Building 3D printing technology

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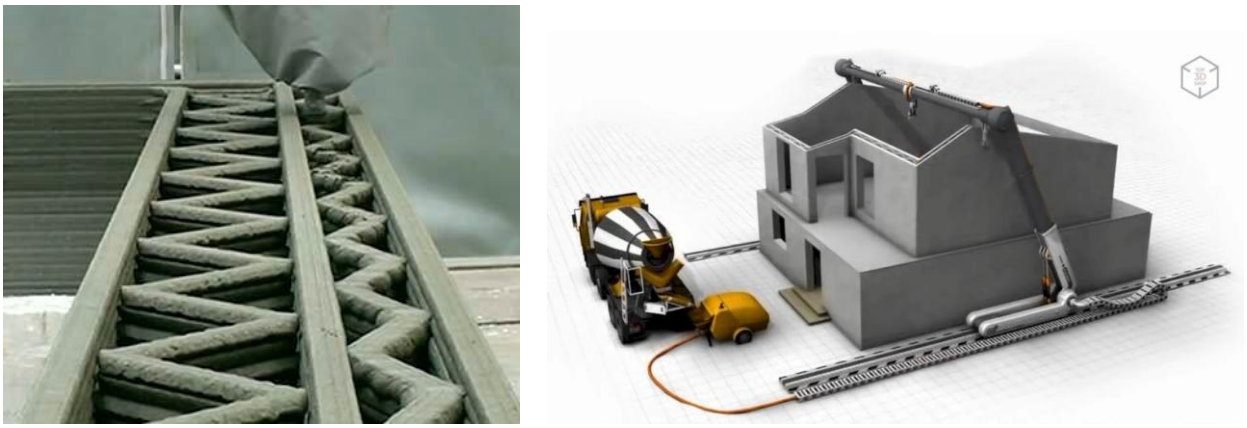
Abstract: 3D printing (3DP) is considered an innovation that promotes automation in civil engineering and offers advantages in design, sustainability and efficiency.
With its potential to automate, eliminate formwork, reduce construction waste and improve geometric accuracy, 3DP has promising applications in the building construction and civil engineering.
3DP is an effort to put digital manufacturing into practice, enabling a direct transition from building design / modeling (BIM) to 3DP.
This article provides various aspects of application in construction, materials and their compositions, as well as examples of the use of 3DP: buildings, structures, polymer sleepers, etc.
Keywords: 3D technologies in civil engineering and construction, materials.

3D printed technology

For the construction of low-rise buildings, 3D printing technology (view Pic. 1) is considered quite promising. Technology, methodology and organization have been developed in various fields, using various materials, for example, engineering, automotive, medicine, design [1].

This technology allows the use of recycled building material and thus saves 30-60% of building materials. In addition, construction time is significantly reduced (up to 70%).



Pic. 1: 3D printing process.

Today, the main disadvantages are: the bulkiness and inconvenience of using machines for 3D printing of buildings, the problem of reinforcement, difficulties in

high-rise construction, technical problems on hilly terrain, difficulties with printing horizontal elements (floors and roofs), finishing work.

General analysis

In 1986, Charles Hull, an American scientist, developed the first commercial 3D printing (3DP) machine. Experimental application of 3DP in the construction industry began in the late 1990s with conventional concrete in combination with 3DP.

The use of 3DP includes several aspects: technical (materials, equipment, printing processes and technologies) and non-technical (economic, environmental, regulatory, etc.) [2].

Main aspects of using 3DP

Materials for 3D printing and their properties are of significant research interest.

Building materials printed on a 3D printer must have exceptional printing speed. This includes the possibility of pumping, extrudability, ability to assemble.

Recently, 3DP has been developed as an attempt to put digital manufacturing into practice, enabling a direct transition from building design/modeling (BIM) to 3DP printing production. The technical part of the transition from BIM to print is already largely automated.

Materials

Currently, most of the materials used for 3DP in construction are concrete, gypsum, steel, and polymeric materials. As well as new materials such as stable cement-based composites, stable cement pastes and various composites. And also possibility of combine different materials, for example, steel and several types of concrete, including polymer-concrete [3].

Researchers from NTU Singapore used recycled glass instead sand in 3D printing concrete.

Concretes and nano-additives

The HTTM CO RAN proposed to replace the base in cement binders with a silicate one. It will improve the quality of the material used: heating at a lower temperature during manufacture, higher compressive strength, no swelling when heated.

Replacing conventional rebar with basalt rebar. Such fittings are lighter, radio-transparent and resistant to corrosion compared to conventional ones. The shock-resistant characteristics of such reinforcement increase by 4.5 times, and the durability by 5 times.

Various nanostructured additives to concrete: For example, 0.1% Kemerit in the total cement mass of such an additive will increase the strength of structures by 25%.

Concrete and dispersed reinforcement

The development of promising concrete mixtures that can withstand the action of external loads is an important scientific problem of modern construction.

