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NEW 3D PRINTING TECHNOLOGY

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Annotation. 3D printing (3DP) is considered an innovation that promotes automation and efficiency in many fields, for example civil engineering, machinery, medicine, biology and more. In addition, options that did not exist and the use of new materials. 3DP enables a direct transition from design/modeling (BIM) to 3DP to create a product/object. BIM and 3DP subjects are taught in Israel in universities using several different software, depending on the specialization (machines, architecture, etc.).

Keywords. 3D technologies, materials for 3DP, 3D concrete printing, dispersive reinforcement concrete.

This article provides some examples of the most innovative in several different areas of technology of 3D printing.

Innovation is an integral part of additive manufacturing in all its forms. Recently, a large number of startups have emerged covering all markets, from aerospace to construction to healthcare and consumer products. Developments and new approaches to creation products are provided. goddess.

Developments help combine design with forward thinking and goddess. Those developments helps combine design with forward thinking and industrial reality, whether it's a one-of-a-kind rocket engine or the house next door.

General analysis

Main aspects of using 3DP

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

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

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 intellectual property protection for 3D models.

Building 3D printed technology

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

In the future, with the popularity of this technology, private consumers will also be able to complete their homes. 3DP also has great development potential in the field of personal interior design.

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

An example of some of the largest 3D printing companies in the world by market:

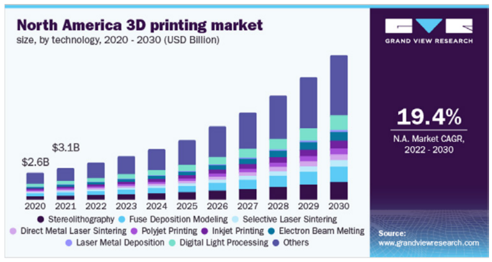

Figure 1. North America investment in 3D printing technology

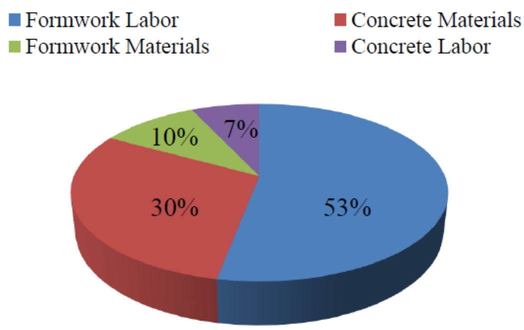

Figure 2. Typical cost distribution for new concrete construction project [2]

Below is presented a general functional scheme of the process of using 3D printing technology in construction.

The whole 3D printing process can be described in two ways:

– the software segment (left side of Fig 3)
– hardware segment (right side of Fig 3).

At a 3D software (like AutoCAD, Revit, Inventor, Solid Works or others) is used to model the objects as 3D object, then it is exported to another software for slicing (define the layer dimension – depending on the printing equipment, material, desired resolution of printing, etc.). Thereafter, a program file in the form of G-code is generated for the whole object for the printer to read and perform the job as shown in Fig 3. In the hardware segment, an integrated printer (either gantry or robotic) with material delivery system that is connected with a supply of the material system (like pump or others) and leading pipe are required to deliver the material to the nozzle orifice/head, which is connected at the end part of the hosepipe to deposit the material in layer by layer. A controller is also required to control the printer and pump according to the design (shape, size, etc. according to the necessary parameters) of the printed object.

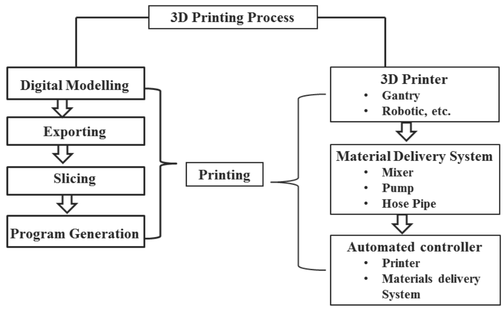

Figure 3. The process of 3D printing for construction industry

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

Figure 4. A basic scheme of the building prosses using the 3D printing method

Today the main disadvantages are: volume and the inconvenience of using machines for 3D printing of buildings, reinforcement problem, difficulties in building to height, technical problems in mountainous terrain, difficulties in printing horizontal elements (floors and roofs), exterior finishing works.

