

THE STUDY OF 3D CONCRETE PRINTING TECHNOLOGY APPLICATION IN THE PRACTICAL PROJECTS

Pham Thi Loan, Nguyen Thi Hoai Thu, Do Trong Quang
Faculty of Engineering and Technology
Email: loanpt80@dhhp.edu.vn

Received: 29/7/2024

Revised: 14/8/2024

Accepted: 18/10/2024

Abstract: Additive manufacturing, widely known as 3D printing technique, has drawn the attention of researchers from all over the world for a few recent decades. Thanks to the ability to transform a drawing into an object, the idea of 3D printing has also attracted the attention of engineers, architects, and investors. However, the big question is how to approach and keep up with the 3D concrete printing technology trend with limited conditions such as printers, technology issues, and costs. Therefore, this study focuses on clarifying the in-depth perspective on typical projects applying 3D concrete printing technology implemented at Hai Phong University. The highlighted projects presented in detail are the Haiphong University logo, interior and exterior furniture, and a villa in miniature. The study will place special emphasis on the practical techniques in the printing process, such as design, software instruction for use, tomographic modeling method, and the visual image of a specific model. These models have been utilized at Haiphong University, Hai Phong Children's Hospital, and two investors in Haiphong. Based on the research results, recommendations are also given, which can be considered the reference and orientation documents to apply 3D concrete printing technology to the construction field.

Keywords: 3D concrete printing, mix design, concrete printers, printing techniques, Simplify3D, Mach3.

NGHIÊN CỨU ỨNG DỤNG CÔNG NGHỆ IN BÊ TÔNG 3D VÀO CÁC DỰ ÁN THỰC TIỄN

Tóm tắt: Sản xuất đắp dần, được biết đến rộng rãi là công nghệ in 3D, đã thu hút sự chú ý của các nhà nghiên cứu trên toàn thế giới trong vài thập kỷ gần đây. Nhờ khả năng biến

đổi bản vẽ thành vật thể, ý tưởng in 3D cũng đã thu hút sự chú ý của các kỹ sư, kiến trúc sư và nhà đầu tư. Tuy nhiên, câu hỏi lớn là làm thế nào để tiếp cận và theo kịp xu hướng công nghệ in bê tông 3D trong điều kiện hạn chế như thiết bị, vấn đề công nghệ và chi phí. Do đó, nghiên cứu này tập trung vào việc làm rõ góc nhìn sâu sắc về các dự án tiêu biểu ứng dụng công nghệ in bê tông 3D tại Đại học Hải Phòng thực hiện. Các dự án nổi bật được trình bày chi tiết là biểu tượng Đại học Hải Phòng, đồ nội thất và ngoại thất, và một biệt thự thu nhỏ. Nghiên cứu sẽ đặc biệt nhấn mạnh vào các kỹ thuật thực tế trong quá trình in, chẳng hạn như thiết kế, hướng dẫn sử dụng phần mềm, phương pháp mô hình cắt lớp và hình ảnh trực quan của một mô hình cụ thể. Các mô hình này đã được sử dụng tại Đại học Hải Phòng, Bệnh viện Nhi Hải Phòng và hai nhà đầu tư tại Hải Phòng. Dựa trên kết quả nghiên cứu, các khuyến nghị cũng được đưa ra, có thể được coi là tài liệu tham khảo và định hướng để áp dụng công nghệ in bê tông 3D vào lĩnh vực xây dựng.

Từ khóa: In bê tông 3D, thiết kế cấp phối, máy in bê tông, kỹ thuật in, Simplify3D, Mach3.

