AN OVERVIEW ON THE 3D PRINTING TECHNOLOGY IN CONSTRUCTION INDUSTRY

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Abstract- Innovations have started to emerge in the construction sector with the developing technology. One of these innovations is the utilization of 3-dimensional printing technology. Civil engineers build structures using materials and techniques available in the times. 3D printing technology attracts attention since it is faster than traditional construction, less costly, less labor and less error margin in today. It is possible to produce structures with complex designs and small scaled various products, under favor of this technology. First of all, 3D model design is needed in order to produce structures with 3D printing printers. Optimized cement-based mortar material is used in 3D printing printers. In order to be able to build layers on top of each other without collapse, and to perform 3D printing without shrinkage cracks, a building material recipe should be prepared by obtaining appropriate mixing ratios. While placing the building material, layered production is made without using a mold, and the width and thickness of the printing layer is constantly controlled during placement. Attention is paid to the use of sustainable building materials in buildings built using this technology. In addition, studies are carried out for zero waste in the use of materials. In this study, it is aimed to briefly introduce this new generation method along with its benefits, shortcoming and possible use as future of construction industry after eliminating these shortcomings.

Keywords- 3D printing, Cementitious material, Construction automation, Digital construction, Sustainability.

1 Introduction

Industries have begun to re-establish their production systems with the developing technology. 3D printing technology has also been improving of late years, along with additive manufacturing. 3D printing technologies enable design optimization and have advantages over traditional manufacturing methods. It is necessary to keep up with the new age in order to survive in the variable sector with the increase in the competitive environment. The construction industry is also under the pressure of change due to technological developments. Therefore, it is attracting great attention in the construction industry as a new strategic challenge [1]. The application of 3D printers has taken its place in the field of engineering, especially in the field of medicine and automotive. There have been developments in additive production technology in layers with cement and various materials. This technology has emerged as a joint product of materials science, robotic coding and architectural design studies, using the advantages of shotcrete and self-compacting concrete. In this type of printing, the ability to pump, workability and construct of fresh concrete and the strength of hardened concrete are of great importance [2][3]. Rheological properties such as viscosity and yield stress are also considered critical properties to control the printable property of printer concrete. The lack of a certain standard in the mixture design and the insufficient number of studies affect these properties negatively [4]. Ultra-high strength concrete was also developed by [5] and it was revealed that the concrete samples printed by 3D printing technology provided high toughness than conventional method. A few researchers have also developed ways to print foam concrete by the 3D printing technology for various civil engineering applications. The type of concrete was found as sustainable and lightweight. This foam concrete developed by those researchers is applicable where the weight of structure matters [6]. The main purpose of this paper is to briefly review 3D printing technology and its applications in the construction industry. The studies discuss the future of 3D printing technology in the field of construction and suggestions are made for possible uses in the construction industry.

2 3D Printing Technology

Traditional manufacturing methods are based on the principle of subtracting material from the raw material during the manufacture of parts. In additive manufacturing, which is one of the new production techniques that has become widespread today, unlike traditional manufacturing methods based on material reduction techniques from the part, the part is produced directly from the material. The device used in manufacturing manufactures the part layer by layer by following a tool path derived from the geometry of the part to be produced. It is possible to produce parts with complex geometries and the loss of material during manufacturing is at a minimum level due to this unique feature of additive manufacturing [7]. The foundations of the additive manufacturing method date back to the 1980s. It is known that the SLA-1 device produced by the 3D System company is the first 3D printer system [8]. Additive manufacturing is one of the modern manufacturing methods that has gained importance in recent years. It is a form of manufacturing in which the 3D model is obtained by adding layer by layer the powders to be built using geometric data. With additive manufacturing methods, parts with complex geometry can be obtained quickly [9]. The 3D manufacturing process is divided into subclasses such as SLA (Stereolithography), SLS (Selective Laser Sintering), FDM (Fused Deposition Modelling), DLP (Digital Light Processing), EBM (Electron Beam Melting) and LOM (Laminated Object Manufacturing) according to the materials used and the principle of combining materials. Table 1 shows a comparison of some additive manufacturing methods [10].

