3D CONCRETE PRINTING STRUCTURAL AND NON-STRUCTURAL SOLUTIONS



https://doi.org/10.32970/CS.2022.1.7

Marwah M. Thajeel - Naser S. Alimrani - György L. Balázs

Digital production has been applied in many branches of the industry; however, the construction industry was an exception. Applying this new technology could help to reshape the construction world as we know it today. Using 3D printing technologies in construction offers significant potential to increase efficiency in terms of speed construction, waste reduction, design freedom, reduce human error as well as green building construction materials. In the current research, the authors review the structural and non-structural applications of the 3D concrete printing, as well as the potential applications, challenges, and possible solutions, respectively.

Keywords: 3D concrete printing, digital manufacturing, structural application, non-structural application

1 INTRODUCTION

1.1 3D concrete printing geometry

3D concrete printing or cementitious 3D construction printing (3DCP) is a form of additive manufacturing used to fabricate buildings or construction components in completely new shapes not previously possible with traditional technologies. Concrete is extruded, using this new technology, through a nozzle to build structural components layer-by-layer without the use of formwork or any subsequent vibration. Extrusion/deposition method of 3D printing is one of the most studied techniques where material has three planes, with perpendicular symmetry between these planes producing an orthotropic material (*Fig. 1*). Hence, its mechanical behaviour differs based on the three axes as defined by the direction of the deposition, the layer width and the structure height to be printed. In addition, the interfacing between layers conjectural appears to be a critical zone, which can have a large effect on the overall mechanical characteristics of the printed material (Perrot, 2019).

1.2 Functionality of 3D printed materials

Specific requirements must be taken into a count at the phase of designing a structure. Structural requirement is one of the important requirements that deal with safety, ability of the structure to support all loads, and to completely understand the mechanical properties of printed structures. In addition, the degree of orthotropy should be taken into considerations. This could be possible by contrasting its mechanical behaviour in different directions of loads, as shown in *Fig. 2*, or by comparing the properties of a 3D printed material with the same conventional cast material. Several studies measured the perpendicular and parallel compressive strength and compared to the cast concrete, in which all results were higher than the conventionally cast samples. The compressive strength in the parallel direction is slightly lower than the cast samples while the perpendicular is the same (Lim et al., 2012). Moreover, they concluded that anisotropy in terms of compressive strength is due to defects at the interface of the layers whereas the flexural strength in all direction is higher than the cast concrete. As a result, the printed materials have a better bending strength than conventional poured concrete (Malaeb et. al., 2015, Nerella et. al., 2017).

Furthermore, several authors have proposed combinations that contain natural fibres, silica fume and fly ash to improve the mechanical propertied particularly tensile characteristics to the printed cementitious materials (Ogura et. al., 2018, Sonebi et. al., 2018). The studies have concluded that it is possible to print concrete or mortars with obtained mechanical characteristics that can be qualified as high or very high performance by choosing the best methods of printing (Xia and Sanjayan, 2016, Weger et. al., 2016, Shakor et. al., 2017, Weger et. al., 2018, Pierre et. al., 2018 and Gaudillière et al., 2019). In addition, it is suggested to reduce time intervals between layers to improve the bonding between the layers and prevent cold joints to be formed (Wangler et. al., 2016). Finally, spraying the water on the layer before the print of a new layer increases the compressive strength compared to the sample printed without wetting (Sanjayan et. al., 2018).

2 STRUCTURAL APPLICATION

2.1 Formwork freedom

Architects and designers often attend to create especial structure resulting in complex structure that is a challenge to perform. Nevertheless, 3D printing concrete provides matchless freedom of form for architects and designers of concrete elements. From this point of view, this new digital production might open new fields of chances that were previously difficult for architects. In addition, it has a green impact on environment, since the production and management of forms can produce a large amount of waste, particularly in the case of forms for complex structures with assembly components that are utilized just a single time.

However, this method does not provide completely freedom

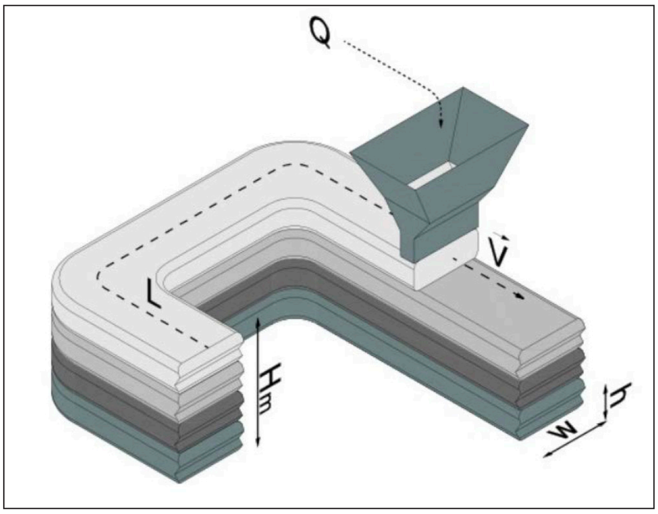


Fig. 1: Extrusion/deposition of 3D printing process (Wangler et al. 2016)