1. Introduction

Sustainability in building construction is an inevitable aspect of future construction projects, which is a standout advantage in 3D concrete printing construction over traditional construction practices. Justification of sustainability is highly appreciated by comparison of 3D concrete printing technology with conventional construction techniques in terms of reduced labor requirement, absence of formwork requirement, and decreased waste production. For example, it has been reported that the Dubai project (the United Arab Emirates National Committee) has resulted in a 50 to 80% reduction in labor costs and a 30 to 60% reduction in construction waste. [1-2]. Thanks to its capability to transform a drawing into an object, the idea of 3D printing has also attracted the attention of

engineers, architects, and investors. As the construction industry has adopted the new technology, its usage is extended to the final structure production beyond making quick prototypes. Since 2014, many well-known buildings, bridges, and architectural icons have been constructed on-site using 3D printer technology [3-7]. The contribution to the application and development of 3D concrete printing is particularly significant in the USA, China, the United Kingdom, and other developed countries, which have been at the forefront of this technological revolution. Publications related to applying 3D printers in construction have become a hot trend in recent decades [8].

On the Vietnam map, there are currently 04 research groups belonging to universities/institutes, and the successful research and application of concrete

printing technology in practice has been published. The Vietnam Institute of Building Materials (VIBM) has been participating in developing concrete printing technology since 2016. During the

research, the group successfully built a concrete printer, designed the grade, operated the printing process, and launched many products with different designs and sizes, as shown in Figure 1.



Figure 1. Products by Vietnam Institute of Building Materials



Figure 2. Products by Miken 3CDP.

University of Science and Technology - National University of Ho Chi Minh City. HCM - Concrete Miken Team. The Miken team has been approaching concrete technology since 2019 and has succeeded. The research results have been accepted and published through research projects at university and city levels as well as prestigious international publications. During the research process, the team built a concrete printer from laboratory size to a printer in the field, designed the distribution, operated the printing process, and released many products. Products with different designs and

sizes, as shown in Figure 2. The group is leading the country in the scope of construction works printed in the field up to tens of meters long.

Research students at the Ho Chi Minh City University of Technology and Education first announced the robotic arm-style concrete printer around June 2021 [9]. At this point, the published results in the media are an essential milestone for the team's further development. By August 2022, the group had successfully built a model housing project with an announced cost of about VND 50 million [10]. The typical products of the research team are shown in Figure 1.



Figure 1. Products by Ho Chi Minh City University of Technology and Education



Figure 2. Products by QLAT - Haiphong University.

The research group, namely QLAT of Haiphong University, has approached concrete printing technology since 2019 and has initially achieved this technology application's results. The research results have been accepted and published through university-level research projects and published articles in prestigious domestic and international journals [14-15]. During the research, the team successfully built a small to medium-sized concrete printer in the laboratory, created a design process for mixing and printing, and launched many products with different designs and sizes, as shown in Figure 2.

The big question is how to approach and follow the 3D concrete printing technology trend with limited conditions such as printers, technology issues, and

budget. Therefore, this focus is on revealing insight into the highlighted projects produced by 3D concrete printer at Haiphong University. The highlight projects presented in detail are the Haiphong University icon, interior and exterior furniture, and a small-scale village. The practical techniques in the printing process related to design, software manuals, slicing model methods, and the visual appearance of a specific model will be discussed. These models have been employed at Haiphong University, Hai Phong Children's Hospital, and two investors in Haiphong. Based on the research results, recommendations were also given out, which can be considered a reference and orientation to apply 3D concrete printing technology to the construction field.

2. 3D concrete printer, Materials, and Mix proportion

2.1. 3D concrete printer

Because of the simplicity of manufacturing the screw extruder, the authors employed a screw extruder for the printer. The extruder of the printer was

made of metal. The printer's dimensions are 2500x2000x1800 (length x width x height), and the printed sample dimensions are 1500x1200x1200 mm (length x width x height), as presented in Figure 3. The shapes of the nozzle are square and circular, with diameters ranging from 18mm to 50mm.

