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Construction Revolution: 3D Printing as a Motivator for Innovation in the Construction Industry

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Abstract

Background: Three-dimensional (3D) printing is a major technology to be used in the construction industry. There are significant benefits to this in efficiency, costs and creativity. This study seeks to present the implications of this technology on construction sector by discussing its scopes, capabilities and challenges**.**

Method: For this study, the authors conducted a descriptive assessment of research papers and reports concerning 3D printing use within construction industry.

Findings: The research confirms that 3D printing is a viable aligned cost reduction using the improvement in design correctness and execution time that results, while additionally reducing environmental waste as high as sixty-percent. In addition, the technology aids designers in producing their creativity and attains extempore concepts that are usable. But there are significant ethical implications, a dearth of government action and digital skills and training remains the biggest barrier according to survey findings from the sector**.**

Conclusions: The current state of 3D printing technology requires further research, development, and technical support, in order for struggling and utilize the potential of this time-saving tech or should go back once again learning mains basic attacks. Hence, it is important to increase international collaboration and work on creating infrastructure that provides training programs in order for this technology to be adopted faster all over the world**.**

Keywords: 3D printing technology, innovation, sustainability, design, traditional methods.

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1. Introduction

Recently the construction industry saw a drastic change because of adding modern technologies within traditional methods. One of the most famous technologies is three-dimensional printing (3D printing). The design and construction of buildings and structures was reimagined with this technology. Designers had struggled with designing architectural structures that well combined aesthetics and functionality in the past. Therefore, designers have successfully broken free from these limitations by embracing 3D printing technology as a new and innovative solution. In that way, this technology has become a powerful innovation engine for construction (1).

For designers, the significance of 3D printing is that it offers them a tantalizing slice of what could be. This can greatly stifle creativity, especially when tackling intricate designs that require flexibility and high levels of precision. This technology and design principles (isomorphic construction, for example) have made it possible today to build dynamic shapes that would have been expensive and/or unbuildable using traditional methods. In the way, it not only improves building aesthetics but also helps to reduce costs and shorten construction time (2).

3D printing goes back into the 1950s and was used primarily in industrial as well military applications. This technology over time has spread to other fields as well, like medicine, art and architecture. This innovative material and fabrication method have redefined the design of large complex structures within the construction industry. This is having a widespread impact, not only on aesthetics but also increasing material efficiency and reducing waste. Thus, this technology is

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in line with the requirements of environmental sustainability which are amongst key objectives to be achieved at present-day (3).

Sticking with the Fourth Industrial Revolution, another pillar of this movement is 3D printing in modern manufacturing. This technology integrates artificial intelligence to provide advanced solutions in several sectors, including construction. Digital models allow for more advanced and precise architectural components to be manufactured which lowers the risk of mistakes. Additionally, the latter provides potential for multifunctional materials and components catering to contemporary design needs arising from this technology (4). Bringing design innovation together with sustainability is one of the most significant benefit areas in 3D printing. This allows the growth of different environmentally-friendly materials leading to minimal use and consumption of rich, natural resources. 3D printing is increasingly important in sustainable construction practices and along with other green technologies 3 Which used for global solutions towards the environmental protection (5).

Although the construction industry has much to gain from these benefits, 3D printing in this domain is not without its hurdles. These barriers can be the high price of necessary printings equipment, advanced technical skills necessary to have great results from 3D printing(post-processing and printer maintenance), cost of materials. However the evolution of this technology and increasing interest towards its uses have unlocked a wide arena for construction sector to propel. It will increase potential for innovative and creative architectural (design, as well release the classic limitations faced by engineers throughout history in fulfilling their architects vision (6). According to research, 3D printing is forecasted as an

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emerging technology that may increase substantially in years to come. Its worldwide market value is expected to be as high $120 billion in 2020 and could rise to nearly $300 Billion by 2025. Increased incidences of, and investment in R&D activities along with the demand to innovate design as well manufacture are factors responsible for such trends on a global scale; driving overall growth from 2018, followed by peripheral technologies (7).

Reports also state 3D printing, besides time- and cost-efficient it can reduce the construction costs by 50%–70%, labor costs – for a staggering additional saving of 50% to even up to as much as an average labor-cost-reduction of minimum at least another ~80%. It also aids in decreasing on-site waste by 60% These economic as well environmental benefits give reasons to its strategic option. Countries such as Canada, United States of America(USA), Japan, Germany and the U.K are pumping enormous funds to advance their 3D printing technologies across multiple industries from medicine manufacturing aviation to automotive etc (7).

It is Revolution in Construction world to make anything anywhere like we can build building steel & glass frames using 3D Printing. With such technology, it is able to provide better solutions that help in making efficiency improvements through cost reduction, improving creativity and the flexibility of designing and implementing projects. . With the introduction of robotics and digital control systems, it has become possible to accelerate this revolution, thereby opening new horizons for reshaping traditional construction and building processes (1).

This issue is studied by considering 3D printing, digital control and robotics as an integrated whole. For decades, the construction industry has faced challenges related to efficiency, high costs, and time as well as environmental issues

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associated with waste and resource squandering resulting from traditional processes. Recent studies like one from MIT have found a significant reduction in time required to build intricate structures with the high precision and speed of execution that robotics when combined with 3D printing technologies (8).

In another study done by Contour Crafting robots can aid in the construction process to build an entire house within 24 hours, which is much faster than traditional methods taking weeks or even months. All of that new time is as if robots can simply accomplish work faster and better than human labor. Digital control also enables robots to be guided to execute architectural work with extreme precision, reduce errors, and increase execution quality (9).

In addition, by integrating it with robotics, 3D printing simplifies many tasks in architecture and construction due to a reduced price which maximize productivity. Among those investigating the integration of manufactured components is a Royal Institute of British Architects (RIBA) study. In this new research, it was seen that 3D printing paired with robotics can produce unique designs not possible through traditional techniques. Newer technologies including robotics and digital control are allowing engineers to break through engineering limitations that previously hindered engineers from realizing their creativity (10).

In addition, the advantages of this robotics/3D printing synergy are not merely aesthetic beautification but rather an increase in environmental conservation. The use of robots in combination with 3D printing reduces the raw material utilization by even up to 60% according to research from Stanford University, which further decreases waste produced through construction processes. This integration leads to a clearer and faster allocation of resources, helping to reach environmentally sustainability targets in the construction sector (7).