from the formwork. One of the challenges of the 3D printing is the overhanging parts of structures as shown in *Fig. 3*, because they are limited by the elastic properties of the material while it is in a fresh state (Wolfs et. al., 2018, Leventon, 2019). A common way to deal with overhangs is by generating support structures. These are towers that rise up from the ground to hold the sections that can't hold themselves up (*Fig. 4*). They can come in a variety of patterns and forms, depending on what software was used to generate them. After the print is finished, they can be ripped out to leave the model as intended (Higgs, 2018), or use printers have two nozzles that are able to print two separate materials in the same print. Special foundation materials can be used in these prints to make support structures that come cleanly off the rest of the print without hassle. Many research projects today focus on simultaneous and collaborative works performed by a team of robots with two different materials, *Fig. 5* (Duballet et. al., 2018). Although it sounds as ideal, it is also the downside to this method, in which the places where the model had support structures attached will have a rougher and less clean finish.

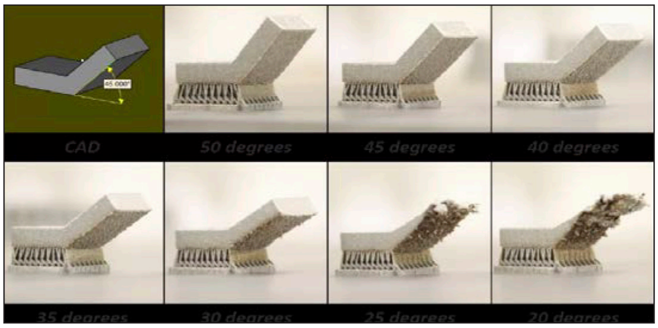


Fig. 3: A 3D-printed overhang of less than 45 degrees generally needs support structures to prevent it from crumbling (Leventon, 2019)

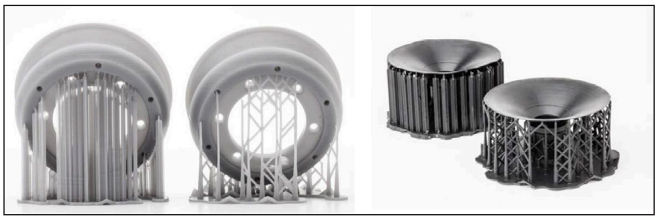


Fig. 4: Different software have different algorithms for support structures (Baptiste, 2018)

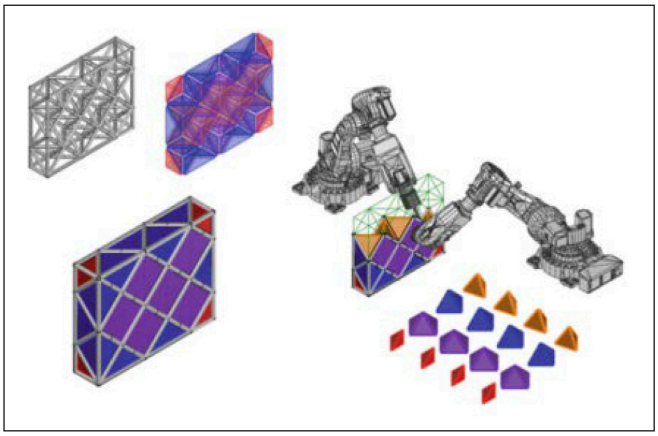


Fig. 5: Production of concrete walls with two robots working together (Duballet et. al., 2018)

