3D Printing in Construction: Benefits and Challenges

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***Abstract*—This paper investigates briefly the different 3D printing systems in construction, their benefits and challenges associated with their use in construction projects. The use of 3D printing technology offers several advantages over the traditional methods. However, additional challenges and risks are faced due to the introduction of this new technology in construction projects. A literature review was performed to identify the benefits of 3D printing. Five key benefits were identified: faster construction, cost reduction, more geometric freedom, sustainability and safety benefits. Eleven challenges were identified and grouped into four categories: material, robot system, design and construction, and regulation and liability. 3D printing is a promising new technology with several key benefits. However, the widespread adoption of the new technology is dependent on addressing its key challenges.**

***Index Terms*—3D printing in construction, benefits, challenges**

I. Introduction

The construction industry has an annual revenue of nearly 10 trillion USD, which represents around 6% of the global GDP. Indeed, the engineering and construction industry is a cornerstone of the world's economy [1]. Construction companies are consistently seeking new means to increase productivity while reducing cost [2]. Studies have shown that over the years, labor productivity in the construction industry has been declining [3]. Lack of implementation of new technology is one cause of this decline [4]. Additive Manufacturing (AM), or more commonly 3D printing, is one of the newest forms of technology that has been introduced in the construction industry. A number of drivers are pushing construction towards automation: lowering labor for safety reasons; reducing construction time on site; reducing production costs; and/or increasing architectural freedom [5]. Additionally, 3D printing helps address sustainability issues. The construction industry has been recognized as one industry that consumes a considerable amount of resources and poses significant environmental stresses [6]. This paper investigates briefly the different 3D printing systems in construction, their benefits and challenges associated with their use in construction projects. The use of 3D printing technology offers several advantages over the traditional methods. However, additional challenges and risks are faced due to the introduction of this new technology in construction projects.

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II. 3D Printing

3D printing is defined as the process of making an object from a three-dimensional model by generating successive stacked thin layers of material [7]. A schematic showing the difference between classical manufacturing (subtractive) and 3D printing or Additive Manufacturing (AM) is shown in Fig. 1. AM is defined by the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO) as 'the process of joining materials to make objects from 3D model data, usually layer upon layer [8].

Different techniques are used for AM. Fig. 2 lists the most common ones used for each process. It is worth mentioning that this classification is based solely on the type of material used in each process. The two techniques related to Additive Manufacturing for Construction (AMC) are the Binder jetting, using a technique called D-Shape, and the molten material system. In this latter, the material used is a concrete mix, which is fed in through the nozzle using a pump.

This paper focuses on the application of 3D printing in construction. Large scale 3D constructions are needed. Experimental application using 3D printing in the construction industry started in the early 1990s [9]. An interesting application of 3D printing in construction is the reproduction of historical building ornamental components [10].

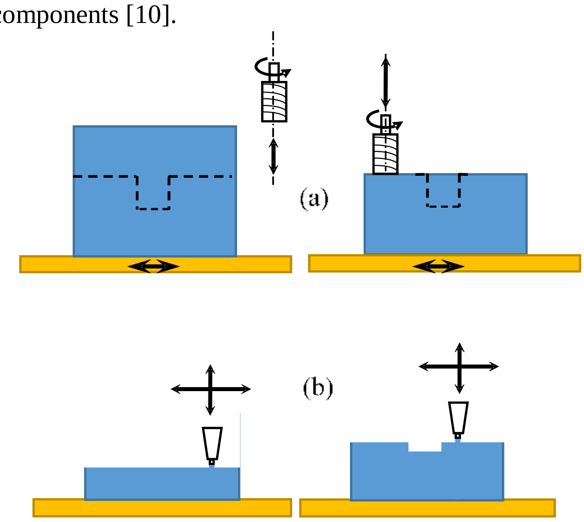

Figure 1. Comparison between (a) classical Subtractive Manufacturing and (b) AM.

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There exist three techniques of 3D printing in construction, i.e., Contour Crafting, D-shape, and Concrete Printing. All these methods use material extrusion through a nozzle to generate the layers.