But even though it has these takeaways, there are many problems when integrating this. First, costs associated with the development and upkeep of robots such as advanced digital technologies are high; Meanwhile, workers also need to be trained . According to a University of Cambridge study, the high cost in technological infrastructure for transitioning into using 3D printing as construction method undoubtedly raises an important hurdle that prevent these technologies from wide adoption especially at developing countries (11, 12).

These examples demonstrate a new style of construction called 3D printing with robotics and digital control. Its ability not only to provide solutions for the faster ways of building, but also poses a vast array of unprecedent possibilities regarding creativity, efficiency and sustainability. The integration raises questions about how deeply these new technologies will impact conventional construction processes and whether they can break through past barriers to the transformative future they herald.

Therefore, it is necessary to examine how 3D printing could be a driver for innovation in construction and as such leading the way of disruptive measures within this sector. This brings us to the essential question: How much actual change can 3D printing provide in construction? the answer to this could be brought through some questions that are;(1) What impact is shown by 3D printing in construction? (2) What value for construction projects can this tech bring in terms of efficiency and cost savings?, (3) How does 3D printing help the environment regarding sustainability and reducing material waste? (4) What are

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the key challenges in this sector, particularly for developing countries, that preclude 3D printing adoption?

2. Methods

In this study, a descriptive analytical method was employed. It is based on a review and content analysis of previous studies, academic literature regarding 3D printing technology in the construction industry. The authors analyzed from various sources that included scientific papers, technical reports and research institutions etc. Thus, with this methodology the present study aims to provide a broad view of how the use of 3D Printing technology can improve such efficiency in construction processes by diminishing cost and waste raw material production; reducing time and labor needed for projects execution; as well as saving environment. Use of this methodology will provide insight into different uses of 3D printing in construction and compare those with traditional methods, to identify the advantages or issues that may prevent from large scale adoption.

3. Result

3.1 3D printing technologies

Nowadays 3D printing is a novel technology in the domain of modern manufacturing. As stated by Choi and Yu,(13) 3D printing is a method of making three-dimensional objects from digital representations imposed on flat, typically 2D surfaces called the “build plate” Then we melted these materials to get the forms that we wanted.

3D printing is simply defined by the ASTM International Committee as "the process of manufacturing three-dimensional objects by depositing material using a printhead, nozzle, or other print head"—Noorani (14), this report based on Wohler 2014. I find applications for this technology in manufacturing through to the medical field. Abdul Rahim and Suleiman (15) described it as a technology that creates models by layering material directly where the input materials are fed to the process in powder, paste, or suspension. The most prominent 3D printing technologies are Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), and stereolithography (SLA) (16), which are discussed in detail, focusing on how they work, their development history, and their advantages.

3.1.1 Selective Laser Sintering (SLS)

Another type of 3D printing technology is Selective Laser Sintering (SLS). Developed in the mid-1980s by Dr. Carl Deckard at the University of Texas, SLS was initially overseen by DARPA (the U.S Defense Advanced Research Project Agency). It has since been developed to become one of the leading 3D printing technologies, applied extensively throughout many industries like medical and aerospace. It utilizes a powerful laser to combine small particles of plastics, metals, ceramics or glass as examples. A thin layer of powder is spread over the printing surface and fused to certain areas in accordance with a digital design using laser. From there a new layer of powder is added to the platform, which once again goes up slightly and the laser fuses successively until you have an object. The main advantage of this technology is that it eliminates the need for external support during the printing process. The layers unaffected by the laser remained intact and provided a natural support for the printed layers. Moreover, the powder not used can be recycled to use for printing, which is an eco-friendly and cost-effective protocol (16)

3.1.2 Fused Deposition Modeling (FDM)

Fused deposition modeling (FDM) is one of the most commonly used 3D printing technique. It was first created in the late 1980s and patented by Scott Crump. In 1988 he established the Stratasys Company to commercialize the technology (17). It uses thermoplastic materials (18). This spool of plastic filament or metal wire is unspooled and then passed into the printing nozzle where it gets heated until it becomes liquid (molten) from where temperature can be controlled with help of special digital control software.. The material is pushed out molten and then it solidifies just after extrusion, allowing you to build the object bit by bit. A computer then digitally designs the nozzle, such that it moves mechanically and physically constructs complex objects with greater precision (16). These techniques are cheap and user friendly, and hence have applications in various fields like education sector to engineering. Eventually, the very same technology was given another name: fused filament fabrication (FFF). Because of the RepRap open-source project, 3D printing has been widely adopted by all through self-replicating printers (17).

3.1.3 Stereolithography (SLA)

One of the pioneers in Additive Manufacturing, Stereolithography (SLA) is still one of the most precise 3D printing methods around. 3D printing was first introduced in 1986 by Charles Hull, who then went on to set up a company called "3D Systems". This technology relies on a photo polymerization process: the UV laser shines on to liquid photo polymer resin and solidifies layers one by one until an object is formed(18).

How this works is first a tank with special liquid resin layer inside it and then on the surface of that liquid, laser creates a cross section from desired object. The laser cures the resin — hardening it where exposed while leaving the rest of liquid. Once the first layer is drawn , the print platform moves lower, so it has a thickness equal to what we drew and then the surface changes state in order for us pour more resin. They did this iteratively until they had the full object built. It is considered that this technology approach has high detail precision and capable of creating accurate models even in intricate forms, however since the model needs to be supported while being printed it requires additional supports. Although it is expensive compared to most others technology, that would be the right one if we need models with excellent precision and quality (16).

3.2 Materials used in forming products in 3D printing

3D printing has come a long way from its beginnings and is offering a wide range of usable materials. This ranges dramatically by means of the product or service. They have many shapes such as powders, filaments, pellets and granules etc. Filaments are the most common type, with many sizes that can be used in all colors and types, which giving users significant manufacturing flexibility However, in order to use it as construction material we need appropriate physical properties: hardness, heat resistance and chemical stability of the corresponding materials for high temperatures at long periods (18). Some materials used to 3D print products, shown in Figure 1.following is a review of the most important materials used in 3D printing.

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Fig. 1: Materials employed in the fabrication of products manufactured through 3D printing (18).

3.2.1 Polylactic Acid (PLA)

PLA (Polylactic Acid) is one of the most common materials used in 3D printing. The following are made from corn starch, which is renewable. Eco-friendly & works with most printers Unlike traditional plastics, it takes far less energy to process. In addition, it is odorless with minimal warping and comes in various colors — either transparent or opaque. It is widely used for making prototypes and ornamental products due to its strength and workability (19).