2.2 Structures with shape optimization

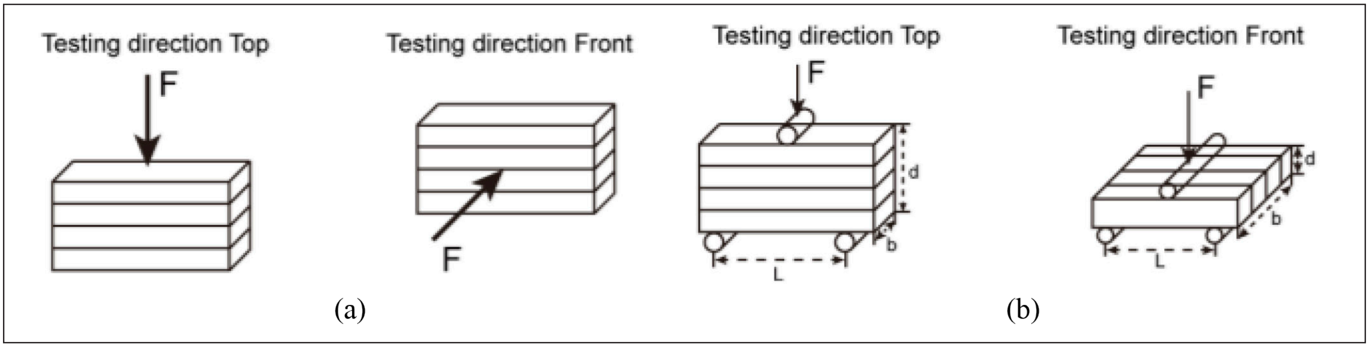
2.2.1 Topological optimization

Digital manufacturing can also help to optimize the amounts of materials installed since the materials are only placed where they are important for the structural stability. Thus, the building design and structural construction can be done using the concept of topological optimization. In many areas of application, digital manufacturing is related to a design using this topological optimization (Hollister, 2005, Brackett et. al., 2011). Topological optimization is a design tool that uses mathematical methods that allow the amounts of materials to be minimized in each volume subjected to mechanical stress (Bendsoe, 2001). Figure 6 (a) shows the application of topological optimization on simply supported beam subjected to concentrated load at the mid-span (Vantyghem et. al., 2018), while *Figure 6 (b)* shows the reduction in quantities of materials using topological optimization during the design phase (Tripathy, 2016).

2.2.2 Inspired by nature

It is also possible to print designs from the living world and inspired by nature through a slow process of natural selection. This process has ultimately been able to produce structures that

Fig. 2: Testing direction (a) compressive strength and (b)flexural strength (Marchent, 2017)



(a) (b)

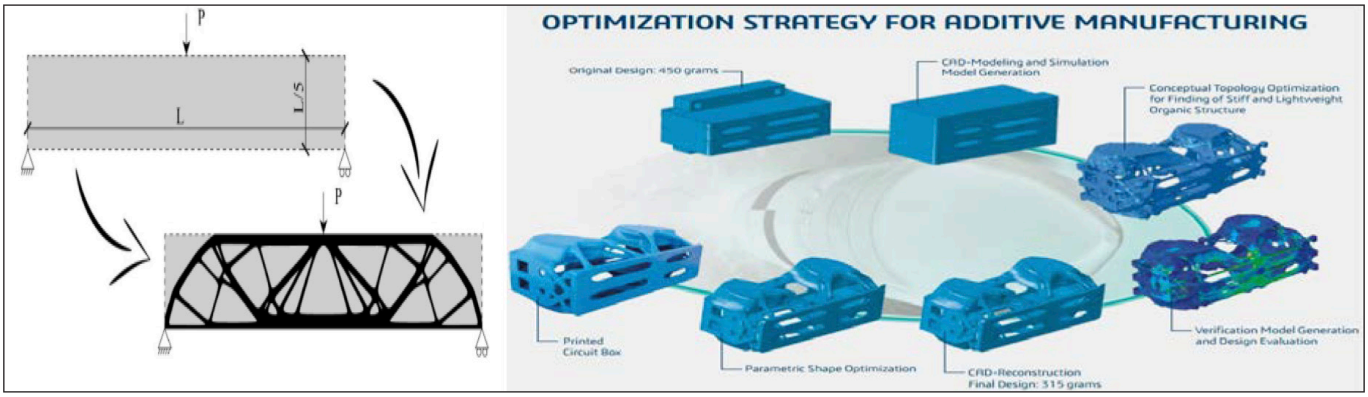


Fig. 6: *Topological optimization concept, (a) simply supported beam subjected to load (Vantyghem et. al., 2018), and (b) reduced amounts of materials during the design phase (Tripathy, 2016)*

(a) (b)

Fig. 7: *Column inspired from human bones, (a) initial sketch, and (b) printed (Nadja et. al., 2019)*

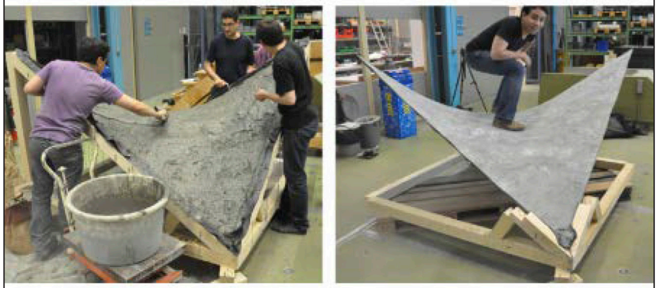
optimize the use of materials to design load bearing elements that can decrease the volume of the material. From this point of view, a porous structure inspired by human bones is shown in *Fig. 7*. The structure was printed in segments at the factory and then assembled on site. The finished piece stands 4 meters tall and blends seamlessly with the concrete of the preschool building (Nadja et. al., 2019).