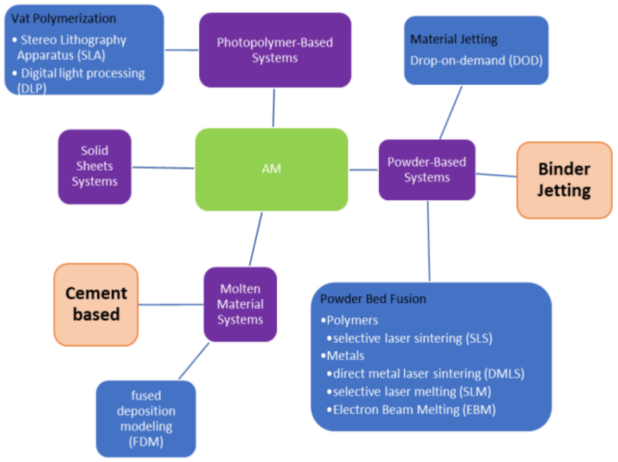

Figure 2. Different types of additive manufacturing.

In recent years, there has been significant improvement in developing large-scale 3-D printers to have a larger workspace, capable of printing industrial-scale 3D buildings. The gantry system (Fig. 3) and the articulated robot systems are the two most common structures used in 3D printing in construction. Gantry system allows Cartesian motions of the nozzle in the three 3 axes (X, Y, Z). The challenges with this technology include transportation, installation and size. The articulated robot structure (Fig. 4) is also used for 3D printing concrete. However, this structure suffers from limited workspace, which makes it unsuitable for large buildings.

Figure 3. Gantry robot structure [11].

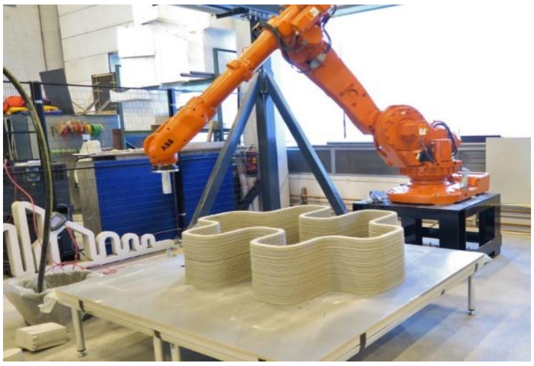

Figure 4. Articulated robot structure [12].

III. Benefits of 3D Printing in Construction

Based on literature review, the main benefits are time, cost, geometric freedom, sustainability and safety. 3D printing allows to reduce the construction time considerably. Faster construction is the most cited benefit of 3D printing [2], [13], [14], [15], [6], [16], [18], [19], [21], and [23]. Reduction of construction cost is also cited as a main benefit [6] [23]. The labor cost of this office, in Dubai, was 60% lower than traditional buildings of the same size [22]. 3D printing also improves productivity which results in cost savings. AM is seen as a way of addressing construction productivity challenges [10]. Using 3D printing technology allows more geometric freedom to design structures that are not otherwise possible. Geometric freedom is often cited as one of the main benefits [14], [15], [6], [16], [7], [18], [19], [21], and [23].

Sustainability is a main benefit of 3D printing. 3D printing allows for the design and construction of eco-friendly structures [6], [16], [17], [19], [21], and [23]. Using 3D printing reduces waste produced during construction [13] and also reduces formwork [10]. The printing process will eliminate unnecessary waste of materials, thus reducing the environmental impacts of the production/construction process [6]. Reducing the use of formwork reduces the amount of wood and therefore trees' use [10]. The new technology also improves safety on construction sites. 3D printing results in safer sites [6], [9], [15], [16], [7], and [18]. 3D printing reduces the number of injuries and fatalities onsite as the printers will be able to do most of the hazardous and dangerous works [6].

IV. Challenges

The challenges are grouped into four categories: material, printer, design and construction, and regulations. Fig. 5 shows the main categories and associated challenges. Based on the literature review, the main challenges are related to the 3D printing material. The material challenges can be summarized in three key challenges: printability, buildability and open time. The material must have the desired printability, to be able to be extruded from the nozzle, and buildability, to be able to maintain its shape [6] [20]. Printability is often cited as the main challenge [6], [11], [15], [6], [17], [7], [18], [19], [20], [21]. It refers to how the material is going to be pumped and printed. Buildability is another key challenge [12], [6], [16], [17], [7], [19], [20], [21], and [24]. The material has to support itself quickly and the layers need to develop enough bonding between them. Open time is the third challenge [14], [15], [16], [17], and [20]. Lim et al. [15] defined open time as the period where the printability and buildability are consistent within acceptable tolerances. There is a limited time that is available to print the material. Any delays may cause the concrete to harden. Therefore, special material mixes are needed that allow enough time for the material to be printed.

