CONSTRUCTION 3D PRINTING

The difference between large scale and small scale 3D printing technology

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ABSTRACT

The purpose of the Bachelor's thesis was to start study in the sphere of the construction 3D printing for university, to begin to analyse the topic and to present relevant data for other authors who could continue to study 3D construction printing area. The research constituent of the thesis comprises comparison of large-scale 3D-printers (construction 3D-printers) to small-scale ones (ceramic 3D-printers).

The first part of the thesis comprises a description of the process of 3D printing, in this section the author shows companies and real models produced with ceramic 3D printers, their specifications, and performance. Information on prices and technical characteristics were gathered from the official websites of producers.

The second part of the thesis comprises a description of methodology of additive production for small-scale 3D printers. 3D printing was taken as example by the author because it bears much resemblance to the concrete 3D printing. Various key methods were collected and described based on data from other publicly available research articles and reports.

The third part of the thesis contains practical issues and difficulties of construction 3D printing. 3D printing is known by its several benefits over standard methods. The author`s main point was to demonstrate the advantages and findings obtained from real projects. This section describes the major manufacturers and construction 3D printers. Also, this part contains the analysis of the workflow and various kinds of 3D printers.

The outcome of the thesis deciding on the selection of construction 3D printing technology based the results of a comparative analysis of small-scale and large-scale construction 3D printing.

Keywords 3D printer, additive manufacturing, construction, ceramics.

Pages 25 pages

CONTENTS

1 INTRODUCTION

«3D printing, or additive manufacturing, is the construction of a three-dimensional object from a CAD model or a digital 3D model. The term "3D printing" can refer to a variety of processes in which material is deposited, joined or solidified under computer control to create a three-dimensional object, with material being added together (such as plastics, liquids or powder grains being fused together), typically layer by layer.

As of 2019, the precision, repeatability, and material range of 3D printing have increased to the point that some 3D printing processes are considered viable as an industrial-production technology, whereby the term additive manufacturing can be used synonymously with 3D printing. One of the key advantages of 3D printing is the ability to produce very complex shapes or geometries that would be otherwise impossible to construct by hand, including hollow parts or parts with internal truss structures to reduce weight. Fused deposition modeling (FDM), which uses a continuous filament of a thermoplastic material, is the most common 3D printing process in use as of 2020». (Wikipedia, n.d.)

3D printing models can be designed with a computer-aided design (CAD), a photogrammetry software, and a 3D scanner or a simple digital camera. 3D prototypes for print designed with CAD lead to a smaller number of errors in relation to alternative methods. Inaccuracies in 3D printed prototypes can be discovered and fixed before printing starts. The procedure of geometric data preparation for 3D computer graphics using manual modelling resembles certain kinds of plastic arts, for instance sculpting. The procedure of 3D scanning is gathering digital data regarding form and appearance of a physical object and designing a computer model created on the basis of these data. (Wikipedia, n.d.)

Prototypes can be saved as a file and a simple USB flash drive can serve as memory cloud for each project. The prototype can be edited before printing as well as during the process. (Wikipedia, n.d.)

Normally, 3D printing has concentrated on polymers for printing process by cause of polymeric materials producing and processing ease. Nonetheless, this technique has fast developed not only for the production of different polymers, but also for concrete and ceramics, which makes 3D printing a universal production choice. (Wikipedia, n.d.)

The Author's idea was to conduct a fundamental comparison throughout the entire dissertation between large-scale and small-scale 3D printers, to state a whole idea of beginning to use widely construction 3D printers as clear and precise as possible in the thesis. The comparison will present the key difficulties and possible problems of 3D printing on a construction site.

It is worth noting that ceramic 3D printing is highly similar in viscosity to concrete. That is why the concept of comparing two different size was suggested by thesis supervisors. Questions about the central thesis topic and a work plan were formulated during the online meeting. An entire thesis describes the operation of 3D printers, their advantages and some difficulties in the process.

There is no doubt that 3D printers will partially replace the workforce in the immediate future. Moreover, this practice have already begun because a lot of new projects such as colonization of Mars, emergence of extraordinal building shapes and bridges constructed with 3D printing are broadly used nowadays. The application of 3D printing facilities on large-scale repetitive site works can accelerate building projects, improve safety conditions on site and quickly reduce costs, which already indicates how effective 3D printing can be in the construction area according to its benefits.

2 PRESENT ADDITIVE MANUFACTURING

This chapter describes 3D ceramics printing. The demonstration of similarity between ceramic 3D printing and construction printing on the site were the concept of the thesis and the most important reasons why the author decided to consider a ceramic 3D printer. Because the viscosity of concrete and its casting method is similar to ceramics and its manufacturing technique, the author decided to consider ceramics.

2.1 What is ceramic 3D printing?

Ceramics have been used as a material for 3D printing. Although ceramics is more frequently associated with pottery or tableware, it is virtually in every sphere of our everyday life and it is regularly used in numerous areas. (Cherdo, 2021)

Nowadays, ceramic 3D printers are mostly producing structures of industrial additive. The 3D printing techniques, such as binder jetting, photopolymerization, extrusion, and powder sintering, are the main differences in 3D printing systems of this kind. (Cherdo, 2021)