The concept of optimization offers the advantage of a potential reduction in the supplies of raw materials, especially aggregates, which have become increasingly scarce. However, it is important to note that the formulas of cement-based materials tested in the literature often use reduced maximum grain sizes, which significantly increases the cement dosage. Similarly, a significant use of chemical admixtures has also been reported in many cases. As a result, the environmental impact of the printable material is greater than that of conventional concrete. Thus, for the printed concrete to have less of an impact, the design must be optimized at least to compensate for the higher environmental cost of the formulas used for printing. Therefore, this technology encourages us to reconsider the way in which buildings are designed, in order to have structures that optimize the forms and the quantities of materials used (Martens et al., 2017).

2.3 Possibility to print shell elements

One more component of 3D concrete manufacturing is to print structures that are only subjected to compression loads, like masonry structures in the form of a dome or an arch. Since the concrete tensile strength is low, this method allows to overcome on the natural tensile fragility of the concrete. This technique has been especially utilized by the set of Pr. Block at ETH University, Zurich, Switzerland (Rippmann and Block, 2013).

(a) Cable net and timber frame (b) Fabric layer



(c) Hand-rendered mortar (d) Shell with two 0.32 kN point

Fig. 8: *Shell construction by reducing the tensile forces (Veenendaal and Block, 2014)*

The thought is to utilize the strategies of the digital production of forms dependent on reinforcing cables and fabrics as a help for the projection of a thin strata of concrete to be utilized in compression (*Fig. 8*). Other digital production methods using concrete (injection into particle beds or by extrusion/deposition) may be utilized in the future in a trail to reprinting traditional structural forms, active in compression, as in cathedrals, like arches and keystones without steel reinforcing (Veenendaal and Block, 2014).

2.4 Prominent 3D printed construction models

2.4.1 The highest 3D printed building across the globe, in China

The world's highest 3D printed building was built in 2015 in China. The apartment building was consisted of five-story (*Fig. 9*). The method of construction was off-site, elements such as walls, doors and windows were fabricated, transported and assembled on-site. Finishing works were carried out using traditional methods (Winsun, 2015).

2.4.2 The world largest 3D printed office, in Dubai

The first largest 3D printed office building was opened in 2016 in Dubai, UAE, known as the "office of the future" (Augur, 2016). The office was designed by an Emirati Architecture Firm and 3D printed in Shanghai. Once all parts were ready, they were shipped to Dubai, where the components were assembled. The construction process took only 17 days to print 240-square-meter, which were followed by an on-site installation that took an additional two days. According to Gensler, using 3D printing technology instead of conventional methods has saved labour cost by 50-80%, and reduced construction waste by 30-60% (Ferro, 2016). This 3D printed office is a fully functional building featuring electricity, water, telecommunications, and even air-conditioning systems, *(Fig. 10).*

Fig. 9: 3D printed five story apartment building in China (Hossain et al., 2020)

Fig. 10: World's largest 3D printed office in Dubai (Ferro, 2016)

Fig. 11: 3D printed villa in China (Hossain et al., 2020)

2.4.3 3D printed two-story villa, in China

The two-story villa as shown in *Fig. 11* was completely printed on site in Beijing, China, in 2016. The entire construction process of 400-square-meter villa took only 45 days. However, a same building with traditional construction would take up to 7 months. In contrast with other 3D printed construction, the construction process was first carried out by installation the frame of the villa with steel reinforcement, then the C30 class concrete was printed by a huge 3D printer on site. Seismic testing estimates found that this 3D printed villa could be able to withstand an 8.0 earthquake on the Richter scale (Scott, 2016).

2.4.4 The first 3D printed footbridge, in Spain

The world's first 3D printed footbridge was inaugurated in 2016 in Madrid, Spain. The building was designed with a total length of 12 m and width of 1.75 m (*Fig. 12.b*), taking a total process to complete, of one year and a half. The 3D printed footbridge shows difficulties of the forms of nature, it was developed through parametric and computational designs that allows optimizing the distribution of materials and maximizing the structural performance. This enables the engineers to use the material only where it is needed, with total freedom of forms (Valencia, 2017).

Fig. 12: *3D printed bridges, (a) bike bridge in Netherlands (Saunders, 2017), and (b) footbridge in Spain (Valencia, 2017)*

2.4.5 3D printed bike bridge in Netherlands

The process of designing and printing the bike bridge was started in the Netherlands in 2017, with a total length of 8 m and width of 3.5 m (Fig. 12 a). The goal of the project was announced to "connect the future, to look for a newer, smarter approach to addressing infrastructure issues and thus making a significant contribution to improving the mobility and sustainability of society," (Saunders, 2017).

