Journal of Composites and Compounds 6(2024) 1-5

Available Online at www.jourcc.com

Journal homepage: www.JOURCC.com

Journal of Composites and Compounds

A mini review of additive manufacturing in medical, automotive, and construction applications

Fatemeh Heidari [a]*, Saeid Gholizadeh

[a] Department of Materials Engineering, Yasouj University, 75918-74934, Yasouj, Iran

[b] Department of Pharmaceutical Chemistry, School of Science and Technology, The University of Georgia, Tbilisi, Georgia

A B S T R A C T

Additive manufacturing (AM), commonly known as 3D printing, is a transformative approach to producing complex geometries that uses digital models to directly layer materials. Compared to conventional subtractive methods, AM uses minimal material waste and reduces production time, thereby lowering manufacturing costs. These advantages show the growing demand for 3D printers, especially where precision, customization, and efficiency are important. In this brief review, we focus on AM applications in medicine, where it enables patient-specific solutions; in the automotive sector, where it supports lightweight and optimized designs; and in construction, where it contributes to sustainable and rapid development. This review presents AM as a versatile technology that is reshaping multiple industries.

A R T I C L E I N F O R M A T I O N

Article History
Received 28 December 2023
Received in revised form 17 March 2024
Accepted 19 March 2024

Keywords:
3D printing
Additive manufacturing
Construction
Medical
Automotive

1. Introduction

Additive manufacturing (AM), considered one of the most advanced technological approaches, enables the creation of complex geometries and structures by building object layers based on 3D model data [1, 2]. Unlike traditional subtractive methods, which produce parts by removing material from a larger raw block, AM constructs components by adding material layer by layer. Since the process constructs parts directly from design cross-sections, it reduces significantly the generation of materials wastes, decreases production time significantly, and eliminates most manual and skill-intensive steps. As an illustration, while changing from traditional machining to AM procedures has been said to reduce raw materials wastes in metal fabrication by up to 40% [3].

The key advantages of additive manufacture with respect to traditional manufacture are radically precise production of intricate shapes and tailored parts, raw materials wasted during manufacture reduced, superior design greater flexibility and quicker cycle times, particularly for short runs. This process by layer enables in order to achieve accurate control over manufacture process with a view to achieve extremely fine components by a process usually unthinkable with traditional techniques[4]. Moreover, mesh-free fabrication From CAD models without molds provides significant benefits to cost savings and lead times, especially when planning or adjusting work to suit unique individual demands [5]. As compared to

* Corresponding author: Fatemeh Heidari, Email Corresponding author: f.heidari@yu.ac.ir
https://doi.org/10.61882/jcc.6.1.3

traditional machining, AM methods that utilize powders, filaments, and resins, along with the reuse of unused materials contribute to further waste reduction [6].
Today, additive manufacturing has a broad range of applications spanning industries such as automotive, healthcare, construction machinery, and consumer products, among others (Fig. 1). Hence, this paper focuses on these applications.

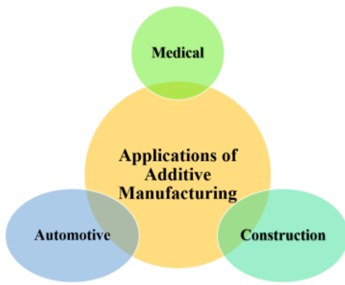

Fig. 1. Different applications of AM.

2. Medical applications

AM has astoundingly changed and is yet significantly influencing healthcare disciplines, especially when it comes to bioprinting cardiac tissues like 3D-printed heart valves, currently being one key area of research work [7-9]. Although the core principles of AM remain the same, there is now greater access to resources and tools to further explore and develop these technologies, paving the way for new medical innovations [10, 11]. However, despite the promising opportunities in medicine and biomechanics, several challenges remain. These include issues such as incomplete vascular networks in fabricated grafts and organ models, the need for large, multidisciplinary teams to support development, limitations in the layer height of printed models, and ethical considerations related to the use of 3D-printed devices in human applications [12].

2.1. Prosthetics and implants

The use of AM, along with advanced medical imaging and reverse engineering (RE), holds significant potential for producing customized implants that offer better clinical and aesthetic results, as well as biocompatible materials with strong mechanical properties [13]. However, it is extremely difficult to achieve tissue compatibility and it can take months to obtain an approval. The implant's characteristic properties are: The membranes can also influence adherence by cells to them. Certain recent studies have explored incorporation of materials to implants such as integrating drug delivery systems [13-16]. For customized implants, AM is uniquely beneficial since it can frequently start with immobilizing the patient's unique anatomy, oftentimes using medical models, and these can act as a template for producing personalized, patient-specific solutions [12].