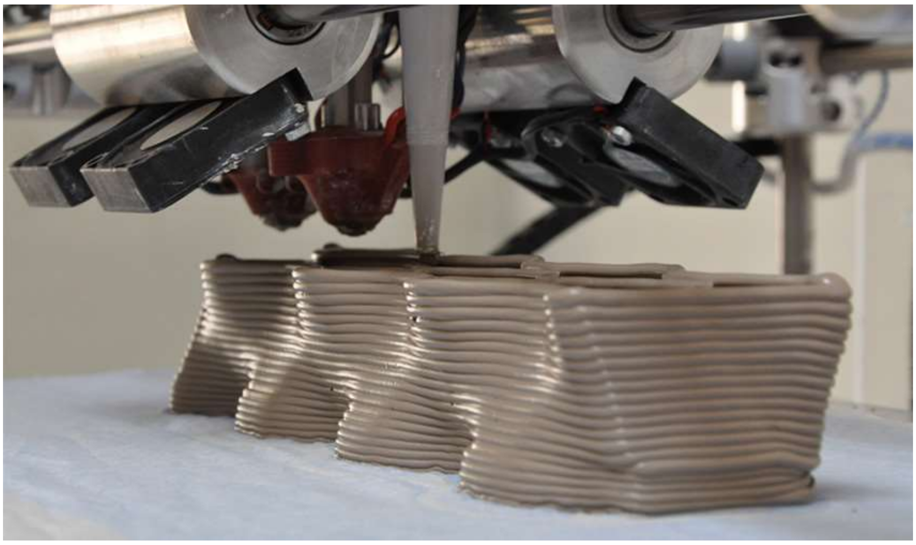

Figure 1. Ceramics 3D printer during the operation (3Dnatives, 2019)

Although, 3D printing is just one stage of a lengthy production procedure. Ceramic 3D printers produce green details, which mean they have to undergo difficult phases of further handling to get their final shape. For instance, one of such stages is firing the ceramic detail or model in a furnace with extremely high temperature. (Cherdo, 2021)

Ceramics is regularly used in a several areas. Obviously, pottery or tableware are the most popular use for ceramics, but this material is almost in every sphere of our life and is used in various forms. For instance, industrial sector (such as automobile or aerospace field) can broadly use ceramic, and several kinds of ceramics are regularly used in healthcare for manufacturing of medical instruments and devices. (Cherdo, 2021)

Figure 2. Ceramics vase made by 3D printer (Pinshape, 2017)

There are high mechanical strength and firmness, good chemical and thermal stability, and viable thermal, optical, electrical, and magnetic characteristics among the qualities that make ceramics such a universal substance. Ceramic elements are usually formed into the needed shapes, beginning with a mixture of powder with or without binders and other additives by means of conventional technologies. Also, to achieve densification sintering of green components at higher temperatures is required. However, these methods of forming ceramics result in constraints on the long processing period and high costs. Structures with extremely complicated geometry and interconnected holes are not possible because these techniques frequently involve molding. On the contrary, processing of ceramic components is usually extremely complex because of their extreme hardness and fragility. Various defects such as cracks in ceramic details, wear of cutting tools constitute significant difficulties in processing ceramic materials, as well as the problem of reaching high quality surface and dimensional accuracy. (Gibson, I., Rosen, D., Stucker, B., p. 4, 2015)

2.2 Methodology

Stereolithography (SL) is thought to be the most outstanding and popular 3D printing method. It is broadly used all over the world. Stereolithography is a technology where a source of light of a particular length of wave (generally in the ultraviolet range) is used to selectively solidify the fluid surface in a vat containing predominantly photopolymerizable monomer, and further additives in very insignificant quantities, containing photoinitiators. The polymerization is initiated by light, it is typically proceeding in such manner: point-to-line, line-to-layer, and then layer-by-layer, along with scanning of light on the liquid surface. When the polymerization is complete for one layer, the vat or platform backing the element being created is raised or lowered to the thickness of the layer, based on whether the construction process is performed in top-down or bottom-up mode. (Shenzhen University, 2018)

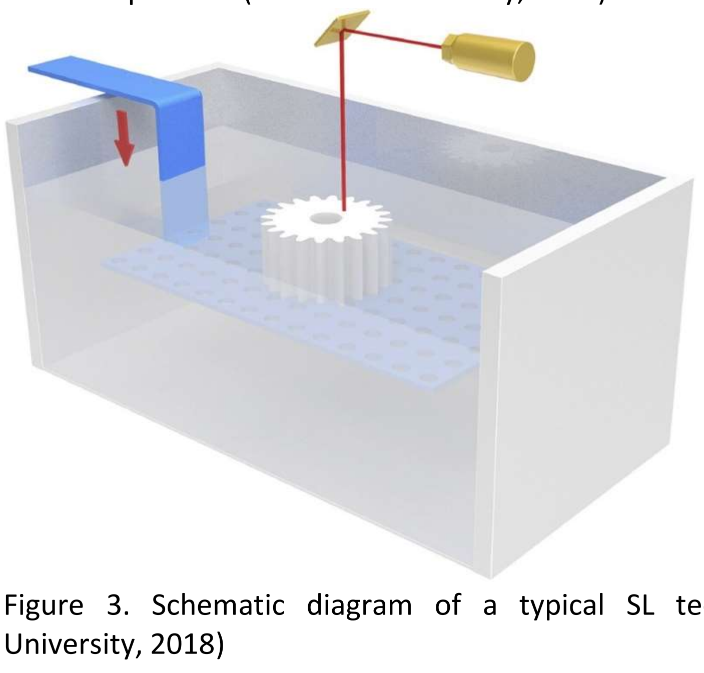

Figure 3. Schematic diagram of a typical SL technique (Shenzhen University, 2018)

The SL of ceramics continues to add fine ceramic particles to micro or nanometer size in a photo-cleaning medium, that may be aqueous or non-aqueous. The liquid becomes a ceramic suspension after it is properly dispersed in the medium with the assistance of basic surfactants and additives. Similarly, polymerization acts exclusively in an organic monomer phase under light irradiation, since the ceramic components are inert to light emission. The ceramic particles then evenly surrounded by the crosslinked organic network, that polymerizes to form a pre-designed shape of each layer until the whole 3D ceramic element is generated. (Shenzhen University, 2018)