3.2.2 Acrylonitrile Butadiene Styrene (ABS)

Acrylonitrile Butadiene Styrene (ABS) is one of the most commonly used materials for practical 3D printing right behind PLA. Cheap, versatile and light in weight. ABS is perfect for furniture, sports goods and bicycle helmets, etc. That said, it has its own issues too and one of the biggest criticisms is emitting toxic fumes during printing which can be harmful to people with respiratory problems. Hence, good ventilation during printing is critical (20).

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3.2.3 Nylon

Nylon filaments are also one of the popular materials to be printed as they provide a sturdy and durable co-creation. They are not as brittle as PLA and ABS but possess superior strength. It find wide applicability in miscellaneous items like d decorative tiles, containers, tools, consumer products, and toys. Moreover, nylon is tough and results in good impact resistance or abrasive and toughness, making it suitable for applications requiring high durability and strength (21).

3.2.4 High-Impact Polystyrene (HIPS)

In the realm of dual-extrusion 3D printers, HIPS ranks among popular choices. This is white and biodégradable. Most are used for packaging applications in the food sector. In addition, the colorless liquid hydrocarbons in which it is soluble ensures its beneficial properties for temporary support of ABS complex objects (22).

3.2.5 Resin

Resin is a light-sensitive liquid material using light-based techniques such as Stereolithography (SLA). The resin can produce extremely fine details. Hence used extensively in precision manufacturing like jewelry, prosthetics, medical instruments and tiles. The resin is cured with ultraviolet light, creating objects of high strength and accuracy (23).

3.3 Construction and building using 3D concrete printing (3DCP3)

Concrete is the most widely used building material and annual global production exceeds 30 billion tons. But that's just a fraction of the construction cost Overall molds cost make up 35–60% of the entire concrete construction costs. A mold is a formwork for casting wet concrete, usually made from wood. Molds are a major contributor to the world's waste as they all end up getting thrown away. Traditionally, the use of molds for concrete casting is considered to be standard; it creates a limitation on imaginative free-form shapes without splurging an exceptional budget in fabricating tailored-made molds (1).

3D concrete printing (3DCP) is a new technology that allows free-flowing construction without the need for a mold. it have attracted increasing attention in various industries With the increasing interest in 3D printing technologies from various industries; Nonetheless, technology penetration in some sectors has been higher than others. Hence, integrating the 3D printing technology in civil engineering can revolutionize building design and open our minds to new ways of designing structures where economical use of material will be more important than form itself (24).

Since the 1990s, it has basically been a quicker and less expensive approach to produce structures. However, pegna was the researcher to implement Concrete 3D printing first(25). Some solutions have been developed to enhance the performance of 3D-printed concrete compared with conventional concrete**.**

3.3.1 Thermosetting 3D printing

In concrete extrusion, a layered structure is created with a nozzle that deposits new cementitious material along a specific path. To ensure the quality of printed components, the material must possess certain properties. These include: (1) pumpability, as the concrete needs to flow through the nozzle and prevent particle

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separation through the hose; (2) extrudability, as the concrete needs to flow through the nozzle and the deposited filament must retain its shape; and (3) interlayer adhesion, as the new layer bonds to the underlying layer and does not deform significantly under the weight of the layers above it (26). The following figure illustrates concrete extrusion using the thermosetting technique:

Fig 2: Concrete extrusion using the thermosetting technique (1)**.**

Several concrete extrusion processes have been developed in recent years. They can be divided into three types based on filament size (26):

- Deposition of fine filaments less than 1 cm in diameter: such as 3D concrete printing (3DCP) at Loughborough University, which uses a gantry-sized three-axis robot.

- Deposition of medium-fine filaments with cross-sectional dimensions up to several centimeters, such as Contour Crafting at the University of Southern California.
- Deposition of coarse filaments in several sizes, such as CONPrint3D at the University of Dresden, which seeks to use established standards for concrete and construction equipment.

Additive manufacturing (AM) systems suitable for printing are classified according to the size of the printed model, layer thickness, printing environment, assembly strategy, use of supporting structures, and associated costs. 3-axis printers have been shown to be the most common, often producing models in small sizes. The office building project printed by Winson is among the projects that have used AM systems. In this project, a printing process similar to Contour Crafting was used, with parts produced and assembled within two days (27).

3.3.2 Particle-bed printing processes

Aggregates, liquids, and activators are mixed prior to settling in concrete extrusion processes. In these processes, a bed of dry particles is created, and then liquid is selectively added to bind the particles together. Post-processing processes (such as filtration and heat treatment) can increase the strength and durability of printed structures (28). The main variations in powder-based concrete printing processes are as follows (29):

- Selective Activation Binder: A layer of selectively adhering powder, which can be fused or solidified (such as sand mixed with cement). This mixture is consumed with a liquid agent, water or similar compounds and mixed to interact with the selective form.

- Selective Intrusion Paste: This has aggregates in the print, and its selective liquid binder is a paste produced using cement as well as water with additives.
- Binder Jetting: print this mixture of aggregates and activator. The liquid binder is applied only selectively to the mixture. This would be commonly used to create molds of sand from a 3D print that at is coated with resin.

3.4 Construction and building applications using 3D printing

3D Printing is a modern construction technology taking its origin in the creation of three-dimensional objects with stacking materials layer by layer, which are described in digital plans. This technology enables the construction of life-size 3D models, enhances design accuracy, and has the potential for achieving innovative architectural visions (1). The following are the most prominent global applications in the field of construction and building using 3D printing technology.

3.4.1 Winsun (Chinese company)

Winsun adopted innovative environmental technology as a key factor in promoting sustainable development. The company embraced green innovation as a key driving force. Collaborating with several green building advocates and practitioners both inside and outside China, the company has leveraged 3D printing technology to provide comprehensive solutions for eco-friendly building construction. Winsun was a pioneer in adopting a global sustainable development

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strategy by developing a new industry based on environmental protection and resource conservation (30).