Various types of dispersed reinforcement are being developed and introduced. These developments include mathematical planning methods and experimental tests. A 35% increase in compressive strength was obtained in fiber-reinforced concretes made using a combination of steel and basalt fiber with a volume concentration of 2% steel fiber and 2% basalt fiber.

The maximum bending strength increased by 79%, the ultimate strain in axial compression decreased by 52%, the ultimate strain in axial tension decreased by 39%, the modulus of elasticity increased by 33%. Similar results were obtained for other combinations of dispersed reinforcement. The studies carried out made it possible to determine the most effective combinations of fibers of various types of fibers among themselves and their optimal volume concentration.

Self-healing materials for 3D printing

Researchers at Imperial College London have created three-dimensional building blocks that can self-repair after damage. They later found a method to use this technology in 3D printing.

Engineered Living Materials (ELM) harness the ability of plants to heal and replenish material and can respond to damage in harsh environments with a "sense and reaction" system.

The journal Nature Communications published that this could lead to the creation of new materials that detect and heal damage. By integrating building blocks into self-healing building materials, scientists want to reduce maintenance and extend the life of the material.

The same technique is used in architecture, for example as modular elements that can be assembled into various building structures.

To create the ELM, the researchers genetically engineered a bacterium called Komagataeibacter rhaeticus. This is to get them to produce fluorescent 3D sphere-shaped cell cultures, known as spheroids, and equip them with damage-detecting sensors. They built spheroids into various shapes and patterns, demonstrating the potential of spheroids as modular building blocks.

Processes

3DP was originally developed for the production of small, complex, low volume products and was known as fast modeling.

Over the years, several large-scale technologies have been developed to enable 3DP designs and applications. For example, the use of mobile robots for large scale and parallel 3DPs on concrete structures.

Currently, there are many examples of 3DP technologies that are under development and testing. For example, printhead configuration, printer kinematics, print strategy.

Economic aspects and trends

Undoubtedly, the demand for mass construction in construction will create a need for 3DP, new and more economical technological solutions will appear.

3DP has enormous design potential and can be used to build buildings with complex shapes or in special conditions. In the future, with the popularization of this technology, private consumers will also be able to complete their homes. 3DP also has great development potential in the field of individual interior design.

Some known today conditions of introduction 3DP: The first condition is time. It takes more time to get a better surface quality, which increases the time cost. The second condition is the cost of optimization. Any optimization process will increase the cost due to additional design work and the structure may become unnecessarily complex.

To measure whether a 3DP can reduce costs, it is necessary to assess the financial performance of a building product throughout its entire life cycle.

Further empirical research is needed to evaluate the life cycle cost of 3DP in raw materials, printing systems, process optimization. This is to determine how to select theoretically efficient and economical technologies [4,5].

Environmental issues and trends

To assess the environmental friendliness of the 3DP, indicators such as energy consumption, carbon emissions, use and production of toxic substances are selected. One avenue for future research is using the Life Cycle Assessment (LCA) to assess the environmental impact of 3DPs. LCA is one of the most widely used environmental assessment tools in buildings.

As an assessment method, LCA involves the collection, processing and analysis of vast amounts of data. It takes a lot of time and effort. Therefore, information software tools such as BIM are required to support LCA. BIM is a construction management method based on the life cycle with a wide range of stages, including design, planning and operation, energy consumption and

emission, etc. Relevant research is currently underway on a building environmental impact assessment method called BIM-LCA, and 3DP environmental impact assessment has shown that it can improve efficiency and accuracy.

Legislative issues and trends

Despite its potential benefits, 3DP has not yet reached its full potential in the construction industry and is not a technology capable of completely replacing traditional construction methods.

In terms of intellectual property, there are laws and regulations that protect new inventions and inventors. One area of future research will be to establish principles for the protection of intellectual property for 3D models.

Building standards

The application of 3DP in construction requires the creation of standardized building codes, which currently do not exist. There are many materials, types of equipment and processes, but there are no clear requirements for materials, processes, calibration, testing and document format standards. In the future, it will be necessary to set standards for materials, manufacturing processes and designs.

With the development of 3DP, the compatibility and accuracy of BIM software needs to be improved.

Some examples of the use of 3D printing in construction

New developments

Company Diamond Age has created a technology that will speed up the construction of residential buildings from 9 months to 30 days using 3D printing.

Diamond Age believes that there is only one solution to this problem - the automation of construction projects and the abandonment of most of the staff.

The company relies on robotic installations and efficient 3D printing. These units include a set of 26 different attachments for construction robots to assist with transporting building materials and laying foundations. An effective 3D printing is

achieved through “portal-based” printers – large-sized units quickly print the internal and external walls of the future building [6].

1. China

China builds 3D-printed swing bridge

Pic. 2: A swing bridge built with 3DP in China.

Recently, China has come out on top in the world in terms of innovation. For example, the Bay of Wisdom in Shanghai is built on the site of a former wool textile factory and is home to over 300 international companies involved in 3D printing, smart micromanufacturing, virtual reality (VR), augmented reality (AR) and artificial intelligence. (AI) robotics projects. It is supposed to be the only 3D printing museum in the world.