Environmental issues and trends

3D technology not only does not create waste, it also enables reuse of materials and this is true for example according to indicators such as energy consumption, carbon emissions, use and production of toxic substances. One avenue for future research is to use life cycle assessment (LCA) to assess the environmental impact of 3DPs. LCA is one of the most widely used environmental assessment tools in buildings.

An evaluation method, LCA involves the collection, processing and analysis of huge amounts of data. It takes a lot of time and effort. Information software tools such as BIM are therefore 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 energy emission, etc. These days, relevant research is being carried out on a building environmental impact assessment method called BIM-LCA, and 3DP environmental impact assessment has shown that it can improve efficiency and accuracy.

Materials

The 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. So, 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 %.

The polymer concrete is concrete protected by an American patent [9]. Rubber concrete is the first polymer concrete in the world, in which liquid rubber (polybutadiene) is used as a binder and not epoxy, polyester or furan resin. Such concrete has a compressive strength of up to 90 MPa and a tensile strength of up to 30 MPa. (This is especially important since this tensile strength is significantly higher than the tensile strength of regular Portland cement concrete).

Water absorption of polymer concrete does not exceed 0.06 %. Polymer concrete has high chemical resistance, both in alkalis and acids. In fact, the polymer concrete binder itself can be used as an independent, chemically highly resistant protective coating, which has high adhesion to steel (up to 11.5 MPa at separation) and is operable up to a temperature of 95 °C.

Table 1. Basic physical-chemical and mechanical properties of RubCon

Indices	Units	RubCon
Density	kg/m^3	2100-2300
Strength at – compression – bending – tension	MPa	80-95 25-30 12-15
Modules of elasticity	MPa104	2.0-2.7
Poison’s ratio		0.26-0.28
Thermal conductivity coefficient	W/m/°C	0.3-0.5
Wear resistance	(kg/m2)10-3	2-3
Specific toughness	(J/m2)103	3.5-4.5
Heat stability	°C	80-100
Water absorption	%	0.05-0.06
Coefficient of chemical resistance at 20 ºC (based on 360 days of exposure) – 20% H_2SO_4 – 10% Lactic acid – 20% Caustic potash – 35% H_3PO_4		0.97-0.98 0.95-0.96 0.97-0.98 0.96-0.98 0.99-0.995 1.00-1.05
Resistance to abrasion	(kg/m2)10 $^{-3}$	2-3.5

Concrete and dispersed reinforcement. [4][9]

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

Different types of distributed reinforcement are developed and presented. These developments include mathematical design methods and experimental tests. A 35 % increase in compressive strength was obtained in fiber reinforced concrete made with a combination of steel and basalt fibers with a volume concentration of 2 % steel fibers and 2 % basalt fibers.

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

Distributed reinforcement of concrete by iron/polymer fibers can be convenient for use in 3D printing. This will save a considerable amount of work to perform concrete reinforcement during the prosses.

Dynamic load of polymer reinforced concrete [9]

A laboratory experiment was conducted at the University of Voronezh, Russia. The dimensions of the samples were 16x4x4 cm. An experiment was conducted for loads that correspond to requirements for high-speed train sleepers ($2*10^6$ loading cycles). Two types of tests were conducted: bending and pressing. Here are some results of the experiments:

In dynamic bending:

– Strength of a sample with steel fibers 40/0.8 mm relative Kb,pul= 0.301 and it is Rbn,pul= 12,15 MPa

– Strength of a sample with brass fibers 15/0.3 мм relative Kb.pul= 0.413 and it is Rbn,pul= 10,91 Mpa

In dynamic pressing:

– Relative strength of a sample with steel fibers 40/0.8 mm is Rpr,pul= 77.97 MPa

– Relative strength of a sample with brass fibers 15/0.3 mm is R pr,pul= 75.83 MPa

– Relative strength of a sample with polypropylene fibers 12/0.12 mm is Rpr,pul= 62.91 MPa

For comparison, in ordinary concrete axial compressive strength under such loadings is in the range of 15-40 MPa.

3D printing and automatic reinforcement concrete mix.[1]

3D printing technology of concrete mix with automatic reinforcement integration system. Researchers tested the effect of the mixture on the dynamics of a construction printer. The reinforcement supply has been organized in such a way as to ensure an almost stress-free application. For this purpose, a roller feeder is opened to the back of the nozzle. During the operation of the constructive 3D printer, data was obtained from the accelerometer in the form of graphs of the frequency of oscillations of the construction printer, which characterize the main operating parameters. Experimental displacement curves are shown for reinforcement-reinforced 40 × 40 mm specimens.