Figure 4. The result of a typical SL technique (ScienceDirect, 2018)

3D printers with selective laser sintering (SLS) technology commonly considered more complex than FDM and SL since they produce components using more powerful laser and thermoplastic polymer-ceramic composite powder. (Gregurić, 2019)

The structure of SLS 3D printers includes such elements as a powder container, a manufacturing stage, a powder re-coater, a laser (CO2, diode, or fiber), set of galvanometers, heaters, and powder feeder. (Gregurić, 2019)

As a rule, the first step in printing process is filling the powder container with a particular quantity of polymer powder. After that the container is set in the system and the heating phase launches. Prior to printing, using heaters, powder is obtained to a temperature slightly below the melting point. (Gregurić, 2019)

Printing starts with re-coating by applying one coating of powder on the construction stage. At this point CO2 laser is activated. The objective of the laser is to selectively activate merging among fragments to create solid substance in certain spots. (Gregurić, 2019)

Galvanometers (that may be compared to tiny mirrors) are used to direct laser ray to a certain point on a construction stage.
A laser goes corresponding to the "point-to-point" scheme, solidifying the entire cross-sectional component of the layer. After the completion of a layer, the re-coating apply a new coating of powder, and the production stage falls one layer in height. After that, this procedure is done again until the element is produced. (Gregurić, 2019)

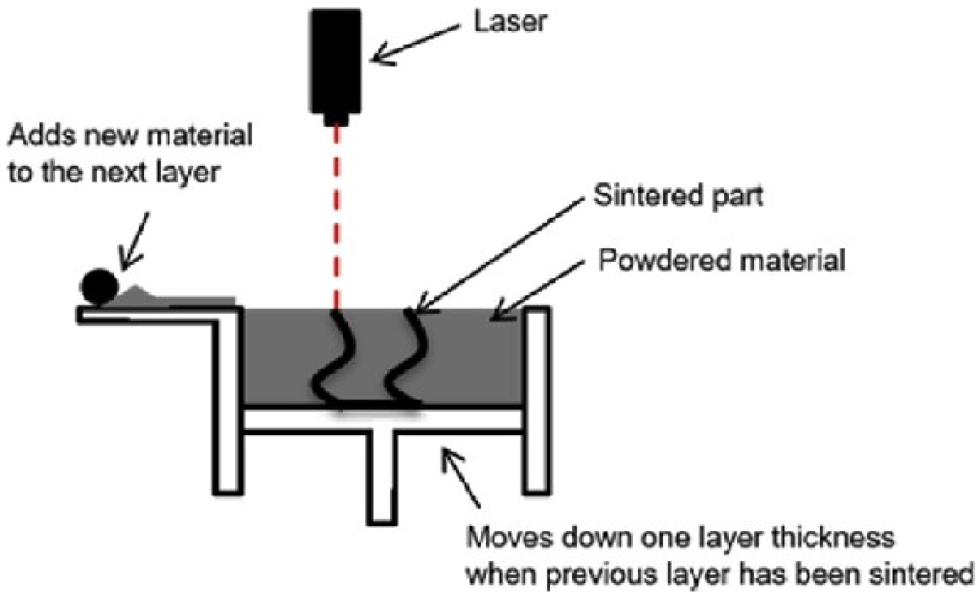

Figure 5. The result of a typical SL technique (ResearchGate, 2018)

In fused deposition modeling (FDM or 3D printing) coats of materials are merged into a certain pattern to generate an element. The substance is usually melted only when the temperature rise more than glass transition one, and then extruded in accordance with the example near or on top of the previous extrusions, producing an item layer by layer. (Grames, 2020)

In simple words, a standard FDM 3D printer holds a plastic crimping thread and squeezes it through the hot end, melting it down it and applying it in coats to the print tray. Such coats merge together, accumulating all over the print, and ultimately they constitute a completed element. (Grames, 2020)

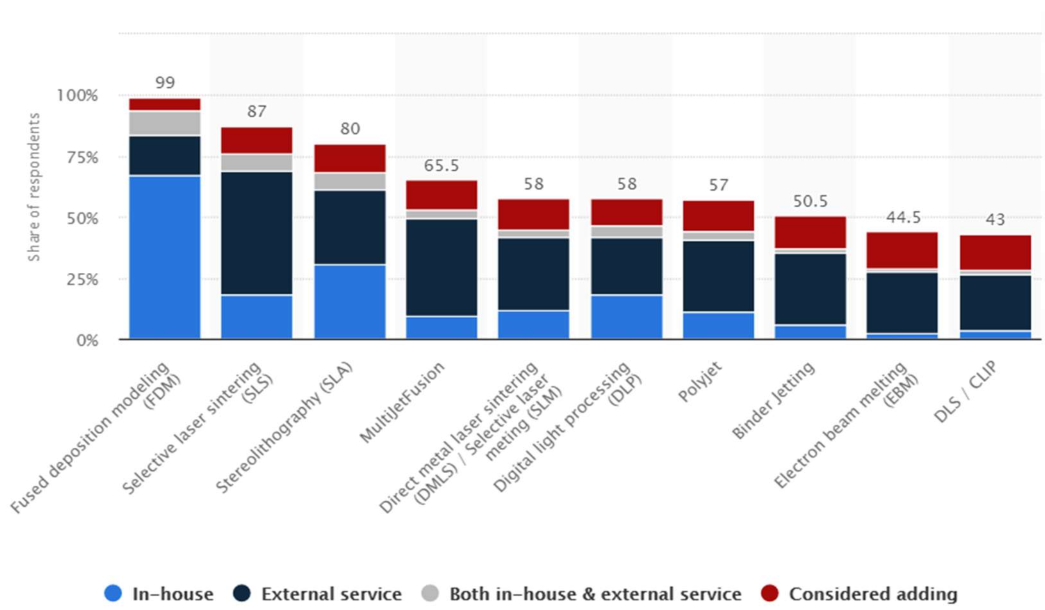

Figure 6. The most used principles of 3D printing (Statista, 2020)