2.2. Bioprinting and tissue engineering

3D bioprinting has already been patented ever since 2003 and has already been utilized to create tissues and organs. This involved producing three-dimensional tissue-like constructs by printing cells layer by layer on top of a biocompatible scaffold to obtain a defined layering process. This process involves printing cells by using a 3D printer onto a biocompatible matrix, enabling tissue formation close to natural ones [17]. These cells are then allowed to grow inside the scaffold, by itself normally being 3D printed with 3D printing technologies like fused deposition modeling (FDM) [18]. Among its major benefits is its capacity to print personalized designs from a patient's anatomy unique to them and frequently acquired through 3D scanning or medical imaging. Sterility is always necessary to be ensured during the process and frequently through later sterilization after printing [19]. The cell growth at times needs to take place either in vitro or in vivo prior to final application [20]. 3D models in vitro are informative tools as pertains to understanding interactions at an environment and cellular level and can aid researchers' comprehension towards biological processes and helping to further fields such as cancer research [12].
Scaffold printing techniques preserving microstructures with enhanced reproducibility have also been developed by researchers [21]. Though full-fledged, bioprinting is marred by adverse factors like degradation of cells with time and restricted interactions at the cell-to-cell level. To overcome some of these challenges, printing cells sans scaffolds was conceived by Ozbolat [22] and others, and it shows strong potential for the future of tissue engineering and regenerative medicine. Additionally, AI in discovering and developing biocomposites for tissue engineering marks a major biomedical advancement [23].

2.3. Surgical tools

AM has proved to be a most critical technology with different medical uses like planning surgery, designing implants, and teaching. Surgeons can practice and meticulously schedule surgeries preoperatively by virtue of using AM and it can boost their confidence and accuracy. Due to planning ahead, operation time can reduce and risks during surgery can reduce substantially. Apart from this, 3D printed prototypes are valuable graphic resources to communicate complex concerns to peers or students. Apart from this, AM has wide applicability to develop accurate 3D anatomical models to allow effective teaching and understanding of human anatomy among health care workers and students [24].

3. Automotive applications

The automotive industry is heavily dependent upon new-product innovation, yet it can be difficult and cost-intensive at times. The additive manufacturing process has thus become a main vehicle through which to decrease development time and expenditure and significantly lower cost of manufacture to enhance vehicle design and construction procedures components [5, 25, 26]. However, AM is confronted with some major challenges for this industry, some of them being: (i) generation of thermal stresses during printing, producing performance and consistency issues with parts [27], (ii) surface finish and dimensional accuracy issues [28], and (iii) challenges with producing large-volume components efficiently by [29].

3.1. Rapid prototyping

Employing AM to achieve rapid prototyping has some benefits like quicker product advancement and reduced manufacturing cycles later on, thereby reducing total costs [30]. The process lets manufacturers make tangible prototype models fast from CAD data to support design verification and testing. Technologies involving stereolithography [31-34] and selective laser sintering [35, 36] permit engineers to repeat on design quickly compared to orthodox techniques. It streamlines the process advancement and supports enhanced design teams' cooperation by offering prototype models to test and evaluate for fit, form, and functionality. Early customer feedback incorporation through prototype application further supports enhanced vehicle performance and user satisfaction [37].

3.2. Custom parts and structures

Examples of structural elements like engine valves and turbocharger turbines show how automotive specialized parts can be made using AM [38]. Component customization makes it possible for manufacturers to create tailor-made solutions for high-performance vehicle applications with premium specifications. The technology facilitates realization of intricate geometries impossible with conventional techniques such as tailor-made brackets, housings, and engine parts, all optimized to achieve maximized functionality, minimum weight, and materials efficiency. This flexibility supports low-volume production, making it cost-effective to manufacture niche or personalized parts without the high tooling costs associated with conventional methods [39-41].

3.3. Lightweight component manufacturing

Reducing vehicle weight is vital for improving fuel efficiency and lowering emissions. AM facilitates the production of lightweight parts through advanced design strategies like topology optimization and lattice structures, which remove unnecessary material while maintaining strength and durability [42]. This approach has been successfully applied in manufacturing lightweight brackets [40], chassis components [43], and even entire vehicle frames. These innovations help decrease overall vehicle weight, boosting performance and aligning with industry sustainability goals [44, 45].