3 NON-STRUCTURAL APPLICATION

Current 3D concrete printing technology limits its applications to non-structural applications such as stamped concrete, outdoor living area, fountains, pool areas. Visual arts are perhaps the most obvious non-structural application of 3D printing technology. Art installations, sculptures, and other 3D printed objects can be found almost anywhere. 3D printing gives these artists more freedom to create complex structures that would otherwise be almost impossible to make, or extremely time-consuming and difficult. It also gives artists more creative freedom because they don't require specialist abilities to manufacture the 3D printed objects; all they need is basic CAD design knowledge and a 3D printer (Asherian, 2019).

Fig. 13 shows 3D printed sculpture introduced by an American digital artist Joshua Harker. The declaration of the piece of art was to push the limits of form and dimensions to share vision and exploration into what can be made and how to accomplish it in effort to tell a story or create an experience. Digital tools, software, and technology as well as traditional mediums were incorporated to create art that is unique and engaging. Bolstered by the advent of organic modeling software, visions are now able to be realized sculpturally in archival materials. Never have forms of this organic complexity been able to be created. This boon of technology is a revolutionary time for the arts and one which will be boldly marked in history.

3D printing has spread across many different areas, and the furniture industry is no exception. Furniture is still mass-produced using traditional manufacturing methods, but 3D printing has come in handy for designers who want to bring innovation into the market. However, 3D printing still is not the most appropriate tool for furniture. 3D printing offers a great tool for producing high-end furniture, often developed by famous designers who want to explore new shapes and ideas. Such furniture is produced in rather limited quantities and often features complex geometries, which is easier to produce using 3D printing. This often results in extraordinary designs, which are hard or impossible to produce with molds. *Fig. 14 (a)* shows 3D printed concrete furniture piece (Aduatz, 2020). *Fig. 14 (b)* shows intricacy of the shapes and surfaces (artificial reefs) that can be made through the digital manufacturing methods of 3D concrete printing. The servals air holes produced by the concrete encourage sea animals to settle in the region (Xtree, 2018).

Fig. 13: *3D printed sculpture (Harker, 2014)*

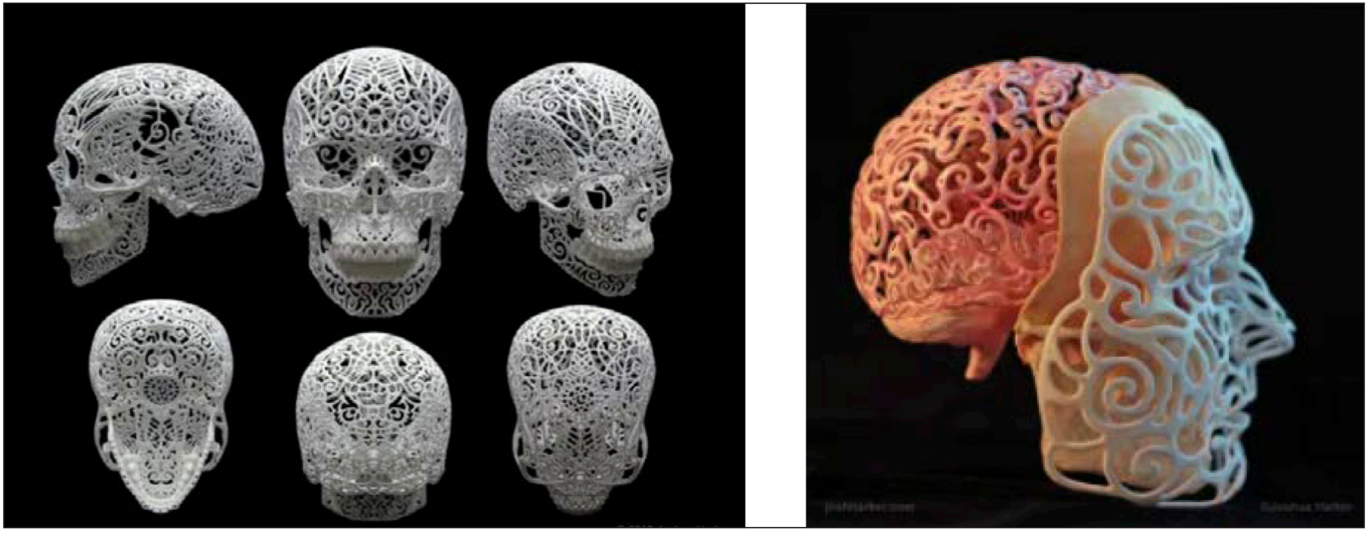


Fig. 14: Non-structural 3D printing concrete, (a) furniture (Aduatz, 2020), and (b) artificial underwater reefs (Xtree 2018)

4 CONCLUSIONS

3D concrete printing is an innovative construction method that promises to be highly advantageous in the field of construction in terms of optimizing construction cost, time, error reduction, design flexibility and environmental effect. It can be utilized to build the affordable housing in low-income countries, constructs military bunker in the wild, build in Mars or Lunar using in site material, and print the complex structure when the form is difficult to production, manufacture, restore or repair.