FDM is identical to fused filament fabrication (FFF), but the phrases "fusion modeling" and "FDM" abbreviation were registered by Stratasys in 1991, establishing a necessity for another title. (Grames, 2020)

Several kinds of substances may be used in FDM methods, along with widespread materials such as thermoplastics, chocolate, pastes, or "exotic" substances, such as metal- or wood-infused thermoplastic. (Grames, 2020)

Feedstock form	Ceramic 3D printing technology type	Abbreviation
Slurry-based	Stereolithography	SL
	Digital light processing	DLP
	Two-photon polymerisation	TPP
	Inkjet printing	IJP
	Direct ink writing	DIW
Powder-based	Three-dimensional printing	3DP
	Selective laser sintering	SLS
	Selective laser melting	SLM
Bulk solid-based	Laminated object manufacturing	LOM
	Fused deposition modelling	FDM

Figure 7. Ceramics 3D printing technology type (3Dnatives, 2019)

2.3 The Generic AM Process

Primarily, all the production of all the details have to begin with a software model that completely explains the exterior geometry. For this purpose, virtually any professional solid modelling software may be used, but the output should be 3D solid or surface image. (Gibson, I., Rosen, D., Stucker, B., p. 4, 2015)

On the second hand, almost every device recognizes the standard STL file format, and today almost every CAD system can issue such a format. The file explains outer closed surfaces of the primary CAD prototype and shapes the core for the calculation of sections. (Gibson, I., Rosen, D., Stucker, B., p. 4, 2015)

Figure 8. The STL CAD model (Springer, 2020)

The STL file depicting the element have to be relocated to the printer. There can be particular common maneuverings with the file to match the correct size, orientation and location. (Gibson, I., Rosen, D., Stucker, B., p. 4, 2015)

Thirdly, the AM device has to be accurately configured before construction begins. These settings will apply to build-up parameters such as material limitations, power source, coat thickness, timing, and so on. (Gibson, I., Rosen, D., Stucker, B., p. 4, 2015)

Manufacture of component is basically an automated procedure, and the system can mostly work unattended. At this time, only superficial examining of the system is required to guarantee that there are no inaccuracies, such as material expiration, power supply or software failures and so forth. (Gibson, I., Rosen, D., Stucker, B., p. 4, 2015)

When the AM system finished the construction, components have to be removed. This may need contact with the system, that can have safety locks to guarantee, for instance, sufficiently low operating temperatures or the absence of active moving parts.

After the removal from the machine, components may need extra cleaning before they are ready for use. At this stage, the components can be fragile, or they can have auxiliary elements that need to be separated. They may need priming and painting to provide an appropriate surface quality and completion. This stage can also include heat treatment. Further processing can be costly, time consuming and laborious if the processing requirements are extremely demanding. (Gibson, I., Rosen, D., Stucker, B., p. 4, 2015)

The components are ready for use and assembling with other mechanical or electronic elements to create the final prototype or product after this process. (Gibson, I., Rosen, D., Stucker, B., p. 4, 2015)

Figure 9. The ceramics 3D printing process map (Aniwaa, 2021)

2.4 Ceramic 3D printing companies

In terms of production and market distinctions, comparison of companies that produce ceramics 3D-printing products and construction 3D-printing producers is of ultimate importance.

French company 3DCeram can provide indeed professional services since it operates on the market of ceramic 3D printing over 15 years. The services of the company include customized and serial production, consultation on the selection of materials for printing, research and development of new elements and components. It is worth noting that 3D Ceram has developed their own ceramic 3D printers, which it now widely uses to render services. (3DCeram, 2021)

Kwambio is a company that specialize in 3D printing, particularly with ceramic materials. Artists and designers broadly employ services of Kwambio for a multitude of products, such as kitchen utensils and sculptures. The company manufactures components for industrial sector as well, for instance conductive ceramic plate for Coca-Cola.
Despite the company is situated in New York, the production is performed in Ukraine. Kwambio developed 3D-printers and patented its own

technology, recognized as the process of ceramic binder jetting technology (CBJ), which can perform high-accuracy printing without the conventional coats on the surface of components. (Kwambio, n.d.)

Formatec Ceramics specializes in the development and manufacturing of ceramic technical parts. The Dutch company has been using 3D printing technology not so long ago, because it has mostly concentrated on ceramic injection molding (CIM) procedures for the manufacturing highly efficient ceramic components. (Formatec, n.d.)

Lithoz is an additive producing company situated in Austria which company concentrates on the development of materials and machinery. Not long ago it announced a launch of a new ceramic 3D printers group called CeraFab system which includes three models (specifically S25, S65 and S230). These models vary in resolution and build size. (Lithoz, n.d.)

2.5 Ceramic 3D printers and material

It is important to understand that clay and ceramics are frequently for description of various substances for producing pottery. Clay is kind of ceramics, however, not all ceramics is produced of clay. The distinctions of there two materials is that clay is a natural one obtained from the ground, while ceramics includes different materials including clay that harden when interacted with high temperatures.

Certain printers work with various ceramics made of clay they can also contain numerous types of substances to enhance goods. Conventional ceramics is produced from organic substances such as clay or quartz, whereas enhanced ceramics are manufactured from synthetic powders including aluminum oxide, silicon carbide and nitride and so forth.

The author decided to choose the cheapest models as product examples in order to demonstrate a comparison of large scale printers from an economic point of view, as prices can range from 3.5 thousand dollars to 300 thousand dollars. Also, only the extrusion method casting was considered.