3.4. Tooling and manufacturing aids

Aside from creating final parts, AM is essential in developing tooling and aids for automotive production lines. AM enables quick, customized production of jigs, fixtures, and molds, which enhances precision and efficiency in assembly processes [46, 47]. The ability to rapidly produce complex tooling geometries at a lower cost allows manufacturers to adapt swiftly to changing demands or design updates [48]. Furthermore, using AM for tooling significantly reduces lead times compared to traditional manufacturing, fostering more flexible and responsive manufacturing operations [49, 50].

4. Construction applications

AM is developing the construction industry by making it possible to create building components directly from digital models.

4.1. 3D Printed building components

This technology enables the quick production of customized parts such as structural panels, cladding, columns, and even entire sections of a building [51-53]. Unlike traditional construction methods, 3D printing can craft intricate designs and personalized elements on demand, reducing dependence on standard prefabricated parts and providing greater flexibility in architectural design [39, 54]. The materials employed for 3D printing in construction include specialized concrete mixes, recycled plastics, and advanced composites, offering the ability to tailor properties and performance to specific project needs [55].

4.2. Advantages and sustainability in 3D printing for construction

3D printing technology in construction offers significant advantages over traditional methods, combining enhanced construction efficiency with sustainable practices [56]. Moreover, sustainability is a key advantage of additive manufacturing in construction [57]. The technology supports environmentally friendly building approaches. The capacity to print complex, energy-efficient structures allow incorporation of features like integrated insulation, reduced thermal bridging, and other energy-saving elements directly into building components [58]. A summarized Table 1 shows some of these benefits across various construction applications.

Table 1.
Advantages of 3D printing in construction across performance and environmental dimensions.

Benefit	Brief Description	References
Speed & Efficiency	Faster construction, ideal for urgent needs and on-site builds.	[59, 60]
Design Flexibility	Creates complex, innovative shapes that traditional methods can't easily achieve.	[61, 62]
Cost Savings	Lower labor costs, reduced errors, and optimized material use.	[63]
Material Efficiency and Waste reduction	Significantly reduces raw material consumption and landfill waste; supports circular economy via recyclable materials.	[64]
Energy Conservation	Lowers carbon footprint throughout the lifecycle of the building, from production to use.	[41]
Automation & Safety	Continuous, minimal-supervision operations improve safety and reduce downtime.	[65]

5. Conclusion

Additive manufacturing is developing different industries like medical, automotive, and construction by boosting rapid prototyping, allowing for personalized parts, supporting the production of lightweight components, and streamlining tooling processes. As technological progress persists, additive manufacturing is anticipated to become even more vital in fostering innovation and enhancing efficiency within various sectors. Overall, this technology is set to speed up production, reduce costs, and promote sustainability, paving the way for innovative and eco-friendly solutions.

Author Contributions

Fatemeh Heidari: Writing – original draft, Writing – review & editing; **Saeid Gholizadeh:** Writing – original draft, Writing – review & editing.

Funding

No funding was received for this study.

Conflict of Interest

The authors declare No conflict of interest.

Data Availability

None.