Table 1 Comparison of additive manufacturing methods [11]

Method	FDM	SLA	SLS	EBM	LOM
Working principle	Extrusion Stacking Technique	Solidification of photopolymer material with UV light	Sintering of powder with CO2 laser	Electron Beam Melting	Laser Cutting and Gluing of Sheets
Material used	ABS, polyamide, polycarbonate, polyethylene, polypropylene and investment casting wax.	Resin-based materials, acrylic epoxy, polypropylene.	Polyamide, polystyrene, carbon fiber and Aluminum added polyamide, polycarbonate, stainless steel, cobalt chrome, nickel chrome, titanium, ceramic.	Cobalt chrome and titanium alloys, ceramics.	Paper, plastic foam, metal and ceramic powder impregnated materials.
Resolution	Medium	Good	Weak	Weak	Medium
Strength	Good	Medium	Good	Good	Medium
Roughness	Medium	Good	Weak	Good	Medium

3D printing technology, which has caused changes by breaking new ground in diverse sectors, has moreover affected the construction sector. Building production in construction contains of significant stages like design, projecting and implementation. With the improvement of innovation, digital manufacturing has been used for a long time in the design and projecting phase of buildings. The design and projection of the building is supported two-dimensional (2D) drawings and scale models. Today, 2D drawings and prototypes are replaced by three-dimensional (3D) modelling techniques. Designers, architects and engineers have had the advantage of making the necessary changes in their projects easily, seeing the problems that may arise before the implementation and making the changes that occur in unforeseen situations during the implementation phase with digital modelling methods. The implementation phase of building production, on the other hand, did not change as fast as the design process and remained dependent on the traditional method of building production.

İn the last years, the interest in 3D printing technology has increased because of the act that it provides design freedom, less error margin, less material wastage, less waste material, and reduced cost compared to the traditional method in the

