing technique. 3D model produced by this technique allows to get a mold and reproduce it with another material. That piece could even be sent to a factory or a workshop to produce a bigger quantity of it using other techniques, like concrete casting or injection molds.

3D printing can be used in interior design projects as well. This technology allows architects to design objects like lamps, panels, sculptures, and decorative objects that can be 3D modeled and printed to be directly used as finished products and enhance interior designs. Building an entire house is a very difficult job that involves a lot of people, expenses, and time. But in recent years a lot of 3D printed house prototypes have emerged, proving that it is possible to 3D print an entire home with sustainable materials in a few weeks and with a very affordable price.

A lot of news has already been published on the Internet that the Chinese engineers have learned to print inexpensive houses using 3D printers (Figure 1). These are not palaces, of course, but the houses are quite livable. And taking into account the fact of China's population, this technology is in great demand.

Figure 1. **How the Chinese print 10 houses in 24 hours (2014)**

It is obvious that the cost of creating such a house is affordable for many Chinese. It is a low-cost social housing that is constructed from cement, construction waste, fiberglass and several other components. The resulting mixture is not harmful to humans. The fact, that it is created from construction waste, makes the technology "green".

By 2020, this technology has already overcome a number of regulatory challenges in China. This is a long process – after all, it is necessary to have permission from various commissions and services, which need to make sure that the house does not fall apart in the first month after the occupants move in.

The principle of operation is to extrude (squeeze out) concrete, layer by layer, according to a given three-dimensional computer model. With the help of a complex for preparation and supply of a construction mixture, concrete is mixed with water and other additives and pumped into a hose. The hose is connected to the printer head. Pressurized by a pump, concrete is

pumped to the printer head, the mixture exits the printer nozzle and is applied to the pad surface or previous printed layers.

Construction printing concrete must be suitable for extrusion through the print head. This is not as easy as it might seem at first glance. The difficulty is that the concrete must be laid in correct even layers, without spreading, and set fast enough to maintain its shape, but not too quickly (Figure 2). The layers to be applied must remain chemically active in order to form a single structure at the point of contact. Reducing the setting speed is also important for maintaining the equipment's performance – the nozzle should not be clogged with hardening concrete.

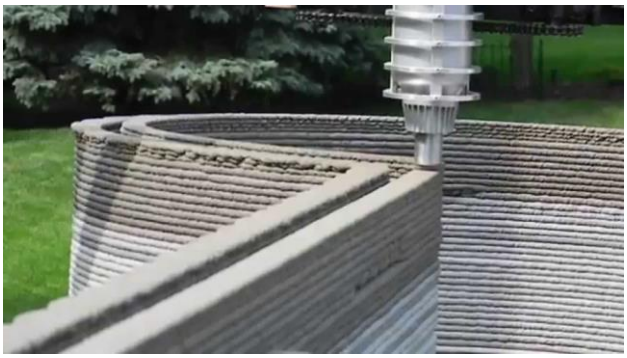

Figure 2. **An example of how concrete should be laid in even layers without spreading**

For printing fine-grained mixtures are used which differ from traditional concrete. Each company develops its own recipe that matches the design of the printer and its nozzle, as well as the specifics of the target products. The most important parameters of concrete for a 3D printer are strength, rate of strength, plasticity. The required concrete strength is selected by adjusting the composition of the mixture – the amount of cement and the quality of aggregates, as well as the addition of plasticizers. Plasticizing agents significantly increase the mobility of the mixture and reduce the water-cement ratio, which increases the strength of the concrete.

Both the advantages and disadvantages of modern 3D printed buildings technology should be considered to understand the effect of this tech advancement.

Among the advantages are the following ones: low cost, decrease in the number of personnel, reduced construction time, cleanliness, simplicity, savings.

Low cost. The first printed Russian house cost only 593,568 rubles. This price included finishing and communications. Now, for about the same money, it is possible to build only a frame-panel house, or from a bar, without finishing and communications. With the spread of technology, the cost of 3D printed buildings is expected to be lower in the near future than it is now.

A decrease in the number of personnel involved in construction leads to a decrease in labor costs: 50–80% less man-hours are spent on the construction of 3D-printed objects, because the participation of people is needed only for servicing machines, carrying out communications and assembling structures.

Reduced construction time. When building on a finished foundation, the construction of walls can take place in a matter of days. The most time-consuming part is the construction of the roof, communications and interior decoration. In contrast, panel houses, the fastest of the traditional ones, are delivered by leading manufacturers within a month.

Cleanliness. During the construction process, no construction waste is generated, which requires removal from the construction site and disposal. Traditional construction leaves tons of waste in its wake – scrap material, concrete pieces, scaffolding and contaminated formwork.