Printing foam into the construction to create good isolating ability [9].

Foam printing to create panels with good insulating ability. The prototype slab created by the DBT team shows how versatile concrete structures (Figure 5) and 3D printed foam can be combined. The slab uses ribs derived from isostatic lines that indicate the direction of compression and tension. Based on the principal stress diagram, the geometry of this slab has 24 cavities for foam inserts in 12 different shapes.

This process can be replicated for other standardised or more complex concrete structural elements. The calculation of basic stress structures can be used to design and manufacture various structural elements with efficient use of materials. They can range from standard elements to customised slabs and walls. Since no scraps are created when using FoamWork, the entire production system can potentially be of zero waste. Along with minimising material waste, the lighter mass of structural members allows for easytransport, handling and assembly at construction sites.

Figure 5. Foam 3D printing inside concrete construction [9]

3D Printing Green 3D printing: AN ORGANIC at ARCHITECTURE in Israel

Between 23 and 30 June 2022, Jerusalem Design Week welcomed over 40,000 design enthusiasts to the Hansen House Center for Design, Media and Technology, for the showcase of an eclectic mix of exhibitions, installations and projects from over 150 Israeli and international designers. Work by invited designers centered around this year's theme 'For Now', exploring both the ephemerality of design and the design of ephemerality, and examining ways in which time can be harnessed to bring about a positive effect in periods of uncertainty.

Among the participating exhibits was the 'To Grow a Building' project, which examines possibilities of an organic architecture in the face of a global ecological crisis. With the use of industrial and non-local resources only increasing, 'To Grow a Building' proposes architecture that uses raw, natural materials such as local soil and roots as structural elements to replace unsustainable buildings made of concrete and steel. The project presents a new approach of integrating flora into the architectural design process, by developing a novel material for 3D printing through which seeding is an inseparable part of the fabrication process.

Figure 6. Example of printing process and green life results

Some new 3DP technologies

Compositions and Methods for 3D Printing of Calcium Phosphate Cement Composite Scaffolds [10]

ADASRI researchers have developed new compositions of matter (inks) and associated 3D printing methods that allow room-temperature printing of high-resolution and mechanically stronger composite scaffold structures. The 3D printing inks include calcium phosphate cement (CPC) powders and a biocompatible polymer. Upon printing in an aqueous environment, the polymer material hardens first and provides initial strength for the composite structure as well as flexibility. A self-setting reaction of the co-deposited CPC materials in the aqueous solution then forms, in-situ, a cement, such as hydroxyapatite, which then hardens to produce the final composite structure.

Liquid Metal Printing [11]

Researchers at the Massachusetts Institute of Technology (MIT) have developed 3D printing technology that can quickly create large parts from liquid metal. For example, table legs and chair frames can be printed in minutes.[11]

The method uses molten aluminum deposited along a programmed path into a layer of tiny glass beads. Aluminum quickly hardens and acquires a three-dimensional structure. The developers estimate that the technology is 10 times faster than a comparable metal additive manufacturing process.

This method sacrifices resolution for speed and scale. While it can print components larger than those typically made with slower 3D printing technologies and at a lower cost, it cannot achieve high resolution.

For example, parts made with the new technology may be suitable for some applications in architecture, construction and industrial design, where components of larger structures often do not require detailing. It can also be used for rapid prototyping using scrap or recycled metal.

Figure 7. Example of Liquid Metal printing

This technology was developed and introduced by printing aluminum frames and parts for tables and chairs that were strong enough to withstand subsequent processing and use. The engineers also showed that components produced by the new method can be combined with high-resolution processes and complementary materials to create functional furniture.

Alloy with paradox – "Invar" How to avoid expanding when heated? [8]

The new alloy of iron and nickel exhibited non-standard required properties. It was given the name “Invar”, which comes from the word “invariant”, meaning the relative lack of expansion. Why “relative”? For the simple reason that expansion is still observed, but it is measured in fractions of a percent, and the operating temperature range of the system is very respectable.

Phenotypically complex living materials containing engineered cyanobacteria [7]

Engineers have developed an environmentally friendly solution to purify water from pollutants. Researchers at the University of California, San Diego have developed a biopolymer material with genetically modified bacteria that convert pollutants into harmless components. Bacteria self-destruct in the presence of theophylline, a molecule found in tea and chocolate.