The first example taken for comparison is the Delta WASP 2040 Clay. It is a ceramics 3D printer developed Italian 3D printer producer WASP. This compact model can generate parts with 20 cm (or 7.87in) base and up to 40 cm in height. It consists of such elements as closed chamber, safe hot pad and suspended Bowden, therefore, printing process is quick, precise and stable. (Picosolutions, n.d.)

A feature of WASP Low Density Material Extruder (LDM) it that it can extrude any low-density material without big fragments inside. Also, the kitting of mentioned model contains a certain amount of white porcelain necessary to start with. The consumers can use any paste able to turn into soft substance for pushing through the 4-6 bar of pressure extruder without fragments blocking the 1 mm nozzle. (Picosolutions, n.d.)

The next example is StoneFlower 3.1 Multimaterial 3D Printer. This model is a ceramic 3D printer made by Germany based brand StoneFlower. Using mentioned printer, various material such as ceramic pastes, clay, porcelain, mortar etc. can be extruded under paste or viscous liquid form. The feature of this model is an easily accessible and at the same time large print volume, namely 48 x 55 x 50 cm3, on request the print height can be increased up to 80 cm. Also among the advantages it should be noted that the materials of the components of the printer is of excellent quality, especially closed body and all-metal frame for steady printing at high speeds. This model is also equipped with the 5-inch color touch screen through which users can fully control work and adjust settings in real time via Wi-F i and web interface from PC. (StoneFlower, n.d.)

As the last example the author examined professional ceramic 3D printers of the Netherlands manufacturer VormVrij. The models are called LUTUM 5 and LUTUM 4M. They are unique 3D clay machines with steady and changeable production, Hiwin technology and Igus wire mesh and data cables, constructed from heavy steel parts with a 4 mm thick powder coating. LUTUM 4M is similar to LUTUM 5, although they have some distinctions: LUTUM 4M has no lights or an external control unit and only one extruder which allows to get the print volume around 25x25x40cm. For the greatest print steadiness, there is a fast cartridge replacement. LUTUM 4M is a cost-effective choice for small-scale 3D printing on clay and was specially created for users with a tight budget. (Vormvrij, n.d.)

The best ceramic 3D printers

3D printer	Technology	Material type	Build volume	Country	Price*	Quote
3DCeram C3600 ULTIMATE	Stereolithography	Advanced ceramics	600 x 600 x 300 mm	France	$300,000	Quote
Admatec ADMAFLEX 130	Stereolithography	Advanced ceramics	96 x 54 x 120 mm	Netherlands	$150,000	Quote
WASP DeltaWASP 2040 Clay	Extrusion	Clay	⌀ 200 x 400 mm	Italy	$3,500	Quote
DeltaBots 3D PotterBot 9	Extrusion	Clay	420 x 360 x 480 mm	United States	$4,850	Quote
ExOne x1 160PRO	Jetting	Advanced ceramics	800 x 500 x 400 mm	Germany	$150,000	Quote
Lithoz CeraFab 7500	Stereolithography	Advanced ceramics	76 x 43 x 170 mm	Austria	$250,000	Quote
Lynxter S600D	Extrusion	Advanced ceramics/Clay	⌀ 390 x 600 mm	France	$30,000	Quote
Pollen AM Pam Series MC	Extrusion	Advanced ceramics	⌀ 300 x 300 mm	France	$80,000	Quote
Prodways ProMaker V6000	Stereolithography	Advanced ceramics	120 x 500 x 150 mm	France	$300,000	Quote
Rapidia Metal 3D printer	Extrusion	Advanced ceramics	200 x 280 x 200 mm	Canada	$130,000	Quote
StoneFlower 3.1	Extrusion	Advanced ceramics/Clay	480 x 480 x 500 mm	Germany	$4,000	Quote
Tethon 3D Bison 1000	Stereolithography	Advanced ceramics	110 x 60 x 130 mm	United States	$17,000	Quote
VormVrij LUTUM 5	Extrusion	Advanced ceramics/Clay	430 x 450 x 500 mm	Netherlands	$9,900	Quote
XJet Carmel 700C	Jetting	Advanced ceramics	500 x 140 x 200 mm	Israel	$250,000	Quote

Figure 10. List of ceramics 3D printers available on market (Aniwaa, 2021)

3 CONSTRUCTION 3D PRINTING

This chapter describes concrete 3D printing. The demonstration of similarity between ceramic 3D printing and construction printing on the site were the concept of the thesis and the most important reasons why the author decided to consider a concrete 3D printer after second chapter. The main point of view for this chapter is to show the functionality, present prospects and challenges of the construction 3D printing technology.

3.1 What is Construction 3D Printing?

A construction 3D printer is a device capable of printing constructions layer after layer. Concrete 3D printing resembles method used by Fused deposition modeling machines. Manufacturing is as follows: pastelike substance is pressed through the nozzle in layers to generate structures in 3D. (Cherdo, 2021)

Figure 11. Construction 3D robotic arm printer Apis cor (Apis Cor, 2018)

The advantages of concrete 3D printing in the building industry are time saving and effective use of resources in contrast to conventional building practices. Nevertheless, it is vital to mention that 3D printers are not able to produce completely functional buildings at this time. (Cherdo, 2021)

In home 3D printing, frames and walls are produced and, after that, electricity, tubing or windows settlement require installment independently. Structures as platforms, seats or exterior decorations may be produced with concrete 3D printers as well. (Cherdo, 2021)

The extrusion technique is applied by 3D printers. Particular 3D printers contain a spinning mechanical arm while other are analogous to ultra-large desktop FDM (gantry-style) ones. (Cherdo, 2021)

Pastelike elements, for instance concrete, are applied as filament in each case. In simple terms, this process resembles the spread of cake coating with a pastry bag. Thus, the substance is squeezed out of a special nozzle creating layers. (Cherdo, 2021)

The printer layer by layer generates base and walls of a building on the ground which serves as a work surface. However, brick molds are manufactured with certain concrete 3D printers. After that, the bricks are placed on top of each other by hand (or with a robotic arm). (Cherdo, 2021)

3.2 The process and types of 3D printers

The extrusion of a particular mixture corresponding to developed prototype layer after layer is a technique of house 3D printers.