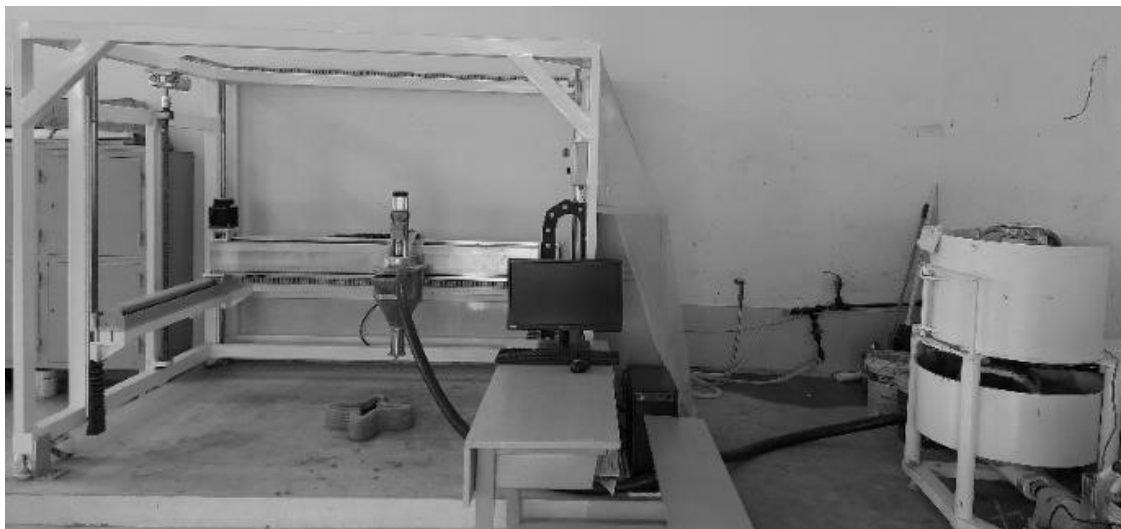


Figure 3. 3D concrete printer

2.2. Materials and Mix proportion

Based on the approaches and achievements of previous authors, the authors highly respect practical methods in the laboratory and on-site and suggest the following mixed proportion design process. The mix design via coefficients and slump value approaches has been employed in this method proposed by the authors.

In this research, ordinary Portland cement (OPC) from Chiffon PC40 and fly ash (FA) from Haiphong thermal power plant was used to form the binder component, thanks to

many other researchers' successful applications of cement-based materials [16-21]. Commercially available natural and crushed sand with nominal maximum aggregate sizes of 1.25 mm and 2.5mm, respectively, were used.

Polypropylene (PP) fibers were used to decrease the shrinkage of the printed concrete—the main properties of PP fiber. Superplasticizer, namely Visconcrete 3000M [19], was used to adjust the workability of the fresh concrete. Materials used for mixing concrete in this research are presented in

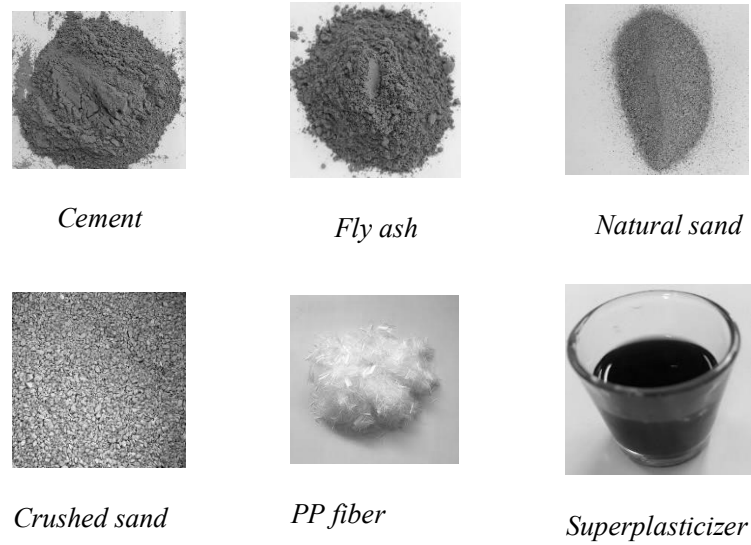


Figure 4. Materials used for mixing concrete.