The engineers used alginate, a natural polymer obtained from seaweed, as the base material. The researchers hydrated it to form a gel and mixed it with cyanobacteria, a photosynthetic species that lives in aquatic environments.

The finished “mixture” was used for printing on a 3D printer. After testing different geometric shapes, the researchers determined that a lattice structure was suitable for supporting bacterial life. It has a high surface area to volume ratio. Therefore, most cyanobacteria are located near the surface and gain access to nutrients, gases and light.

To demonstrate how the cleaning system works, the researchers genetically modified cyanobacteria to continuously produce the disinfecting enzyme laccase. This substance neutralizes a variety of organic pollutants, including bisphenol A (BPA) used in plastics, dyes, antibiotics and other pharmaceuticals.

The researchers also developed a way to kill cyanobacteria after removing contaminants. They genetically modified bacteria so that they responded to the theophylline molecule. It causes bacteria to produce a protein that destroys cells.

3D bioprinting of human neural tissues with functional connectivity [12]

Researchers at the University of Wisconsin-Madison have developed a technology for 3D printing functional brain tissue. It can be used to study brain function, search for the causes of various neurological disorders and test drugs. Instead of a “vertical” 3D printing approach, the researchers created patterned fabric by printing one thin layer or strip of cell-filled gel next to another horizontally. They placed neurons grown from induced pluripotent stem cells in a soft gel “bioink.” In this case, the cells are located next to each other, like pencils lying next to each other on a table.

The results of a study of printed tissue showed that cells in such a structure can indeed “communicate.” Neurons penetrate the medium, forming connections within each printed layer, as well as between layers, forming networks comparable to the human brain. The cells communicate, send signals, interact with each other through neurotransmitters, and even form regular networks with supporting cells added to the printed tissue.

Scientists printed the cerebral cortex and striatum and found that cells belonging to different parts of the brain could exchange very special and specific signals with each other.

The printed brain tissue could be used to study signaling between cells in Down syndrome, interactions between healthy tissue and neighboring tissue affected by Alzheimer’s disease, testing new drug candidates, or monitoring brain growth.

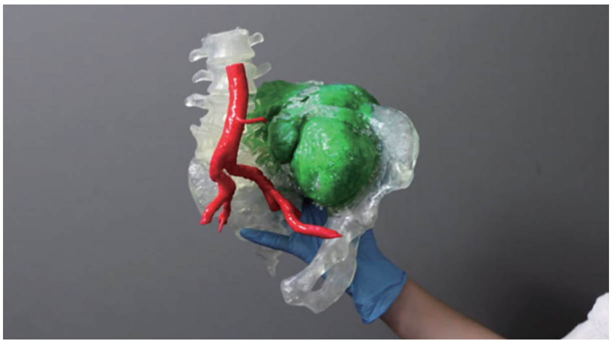

Figure 8. Axial3D – 3D printing as a service to healthcare professionals

Conclusion

Today, thanks to 3D modeling in computers and printing equipment, there are studies with immediate application in the field of 3DP in various fields, such as construction, design, machinery, biology, medicine, food and much more. All areas of creation, 3D technology also enters as one that enables efficiency and cheapness, but also adds possibilities that were not there before.

However, it is too early to say whether 3DP can fully replace all current methods. At this moment it is necessary to research and develop the methods. There are many reasons, including economic ones, for developing 3DP methods. One of the advantages of 3DP is the ability to create complex 3D geometries with high precision with minimal time and human interaction.

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НОВЫЕ ТЕХНОЛОГИИ 3D-ПЕЧАТИ

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Аннотация. 3D-печать (3DP) считается инновацией, которая способствует автоматизации и повышению эффективности во многих областях, например, в гражданском строительстве, машиностроении, медицине, биологии и других. Кроме того, возможны варианты, которых не было, и использование новых материалов. 3DP обеспечивает прямой переход от проектирования/моделирования (BIM) к 3DP для создания продукта/объекта. BIM и 3DP преподаются в университетах Израиля с использованием разных программ, в зависимости от специализации (машиностроение, архитектура и т. д.).

Ключевые слова. 3D технологии, материалы для 3DP, 3D печать бетона, дисперсионный армированный бетон.