Substance which includes cement, filler and other additives is prepared in advance and after that is put into the hopper and passed to the print head. This substance is put to the surface of the base or already generated layers. A majority of house 3D printers operate on such technology. Three categories of such machines may be distinguished among them.

The first type is gantry 3D printers that contain frame, three gantries and a print head. Buildings can be constructed with these printers in parts or in full if they are suitable below their arch.

Figure 12. COBOD gantry 3D printer (Peri, n.d.)

The second type is Delta machines that can print more complicated forms. Delta printers do not depend on 3D guides, in their building the print head is suspended on levers that are connected with vertical guides.

Figure 13. BigDelta 3D printer by WASP (WASP, n.d.)

The last type is automated printers which can include either one robotic device or a set of robots. Among such systems, there is a manufacturing mechanic arm with extruders, operated with a PC. (Top3Dshop, n.d.)

Some other techniques of 3D printing are also distinguished. They include D-Shape machinery working by layering with powder substance and attaching it with use of an adhesive solution. (Top3Dshop, n.d.)

13 house construction 3D printers

House 3D printer	Category*	Type**	Build size (m)	Country
BetAbram P1	Available	Gantry system	16 x 8.2 x 2.5	Slovenia
COBOD BOD2	Available	Gantry system	14.62 x 50.52 x 8.14	Denmark
Constructions-3D 3D Constructor	Available	Robotic arm	13 x 13 x 3.8	France
CyBe Construction CyBe RC 3Dp	Available	Robotic arm	2.75 x 2.75 x 2.75	Netherlands
ICON Vulcan II	Available	Gantry system	2.6 x 8.5 x ∞	United States
MudBots 3D Concrete Printer	Available	Gantry system	1.83 x 1.83 x 1.22	United States
Total Kustom StroyBot 6.2	Available	Gantry system	10 x 15 x 6	United States
WASP Crane WASP	Available	Delta system	Ø 6.3 x 3	Italy
Apis Cor	Project	Robotic arm	8.5 x 1.6 x 1.5	Russia
Batiprint3D 3D printer	Project	Robotic arm	Up to 7m high	France
SQ4D - ARCS	Service	Gantry system	9.1 x 4.4 x ∞	United States
Contour Crafting	Service	Gantry system	-	United States
XtreeE	Service	Robotic arm	-	France

Figure 14. List of construction 3D printers (Aniwaa, 2021)

3.3 Materials

Fine-grained mixtures that vary from conventional concrete are the basic substances for 3D printing of objects. Substances are produced individually by every company, and they correspond to the printer and its nozzle composition, and to particular attributes of the completed good. (Top3Dshop, n.d.)

Durability, rate of hardening and setting, plasticity are the key concrete characteristics for a 3D printer. The features of concrete are controlled by mixture structure, namely the cement quantity, fillers and plasticizers quality. (Top3Dshop, n.d.)

Already prepared mixtures enable users to produce components of different complexity, height and width (from simple architectural structures, such as garden-bed and seats, to the whole houses, platforms and tower building. (Top3Dshop, n.d.)

3.4 Benefits of house 3D printing

The first pros of house 3D printing is ecologically friendly approach. 3D printed buildings can be manufactured from natural, environmentally friendly raw products. Furthermore, certain 3D printed houses operate with use of alternative energy and produce minimal CO2 emissions. (Cherdo, 2021)

Another advantage is affordability because 3D printers can produce economically advantageous buildings. This feature is extremely helpful for poor areas or disasters affected zones. (Cherdo, 2021)

Construction 3D printers can be characterized as scalable since they decrease manufacturing expenses. For instance, the price of 1 m2 of wall built by conventional techniques is about $75, while by construction 3D printer Apis Cor is $27. (Cherdo, 2021)

Construction 3D printers are productive because the elements are manufactured on demand, as a result there are less wastes. In addition, house 3D printers can complete the foundation in less than a week, although, standard manufacturing approaches require several weeks or months. (Cherdo, 2021)

Design flexibility is also worth noting because users can develop walls of different shapes as well as exclusive facades. With a 3D manufacturing it is probable to generate suitable furniture for the unique forms of walls. (Cherdo, 2021)

3.5 Limits of 3D printing houses

There are some drawbacks of house 3D printers as well. One of the main disadvantages is costly initial investment since the cost of certain home 3D printers goes as high as $1 million. Not whole building might be completed with 3D printer, they produce just frames, so the structure is only partially built. Building is interrupted for installing water system, electric wiring and rebars. (Cherdo, 2021)

The facade of a majority of 3D-manufactured buildings is not as even as conventional house one so one of drawbacks is a rough exterior. (Cherdo, 2021)

Construction sites are governed by legislation under high safety standards. In house 3D printing it is complicated to meet such requirements because of different repeatability, steadiness and so forth, it is resulting in absence of certification. (Cherdo, 2021)

One more disadvantage which is already observed for a long time is that 3D printing may possibly worsen regional economy, particularly in zones affected by poverty or towns with elevated level of unemployment. 3D printers generate less jobs for citizens because they diminish the necessity of manual work. (Cherdo, 2021)

3.6 The Challenges of 3D Printing in Construction

Regardless of the advantages and prospects of 3D printing in the building area, there are a several issues that can prevent technology from becoming publicly available. It is worth considering these challenges. (Ellis, 2020)

Key issue of the common implementation of 3D printing techniques on building sites is expensive buying or leasing such machines and the logistics associated with delivering these big 3D printers to the workplace. 3D printers are expensive, and their price does not comprise the cost of raw materials and maintenance. Nowadays, many building specialists find it challenging to rationalize the expenses of 3D printing compared to the advantages of this method. (Ellis, 2020)

The building industry is growing rapidly, and experienced employees are in great demand, even the amount of qualified specialists is not enough.