However, the behaviour of 3D printed concrete is orthotropic, changing the conventional concrete behaviour which exhibits as isotropic material. Thus, the utilization of the principles and test techniques utilized for traditional concrete may not be suitable for printed materials and structures. It is important to modify the standards and the new regulations to measure and assess the mechanical exhibition of the 3D concrete printing, as well as to develop new theoretical models to evaluate their structural behaviour. New standards design is very crucial to make sure the 3D printed elements able to carry all loads. At present, many constructions have been printed successfully and even put into practice, but it still needs a lot of work to do to encourage the growth of 3D concrete printed technology.

Non-structural applications of 3D concrete printing are still limited. The most used of this technology is sculptures, art installations and interior decorations. However, one of the extraordinary applications of this technology is 3D concrete printing artificial reefs with various air hols that helped underwater animals to settle in it.

ACKNOWLEDGMENT

Authors acknowledge the support by the Hungarian Research Grant VKE 2018-1-3-1_0003

"Development of advanced concrete elements".

5 REFERENCES

Aduatz, P. (2020), *"philipp aduatz creates 3D printed concrete outdoor furniture"* available at https://www.designboom.com/design/philipp-aduatz-3d-printed-outdoor-concrete-furniture-07-27-2020/, July 27, 2020, (Accessed on 20 October 2021)

Asherian, N. (2019), *"3D Printed Art: How 3D Printing Makes its Way into Creativity",* July 17, 2019, Available online at: https://all3dp.com/, (Accessed on 19 October 2021)

Augur H. (2016), *"3D Printed Office Building Unveiled in Dubai",* published May 27, 2016, Available online at, https://all3dp.com/3d-printed-office-building/ , (Accessed on 19 October 2021)

Bendsoe, M.P. (2001), "Topology optimization", in Encyclopedia of Optimization, Springer, pp. 2636–2638, 2001. https://doi.org/10.1007/0-306-48332-7_527

Brackett, D., Ashcroft, I., Hague, R. (2011), *"Topology optimization for additive manufacturing",* in Proceedings of the Solid Freeform Fabrication Symposium, Austin, TX, vol. 1, pp. 348–362, 2011.

Dfab house (2018), "Building with robots and 3D printers", Available at: http://dfabhouse.ch/, 2018, (Accessed on 15 October 2021)

Dubai building (2019), *" World's largest 3D-printed building completes in Dubai"*, available at: https://www.dezeen.com/2019/12/22/apis-cor-worlds-largest-3d-printed-building-dubai/, 2019, (Accessed on 15 October 2021)

Duballet, R., Baverel, O., Dirrenberger, J. (2018), *"Design of Space Truss Based Insulating Walls for Robotic Fabrication in Concrete",* Humanizing Digital Reality, pp. 453-461, 2018. https://doi.org/10.1007/978-981-10-6611-5_39

Ferro, S. (2016), *"The World's First Fully 3D-Printed Office Building Is Opening in Dubai"*. Published May 30, 2016. Available online at: http://mentalfloss.com/article/80738/worldsfirst-fully-3d-printed-office-building , (Accessed on 15 October 2021)

Gaudillière, N., Duballet, R., Bouyssou, C., Mallet, A., et al. (2019), *" Large-Scale Additive Manufacturing of Ultra-High-Performance Concrete of Integrated Formwork for Truss-Shaped Pillars",* in Robotic Fabrication in Architecture, Art and Design, pp. 459–472, 2019. https://doi.org/10.1007/978-3-319-92294-2_35

Harker, J. (2014), "21st Century Self-Portrait", Available online at: https://www.joshharker.com/art/self-portrait/, (Accessed on 19 October 2021)

Higgs, B. (2018), *" 3D Print Overhangs and How To Deal With Them",* available online at: https://medium.com/bravovictornovember/3d-print-overhangs-and-how-to-deal-with-them-9eed6a7bcb5d, last edit Feb 21, 2018, (Accessed on 10 October 2021)