Table 1. Mix proportions

Project name	Cement	Fly Ash	Water	Natural sand	Crushed sand	PP Fiber (%)	SP (%)
Haiphong University Logo	1.0	-	0.32	0.5 (2.5mm)	0.5 (2.5mm)	0.25	0.4
Small-scale villa	0.5	0.5	0.32	1.0 (1.25mm)	-	0.25	0.4
Haiphong Children's Hospital	1.0	-	0.32	0.5 (2.5mm)	0.5 (2.5mm)	0.25	0.4

(Note: Binder = Cement and Fly Ash; values in Table are ratios of each ingredient to binder)

3. Inside into the highlight projects

3.1. Hai Phong University logo

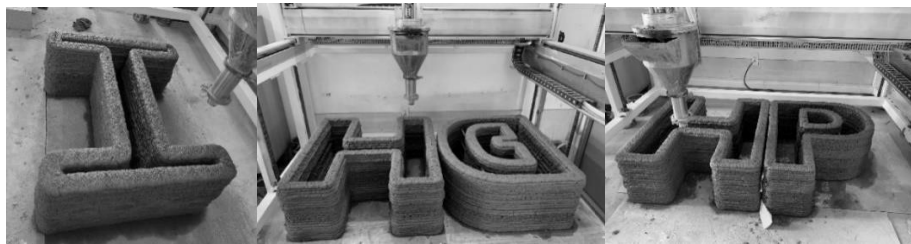
The logo is designed with a total length of 7m, a width of 0.65m, and a height of 1.2m, as shown in Figure 5.



Figure 5. Design of the Hai Phong University logo

The printing process is guaranteed according to the steps shown in sub-section 4.1. The letters were printed with a 35mm circular nozzle. The height of each print layer is 10mm, and the print width of filaments ranges from 45mm to 50mm. The heart shape was printed with a 35mm diameter circular nozzle. The height of each print layer is 10mm, and the print width of filaments ranges from 45mm to 50mm. The heart

shape was printed with 02 close strokes to form a double filament width of about 90mm to 100mm. The base is divided into 17 segments for printing and then assembled with adhesive. A circular nozzle of 35mm was used for the diameter. The height of each printing layer is 12mm, and the print width of filaments ranges from 45mm to 50mm. The pictures illustrate the printing process, as shown in Figure 6



a) Printed letters



b) Printed heart-shape



c) Print segments of the base

Figure 6. The process of printing the components of the logo

Because the base length is 7.0m, which is over the size of the printer, the method of dividing the base can be carried out in the following pictures. During printing time, temporary support was used when printing the segments with inclined surfaces, as shown in Figure 6 (c).

After completing the printing, all components were coated with paint according to the designed color. Then, the logo was transported by a specialized crane truck, as shown in the images in Figure 7. The erection and connection of the logo used special reinforcement and ramset in the junction of the structure. Finally, the logo has been completed, as captured in Figure 8.



Figure 7. The process of transporting and erecting the logo



Figure 8. The completed Haiphong University logo

3.2. The small-scale villa

The design model with the 1:20 scale of the villa is shown in Figure 9. The villa has four main parts: the base is 50mm high, 640mm wide, and 690mm long; the 1st floor is 200mm high, 450mm wide, and 480mm long; the second floor is 300mm high to the roof, 450mm wide, and 480mm long; and the 2-sided sloped roof is 150mm high, 750mm wide, and 810mm long. The base is designed in a 4-petal flower shape, with 550x550x600 (mm) dimensions.

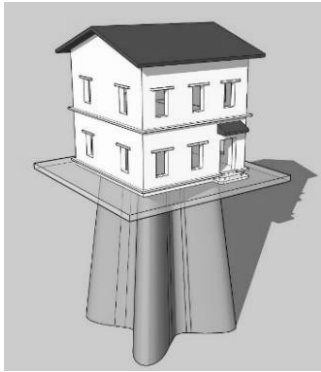


Figure 9. Design of the small-scale villa.