In 2016, Winsun printed a traditional Chinese-style house with an interior courtyard using 3D printing to design both the interior and exterior. The printing process was comprehensive and included eco-friendly green walls, aesthetically pleasing hollow walls, and patio furniture. Winsun used 3D printing to produce stone flooring, making the construction experience more integrated and innovative(31). One innovative technology implemented by the company was the printing of hollow walls, a technology that not only reduces the weight of walls but also helps enhance thermal insulation efficiency, improves the quality of the living environment inside the building, and makes it more comfortable. Furthermore, this design enabled the wall thickness to be reduced without sacrificing the functional efficiency or aesthetic value. The cost of building this house was approximately 5,000 Chinese yuan per square meter, which is equivalent to approximately $750 (1). Winsun did not stop there; it developed and printed multifunctional and environmentally friendly walls. These walls not only boast an aesthetically pleasing appearance but also offer sound insulation. While traditional barriers made of materials such as laminated glass, clear acrylic, or sawdust reduce noise by 20–22 dB, Winsun's 3D-printed sound barriers can reduce noise by 30 dB. This achievement has improved quality of life in residential areas near highways and busy areas. Additionally, the sound barrier was innovatively designed to include plant pots that can be used to grow plants with natural noise-reducing properties, such as flowers and climbing plants. This design creates a vertical green wall that absorbs sound and beautifies the surrounding environment (32).

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Currently, Winsun is seeking to expand its technology. It signed a deal with the Egyptian government to ship 20,000 3D-printed housing units. The company also announced a collaboration with Nile Sand Company Limited to establish 12 factories in the Egyptian Desert over the next two years (1)

Furthermore, Winsun aims to establish factories in more than 20 countries worldwide over the next three years, with a particular focus on the Middle East and North Africa. The company aims to provide affordable and efficient housing units, particularly for low-income groups, thus contributing to the housing crisis in many poor areas. Despite Winsun's significant success, it has faced some challenges, such as printing components off-site, which can impact operational efficiency and increase logistics costs. The company is now seeking to improve these experiences, overcome shortcomings, and expand the use of 3D printing in the residential sector (1). The following images show the company's 3D printing projects for some residential buildings

Fig 3: Chinese company Winsun printing 10 micro-dwellings in 24 hours, and the world's tallest 6-story building (1)

Fig 4: Multiple examples of Winsun's multifunctional soundproof wall (1)

3.4.2 Huashang Tengda (Chinese company)

The Chinese company Huashang Tenda completed an innovative project in Beijing. It was able to print a complete, two-story villa with an area of 400 square meters in just 45 days. What sets this company apart from others is its unique process that allows it to print entire buildings on-site and in one batch, eliminating the need to print components elsewhere and then transport and assemble them on-site (33).

In this project, the house frame was designed to incorporate built-in steel reinforcements and the necessary plumbing. The concrete mixture was extruded using a large 3D printer and a specially designed nozzle. Concrete is pumped around the steel frame and tightly encased within the walls, providing significant structural strength (1). The following figure illustrates this villa.

Fig 5: A two-story villa built entirely using 3D printing technology from Huashang Tengda (1)

This novel design is thereby considered a significant advancement in overcoming one of the fundamental challenges associated with 3D concrete printing (DCP) technology; its capability to combine conventional steel bars within printed concrete as illustrated below. This increases the life-span and structural sustainability of the DCP-printed structures (34).

Fig 6: Integrating traditional steel reinforcements with 3D structural concrete printing (1)

The company stated that a 2-story villa whice created using this technologyhas excellent earthquake-resistance properties. The villa is earthquake-resistant up to 8 on the Richter scale, so it can be placed in areas affected by natural disasters. The giant printer used has a unique feature: a bifurcated nozzle that extrudes concrete on both side of the rebar at once ensuring full encapsulation throughout the walls while enhancing its strength (33).

This means this project is a huge push in erasing the technical hurdles of construction 3D printing. Regardless, this project does show how printing technology is both a sustainable and durable solution to traditional construction in areas that are increasingly affected by environmental disasters

3.4.3 Dubai's experience with 3D Printing Construction

In 2016, Dubai witnessed significant achievements in 3D printing. The world's first 3D office building was printed in just 17 days (Figure 7). A giant printer was used, which relied on a special mix of printing materials, including fiberglass-reinforced gypsum, concrete, and fiber-reinforced plastic. This project is unique not only in its use of advanced construction technology but also in its cost, which amounted to approximately $2.5 million, roughly half the cost of similar projects implemented using traditional methods (35).

The construction process required 19 employees including installers, electricians, and mechanical engineers. However, only one person was responsible for operating the giant printer, highlighting the technology's effectiveness in saving time, effort, and labor (36).

Immediately after the opening of the building, the Dubai government announced ambitious plans for 3D printing. Its goal is to build 25% of Dubai’s buildings using this technology by 2023. The government also believes that 3D printing will play a fundamental role in the future of cities and become an integral part of all aspects of life (36,37). Dubai aims to become a global center for 3D printing research and development.

Fig 7: Dubai government building constructed using 3D printing technology (35)

This strong interest from the Dubai government in 3D printing has helped attract international companies, such as Casa, which relocated its headquarters to the UAE. In 2017, Casa launched its own line of 3D printers for robotic constructions. Through this project, Casa aims to increase construction speed, improve safety levels, and reduce costs and environmental impacts. The company announced ambitious plans to build a skyscraper in Dubai using 3D printing technology, which is expected to be completed by 2023. Dubai's experience with 3D printing represents a major turning point in the world of construction, aiming to redefine the concept of construction and reduce costs and time, while maintaining high standards of quality and sustainability (37).

3.4.4 Rudenko's D3 Concrete Printers

A massive undertaking started in the backyard of Andrey Rudenko, back in August 2014. He developed an FDM (heat and melt printing) printer to to be able to print in concrete. As a matter of fact, Rudenko had remarkable success in printing one castle made of concrete layers. The project took Rudenko 2 years to work on. Throughout the project, he had multiple technical bottlenecks such as programming barriers, exams on mortar mixtures failed and more errors related to cement physical properties regarding printing nozzle cloggings. Nevertheless, Rudenko managed to create the layers with various heights and thickness(1).

After finishing with his castle project, Rudenko decided to retool his printer for improved results. In September 2015, he also started a cooperation with the Louis Grand Hotel in Filipino to make it his first project emerging due to its signposting of designing a villa measuring less than 130 square meters using printed objects (Fig. 8) . This project not only included printing the villa's structure, but also a spa bath. Rudenko used additives like sand and volcanic ash in the mixture to not only toughen its structure, but also bond together the layers of concrete being printed (38).

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Fig 8: Rudenko's printed villa in the Philippines (1).

The projects of Rudenko are among the most advanced applications and still fascinate both academic researchers and practitioners in construction industry inspiring a creation new technologies that can change whole future of in-construction process (1).