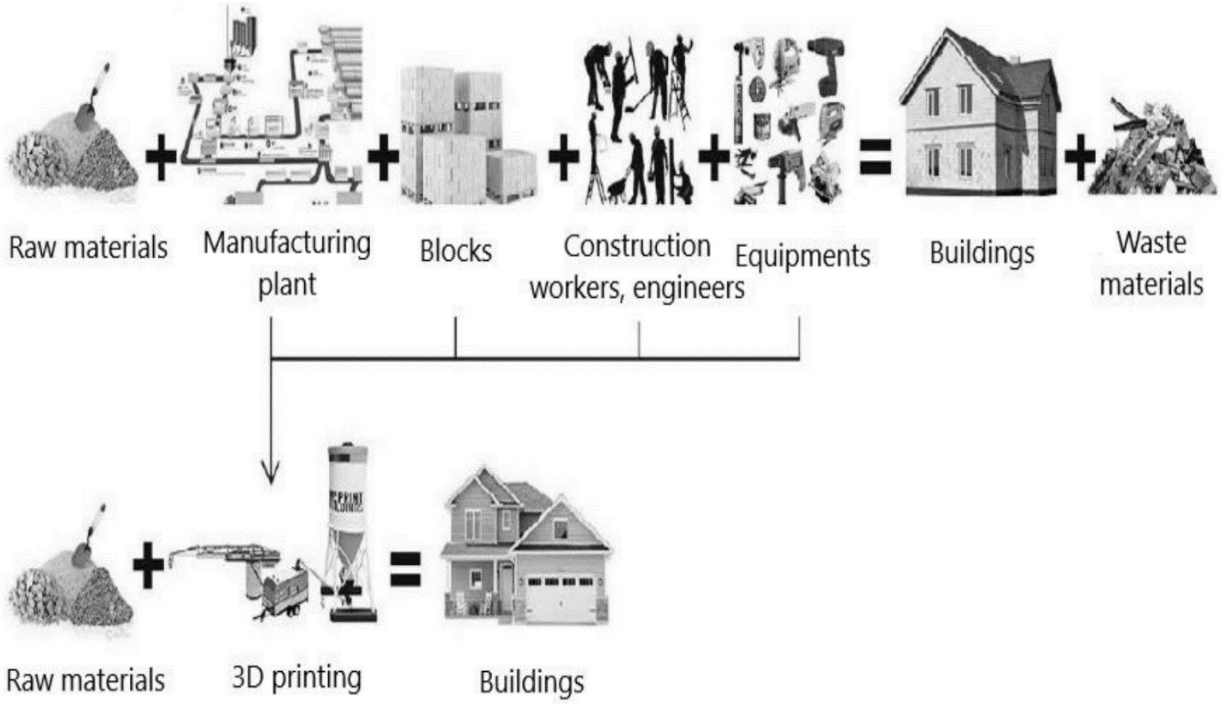

Figure 1: Comparison diagram of 3D printing automated building production with the traditional method [11]

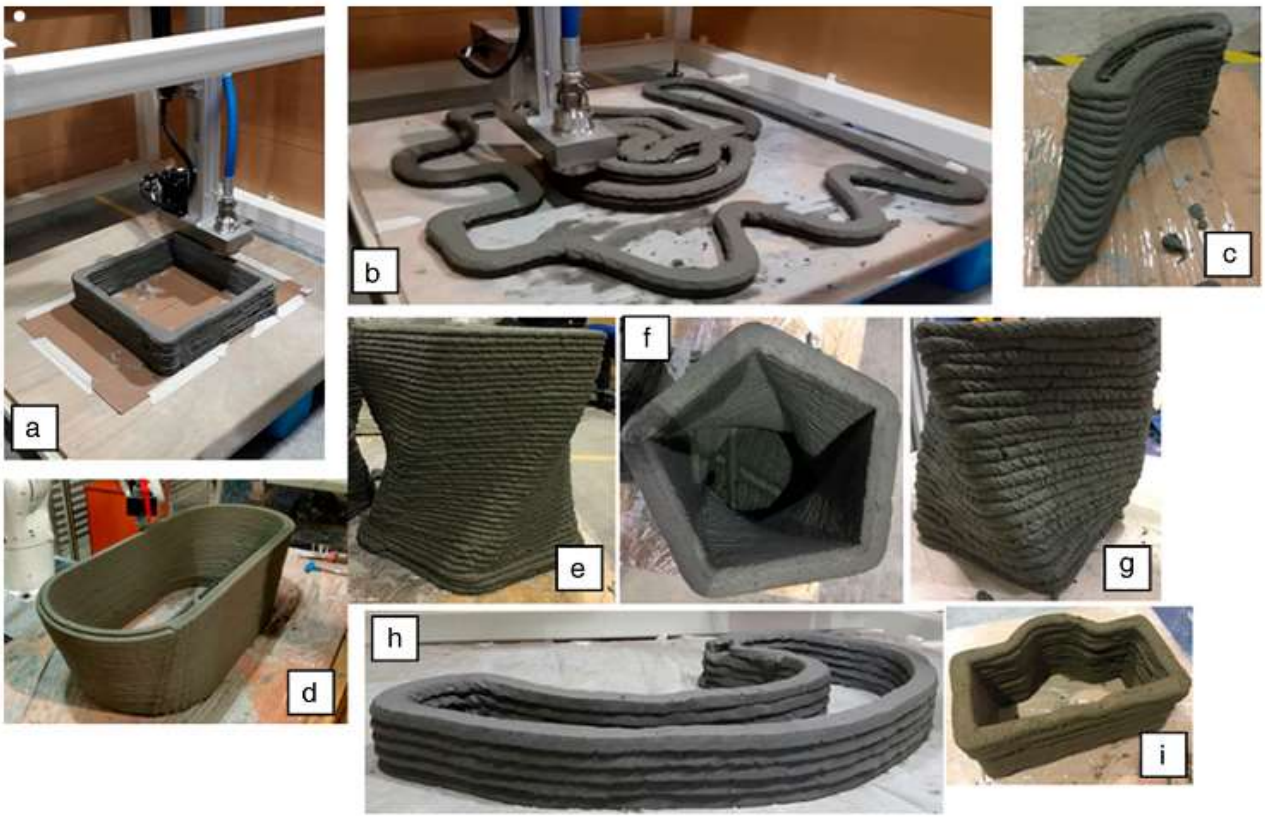

Figure 2: 3D concrete printed objects at SC3DP (prototype) [12]