REFERENCES

[1] P. Parandoush, D. Lin, A review on additive manufacturing of polymer-fiber composites, Composite Structures 182 (2017) 36-53.
[2] P. Kocovic, 3D printing and its impact on the production of fully functional components: emerging research and opportunities: emerging research and opportunities, (2017).
[3] S.J. Hollister, T.L. Bergman, Biomedical applications of integrated additive/subtractive manufacturing, Additive/Subtractive Manufacturing Research and Development in Europe 1001 (2004) 55.
[4] W. Harun, M. Kamariah, N. Muhamad, S. Ghani, F. Ahmad, Z. Mohamed, A review of powder additive manufacturing processes for metallic biomaterials, Powder Technology 327 (2018) 128-151.
[5] H. Kim, Y. Lin, T.-L.B. Tseng, A review on quality control in additive manufacturing, Rapid Prototyping Journal 24(3) (2018) 645-669.
[6] M. Srinivas, B.S. Babu, A critical review on recent research methodologies in additive manufacturing, Materials Today: Proceedings 4(8) (2017) 9049-9059.
[7] A. Jain, T. Mathur, N.K. Pandian, A. Selahi, Organ-on-a-chip and 3D printing as preclinical models for medical research and practice, Precision medicine for investigators, practitioners and providers, Elsevier2020, pp. 83-95.
[8] Z. Chen, Z. Li, J. Li, C. Liu, C. Lao, Y. Fu, C. Liu, Y. Li, P. Wang, Y. He, 3D printing of ceramics: A review, Journal of the European Ceramic Society 39(4) (2019) 661-687.
[9] D. Mohan, Z.K. Teong, A.N. Bakir, M.S. Sajab, H. Kaco, Extending cellulose-based polymers application in additive manufacturing technology: A review of recent approaches, Polymers 12(9) (2020) 1876.
[10] J. Jockusch, M. Özcan, Additive manufacturing of dental polymers: An overview on processes, materials and applications, Dental materials journal 39(3) (2020) 345-354.
[11] E.R. Ghomi, F. Khosravi, R.E. Neisiany, S. Singh, S. Ramakrishna, Future of additive manufacturing in healthcare, Current Opinion in Biomedical Engineering 17 (2021) 100255.
[12] Y. Adugna, A. Akessa, H. Lemu, Overview study on challenges of additive manufacturing for a healthcare application, IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2021, p. 012041.
[13] A. Mohammed, A. Elshaer, P. Sareh, M. Elsayed, H. Hassanin, Additive manufacturing technologies for drug delivery applications, International journal of pharmaceutics 580 (2020) 119245.
[14] J.S. Akmal, M. Salmi, A. Mäkitie, R. Björkstrand, J. Partanen, Implementation of industrial additive manufacturing: Intelligent implants and drug delivery systems, Journal of functional biomaterials 9(3) (2018) 41.
[15] L.K. Prasad, H. Smyth, 3D Printing technologies for drug delivery: a review, Drug development and industrial pharmacy 42(7) (2016) 1019-1031.
[16] T. Mohammadi, G.I.T. Mukete, Biocompatible coatings for composite medical implants: enhancing integration and performance, Journal of Composites and Compounds 5(17) (2023).
[17] E.J. Hurst, 3D printing in healthcare: emerging applications, Journal of Hospital Librarianship 16(3) (2016) 255-267.
[18] S. Costa, F. Duarte, J. Covas, Thermal conditions affecting heat transfer in FDM/FFE: a contribution towards the numerical modelling of the process: This paper investigates convection, conduction and radiation phenomena in the filament deposition process, Virtual and Physical Prototyping 10(1) (2015) 35-46.
[19] M. Salmi, Additive manufacturing processes in medical applications, Materials 14(1) (2021) 191.
[20] V. Mironov, T. Boland, T. Trusk, G. Forgacs, R.R. Markwald, Organ printing: computer-aided jet-based 3D tissue engineering, TRENDS in Biotechnology 21(4) (2003) 157-161.
[21] G. Zhong, M. Vaezi, P. Liu, L. Pan, S. Yang, Characterization approach on the extrusion process of bioceramics for the 3D printing of bone tissue engineering scaffolds, Ceramics International 43(16) (2017) 13860-13868.
[22] I.T. Ozbolat, Scaffold-based or scaffold-free bioprinting: competing or complementing approaches?, Journal of Nanotechnology in Engineering and Medicine 6(2) (2015) 024701.
[23] M. Mohabbatkhah, D. Nejadkoorki, Artificial intelligence to discover and create innovative biocomposites for tissue engineering applications, Journal of Composites and Compounds 5(17) (2023).
[24] A. Kantaros, F.I.T. Petrescu, H. Abdoli, O. Diegel, S. Chan, M. Iliescu, T. Ganetsos, I.S. Munteanu, L.M. Ungureanu, Additive manufacturing for surgical planning and education: A review, Applied Sciences 14(6) (2024) 2550.
[25] N. Guo, M.C. Leu, Additive manufacturing: technology, applications and research needs, Frontiers of mechanical engineering 8 (2013) 215-243.
[26] L. Bazli, M. Bazli, A review on the mechanical properties of synthetic and natural fiber-reinforced polymer composites and their application in the transportation industry, Journal of Composites and Compounds 3(9) (2021) 262-274.