Challenges related to the 3D printer include scalability, directional dependency and cybersecurity. The size of the construction projects creates additional challenge to 3D printing [11], [16], [17], [7], [18], [20], and [24]. Directional dependency is often cited as a main challenge [20], [21], [25]. Cybersecurity is another challenge [7], [25]. Cybersecurity and risk of hacking poses a threat since the construction process is automated and all the information are in the 3D model [7].

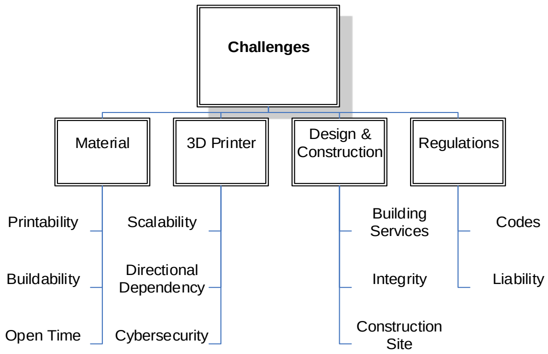

Figure 5. Challenges of 3D printing.

Design and construction challenges include exclusion of building services, structural integrity and suitability of the construction site. Exclusion of building services, such as electrical and mechanical, is a challenge [6], [26]. Structural integrity is another key challenge [14], [6], [17], [20], and [26]. Berman [24] stated that the quality of the printed parts has been found to be brittle and therefore has faced problems in printing load bearing components. Construction site setup is another challenge [2], [3], [9], [26]. Construction site are open environment which may not be suitable for 3D printer that need more controlled environment. Additionally, the site conditions may be irregular that hinder the movement and installation of the 3D printer. Lack of codes and regulations pose additional challenges to 3D printing in construction [16], [17], [7], [19], and [22]. Since the technology is still new, there is a lack of regulations governing the use of 3D printing in construction projects. Liability issues are also challenging [17], [7]. There is an issue of who would be responsible in case of failure [7].

V. Summary and Conclusion

A literature review was performed to identify the benefits of 3D printing. Five key benefits were identified: faster construction, cost reduction, more geometric freedom, sustainability and safety benefits. Eleven challenges were identified and grouped into four categories: material, robot system, design and construction, and regulation and liability. 3D printing is a promising new technology with several key benefits. However, the widespread adoption of the new technology is dependent on addressing its key challenges.

Conflict of Interest

This work has no conflict of interest.

Author Contributions

All authors approved the manuscript and they contributed in the writing. The first author covered mainly the robotic part and the second author concentrated more on the challenges and risks parts.

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References

[1] P. Gerbert, S. Castagnino, C. Rothballer, A. Renz, R. Filitz. (2016). The transformative power of building information modeling, March 08, 2016 Boston Consulting Group, [Online]. Available: https://www.bcgperspectives.com/content/articles/engineered-products-project-business-digital-engineering-construction/, [Accessed 28 Jan. 2019].

[2] S. El-Sayegh, L. Romdhane, and S. Manjikian, (2020). A critical review of 3D printing in construction: benefits, challenges, and risks. Archiv.Civ.Mech.Eng 20, 34. [Online]. Available: https://doi.org/10.1007/s43452-020-00038-w

[3] T. Bock, "The future of construction automation: Technological disruption and the upcoming ubiquity of robotics," *Automation in Construction*, vol. 59, pp. 113-121, 2015.

[4] B. García de Soto, I. Agustí-Juan, J. Hunhevicz, S. Joss, K. Graser, G. Habert, B. Adey, "Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall," *Automation in Construction*, vol. 92, pp. 297-311, 2018.

[5] S. Lim, R. A. Buswell, R. A. Le, Austin, A. G. F. Gibb, T. Thorpe, "Developments in construction-scale additive manufacturing processes," *Automation in Construction*, vol. 21, pp. 172–268, 2011.