construction industry [11]. Figure 1 shows the comparison of 3D printing and conventional methos whereas figure 2 shows the 3D concrete printed objects. A Chinese construction company produced 2 buildings with 3D Printer. Recycled concrete was used to produce the structures with a 3D Printer. After the 1100 m2 building was produced in the factory, it was moved to the place where the building will be installed to be combined. A 3D Printer cement-like material is used to produce parts with a length of 32 m, a width of 10 m and a height of 6 m. This proprietary material includes fiberglass, concrete powder, sand and hardening material. It is also stated that it is a very earthquake proof material [13]. This 3D printed building is shown in figure 3. There are many restrictions which are imposed by material processing constraints but on the other hand progress of 3D printing study is quite rapid. Due this phenomenon the additive manufacturing technology's potential can be fully utilized [14]. Biomimicry and bio-inspiration provides the background for the making new structures and low consumption of materials at same time so, this idea is critical. However, these techniques provide high sustainability and better mechanical qualities [15]. The primary importance is the evaluation of printing techniques and about thirty 3DCP initiatives has been taken around the globe. In 3DCP, by the use of material stacking deposition, target components are formed. The precision of extrusion control is a major concern during extrusion quality control [16]. In this regard, the use of real-time feedback control is a workable option. Real-time control systems have been developed by the researchers that not only controls the motions of robot arm use in 3D printing but also monitors the extrusion parameters. Conventional building techniques cause high accidents and rates of injuries are also countless while traditional techniques of building are connected with higher prices, lower efficiency and labor resilience [17].

(a) Connection details of the 3-D printed villa (b) The concrete mould printed

Figure 3 (a & b): 3D printing production by WinSun [18]

3 Usability of 3D Printing Technology

Kazemian et al. (2017) carried out several experiments on the workability, printing accuracy and durability, and ease of printing of cementitious printing mixtures. In the experimental results, it was observed that the use of silica fume and Nano-clay for four types of mixtures increased the stability of the printing mixtures considerably [19]. Hojati et al. (2018) investigated the physical and mechanical properties of 3D printer concrete. The rheological properties of the mixture were considered in the design of the appropriate printhead. In addition, the length of the fiber to be included in the mixture in accordance with the diameter of the print head was investigated in the relationship between the interlayer bonding. The 3D printer machine consists of a fixed pump with a 15 mm diameter printer head and a 6-axis robotic arm that can provide various movements in different axes so that the material can be extruded properly. Consequently, it was defined that the hardening speed of the material should be adjusted well for printing and the width of the 3D printer head should be compatible with the fiber to be used, otherwise it is possible to clog the pump during the extruding process. In addition, it was concluded that attention should be paid to the ability of the material to carry the layer that will come on top of the layers [20]. Xia et al. (2019) developed geopolymer binder materials using only slag mixtures for use in powder-based 3D printers. With the research, geopolymer materials that can be used in powder-based 3D printers have been expanded with

mixtures of fly ash and slag. The effect of the amount of fly ash on the 3D printability properties of the geopolymer mixture and its compressive strength were investigated. As a result of the research, it was observed that the increase in the amount of fly ash did not affect the mixture settleability, but negatively affected the wettability and compressive strength of the mixture. It was determined that the best mixture was the samples containing 50% slag and 50% fly ash [21].

Arunothayan et al. (2020) have conducted research to produce ultra-high-performance fiber reinforced concrete with a 3D printer. Fiber less and 2% fiber reinforced UYPFRB was fabricated by 3D printer and compared with standard manufactured UYPFRB. As a result of the experimental study, the printability and shape stability of the UHPFRC were adequately provided. However, the compressive strength of the one poured into the normal mold was higher [22]. Marchment and Sanjayan (2020) discussed the problems affecting interlayer adherence, which has become one of the disadvantages of 3D printer concrete. They stated that the printing material should be fluid for the pumping process, but the mixture recipe created should not decrease the strength while affecting the consistency [23]. Ma et al. (2020) investigated the inadequacy of compatibility between adhering layers, which is one of the biggest problems of 3D printer concrete in the construction industry. A new cement mortar with additives was developed and cellulose fiber was used. When the mixture used is pumped, the amount of moisture on the surface of the printed layers is at the maximum level. Cellulose fiber retained excess water on the surface and contributed as an internal curing agent. Small amounts of clay and superplasticizer additives are used to optimize the rheological properties. Silica fume was used to improve water retention, silica powder was used to increase material density and fill micropores. According to the SEM results, the compatibility between the layers was significantly improved [24].