3D printing needs precise skills that would have to pull from a smaller number of applicants even with labor shortage. The search of highly qualified candidates is complicated nowadays because of this reason and can be even more complex in the future. (Ellis, 2020)

Weather conditions may slow down the process of building, but nature disasters can have even much impact on construction 3D printing. Weather, environmental aspects, and so forth can result in losses rather than profits. In addition, quality monitoring in manufacturing is a difficult task, because if it is not regularly supervised and controlled by real people, the quality may significantly worsen. (Ellis, 2020)

Another unobvious disadvantage is 3D printing regulation because it has not yet entirely affected the building industry, although began to be developed. Nonetheless, there is also a responsibility related to usage of printers to carry out specific construction assignments. This aspect of 3D printing in construction is extremely unstable at this time since the legislation is not obviously specified. Thus, it prevents 3D printing from having much effect on the building industry. (Ellis, 2020)

3.7 Present 3D Printed Projects

A striking case manufactured with 3D printers is Dubai municipality office in United Arab Emirates. Apis Cor finished the production of world’s biggest specific 3D printed building in December 2019. The volume of this object is impressive, namely 640 m2 square and 9,5 m in height office building. (O'Malley, 2020)

The manufacturing was performed with Apis Cor’s machine that produced numerous components of the object by moving it in the out of doors construction area with a crane. (O'Malley, 2020)

Figure 14. World`s largest 3D printed building (Dubai, 2019)

Another notable 3D-printed object in United Arab Emirates is named Office of the Future. It is a exceptional object, which at this time serves as a residence of the Emirate Foundation. (O'Malley, 2020)

All the elements for this case were generated in seventeen days, the installment took two full day. For this object, manufacturing was performed out of the construction area. (O'Malley, 2020)

Figure 14. Office of the Future (Dubai, 2017)

Chinese company WinSun also perform 3D house printing with their own machines. WinSun developed numerous house projects, among which there is a miniature apartment construction. Consumers are able to choose the prototype and fast and inexpensively produce components prior to establishing them on building site. (O'Malley, 2020)

Figure 15. Five story 3D printed building (WinSun, 2015)

The price of a building with 5 stores is estimated to be only $161,000 to manufacture. (O'Malley, 2020)

3.8 The Apis Cor Engineering company and construction 3D robotic arm printer

Russian based company Apis Cor Engineering develops an exclusive mobile 3D gadget able to fully produce a building on a construction area. (Apis Cor 3D Printer, n.d.)

The overall size of the 3D-printer in the assembled form is 4 × 1,6 × 1,5 m and weight are 2 tons which allows to increase the printing area up to 131 m2. Users can apply multiple synchronized 3D printers to manufacture big houses and constructions. (Apis Cor 3D Printer, n.d.)

Due to its relatively compact size the printer can be moved to different building sites. However, the building volume reaches 8500 x 1600 x 1500 mm. (Apis Cor 3D Printer, n.d.)

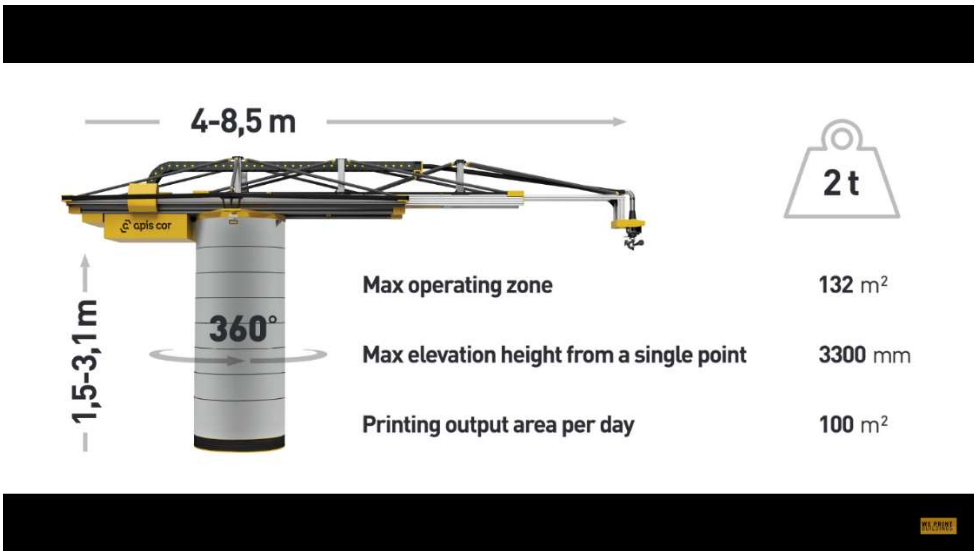

Figure 15. Apis Cor 3D robotic arm printer (Russia, 2017)

Work of Apis Cor 3D printer involves the presence of only two persons to control and deliver the material, in all other aspects it is completely automated. The installment procedure takes approximately half an hour. One of the Apis Cor`s main advantages is its cost-effectiveness since it reduces costs up to 40% in comparison with conventional manufacturing methods. (Apis Cor 3D Printer, n.d.)

This 3D printer does not generate excess manufacture waste because the material is delivered in predefined amounts. (Apis Cor 3D Printer, n.d.)

Eventually, stabilization technique allows to install mentioned 3D printer on practically any surface with a height difference less than 10 cm while the installment of analogous machines needs a flat and smooth concrete foundation. (Apis Cor 3D Printer, n.d.)