Hollister, S.J. (2005), *"Porous scaffold design for tissue engineering",* Nature Materials, vol. 4, no. 7, p. 518-524, 2005. https://doi.org/10.1038/nmat1421

Hossain, M.A.; Zhumabekova, A.; Paul, S.C.; Kim, J.R (2020), *"A Review of 3D Printing in Construction and its Impact on the Labor Market".* Sustainability *2020,* 12, *8492.* https://doi.org/10.3390/su12208492

Leventon, W., (2019), *"Less support is a good thing—when 3D printing",* available online https://www.thefabricator.com/additivereport/article/additive/less-support-is-a-good-thingwhen-3d-printing, last edit October 4, 2019, (Accessed on 10 October 2021)

Lim, S., Buswell, R.A., Le, T.T. *et al.* (2012), *"Developments in construction-scale additive manufacturing processes",* Automation in Construction, vol. 21, pp. 262–268, 2012. https://doi.org/10.1016/j.autcon.2011.06.010

Malaeb, Z., Hachem, H., Tourbah, A. *et al.* (2015), *"3D concrete printing: Machine and mix design",* International Journal of Civil Engineering, vol. 6, pp. 14–22, 2015.

Marchent, T., Xia, M., et al. (2017), *"Effect of Delay Time on the Mechanical Properties of Extrusion-based 3D Printed Concrete",* 34th International Symposium on Automation and Robotics in Construction (ISARC 2017). https://doi.org/10.22260/isarc2017/0032

Martens, P.A., Mathot, M., et al. (2017)," Optimising 3D printed concrete structures using topology optimization", Proceedings of the IASS Annual Symposium 2017 "Interfaces: architecture.engineering.science" 25 - 28th September, 2017, Hamburg, Germany. https://doi.org/10.1007/978-3-319-59471-2_37

Nerella, V.N., Hempel, S., Mechtcherine, V., (2017), *"Micro-and macroscopic investigations of the interface between layers on the interface of 3D-printed cementitious elements",* International Conference on Advances in Construction Materials and Systems, 3-8. 9. 2017, Chennai.

Ogura, H., Nerella, V.N., Mechtcherine, V. (2018), *"Developing and testing of strain-hardening cement-based composites (SHCC) in the Context of 3D-Printing"*, Materials (Basel), vol. 11, no. 8, August 2018. https://doi.org/10.3390/ma11081375

Perrot, A. (2019), " *3D Printing of Concrete: State of the Art and Challenges of the Digital Construction Revolution*" First published 2019 in Great Britain and the United States by ISTE Ltd and John Wiley & Sons, Inc. https://doi.org/10.1002/9781119610755

Pierre, A., Weger, D., Perrot, A. *et al.* (2018), *"Penetration of cement pastes into sand packings during 3D printing: analytical and experimental study"*, Materials and Structures, vol. 51, no. 22, available at: https://doi.org/10.1617/s11527-018-1148-5, 2018. https://doi.org/10.1617/s11527-018-1148-5

Rippmann, M., Block P. (2013), *"Rethinking structural masonry: Unreinforced, stone-cut shells"*, Proceedings of the Institution of Civil Engineers - Construction Materials, vol. 166, no. 6, pp. 378–389, December 2013. https://doi.org/10.1680/coma.12.00033

Sanjayan, J.G., Nematollahi, B., Xia M. *et al.* (2018), *"Effect of surface moisture on inter-layer strength of 3D printed concrete"*, Construction and Building Materials, vol. 172, pp. 468–475, 2018. https://doi.org/10.1016/j.conbuildmat.2018.03.232

Saunders, S. (2017), *"3D Printed Concrete Bridge in the Netherlands Officially Open to Cyclists"*, Published October 18, 2017, Available online at: https://3dprint.com/191375/3d-printed-concrete-bridge-open/, (Accessed on 15 October 2021)

Scott, C. (2016), *"Chinese Construction Company 3D Prints an Entire Two-Story House On-Site in 45 Days"*. Published June 16, 2016, Available online at: https://3dprint.com/138664/huashang-tengda-3d-print-house/, (Accessed on 15 October 2021)

Shakor, P., Sanjayan, J., Nazari, A. *et al.* (2017), *"Modified 3D printed powder to cement-based material and mechanical properties of cement scaffold used in 3D printing"*, Construction and Building Materials, vol. 138, pp. 398–409, 2017. https://doi.org/10.1016/j.conbuildmat.2017.02.037

Sonebi, M., Rubio, M., Amziane, S. *et al.* (2018), *"Mechanical properties of 3d printing bio-based fiber cement-based materials"*, RILEM 1st International Conference on Digital Fabrication with Concrete, Extended Abstracts, pp. 50–51, September 9-12, 2018.