3.4.5 Contour Crafting (CC)

Sulfur Concrete Company (SCCC) adopted the 3D printing technology named as Contour Crafting(C.C), to develop a method of building sulfur concrete_blocks. Concrete formation without water using this technology. Also, along with its long service life and also high mechanical strength the above method is notable for very good acid resistance as well as salt resistance. This particular application will enable the robot-sulphur concrete extruder pair to compress browsed for material while undergoing changes in behavior and terrain, thus it is also applicable to Mars- or Moon-based environments (1).

In this SCCC process, composite materials of elemental sulfur with additives and coarse and fine aggregates are made to melt at 150 ° C and mixed together in advance. Following the mixing, these were kept in a separate tank for one hour to

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optimize sulfur content. The sulfur concrete is then pumped through a special mixer mounted on the robot, which deposits the concrete with high precision according to a precalculated path (39).

Fig 9 Building a house using 3D Contour Crafting technology (1)**.**

This concrete had a simple curing time of no more than 10 min. After only 24 h, the sulfur concrete structure reached its maximum compressive strength, making it ready to withstand harsh conditions. The printing technology relies on an extrusion system similar to the FDM technology used in 3D printing. The robot features a pivoting trowel that smoothens the sides of the structure during printing, enabling the production of structures with smooth curved surfaces without the need for additional finishing processes to improve the aesthetic appearance, as is the case with traditional systems such as Winsun and Andrey Rudenko (40,41).

On the other hand, the Contour Crafting (CC) system has the unique advantage of integrating cement materials with 3D printing technology, enhancing the quality of the output. The company began developing lightweight, portable robotic printers in June 2017, making them more effective and efficient than traditional technologies (1). What makes CC even more unique is its drive to automate the entire process to speed up construction and minimize costs. Unlike the traditional approach, which requires assembling a house in parts, Contour Crafting prints directly on-site through layers of cement, eliminating the need for additional processes, significantly improving construction efficiency, and reducing costs.

3.4.6 Apis Cor (Russian company)

In 2017, the Russian company Apis Cor achieved a major breakthrough in the field of 3D printing. The company successfully built the world's first 3D-printed house, built directly onsite. Located in the city of Stupino near Moscow, Russia, the house measures 38 square meters (1). The on-site design of the house demonstrates the great flexibility offered by 3D printing technology in construction. During the construction process, the company used a tent to protect the print from low temperatures, which could affect the quality of the process(42).

One notable feature of this project is that the printing and finishing processes were completed in only one day, including both interior and exterior finishes. The total project cost was $10,134, approximately $275 per m^2 (1).

Apis Cor is a pioneer in this field, but research and development of 3D printing technologies for construction is ongoing. There is no clear winner at this stage of development, as assessing the future direction of technology depends on further research into materials and structural forms. Therefore, it is essential that researchers continue to test advanced 3D printing technologies to determine the most appropriate methods and approaches that will determine the future of this technology in the construction sector (43,44).

3.5 Advantages of using 3D printing technology in design and construction

3D printing in construction (3DCP) is one of the most significant technological developments in the construction industry. This kind of technology has the ability to not only improve construction, but also make it more innovative and less expensive (45). Here is an in-depth explanation of the benefits this technology provides and how they affect construction.

- **Simplifying the process**: 3D printing is an alternative production method, as it does not require significant investment in resources, unlike traditional molds. Thus, there is no longer a need to create a mold. The component can be printed directly from a digital model, which is more cost-effective and less polluting to the environment. This method gives designers great flexibility, enhances their ability to innovate, speeds up the production process, and reduces the costs associated with mold manufacturing (46).
- **Material waste:** 3D printing it is principally material efficient. Only materials are used when necessary, so that waste is greatly reduced. Earlier methods could be wasteful, but with 3D printers a lot of this waste is minimized. This increase in material efficiency helps to maintain environmental sustainability as it reduces waste and can vastly reduce material costs (47).
- **Rapid manufacturing at a cost-effective rate**:3D printing is known as one of the quickest ways to manufacture components, while doing so within cheaper price points compared with traditional means. The printer can complete an entire model very quickly because it continuously prints. This

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advantage cuts costs of both labor and materials from most to all areas of its fluctuating variable (48).

- **Complex architectural designs**: 3D printing is allowing for precedent-defying design where otherwise it would be difficult to achieve using traditional techniques. Enabled by complex, curved shapes and fine details designers can conceive structures beyond those with conventional manufacturing capability. For architectural design, it allows new possibilities and the implementation of original ideas (46).
- **Saving labor costs**: This is an automatic technology so we do not have to pay for humans career. Digital processes have cut manual intervention to a minimum. Therefore workforce cost is minimized, errors are reduced and work accuracy raised (50).
- **Sustainability and Recyclability**: One of the many benefits 3D printing offers is sustainability. This is achieved by recovering and recycling used materials to avoid waste which increases the resource efficiency. This allows 3D printing to act as a sustainable option for cutting down the carbon footprint of building processes (51).
- **Intra-site printing**: implies saving on heavy tools and equipment. This simplifies the transport of heavy equipment to the construction site and eliminates logistical costs. In addition, it minimizes the requirement of big storages for equipment which contributes to optimizing construction works (45).
- **High Quality and Precision Manufacturing**: Displacing traditional moldings, 3D printing offers as a better method of manufacturing in terms of quality & precision. Accurate parts can be obtained to the nearest feature

before post-processing is necessary. This high-quality resolution with machine precision makes 3D printing a popular choice for many of the projects mandated manufacturing to be precise(38).

- **Impact on the design process**: As 3D printing uses sliced CAD data, it helps designers to validate their designs quickly and cost- effectively while enabling instant changes or enhancements based on initial testing of print result. By doing so, it allows designers to innovate and lowers the risks they run as well as the costs of late changes. This allows designers to keep testing and refining new ideas iteratively, without having to wait for the traditional manufacturing process (1).
- **Encourages innovation in design**: 3D printing eliminates the historical boundaries between product designers and manufacturers to stimulate innovative thinking. This means that designers can apply new ideas to their craziest designs and experiments, having in mind a result without the technical limitations of traditional methods. Enabling designers to provide new solutions and interact with the forefront of design trends (45).

3.6 Disadvantages of using 3D printing technology in construction

3D printing technology has several challenges. However, they must be considered before its use in the industry.