4 Comparison of Benefits and Shortcomings for Use of 3D Printing

About 8% of the world anthropogenic CO_2 is produced by cement industry. The 3DCP places the concrete in a precise manner so the consumption of material is reduced by 3DCP [25]. 3DCP has also many positive characteristics like sustainable building materials can be used, save money time and energy. It also lowers the pollution caused by construction without compromising in mechanical properties of concrete. Also, majority of 3DCP is extrusion-based [26]. On the other hand, the idea of digital concrete is quite wide and surrounds the different types of methods which have potential to create bio-based structures. 3D printing formwork was investigated in both in-situ and prefabricated by [27]. 3DP concrete reinforcement building formworks are well defined as compared to the reinforcement construction of 3DPC on-site and its components. The transportation and preparation of concrete, casting of concrete, formwork's printing in factory, transportation of elements and assembly with is use as in-situ assembly are all components of prefabricated 3D printing formwork [28]. The workability of concrete plays a vital role in fresh and hardened properties of concrete [29], [30]. A good workable mix is desired for 3D printing so that desired mechanical properties may achieve. There is need of time research out 3DCP technologies so that it may transfer from laboratory testing phase to real life. No doubt, sand is a natural resource but with the passage of time is becoming limited in many areas; a number of nations are running out of this for utilization in civil engineering applications. By 3D printing recycled aggregates can be used a sustainable construction material. The preparation of mix for 3D printing requires special admixtures for maintaining workability so it takes extra economy. There is need to mitigate these shortcomings to use 3D printing in civil engineering construction industry.

5 Conclusion

In this paper 3D printing technology and usability of 3D printing are described by the state-of-the-art review. The comparison of its shortcoming and benefits along with its possible use in future is briefly discussed. Based upon this study following conclusions have been made:

1. 3D printing is a technique that can be predicted to be used in the construction industry and can provide economic and environmental advantages. The use of this technique depends on the accuracy of printing, printing material, cost and time.
2. The use of 3D printing is dependent on conditions such as usability in large construction, development of building information modelling, production diversity and life cycle cost.
3. This technique will be used at the highest level once these conditions have been successfully overcome. Powder bed fusion (PBF) and directed energy deposition (DED) methods are the most suitable 3D printing techniques to

be used in the construction industry. These methods allow proper fabrication of the structure, but are constrained by cost, time, and maximum element size.

4. The transportation of robot arm, repairing, specific usage of admixtures makes it costly process so it increased the overall cost of the project.
5. Due to higher cost of operation and mixing of materials, it is not recommended on large scale use.

It is suggested to find new ways to make 3D printing economical process as sustainable construction can be performed by 3D printing as it requires less man power and provides greater efficiency.

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References

[1] İ. E. Öztürk and G. B. Öztürk, "The Future of 3D Printing Technology in the Construction Industry: a Systematic Literature Review," *Eurasian J. Civ. Eng. Archit.*, vol. 2, no. 2, pp. 10–24, 2018, Accessed: Jun. 24, 2022. [Online]. Available: https://dergipark.org.tr/en/pub/ejcar/issue/39134/434066

[2] Z. Wu, A. M. Memari, and J. P. Duarte, "State of the Art Review of Reinforcement Strategies and Technologies for 3D Printing of Concrete," *Energies*, vol. 15, no. 1. 2022. doi: 10.3390/en15010360.

[3] C. Liu *et al.*, "Effect of sulphoaluminate cement on fresh and hardened properties of 3D printing foamed concrete," *Compos. Part B Eng.*, vol. 232, 2022, doi: 10.1016/j.compositesb.2022.109619.