Tripathy, S. (2016), " *Topology Optimization for Additive Manufacturing Applications"*, available at: https://blogs.3ds.com/simulia/topology-optimization-for-additive-manufacturing-applications/, August 23, 2016, (Accessed on 10 October 2021)

USA home (2020), *"Largest 3D printed home"*, available at: https://www.sq4d.com/largest-3d-printed-home/, 2020, (Accessed on 15 October 2021)

Valencia, N. (2017), *"World's First 3D Printed Bridge Opens in Spain"*, Published February 07, 2017, Available online at: https://www.archdaily.com/804596/worlds-first-3d-printed-bridge-opens-in-spain, (Accessed on 15 October 2021)

Vantyghem, G., Boel, V., Decorte, W. *et al.* (2018), *"Compliance, Stress-based and multi-physics topology optimization for 3D-Printed concrete structures"*, in RILEM International Conference on Concrete and Digital Fabrication, pp. 323–332, 2018. https://doi.org/10.1007/978-3-319-99519-9_30

Veenendaal, D., Block, P. (2014), *"Design process for prototype concrete shells using a hybrid cable-net and fabric formwork"*, Engineering Structures, vol. 75, pp. 39–50, 2014. https://doi.org/10.1016/j.engstruct.2014.05.036

Wangler, T., Lloret, E., Reiter, L. *et al.* (2016), *"Digital concrete: Opportunities and challenges"*, RILEM Technical Letters, vol. 1, pp. 67-75, 2016. https://doi.org/10.21809/rilemtechlett.2016.16

Weger, D., Lowke, D., Gehlen, C. (2016), *"3D printing of concrete structures using the selective binding method–Effect of concrete technology on contour precision and compression strength"*, Proceedings of 11th Fib International PhD Symposium in Civil Engineering, The University of Tokyo, Tokyo, pp. 403–410, 2016.

Weger, D., Lowke, D., Gehlen, C., et al., (2018), *"Additive manufacturing of concrete elements using the selective paste intrusion – effect of layer orientation on strength and durability"*, 1 st International Conference on Concrete and Digital Fabrication Digital Concrete 2018 – Zurich, Switzerland, 10-12 September 2018

Winsun (2015), *"2015 Global Highest 3D Printing Building"*. Available online at: http://www.winsun3d.com/En/Product/pro_inner_5/id/102, (Accessed on 15 October 2021)

Wolfs, R.J.M., Bos, F.P., Salet, T.A.M. (2018), *"Early age mechanical behaviour of 3D printed concrete: Numerical modelling and experimental testing"*, Cement and Concrete Research, vol. 106, pp. 103–116, April 2018. https://doi.org/10.1016/j.cemconres.2018.02.001

Xia, M., Sanjayan, J. (2016), *"Method of formulating geopolymer for 3D printing for construction applications"*, Materials & Design, vol. 110, pp. 382–390, 2016. https://doi.org/10.1016/j.matdes.2016.07.136

Xtree, (2018), Xtree company, *"Project – Rexcor Artificial Reef | XtreeE*", available at: http:// www.xtreee.eu/, 2018, (Accessed on 20 October 2021)

Marwah M. Thajeel (1991), PhD student at the Department of Construction Materials and Technologies, Budapest University of Technology and Economics. Finished her bachelor (2012) in Civil Engineering at College of Engineering, Al-Muthanna University in Iraq and finished her master studies (2020) Master of Science in Structural Engineering at College of Engineering, Al-Qadisiyah University in Iraq. Research areas: Reinforced Concrete, Shear Strengthening, Fiber Reinforced Polymers, Fiber Reinforced Concrete. Member of the Hungarian Group of ***fib***.

Naser S. Alimrani (1989), PhD Candidate at the Department of Construction Materials and Technologies, Budapest University of Technology and Economics. His main fields of research interest are fire design, behaviour of concrete, shear performance, failure modes of concrete at high temperatures, hollow core slabs, bond properties, bond stress-slip relationships, sustainability, and construction management. Member of the Hungarian Group of ***fib***, as well as member of the YMG in the ***fib.***

György L. Balázs (1958), Civil Engineer, PhD, Dr.-habil., Professor of structural engineering at the Department of Construction Materials and Technologies of Budapest University of Technology and Economics (BME). His main fields of activities are experimental investigation and modeling of RC, PC, FRC, FRP, HSC, HPC, LWC, fire resistance and fire design, durability, sustainability, bond and cracking. He is chairman of several commissions and task groups of ***fib***. He is president of Hungarian Group of ***fib***, Editor-in-chief of the Journal "Concrete Structures". He was elected as President of ***fib*** for the period of 2011-2012. Since then, he is Honorary President of ***fib***. Chairman of ***fib*** Com 9 Dissemination of knowledge.