- **Specialized and complicated equipment, Additional precautions:** The process of 3D printing in the construction industry will always need special machines. The equipment tends to be expensive and has to be maintained regularly in order for it work correctly. In addition, special safety measures must be taken for this type of 3D printing to prevent the area around each construction site from being soiled with dust and hazardous materials that are emitted during printing. preparing digital components and ensuring their readiness for printing requires specialized knowledge of software and digital engineering, which complicates the implementation process (52).

- **Initial cost:** 3D printing initial cost may be even larger than traditional construction methods These costs include the purchase of equipment for printing parts in 3D and training technical staff; Additionally, this process necessitates the development of a digital model that can be expensive and time consuming (66)
- **Materials limitations:** While up to now, 3D printers only print in a select few materials which can restrict total adoption for sure tasks. Researchers are working to develop printers that can work with more cost-effective and eco-friendly materials, but the problem persists. Some of the materials which are available may not perform on budget or work as required to fulfill needs of a given project, therefore limiting applicability across different styles and ways these modular homes can be constructed(7).
- **Size and site adaptation challenges**: 3D printers are large, making it hard to place them at construction sites. These can actually be inapplicable for the limited space project such as homes. This is a challenging problem to solve and requires intricate logistical solutions across multiple settings for optimal technology utilization (54).
- Tech Issues: Factors like equipment errors and print quality come under this scenario as 3D Printers do face technical issues. One of the problems that malfunction makes is reducing quality final product. This includes project

delays or rework, which increases both the cost and time it takes for a project (55).

- **Artistic and hand-craft skill losses**: 3D printing is a strong tool, but lacks the human-creative aspect as given by an artisan. An absolute dependence on technology can also lead to the elimination of an artistic and craftsmanship soul that adds value & humanity in a project (56).
- **Economic implications:** The emergence of 3D printing technology may bring economic complications to many traditional sectors, such as fewer demands on conventional products and services reduced labor demand high unemployment rates local economies weakened (57).
- **The need for continuous development:** 3D printing technology for construction remains in a state of continuous development. To address current challenges, continued investments in research and development are required to improve the ability to use diverse materials, speed up printing, and reduce costs. Therefore, the lack of progress in these areas could hinder wider acceptance of technology in the construction industry (45).

Based on the above, despite the significant advantages offered by 3D printing, this technology faces significant challenges that require attention and innovative solutions to ensure its maximum benefits in the construction sector.

4. Discussion

One of the most significant construction industry technological innovations is 3D printing technology (1). In the precursor, This technology plays an essential role which helps to bring a substantial change in this domain (6). The study showed that the technology could increase efficiency, lower costs and enhance sustainability in construction. From a view of various global experiences, it is evident that 3D printing it's not merely an innovative construction tool and rather another cornerstone for a sustainable impact (32, 36).With practical applications such as printing environmentally friendly buildings (36), wastage minimization (47) speed, efficiency etc. thereby aiding a complete transformation for better future perspectives with considerations to sustainability tags related on the global scale (51). Nevertheless, barriers to diffusion of this technology remain especially in resource-limited settings such as initial costs (53) and logistical challenges (52).

5. Conclusion and Recommendations

The study coins the many advantages of 3D printing for construction. This technology has remarkable benefits, such as increased design accuracy over traditional construction methods and a decrease in cost and time of construction. Experiments have additionally shown how 3D printing supplies creative answers to well-worn building issues. For example; the prospective of fast and precise producing concerning complicated components (in a way which is more reliable, since less time will be spared correcting accidental yet basic measurement errors). In addition, the study found that 3D printing resulted in massive cost reductions by requiring fewer materials and making construction processes faster without labour. Therefore, some companies have managed to construct small homes faster than 24 hours by reducing the costs of labor and materials. For sustainability and wastage reduction: 3D printing leads to a more sustainable use of resources as well as energy efficiency. Data such as Winsun company has shown that the application of sustainable and insulating / isolating materials decreased natural resource consumption providing energy-efficiency. Moreover, though the prospects are as

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such glittering there still remain several barriers on route for a larger scale adoption of 3D printing in construction industry and especially the developing countries. The major challenges are the high initial costs, scarcity of technical expertise and infrastructure to help a large-scale deployment.

Based on preceding research, the current study suggests that further studies be undertaken to increase efficiency of printers, lower costs and develop new eco-friendly materials in 3D printing area. The goal is to widen the scope of technology adoption both within developing and developed countries. Encouraging industries as much towards adoption 3D printing technologies through creating financial benefits and exemptions; In addition, governments should work to ensure that vital infrastructure is developed in order for this technology to be applied more widely within the construction industry. In addition, it is necessary to train those working in developing countries towards such capacity building as many companies lack the technical knowhow which will help deploy 3D printing. There exist opportunities to enhance such programs, which may help build employee skills and increase their employment on construction jobs. Furthermore, the cooperation between international companies, research institutions and governments should be strengthened to accelerate the use of this technology in construction by improving knowledge transfer and utilization.

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Non

Ethical Approval

The authors declare the research did not involve human or animal experiments.

Competing interests

I declare that I have no significant competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript

Availability of data and materials

Data included in article. Material/referenced in the article

References

1. Ghanem, Omar Abdel Fattah, Sara Fathy Ahmed Fahmy, Farida Abdel Rahim El-Hawary. The Role of Interior Design of 3D-Printed Buildings in Environmental Preservation, 2023; 10(3): 139-160. doi: 10.21608/maut.2023.307234

2. Difallah, Mohammed. Impact of Construction, Addition, and Simulation Technologies on Interior and Furniture Design (Scanning, 3D Printing). Journal of Architecture, Arts, and Humanities, 2018; 3(11): 578-597. doi: 10.12816/0046905

3. Korpela M, Riikonen N, Piili H, Salminen A, Nyrhilä O. Additive Manufacturing—Past, Present, and the Future. In: Collan M, Michelsen KE, editors. Technical, Economic and Societal Effects of Manufacturing 40 [Internet]. Cham: Springer International Publishing; 2020. p. 17–41. https://link.springer.com/10.1007/978-3-030-46103-4_2

4. Provaggi E, Kalaskar D. 3D printing families: Laser, powder, nozzle based techniques. In: 3D Printing in Medicine. Springer Cham; 2017. p. 21–42.

5. Chong S, Pan GT, Chin J, Show PL, Yang TCK, Huang CM. Integration of 3D Printing and Industry 4.0 into Engineering Teaching. Sustainability. 2018;10(11):1-13. doi: 10.3390/su10113960.

6. Ngo TD, Kashani A, Imbalzano G, Nguyen KTQ, Hui D. Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. Composites Part B: Engineering. 2018 Jun 15; 143:172–96.doi: 10.1016/j.compositesb.2018.02.012.