Actually, author decided to choose a robotic arm 3D printer Apis Cor as the best example of construction 3D printers for this thesis. Construction 3D printers are still under development, and the best choice was to take the most relevant product for description to stay on the comparison method and not delve into the topic. (Apis Cor 3D Printer, n.d.)

4 COMPARISON ANALYSIS

This section is the end result of the bachelor's thesis, where a database compiled from various scientific papers and reports related to 3D printing technology was used to compare two different scales of 3D printing.

4.1 What is the difference between Construction and Ceramics 3D Printing?

Firstly, size was taken as the main criterion for the comparison method. Size creates various complexities for transportation, production problems, goals, loyalty to the law, security and economy. This means that the larger the size, the more problems the material creates.

Second, the process methodology varies significantly between two sizes of 3D printing. Construction printing proposes a single method, since the only material needed for construction is content of liquid concrete and several powdered substances for fixing, fast pouring and stability of construction. The name of the 3D construction technology is the method of fused demolition or FDM. Nevertheless, ceramic 3D printing offers at least 3 different methods, such as stereolithography (SL), fused deposition modeling (FDM) and selective laser sintering (SLS), but there are more additional methods, which were not mentioned in this report.

Although, in order to clearly distinguish the methods of ceramics and concrete 3D-printers, author described the current situation on real examples of projects. A typical structure file created by CAD programs is converted to an STL file to make multiple layers for printing so that the 3D printer computer can understand how many layers the structure needs to make. Exactly the same method is used in construction technology of 3D printing, but the only difference is the pouring rate, much slower with concrete than with ceramics.

The most noticeable fact in comparison is that the best option for the construction industry is robotic 3D printers such as Apis Cor. Because the construction site is much larger than a typical ceramic model on the hot bed, the 3D printer needs to be moved from side to side to print various details on building. At the same time, the production of additives is usually based on the bridge sliders of 3D printers and delta machines. Although the construction technology of 3D printing has the same types of models, but in our case the best and fastest option for pouring concrete in situ is a robotic arm from the Russian company Apis Cor.

Transportation compared to two different printers is significant in scale. For example, a typical 3D printer for additive manufacturing is a hundred times lighter and only needs to be installed once during its production or on site if it was partially sent, as the authors case when the package came from China to the authors' home. In author`s case, the author had to assemble all parts into one working 3D printer using simple instructions made by the manufacturer on YouTube. In the case of the Apis Cor printer, the entire model is pre-installed in the fabric, and usually the whole machine is easily placed on the truck to go to the construction site. However, most other large-scale 3D printers are transported in several parts, with many trucks and a special engineer always needs to monitor installation process before the construction process begins. This means that transporting and installing large 3D printers takes many times more money and time to be ready for use.

Without material in this procedure, nothing could happen. Definitely, material science is broad, and the purpose of this thesis was to compare two different printers, but compared to two different printers, it should be considered that small-scale printers work with ceramics, different plastics, biological materials for artificial organs, such as hearth and others, aluminum or other soft metals and even wood fibers. For large-scale 3D printing, the use of high-quality concrete is the only material that can be considered.

On the one hand, the current world situation shows that the technology of production of small-scale additives is sufficiently developed for the manufacture of various types of products for everyday use, for medicine, for other technologies and mechanisms. But on the other hand, small-scale 3D printing are not compatible with the size of the buildings because the physical size of the machine.

Taking into account the future prospects, scientists and mechanical engineers have a lot of work to do with large construction 3D printers, as they are the main machine that will be used to colonize Mars. Apis Cor has won the competition for the best method of 3D printing, and today it has several contracts with NASA. Apis Cor is testing various building structures with their 3D printer to make the best choice of building structure that can withstand Mars. Of course, small 3D printers can also be used on Mars and other planets, but the whole product has already been created and is working successfully.

3D printing in large-scale projects has more risk factors, and its own difficulties are more complex, so its development requires a lot of time and money. In addition, it still needs more investment from various large countries and technology companies. The basic idea is quite clear, and the capabilities of this machine show great potential. The small-scale 3D printing sector feels quite economically stable, as more and more investors are coming to this technology today. Possibly the future situation will change, and more and more construction 3D printing technologies will be involved in the modern construction industry.

5 CONCLUSION

The construction 3D printing has evolved over the decades. Today is a revolution in 3D construction printing as printers become available on the market and are used in variety of construction projects around the world. Undoubtedly, their use is much wider, but it is not only a Bachelor's thesis topic, as the main purpose of the thesis was to show that construction 3D printing is already used now, highlight their benefits and disadvantages and, finally, point to prospects. The use of robotics increases the efficiency, productivity and quality of work on sites, as a result, profit of the construction industry increases.

The thesis described several models of ceramics and concrete 3D-printers of different companies to show its availability on the market and modern implementation. The technical characteristics, drawbacks and advantages, costs, its application and features of operation are stated. Moreover, it will continue to evolve. However, for the effective implementation of 3D printers in the construction process, its initial characteristics and features of operation should be first taken into account.

The whole process of 3D printing was described and illustrated with figures to fulfill the content of the thesis and expand knowledge base of 3D printing. The possibility of comparing two different size, after all the described specifications of 3D printers, was justified.

In conclusion, 3D construction printing is a promising area because it is in great demand. According to all material above, construction 3D printing is cost effective, it makes the construction process better, more environmentally friendly and safer. The authors' idea to compare the two types of machines is a good example, because the end result shows the general picture of 3D printing for beginners in this great science. 3D printing is a very broad science, and many books, articles, dissertation reports, and other materials can be found on the Internet. Accordingly, further research can be conducted on the basis of this thesis for other students, which will provide the basis for the next Bachelor's or Master's thesis related to 3D printing.

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