[4] H. G. Şahin and A. Mardani-Aghabaglou, "Assessment of materials, design parameters and some properties of 3D printing concrete mixtures; a state-of-the-art review," *Construction and Building Materials*, vol. 316. 2022. doi: 10.1016/j.conbuildmat.2021.125865.

[5] Y. Yang, C. Wu, Z. Liu, H. Wang, and Q. Ren, "Mechanical anisotropy of ultra-high performance fibre-reinforced concrete for 3D printing," *Cem. Concr. Compos.*, vol. 125, 2022, doi: 10.1016/j.cemconcomp.2021.104310.

[6] C. Liu *et al.*, "Influence of HPMC and SF on buildability of 3D printing foam concrete: From water state and flocculation point of view," *Compos. Part B Eng.*, 2022, Accessed: Jun. 27, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1359836822004516

[7] A. Lou and C. Grosvenor, "Selective laser sintering, birth of an industry," *Dep. Mech. Eng. Univ. Texas, Austin, TX*, vol. 8, 2012.

[8] D. Bourell *et al.*, "Materials for additive manufacturing," *CIRP Ann. - Manuf. Technol.*, vol. 66, no. 2, pp. 659–681, 2017, doi: 10.1016/j.cirp.2017.05.009.

[9] K. Özsoy and B. Duman, "Eklemeli İmalat (3 Boyutlu Baskı) Teknolojilerinin Eğitimde Kullanılabilirliği," *Int. J. 3D Print. Technol. Digit. Ind.*, vol. 1, no. 1, pp. 36–48, 2017, Accessed: Jun. 24, 2022. [Online]. Available: https://dergipark.org.tr/en/pub/ij3dptdi/issue/33982/376178

[10] I. Celik, F. Karakoc, M. C. Cakir, and A. Duysak, "Rapid Prototyping Technologies and Application Areas," *J. Sci. Technol. Dumlupinar Univ.*, vol. 31, no. 8, pp. 53–70, 2013, Accessed: Jun. 24, 2022. [Online]. Available: https://dergipark.org.tr/en/pub/dpufbed/issue/35926/404617

[11] T. Uygunoğlu *et al.*, "3D TEKNOLOJİSİ İLE YAPI MALZEMESİ ÜRETİMİNDEKİ GELİŞMELER," *Int. J. 3D Print. Technol. Digit. Ind.*, vol. 03, pp. 279–288, 2019, Accessed: Jun. 24, 2022. [Online]. Available: https://dergipark.org.tr/en/pub/ij3dptdi/issue/51591/559782

[12] Y. Wei Daniel Tay, B. Panda, S. Chandra Paul, N. Ahamed Noor Mohamed, M. Jen Tan, and K. Fai Leong, "3D printing trends in building and construction industry: a review," *Taylor Fr.*, vol. 12, no. 3, pp. 261–276, Jul. 2017, doi: 10.1080/17452759.2017.1326724.

[13] "No Title," 2015. http://priyoid.com (accessed Jun. 24, 2022).

[14] C. R. Rollakanti and C. V. S. R. Prasad, "Applications, performance, challenges and current progress of 3D concrete printing technologies as the future of sustainable construction - A state of the art review," *Mater. Today Proc.*, Apr. 2022, doi: 10.1016/j.matpr.2022.03.619.

[15] G. H. Andrew Ting, T. K. Noel Quah, J. H. Lim, Y. W. Daniel Tay, and M. J. Tan, "Extrudable region parametrical study of 3D printable concrete using recycled glass concrete," *J. Build. Eng.*, vol. 50, 2022, doi: 10.1016/j.jobe.2022.104091.

[16] G. S. Lakshmi Devi and P. Srinivasa Rao, "Flexural Behavior of Quaternary Blended Fiber Reinforced Self Compacting Concrete Slabs Using Mineral Admixtures," in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 1006, no. 1. doi: 10.1088/1757-899X/1006/1/012020.

[17] G. S. L. Devi, C. V. S. R. Prasad, and P. S. Rao, "Influence of mineral admixtures on structural behaviour of Quaternary Blended Self Compacting Concrete reinforced beams with addition of crimpled steel fibers," *Mater. Today Proc.*, vol. 57, pp. 2325–2329, 2022, doi: 10.1016/j.matpr.2022.01.125.