7. Dubai Future Foundation. Dubai Future Foundation. 2016. Dubai 3D Printing Strategy Launched as the First Initiative of Its Kind in the World.: https://www.dubaifuture.ae/ar/insights/dubai-3d-printing-strategy-launched-as-the-first-initiative-of-its-kind-in-the-world/.

8. Chandler DL. 3-D printing offers new approach to making buildings [Internet]. MIT News; 2017: https://news.mit.edu/2017/3-d-printing-buildings-0426.

9. Leach N, Carlson A, Khoshnevis B, Thangavelu M. Robotic Construction by Contour Crafting: The Case of Lunar Construction. International Journal of Architectural Computing. 2012 Sep 1;10(3):423–38.

10. Burry J, Sabin J, Sheil B, Skavara Fabricate 2020: Making Resilient Architecture. 2020. DOI: 10.2307/j.ctv13xpsvw

11. McMillin ACGR. Innovative Material Production in Post-Industrial Urban Economies: The Case of 3D Printing Technology in London: University College London; 2023.

12. Waqar A, Othman I, Almujibah HR, Sajjad M, Deifalla A, Shafiq N, et al. Overcoming implementation barriers in 3D printing for gaining positive influence considering PEST environment. Ain Shams Engineering Journal. 2024;15(3):1-15. doi: 10.1016/j.asej.2023.102517.

13. Choi H, Yu M. A Study on Educational Utilization of 3D Printing: Creative Design Model-based Class. JKAIE. 2015 Jun 30;19(1):167–174. doi: 10.14352/jkaie.2015.19.2.167.

14. Noorani R. 3D printing: Technology, applications, and selection. 1st ed. 3D Printing: Technology, Applications, and Selection. CRC Press Taylor & Francis; 2017.

15. Fawzy Ahmed, Rasha, and Dasouki Abdel Mawgoud, Ibrahim. An Applied Study of the Design and Implementation of a 3D Ceramic Printer. South Valley University International Journal of Educational Sciences, 2023; 6(11): 211-250. doi: 10.21608/musi.2023.330547.

16. Abdullah, Ibrahim Amin. 3D Printing: Its Applications and Educational and Technological Impact. International Journal of Online Education. 2016; 263–274. doi: 10.32570/ijofe.851257.

17. Izdebska-Podsiadły J. History of the development of additive polymer technologies. In: Polymers for 3D Printing Methods, Properties, and Characteristics. William Andrew; 2022: 3–11. doi: 10.1016/B978-0-12-818311-3.00007-0.

18. Safi El-Din, Ahmed. 3D Printing and Its Impact on Interior Designers and the Interior Design Process. Journal of Architecture, Arts, and Humanities, 2018; 3(11): 44-58. doi: 10.12816/004687.

19. Joseph TM, Kallingal A, Suresh AM, Mahapatra DK, Hasanin MS, Haponiuk J, et al. 3D printing of polylactic acid: recent advances and opportunities. The International Journal of Advanced Manufacturing Technology. 2023;125(3):1015–1035. doi: 10.1007/s00170-022-10795-y

20. Selvamani S, Mahendran S, Subramaniam S, Ngui W, Kadirgama K, Ganesan K, et al. 3D printing: Overview of ABS evolvement. In: AIP Conference Proceeding. Kuantan, Malaysia; 2019. doi: 10.1063/1.5085984.

21. Rodríguez-Reyna SL, Mata C, Díaz Aguilera JH, Acevedo-Parra HR, Tapia F. Mechanical properties optimization for PLA, ABS and Nylon + CF manufactured by 3D FDM printing. Materials Today Communications. 2022;33(1):1-13. doi:10.1016/j.mtcomm.2022.104774

22. Gregor-Svetec D. Polymers in printing filaments. In: Polymers for 3D Printing. William Andrew; 2022:155–269. doi: 10.1016/B978-0-12-818311-3.00002-1.

23. Rosa R, Rosace G. Nanomaterials for 3D Printing of Polymers via Stereolithography: Concept, Technologies, and Applications. Macromolecular Materials and Engineering. 2021;306(10):1-19. doi:10.1002/mame.202100345.

24. Marchment T, Sanjayan J. Mesh reinforcing method for 3D Concrete Printing. Automation in Construction. 2020;109: 1-12. doi:10.1016/j.autcon.2019.102992.

25. Hamidi F, Aslani F. Additive manufacturing of cementitious composites: Materials, methods, potentials, and challenges. Construction and Building Materials. 2019; 218:582–609.doi: 10.1016/j.conbuildmat.2019.05.140.

26. Paolini A, Kollmannsberger S, Rank E. Additive manufacturing in construction: A review on processes, applications, and digital planning methods. Additive Manufacturing. 2019; 30:1-13. doi: 10.1016/j.addma.2019.100894.

27. Placzek G, Schwerdtner P. Concrete Additive Manufacturing in Construction: Integration Based on Component-Related Fabrication Strategies. Buildings. 2023 Jul 11;13(7):1-30. doi: 10.3390/buildings13071769.

28. Lowke D, Mai I, Keita E, Perrot A, Weger D, Gehlen C, et al. Material-process interactions in particle bed 3D printing and the underlying physics. Cement and Concrete Research. 2022;156:1-16.doi: 10.1016/j.cemconres.2022.106748.

29. Diener S, Zocca A, Günster J. Literature review: Methods for achieving high powder bed densities in ceramic powder bed based additive manufacturing. Open Ceramics. 2021;8:1-16.doi: 10.1016/j.oceram.2021.100191.

30. Knight D. Technology and Operations Management (HBS Digital Initiative). 2018. The CAD Fad: Shanghai-Based Winsun Wants to Print Your Next House: https://d3.harvard.edu/platform-rctom/submission/the-cad-fad-shanghai-based-winsun-wants-to-print-your-next-house/

31. Khan S, Al Rashid A, Muhammad J, Ali F, Koc M. 3D Printing Technology for Rapid Response to Climate Change: Challenges and Emergency Needs. Intelligent and Sustainable Manufacturing. 2024;1(1):1-18. doi:10.35534/ism.2024.10004

32. Rogers H, Srivastava M, Tsakou ME, Prashad A. Sustainable supply chain models for 3D printed houses. Supply Chain Forum: An International Journal. 2024:1–16. doi: 10.1080/16258312.2023.2298186.