The villa's printing work is carried out in parts according to the design plan. The printing process is guaranteed according to the steps presented in section 4. The villa was

printed with a square nozzle with a diameter of 22 mm. The height of each printing layer is 12mm, and the print width ranges from 25mm to 28mm.

As presented in Figure 10 Some techniques must be used to print the villa:

- Cutting windows and doors.
- A perimeter beam above doors and windows was printed in advance.
- After placing the perimeter beam, printing work was continuous until the end layer.

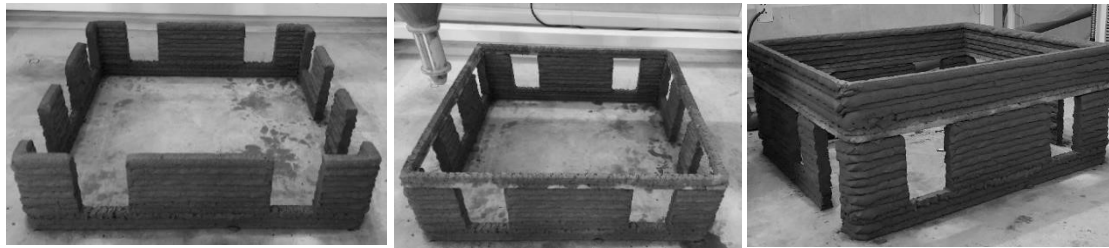


Figure 10. Construction steps of the first floor.

The rule was similar to the second floor. The second floor and roof were printed as shown in Figure 11.



Figure 11. Construction of the second floor and roof

The base with a 4-petal flower shape is designed automatically, adding the cross in the printing process thanks to functions

employed in Simplify3D software with selection commands shown in. The printed product is captured.

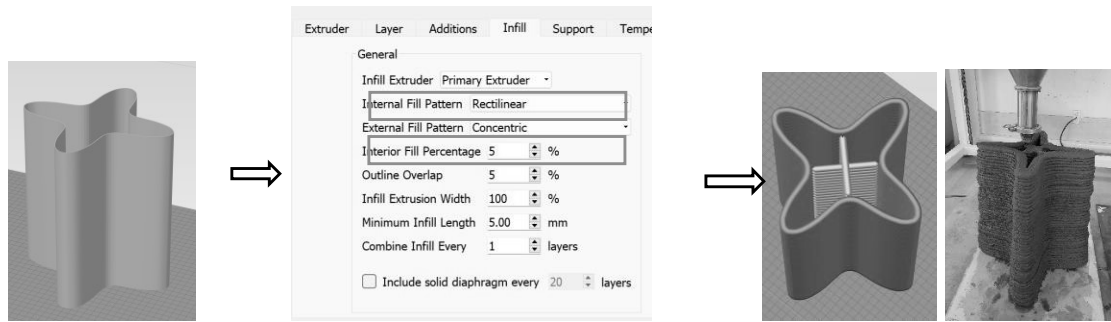


Figure 12. Technique inside Simplify3D

The project was transported and erected at 70 Vo Thi Sau, May To, Ngo Quyen, Hai Phong. The connection between the parts of the building is guaranteed for durability and safety. The completed work is in the courtyard before the old French villa. The finish paint color is similar to the existing paint color of the building. The small-scale villa built with modern technology creates an exciting and meaningful highlight for this villa, as captured in



Figure 13. The villa was built with a 3D concrete printer.

3.4. Furniture at Hai Phong Children's Hospital

International treatment unit waiting room: The function was repaired and renovated from the bridge lobby. Therefore, the design work must match the existing structural systems while still ensuring the luxury and utility of the waiting room, which requires the designer's creativity. The design option was selected, as shown in Figure 14(a).