Several innovative 3D printing projects have taken place in the bay in recent years. One of them is a 3D printed sliding bridge [7].

The sliding bridge weighs only 850 kg, is nine meters long, 1.5 meters wide and 1.1 meters high. The structure was installed over a small pond in Wisdom Bay. The bridge can accommodate up to 20 people at a time.

The bridge is made up of 36 triangular panels, each was 3D printed with a different design, reminiscent of outward waves. Printed within three days, the panels are made from carbonate polyester composite material, which is considered environmentally friendly.

The bridge is divided into nine segments. The retractable element of the bridge is controlled via Bluetooth: the structure unfolds through the water in a spiral shape in less than one minute. The bridge is also equipped with an automatic gravity warning system to prevent overloading.

Economic effectivity: A few years ago, one of the Chinese companies conducted an experiment: 10 houses were printed there in a day. Each cost only $4,800. That's just the example of China around the world is not in a hurry to follow. High technologies are preferred to be used for the manufacture of houses of complex structures.

2. UK

The UK intends to accelerate the construction of the High Speed 2 (HS2) railway network with the help of 3D printing of reinforced concrete structures at the site of the robot. A 3D printing method in which concrete is reinforced with graphene (dispersed reinforcement). It will also significantly reduce the carbon footprint of construction.

The reason for this decision is the advantages of the new technology.

The technology, dubbed "Printfrastructure", is developed by London-based tunneling contractor HS2 Ltd - SCS JV (Skanska Costain STRABAG Joint Venture). It will help build a high-speed rail line in the UK linking London, Birmingham, Manchester and Leeds.

Some advantages of 3D printing:

The use of remote controlled robots will allow SCS JV to 3D print structures on site, eliminating the need to transport them on the road. 3D printing technology

makes it possible to build structures in a limited space, which means that complex and expensive logistics operations will no longer be required.

Since the work is carried out on site by 3D printing robots, there is also no need to suspend work to ensure the safety of people. All this will speed up construction time and cause less inconvenience to the local population.

Reinforced concrete structures built using a reinforcing internal grid that reduces the amount of concrete needed. It also produces less waste.

Finally, the concrete used for the 3D printing process is reinforced with graphene, the strongest material on the planet. Microscopic filaments of graphene, just a few atoms thick, replace steel rods, making it easier to build structures while at the same time giving them greater strength and a smaller carbon footprint. The graphene innovation was developed by SCS JV partner in Worcestershire, ChangeMaker 3D.

From an environmental point of view, this process will reduce carbon emissions from railway construction by up to 50%.

3. USA

In recent years, 3D printing in housing construction has become a mainstream construction technique. And Icon is positioning itself as a major player in this area. Shortly after unveiling plans to print a simulated Mars base with NASA and the Bjarke Ingels Group, the company completed 3D printed houses in East Austin.

To create the ground floor, Icon used its Vulcan 3D printer, which extrudes a proprietary cement-like mixture from a nozzle in layers. However, the top floor was built by builders from wood. This contrasts with the Kamp C experimental house, which was completely 3D printed in Europe.

Pic. 3: General view of houses, ground floor created with 3DP in the USA.

Pic. 4: Interior view of the house.

The project was created in collaboration with 3Strands and Den Property Group, as well as Logan Architecture. While the houses are the first 3D printed homes to hit the US housing market, they almost certainly won't be the last. The

firm has already unveiled its vision for the future of 3D printed housing in collaboration with Lake | Flato Architects.

U.S. Army will be one of the biggest costumer of 3D-printed structure. For example, barracks will be largest in the West. At the next picture is example of barrack for 72 soldiers [8].

Pic. 5: The project will consist of three barracks, each of which will measure over 5,700 sq ft (roughly 530 sq m) ,Logan Architecture [9]

4. Russia

In Russia began to build houses by 3D printers. So in 2022, several regions of Russia plan to print houses using 3D printers. “Since 2014, we have sold more than 220 printers to 15 countries around the world,” Alexander Maslov, CEO of AMT, told RG. “There are houses printed on our printers in Yaroslavl, Ufa, Yekaterinburg and others. There are buyers from Copenhagen too.

Most printers, according to Maslov, are now buying the southern regions of Russia. The materials used for printing work worse in the conditions of the north.

The AMT company, a resident of Skolkovo, does not build, but for the sake of testing developments, it began to print houses at its site near Yaroslavl. They want to build 12 buildings ranging from 60 to 180 square meters and up to three floors high.

Construction speed: 100 square meters in two days, Andrey Rudenko, CEO of Totalkustom, said. Stand the foundation in the usual way and build walls with the help of 3D printing. At the same time, communications are being laid. Printed walls cost 30 percent less, and the entire building costs 8-12 percent less. With mass construction, the cost per square meter of the building is $300.

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