33. Molitch-Hou M. Engineering.com. 2024. 400 Square Meter Villa 3D Printed Onsite in Just 45 Days. https://www.engineering.com/400-square-meter-villa-3d-printed-onsite-in-just-45-days/.

34. Ghaffar S, Corker J, Mullett P. The potential for additive manufacturing to transform the construction industry. In: Construction 40. Routledge; 2020: 155–87 .doi: 10.1201/9780429398100-9

35. Alawneh M, Matarneh M, El-Ashri S. THE WORLD'S FIRST 3D–PRINTED OFFICE BUILDING IN DUBAI. In Dubai, United Arab Emirates; 2018. http://www.econstruct.ae/.

36. Ibrahim I, Eltarabishi F, Abdalla H, Abdallah M. 3D Printing in Sustainable Buildings: Systematic Review and Applications in the United Arab Emirates. Buildings. 2022 Oct 16;12(10):1-19. doi: 10.3390/buildings12101703.

37. Kamal M. Analyzing the Competency of 3D Printing Technology in Architectural, Interior and Product Design. Ter-Martirosyan A, Bazarov D, editors. E3S Web of Conf. 2023;410: 1-14. doi: 10.1051/e3sconf/202341004014

38. Tuli NT, Khatun S, Rashid AB. Unlocking the future of precision manufacturing: A comprehensive exploration of 3D printing with fiber-reinforced composites in aerospace, automotive, medical, and consumer industries. Heliyon. 2024;10(5):1-38. doi: 10.1016/j.heliyon.2024.e27328.

39. Sua-Iam G. Utilization of coal- and biomass-fired ash in the production of self-consolidating concrete: A literature review. Journal of Cleaner Production. 2015;100: 59–76. doi: 10.1016/j.jclepro.2015.03.038

40. Makul N. Modern sustainable cement and concrete composites: Review of current status, challenges and guidelines. Sustainable Materials and Technologies. 2020;25: 1-15. doi: 10.1016/j.susmat.2020.e00155

41. Akhnoukh AK. Advantages of Contour Crafting in Construction Applications. ENG. 2021;15(3):294–300. doi: 10.2174/1872212114666200218111631

42. Pasco J, Lei Z, Aranas C. Additive Manufacturing in Off-Site Construction: Review and Future Directions. Buildings. 2022;12(1):1-24. doi: 10.3390/buildings12010053.

43. Bos FP, Menna C, Pradena M, Kreiger E, Da Silva WRL, Rehman AU, et al. The realities of additively manufactured concrete structures in practice. Cement and Concrete Research. 2022;156: 1-14.doi: 10.1016/j.cemconres.2022.106746.

44. Pessoa S, Guimarães AS, Lucas SS, Simões N. 3D printing in the construction industry - A systematic review of the thermal performance in buildings. Renewable and Sustainable Energy Reviews. 2021; 141:1-13. doi: 10.1016/j.rser.2021.110794

45. Wu P, Wang J, Wang X. A critical review of the use of 3-D printing in the construction industry. Automation in Construction. 2016; 68:21–31. doi: 10.1016/j.autcon.2016.04.005.

46. El-Sayegh S, Romdhane L, Manjikian S. A critical review of 3D printing in construction: benefits, challenges, and risks. ArchivCivMechEng. 2020;20(2):34. doi: 10.1007/s43452-020-00038-w

47. Besklubova S, Skibniewski M, Zhang X. Factors Affecting 3D Printing Technology Adaptation in Construction. Journal of Construction Engineering and Management. 2021;147(5). doi: 10.1061/(ASCE)CO.1943-7862.0002034.

48. Pan Y, Zhang Y, Zhang D, Song Y. 3D printing in construction: state of the art and applications. Int J Adv Manuf Technol. 2021;115(5):1329–1348. doi: 10.1007/s00170-021-07213-0.

49. Beyhan F, Arslan Selçuk S. 3D Printing in Architecture: One Step Closer to a Sustainable Built Environment. In: Fırat S, Kinuthia J, Abu-Tair A, editors. Proceedings of 3rd International Sustainable Buildings Symposium. Cham: Springer International Publishing; 2018. p. 253–268. (Lecture Notes in Civil Engineering; vol. 6): http://link.springer.com/10.1007/978-3-319-63709-9_20

50. Laplume AO, Petersen B, Pearce JM. Global value chains from a 3D printing perspective. J Int Bus Stud. 2016;47(5):595–609. doi: 10.1057/jibs.2015.47

51. Pakkanen J, Manfredi D, Minetola P, Iuliano L. About the Use of Recycled or Biodegradable Filaments for Sustainability of 3D Printing. In: Campana G, Howlett RJ, Setchi R, Cimatti B, editors. Sustainable Design and Manufacturing. Cham: Springer International Publishing; 2017. p. 776–85. (Smart Innovation, Systems and Technologies; vol. 68): http://link.springer.com/10.1007/978-3-319-57078-5_73

52. Singh R, Gehlot A, Akram SV, Gupta LR, Jena MK, Prakash C, et al. Cloud Manufacturing, Internet of Things-Assisted Manufacturing and 3D Printing

Technology: Reliable Tools for Sustainable Construction. Sustainability. 2021;13(13):1-20. doi: 10.3390/su13137327.

53. Attaran M. The rise of 3-D printing: The advantages of additive manufacturing over traditional manufacturing. Business Horizons. 2017;60(5):677–688. doi: 10.1016/j.bushor.2017.05.011

54. Mechtcherine V, Nerella VN, Will F, Näther M, Otto J, Krause M. Large-scale digital concrete construction – CONPrint3D concept for on-site, monolithic 3D-printing. Automation in Construction. 2019;107(3):1-16. doi: 10.1016/j.autcon.2019.102933

55. Shahrubudin N, Koshy P, Alipal J, Kadir MHA, Lee TC. Challenges of 3D printing technology for manufacturing biomedical products: A case study of Malaysian manufacturing firms. Heliyon. 2020;6(4):1-14. doi: 10.1016/j.heliyon. 2020.e03734

56. Patokorpi L. “The Art and Craft of the Machine3D Printing, the Arts and Crafts Movement and the Democratization of Art”. University of Tampere .2014.

57. Chan HK, Griffin J, Lim JJ, Zeng F, Chiu ASF. The impact of 3D Printing Technology on the supply chain: Manufacturing and legal perspectives. International Journal of Production Economics. 2018; 205:156–62. doi: 10.1016/j.ijpe.2018.09.009

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