Front yard campus: This is the highlight location at the entrance from the main gate and the central area of the Hospital, where many main buildings intersect. This place is also a place where a large number of children and patients' families sit to rest. Therefore, the proposed design plan must meet the criteria of aesthetics, function, and symbolism. The design plan is approved, as shown in Figure 14(b).



(a) *Waiting room*



(b) *Yard campus*

Figure 14. Design of the waiting room and yard campus

Printing was carried out in parts according to the design plan. The printing process is guaranteed according to the steps presented in sub-section 4.1. The circular nozzle with an 18 mm diameter has been

employed to print all of the components. The height of each printing layer is 10mm, and the print width of filaments ranges from 20mm to 22mm. The parts of both projects were printed as shown in Figure 15.

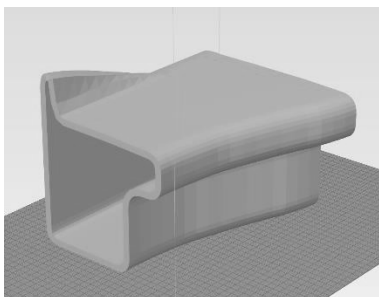


(a) *Waiting room components.* (b) *Yard campus components.*

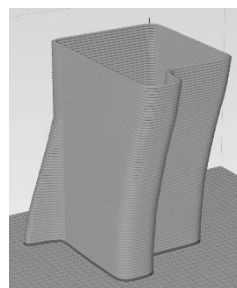
Figure 15. Printed components.

Figure 16 Illustrate the process from the design pieces through the printing

direction to the completed part of the waiting room components.



(a) *Design piece*



(b) *Printing direction*



(c) *Completed piece*

Figure 16. Printing direction of pieces

The transportation and erection of printed concrete products at Hai Phong Children's Hospital. Delivery and erection of the products were done in a few hours,

and the finished products brought a fresh new look to the vibrant spaces in Hai Phong Children's Hospital, as shown in Figure 17.



(a) Waiting room interior



(b) Yard campus exterior

Figure 17. The completed furniture

4. Conclusions

Based on the results of the research projects presented herein with the 3D concrete printer at Haiphong University, some conclusions and suggestions are given:

(1) Simplify3D and Mach3 effectively sliced and printed models, which authors successfully investigated.

(2) The model's design is free in architecture, but the rules suggested in this research should be considered to guarantee the production quality in appearance and printability.

(3) The printability is affected by mix proportion and the relationship between the nozzle printing speed parameter and extrusion speed of motor turning.

(4) The 0.25% amount of PP fibers significantly reduced the printed samples' shrinkage.

(5) The techniques revealed through the practical projects illuminated the process of creating a product with a 3D concrete printer, including design routine, division of the whole model into separate pieces, and printing process.

(6) Highlight projects presented in this study to enhance the application of the 3D concrete printing technology to the practice areas.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the material support from Thanh Hung Concrete Joint Venture Company and the laboratory support at Haiphong University, Vietnam. We especially thank VIDPOL Joint Stock Company for creating the experimental equipment.