3D printing buildings leave much less waste and, moreover, can use recycled waste as a constituent of the concrete mix.

Simplicity. The technology can significantly reduce the cost of constructing buildings with unique architecture. The possibilities of a 3D printer are not limited to straight shapes. Almost any geometric shape is available to developers, and building unusual objects does not take much longer than building traditional houses.

Savings. Some types of materials, logistics and labor costs for them are excluded from the construction process. These include, for example, formwork and concrete slabs. 3D printing buildings straight from the foundation solves this problem.

There are some disadvantages of 3D printed buildings technology, such as high price of 3D printer, sensitivity to external conditions,

High price of a 3D printer. It can be as high as $2.5 million. For small organizations and temporary projects, the cost can be prohibitive. The problem is solved by renting equipment or ordering printing from specialized companies.

Sensitivity to external conditions. Printing is not possible in adverse weather conditions. In cold weather, a dome is usually installed around the construction site to maintain the level of temperature and humidity, protect from precipitation and wind. This requires a separate cost.

There are no uniform standards, interchangeability of consumables. This is most likely a temporary problem. The fittings, communications and ceilings are still being installed manually. A layered wall surface that requires finishing if even walls are required – leveling, plastering or the use of facing materials (Figure 3) [8].

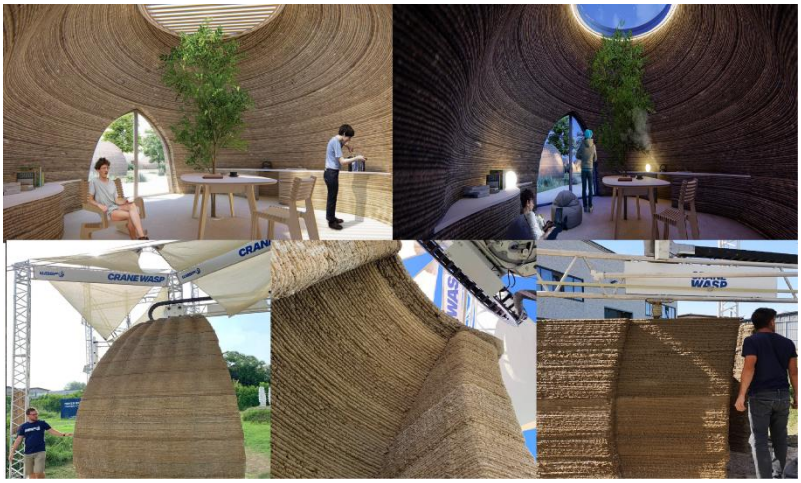

Figure 3. **The result of research in 3D printing and architecture of the Italian company GAIA (2020)**

Inspired by the potential of 3D printing to quickly create homes, Khoshnevis being famous for the development of three novel 3D printing processes called Contour Crafting [7], wants to use it to rebuild disaster-affected cities. The company uses a computer-controlled gantry crane with an extruder attached to it to 3D print buildings. The Contour Crafting process uses a quick-setting, concrete-like material that is applied by crane in layers. Technical elements such as fittings and communications can be added as layers are created (Figure 4).

One of the Ukrainian companies decided to create a house that would be able to retain heat as much as possible, control the indoor air quality and filter water, and also so that, if necessary, it could be easily and quickly transported to another place in 2017 as a startup. The main problem was that the materials that provide the required thermal insulation performance were very expensive. The house gets its energy from solar panels on the roof. The battery

capacity is 68 kWh. The creators promise that when the outside air temperature is -61ºC, in the house he will be able to maintain it at +22ºC. The house also has a 900-liter tank with four-level filtration. The same water can be used for 4–5 months. It is assumed that a system will be installed in the house that will control the temperature, humidity, water level in the tank, oxygen and even the weather, depending on forecasters' forecasts, adjust the room temperature. In addition, the house will be connected to the general system and in the event of any breakdown, the dispatcher will be able to fix it remotely or call a special service.

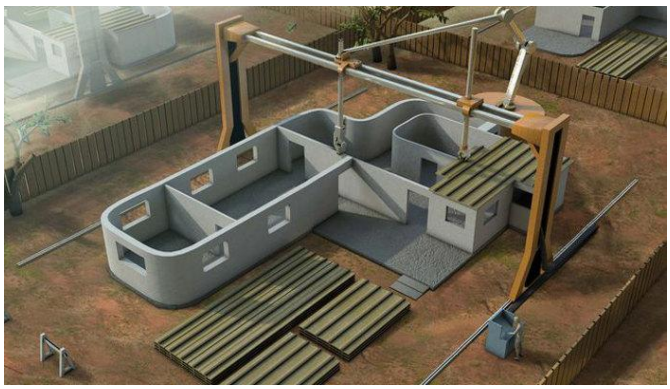

Figure 4. **Contour Crafting develops 3D printing technology pioneered by Berokh Khoshnevis at the University of Southern California (2020)**

The Ukrainian startup Maxim Herbut is the author of the project aims to create the warmest house in the world and enter the Guinness Book of Records [10]. This house is a single integral structure, printed on a 3D printer without seams and gluing. The area of the house is 36 sq. m, the weight is only 12 tons. As to the price, it costs from 30 to 60 euros, depending on the configuration (Figure 5).