[6] P. Wu, J. Wang, and X. Wang, "A critical review of the use of 3D printing in the construction industry," *Automation in Construction*, vol. 68, pp. 21-31, 2016.

[7] N. Labonnote, A. Rønnquist, B. Manum, and P. Rüther, "Additive construction: State-of-the-art, challenges and opportunities," *Automation in Construction*, vol. 72, pp. 347-366, 2016.

[8] ISO / ASTM52900-15, Standard Terminology for Additive Manufacturing – General Principles – Terminology, ASTM International, West Conshohocken, PA, 2015, www.astm.org

[9] D. Camacho, P. Clayton, W. O'Brien, C. Seepersad, M. Juenger, , R. Ferron, S. Salamone, "Applications of additive manufacturing in the construction industry–A forward-looking review," *Automation in Construction*, vol. 89, pp. 110-119, 2018.

[10] J. Xu, L. Ding, P. Love, "Digital reproduction of historical building ornamental components: From 3D scanning to 3D printing," *Automation in Construction*, vol. 76, pp. 85-96, 2017

[11] D Shape Printer. [Online]. Available: https://commons.wikimedia.org/wiki/File:D-shape_printer.png accessed November 18, 2019.

[12] Dubox. [Online]. Available: http://www.dubox.me/dubox-showcase-first-3d-printed-concrete-element-uae/ accessed November 18, 2019.

[13] I. Hager, A. Golonka, and R. Putanowicz, "3D printing of buildings and building components as the future of sustainable construction?" *Procedia Engineering*, vol. 151, pp. 292-299, 2016.

[14] O. Davtalab, A. Kazemian, and B. Khoshnevis, "Perspectives on a bim-integrated software platform for robotic construction through contour crafting," *Automation in Construction*, vol. 89, pp. 13-23, 2018.

[15] S. Lim, R. A. Buswell, R. A. Le, Austin, A. G. F. Gibb, T. Thorpe, "Developments in construction-scale additive manufacturing processes," *Automation in Construction*, vol. 21, pp. 262–268, 2011.

[16] S. Ghaffar, J. Corker, M. Fan, "Additive manufacturing technology and its implementation in construction as an eco-innovative solution," *Automation in Construction*, vol. 93, pp. 1-11, 2018.

[17] S. Uppalla and M. Tadikamalla, “A review on 3D printing of concrete-the future of sustainable construction,” *I-Manager's Journal on Civil Engineering*, vol. 7, no. 3, pp. 49-62, 2017.
[18] Apis Cor. We Print Buildings, Retrieved from: apis-cor.com/en/.
[19] I. Kothman and N. Faber, “How 3D printing technology changes the rules of the game,” *Journal of Manufacturing Technology Management*, vol. 27, no. 7, pp. 932-943, 2016.
[20] M. A. Kreiger, B. A. MacAllister, J. M. Wilhoit, M. P. Case, “The current state of 3D printing for use in construction,” in *Proc. the 2015 Conference on Autonomous and Robotic Construction of Infrastructure*, Ames, Iowa, pp. 149-158, 2015
[21] L. Robichaud and V. S. Anantatmula, “Greening project management practices for sustainable construction,” *Journal of Management in Engineering*, vol. 27, no. 1, pp. 48-57, 2011.
[22] J. Zhang and Z. Hu, “BIM- and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 1. principles and methodologies,” *Automation in Construction*, vol. 20, no. 2, pp. 155-166, 2011.
[23] CyBe. Redefining Construction by Enabling 3d Concrete Printing by Providing Hardware, Software, Material, Education, Certification and Business Development. CyBe Construction, Retrieved from: cybe.eu/. [Accessed 1 Nov. 2018].
[24] B. Berman, “3D printing: The new industrial revolution,” *IEEE Engineering Management Review*, vol. 41, no. 4, 2013.
[25] S. Zeltmann, N. Gupta, N. Tsoutsos, M. Maniatakos, J. Rajendran, and R. Karri, “Manufacturing and security challenges in 3D printing,” *Jom*, vol. 68, no. 7, pp. 1872-1881, 2016.
[26] B. Panda, S. Chandra Paul, and M. Jen Tan, “Anisotropic mechanical performance of 3D printed fiber reinforced sustainable construction material,” *Materials Letters*, vol. 209, pp. 146-149, 2017.

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