REFERENCES

1. M. Sakin and Y. C. Kiroglu, "3D Printing of Buildings: Construction of the Sustainable Houses of the Future by BIM," *Energy Procedia*, vol. 134, pp. 702-711, Oct. 2017, doi: 10.1016/j.egypro.2017.09.562.
2. M. Alawneh, M. Matarneh, and S. El-Ashri, "The World's First 3D-Printed Office Building in Dubai," *2018 Pci/Nbc*, 2018, [Online]. Available: https://www.pci.org/PCI_Docs/Convention-Papers/2018/32_Final_Paper.pdf
3. A. Frearson, "Chinese company 3D prints 10 buildings in a day using construction waste." Accessed: Jun. 23, 2022. [Online]. Available: <https://www.dezeen.com/2014/04/24/chinese-company-3d-prints-buildings-construction-waste/>
4. S. Sarah, "Robotic 3D Printed Yhnova House Officially Inaugurated, Tenants to Move In Soon," 3DR holdings. Accessed: Jun. 24, 2022. [Online]. Available: <https://3dprint.com/207936/3d-printed-yhnova-house-done/>
5. 3dsourced, "The 12 Most Exciting 3D Printed House Builds 2022." Accessed: Jun. 23, 2022. [Online]. Available: <https://www.3dsourced.com/guides/3d-printed-house-2/>
6. L. Alter, "3D Printed House Displayed at Milan Design Week." Accessed: Jun. 23, 2022. [Online]. Available: <https://www.treehugger.com/d-printed-house-displayed-milan-design-week-4853575>
7. L. Stinson, "World's largest 3D-printed building completed in Dubai." Accessed: Jun. 23, 2022. [Online]. Available: <https://archive.curbed.com/2019/12/30/21035765/world-largest-3d-printed-building-dubai-apis-cor>
8. M. Žujović, R. Obradović, I. Rakonjac, and J. Milošević, "3D Printing Technologies in Architectural Design and Construction: A Systematic Literature Review," *Buildings*, vol. 12, no. 9, 2022, doi: 10.3390/buildings12091319.
9. T. Dat, "Sinh viên chế tạo robot in 3D bê tông 'đầu tiên' tại Việt Nam," Thanhnien News. [Online]. Available: <https://thanhnien.vn/sinh-vien-che-tao-robot-in-3d-be-tong-dau-tien-tai-viet-nam-post1081920.html>
10. VLXD.org, "Sinh viên xây nhà bằng công nghệ in 3D." [Online]. Available: <https://vatlieuxaydung.org.vn/nghien-cuu-ung-dung/ung-dung/sinh-vien-xay-nha-bang-cong-nghe-in-3d-16645.htm>
11. T. L. Pham, X. J. Zhuang, T. H. T. Nguyen, P. A. Nguyen, and D. T. Trinh, "Experimental investigations on the rheological properties of the proposed 3D printing mortar," *Minist. Sci. Technol. Vietnam*, vol. 64, no. 2, pp. 50-53, Jun.

- 2022, doi: 10.31276/VJSTE.64(2).50-53.
12. L. T. Pham *et al.*, “Development of 3D printers for concrete structures: mix proportion design approach and laboratory testing,” *Smart Sustain. Built Environ.*, Aug. 2022, doi: 10.1108/SASBE-07-2022-0137.
 13. B. Zhu, J. Pan, B. Nematollahi, Z. Zhou, Y. Zhang, and J. Sanjayan, “Development of 3D printable engineered cementitious composites with ultra-high tensile ductility for digital construction,” *Mater. Des.*, vol. 181, p. 108088, 2019, doi: 10.1016/j.matdes.2019.108088.
 14. Y. Weng, M. Li, M. J. Tan, and S. Qian, “Design 3D printing cementitious materials via Fuller Thompson theory and Marson-Percy model,” *Constr. Build. Mater.*, vol. 163, pp. 600-610, 2018, doi: 10.1016/j.conbuildmat.2017.12.112.
 15. K. Manikandan, K. Wi, X. Zhang, K. Wang, and H. Qin, “Characterizing cement mixtures for concrete 3D printing,” *Manuf. Lett.*, vol. 24, pp. 33-37, 2020, doi: 10.1016/j.mfglet.2020.03.002.
 16. 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, Aug. 2017, doi: 10.1016/j.conbuildmat.2017.04.015.
 17. F. Hamidi and F. Aslani, “Additive manufacturing of cementitious composites: Materials, methods, potentials, and challenges,” *Constr. Build. Mater.*, vol. 218, pp. 582-609, 2019, doi: 10.1016/j.conbuildmat.2019.05.140.
 18. B. Lu *et al.*, “A systematical review of 3D printable cementitious materials,” *Constr. Build. Mater.*, vol. 207, pp. 477-490, 2019, doi: 10.1016/j.conbuildmat.2019.02.144.
 19. Sika, “SikaPlast®-398 SF,” Dongnai, Vietnam, 2022.