Figure 5. **The result of the work of Maxim Herbut**

The main problem is that the materials that give the required performance for thermal insulation in the house are very expensive. With the help of 3D printing, it is possible to print a skeleton of metal-plastic filaments with a complex fiber structure. This is the foundation of the house that makes it as durable as possible. The walls of the house are made of a complex polymer that works like external beams, making the house easy to transport. The beams and walls of the house are 3D printed so that the frame is solid. In construction, fiberglass, polyurethane, special polymers that are resistant to ultraviolet radiation can also be used.

At the Kyiv National University of Technologies and Design (KNUTD), the educational and scientific laboratory of promising polymer materials is leading the way in the field of technologies for obtaining and using polymer mixtures and composite materials; recycling of

polymers; modification of the properties of polymer materials and composites; polymeric materials based on renewable raw materials, biodegradable polymeric materials; technologies of additive formation (Figure 6).

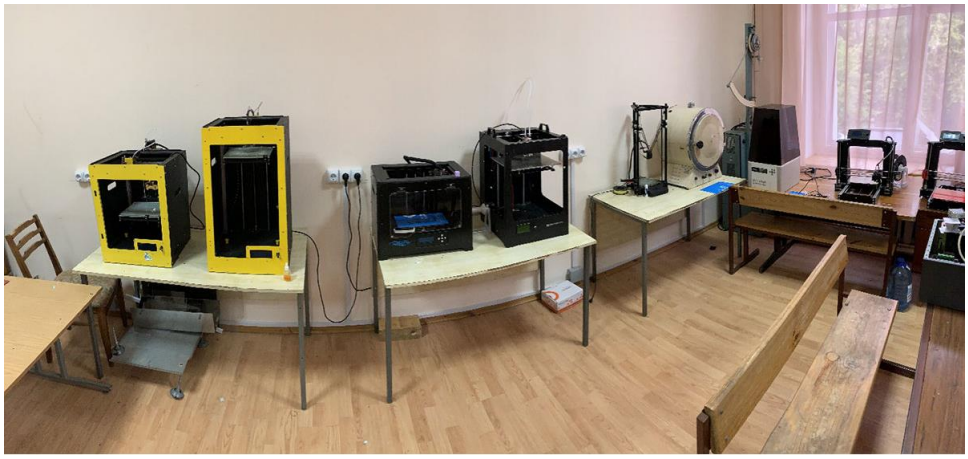

Figure 6. **The educational and scientific laboratory (KNUTD)**

What is more, research is underway in the field of sustainable and functional materials and innovative systems. The projects that the group has carried out so far are fully self-financed. We continue the research into extrusion materials, the path that led the lab to 3D printing with composite materials. The research and development of complex projects in the perspective of a production revolution, that will bring everyone's well-being, requires a lower budget, compared to the usual construction methods.

The laboratory also uses 3D modeling that allows to create quickly a prototype of a product in 3D format. 3D modeling is used to make molds and object prototypes. There is always an opportunity to improve the already modeled object by adding new elements. Programs developed for the design of houses have editors for the foundation, log houses, walls, floors and roofs. There is a 3D visualization. Using the program, it is possible to create a project of any complexity, number the beams, get drawings, plans and specifications.

Conclusions. New technologies always bring innovation, and this is exactly what 3D printing offers architecture: a way to make work not only easier, but also more efficient. The spread of 3D printing in construction is only a matter of time. The technology makes it possible to build houses quickly and with minimal costs. The planet's resources are insufficient to support the ongoing population explosion, and changing development patterns is no longer an option but a necessity. The ability to create a home for everyone is an important element in realizing the horizon of equality and meritocracy, general well-being, the horizon on which projects based on 3D printing technology converge.

The next step will be the use of fully automated processes, where robots do all the work without human participation – they build walls, reinforce them, erect roofs, carry out communications, equip houses with stairs and windows, and make interior and exterior decoration of premises. Progress in the development of concrete mixtures will allow not only to select ready-made compositions for specific conditions and tasks, but also to use construction waste and local materials – hay, soil, sand, and so on as raw materials, only a binder is required. The use of mineral additives in concrete solutions will also help maintain the ecology of the planet. Reduced consumption of cement will help reduce carbon dioxide emissions into the atmosphere.

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