[27] W. Gao, Y. Zhang, D. Ramanujan, K. Ramani, Y. Chen, C.B. Williams, C.C. Wang, Y.C. Shin, S. Zhang, P.D. Zavattieri, The status, challenges, and future of additive manufacturing in engineering, Computer-aided design 69 (2015) 65-89.
[28] N. Gupta, C. Weber, S. Newsome, Additive manufacturing: status and opportunities, Science and Technology Policy Institute, Washington (2012).
[29] M. Yakout, M. Elbestawi, S.C. Veldhuis, A review of metal additive manufacturing technologies, Solid State Phenomena 278 (2018) 1-14.
[30] R. Liu, Z. Wang, T. Sparks, F. Liou, J. Newkirk, Aerospace applications of laser additive manufacturing, Laser additive manufacturing, Elsevier2017, pp. 351-371.
[31] W. Li, M. Wang, H. Ma, F.A. Chapa-Villarreal, A.O. Lobo, Y.S. Zhang, Stereolithography apparatus and digital light processing-based 3D bioprinting for tissue fabrication, Iscience 26(2) (2023).
[32] S. Deshmane, P. Kendre, H. Mahajan, S. Jain, Stereolithography 3D printing technology in pharmaceuticals: a review, Drug Development and Industrial Pharmacy 47(9) (2021) 1362-1372.
[33] Y.T. Kim, A. Ahmadianyazdi, A. Folch, A 'print–pause–print'protocol for 3D printing microfluidics using multimaterial stereolithography, Nature protocols 18(4) (2023) 1243-1259.
[34] A. Unkovskiy, F. Schmidt, F. Beuer, P. Li, S. Spintzyk, P. Kraemer Fernandez, Stereolithography vs. direct light processing for rapid manufacturing of complete denture bases: an in vitro accuracy analysis, Journal of clinical medicine 10(5) (2021) 1070.
[35] W. Han, L. Kong, M. Xu, Advances in selective laser sintering of polymers, International Journal of Extreme Manufacturing 4(4) (2022) 042002.
[36] Y.A. Gueche, N.M. Sanchez-Ballester, S. Cailleaux, B. Bataille, I. Soulairol, Selective laser sintering (SLS), a new chapter in the production of solid oral forms (SOFs) by 3D printing, Pharmaceutics 13(8) (2021) 1212.
[37] M. Liu, W. Yang, Optimizing the design process of 3D printing services for personal customization, International Conference on Human-Computer Interaction, Springer, 2023, pp. 497-513.
[38] D. Cooper, J. Thornby, N. Blundell, R. Henrys, M. Williams, G. Gibbons, Design and manufacture of high performance hollow engine valves by additive layer manufacturing, Materials & Design 69 (2015) 44-55.
[39] I. Fidan, O. Huseynov, M.A. Ali, S. Alkunte, M. Rajeshirke, A. Gupta, S. Hasanov, K. Tantawi, E. Yasa, O. Yilmaz, Recent inventions in additive manufacturing: Holistic review, Inventions 8(4) (2023) 103.
[40] S.K. Samal, H. Vishwanatha, K.K. Saxena, A. Behera, T.A. Nguyen, A. Behera, C. Prakash, S. Dixit, K.A. Mohammed, 3D-printed satellite brackets: materials, manufacturing and applications, Crystals 12(8) (2022) 1148.
[41] I. Fidan, V. Naikwadi, S. Alkunte, R. Mishra, K. Tantawi, Energy efficiency in additive manufacturing: condensed review, Technologies 12(2) (2024) 21.
[42] A. Almesmari, A.N. Alagha, M.M. Naji, J. Sheikh-Ahmad, F. Jarrar, Recent Advancements in Design Optimization of Lattice-Structured Materials, Advanced Engineering Materials 25(17) (2023) 2201780.
[43] E. Dalpadulo, A. Petruccioli, F. Gherardini, F. Leali, A review of automotive spare-part reconstruction based on additive manufacturing, Journal of Manufacturing and Materials Processing 6(6) (2022) 133.
[44] P. Cheng, Y. Peng, S. Li, Y. Rao, A. Le Duigou, K. Wang, S. Ahzi, 3D printed continuous fiber reinforced composite lightweight structures: A review and outlook, Composites Part B: Engineering 250 (2023) 110450.
[45] B. HS, D. Bonthu, P. Prabhakar, M. Doddamani, Three-dimensional printed lightweight composite foams, ACS omega 5(35) (2020) 22536-22550.
[46] J.C. Vasco, Additive manufacturing for the automotive industry, Additive Manufacturing, Elsevier2021, pp. 505-530.
[47] G. Prashar, H. Vasudev, D. Bhuddhi, Additive manufacturing: expanding 3D printing horizon in industry 4.0, International Journal on Interactive Design and Manufacturing (IJIDeM) 17(5) (2023) 2221-2235.
[48] M. Goudswaard, J. Gopsill, A. Ma, A. Nassehi, B. Hicks, Responding to rapidly changing product demand through a coordinated additive manufacturing production system: a COVID-19 case study, IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2021, p. 012119.
[49] M. Javaid, A. Haleem, R.P. Singh, R. Suman, Enabling flexible manufacturing system (FMS) through the applications of industry 4.0 technologies, Internet of Things and Cyber-Physical Systems 2 (2022) 49-62.
[50] A.A. Alogla, M. Baumers, C. Tuck, W. Elmadih, The impact of additive manufacturing on the flexibility of a manufacturing supply chain, Applied Sciences 11(8) (2021) 3707.