[18] P. Wu, J. Wang, and X. Wang, "A critical review of the use of 3-D printing in the construction industry," *Automation in Construction*, vol. 68. pp. 21–31, 2016. doi: 10.1016/j.autcon.2016.04.005.

[19] A. Kazemian, X. Yuan, E. Cochran, and B. Khoshnevis, "Cementitious materials for construction-scale 3D printing: Laboratory testing of fresh printing mixture," *Constr. Build. Mater.*, vol. 145, pp. 639–647, 2017, doi: 10.1016/j.conbuildmat.2017.04.015.

[20] H. Maryam *et al.*, "3D Printing of Concrete: a Continuous Exploration of Mix Design and Printing Process," *42nd IAHS WORLD Congr. Hous. Dign. Mank.*, no. May, pp. 1–14, 2018, Accessed: Jun. 24, 2022. [Online]. Available: https://www.researchgate.net/profile/Maryam-Hojati/publication/325076823_3D_Printing_of_Concrete_a_Continuous_Exploration_of_Mix_Design_and_Printing_Process/links/5af5384c4585157136ca447a/3D-Printing-of-Concrete-a-Continuous-Exploration-of-Mix-Design-and-

[21] M. Xia, B. Nematollahi, and J. Sanjayan, "Printability, accuracy and strength of geopolymer made using powder-based 3D printing for construction applications," *Autom. Constr.*, vol. 101, pp. 179–189, 2019, doi: 10.1016/j.autcon.2019.01.013.

[22] A. R. Arunothayan, B. Nematollahi, R. Ranade, S. H. Bong, and J. Sanjayan, "Development of 3D-printable ultra-high performance fiber-reinforced concrete for digital construction," *Constr. Build. Mater.*, vol. 257, 2020, doi: 10.1016/j.conbuildmat.2020.119546.

[23] T. Marchment and J. Sanjayan, "Penetration Reinforcing Method for 3D Concrete Printing," in *RILEM Bookseries*, vol. 28, 2020, pp. 680–690. doi: 10.1007/978-3-030-49916-7_68.

[24] G. Ma, N. M. Salman, L. Wang, and F. Wang, "A novel additive mortar leveraging internal curing for enhancing interlayer bonding of cementitious composite for 3D printing," *Constr. Build. Mater.*, vol. 244, 2020, doi: 10.1016/j.conbuildmat.2020.118305.

[25] Y. Chen *et al.*, "Mechanical anisotropy evolution of 3D-printed alkali-activated materials with different GGBFS/FA combinations," *J. Build. Eng.*, vol. 50, 2022, doi: 10.1016/j.jobe.2022.104126.

[26] S. Nazar, J. Yang, B. S. Thomas, I. Azim, and S. K. Ur Rehman, "Rheological properties of cementitious composites with and without nano-materials: A comprehensive review," *Journal of Cleaner Production*, vol. 272. 2020. doi: 10.1016/j.jclepro.2020.122701.

[27] G. Cesaretti, E. Dini, X. De Kestelier, V. Colla, and L. Pambaguian, "Building components for an outpost on the Lunar soil by means of a novel 3D printing technology," *Acta Astronaut.*, vol. 93, pp. 430–450, 2014, doi: 10.1016/j.actaastro.2013.07.034.

[28] C. Gosselin, R. Duballet, P. Roux, N. Gaudillière, J. Dirrenberger, and P. Morel, "Large-scale 3D printing of ultra-high performance concrete - a new processing route for architects and builders," *Mater. Des.*, vol. 100, pp. 102–109, 2016, doi: 10.1016/j.matdes.2016.03.097.

[29] M. Abrar, "WORKABILITY OF BANANA FIBERS REINFORCED CONCRETE FOR EASY POURING," *3rd Conf. Sustain. Civ. Eng.*, no. 21, pp. 5–9, 2021.

[30] M. Abrar and M. Ali, "Workability of Concrete Having Hybrid Natural Fibers of Different Lengths for Easy Pouring," pp. 1–6, 2021.