[51] M.A. Khan, A. Latheef, Metal additive manufacturing of alloy structures in architecture: a review on achievements and challenges, Materials Today: Proceedings (2023).
[52] R. Guamán-Rivera, A. Martínez-Rocamora, R. García-Alvarado, C. Muñoz-Sanguinetti, L.F. González-Böhme, F. Auat-Cheein, Recent developments and challenges of 3D-printed construction: A review of research fronts, Buildings 12(2) (2022) 229.
[53] M. Bazli, L. Bazli, R. Rahmani, S. Mansoor, M. Ahmadi, R. Pouriamanesh, Concrete filled FRP–PVC tubular columns used in the construction sector: A review, Journal of Composites and Compounds 2(4) (2020) 155-162.
[54] N. Rane, 3D, 4D, and 5D printing in Architecture, Engineering, and Construction (AEC) Industry: Applications, Challenges, and Future Scope, Engineering, and Construction (AEC) Industry: Applications, Challenges, and Future Scope (September 28, 2023) (2023).
[55] S.F. Iftekar, A. Aabid, A. Amir, M. Baig, Advancements and limitations in 3D printing materials and technologies: a critical review, Polymers 15(11) (2023) 2519.
[56] R. Singh, A. Gehlot, S.V. Akram, L.R. Gupta, M.K. Jena, C. Prakash, S. Singh, R. Kumar, Cloud manufacturing, internet of things-assisted manufacturing and 3D printing technology: reliable tools for sustainable construction, Sustainability 13(13) (2021) 7327.
[57] M. Javaid, A. Haleem, R.P. Singh, R. Suman, S. Rab, Role of additive manufacturing applications towards environmental sustainability, Advanced Industrial and Engineering Polymer Research 4(4) (2021) 312-322.
[58] M. Mehrpouya, A. Vosooghnia, A. Dehghanghadikolaei, B. Fotovvati, The benefits of additive manufacturing for sustainable design and production, Sustainable manufacturing, Elsevier2021, pp. 29-59.
[59] A. Inozemtcev, T.Q. Duong, Technical and economic efficiency of materials using 3D-printing in construction on the example of high-strength lightweight fiber-reinforced concrete, E3S web of conferences, EDP Sciences, 2019, p. 02010.
[60] Y.W.D. Tay, B. Panda, S.C. Paul, N.A. Noor Mohamed, M.J. Tan, K.F. Leong, 3D printing trends in building and construction industry: a review, Virtual and physical prototyping 12(3) (2017) 261-276.
[61] A.M. Arefin, N.R. Khatri, N. Kulkarni, P.F. Egan, Polymer 3D printing review: Materials, process, and design strategies for medical applications, Polymers 13(9) (2021) 1499.
[62] A. Jipa, B. Dillenburger, 3D printed formwork for concrete: State-of-the-art, opportunities, challenges, and applications, 3D Printing and Additive Manufacturing 9(2) (2022) 84-107.
[63] R. Allouzi, W. Al-Azhari, R. Allouzi, Conventional construction and 3D printing: A comparison study on material cost in Jordan, Journal of Engineering 2020(1) (2020) 1424682.
[64] S.A. Khan, M. Jassim, H. Ilcan, O. Sahin, İ.R. Bayer, M. Sahmaran, M. Koc, 3D printing of circular materials: Comparative environmental analysis of materials and construction techniques, Case Studies in Construction Materials 18 (2023) e02059.
[65] J. Pasco, Z. Lei, C. Aranas Jr, Additive manufacturing in off-site construction: Review and future directions, Buildings 12(1) (2022) 53.