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A Review on 3D Printing Technology in Construction and Manufacturing Industry

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ABSTRACT

Three dimensional (3D) printing which is also known as additive manufacturing which can produce complex geometrical shapes with less human intervention and with the help of computer aided design model without any tools or dies. It is being used in manufacturing industry to automate, accelerate and to reduce the wastage of natural resources. Automatic construction systems have become the main focus of the industry because due to its freedom in geometry, formwork –less printing, low waste generation, cost-saving and safety. it explores the current trends and developments in the 3d printing industry This study will addresses the characteristics of the product geometry and structure. To discuss on parameter and experimental research and its large scale application in practice and this study aims to present the technical, sustainability and environmental aspects related to 3D printing and applications prospects of future research and market in the current industry. This paper investigates the challenges faced in the 3D printing adoption in construction industry.

Keywords: Additive manufacturing, computer aided design, Automation, 3D Printing, low waste generation, product geometry, structures, socio-economical, Sustainability

1. INTRODUCTION

The construction industry, traditionally known for its labor-intensive and time-consuming processes, is undergoing a remarkable transformation thanks to advancements in technology. While traditional methods have been the backbone of construction, they often come with challenges like excessive material waste, long project timelines, and significant environmental impacts. However, with the rise of innovative solutions, the way we design and build is changing. Among these innovations, 3D printing has emerged as a game-changer, reshaping what's possible in construction and design.

Unlike conventional techniques, 3D printing builds structures layer by layer, resulting in minimal material waste and promoting sustainability. This technology allows for the creation of intricate and complex designs with unmatched precision and efficiency, while also dramatically speeding up construction timelines. It empowers architects and engineers to explore creative, customized designs, all while meeting the growing demand for faster, cost-effective, and eco-friendly construction solutions.

Moreover, 3D printing is revolutionizing the industry with advancements in automation and scalability. By integrating robotics, AI, and smart sensors, modern 3D printers can operate independently, reducing reliance on manual labor and ensuring consistent quality. This technology is now capable of producing everything from affordable housing in underserved regions to ambitious projects like lunar habitats and space stations. As the construction industry continues to evolve, 3D printing is leading the way toward a future where innovation, efficiency, and sustainability go hand in hand.

2. MATERIAL PREPARATION

Oriented Material preparation is one of the most critical aspects of 3D printing, as the properties and performance of the final product depend heavily on the materials used. In construction, concrete and cement-based materials are the most common choices due to their strength and versatility. These mixtures typically include cement as a binder, fine aggregates like sand or gravel for volume, and water to create a paste that maintains its shape during the printing process. To enhance performance, admixtures such as plasticizers are added to improve flowability, and fibers like polypropylene or steel are incorporated to reinforce the material, making it more durable. This combination enables large-scale 3D printing of structures like walls, bridges, and entire houses, ensuring structural integrity while minimizing waste.

Thermoplastics are another widely used category, particularly in Fused Deposition Modelling (FDM) printers. Popular materials include PLA, ABS, and PETG, each offering unique benefits. PLA is a biodegradable plastic made from renewable sources like cornstarch, making it an excellent choice for prototyping. ABS is known for its toughness and impact resistance, ideal for functional parts, while PETG offers a balance of strength and chemical resistance, often used in applications that require durability and safety. These thermoplastics can also be modified with pigments or fibers to meet specific needs, enabling a wide variety of applications in both consumer and industrial sectors.

In high-performance applications, metal powders are a key material in industrial-grade 3D printers. Aluminium alloys, such as AlSi10Mg, are lightweight and corrosion-resistant, making them ideal for aerospace and automotive parts. Titanium alloys, like Ti6Al4V, provide a high strength-to-weight ratio and biocompatibility, making them suitable for medical implants. Stainless steel is widely used for its versatility and durability in structural and mechanical components. These metal powders are processed through advanced technologies like Direct Metal Laser Sintering (DMLS) and Selective Laser Melting (SLM), which create precise, high-quality parts.

Other materials, including resins, ceramics, and composites, are also integral to 3D printing. Resins, used in technologies like Stereolithography (SLA) and Digital Light Processing (DLP), excel in creating intricate designs and are often used in medical and dental applications. Ceramics, valued for their heat resistance and aesthetic appeal, are used in both functional and artistic projects. Composite materials, such as carbon fiber-infused polymers, combine strength and lightness, making them essential in aerospace and automotive industries.

3. Different methods in 3D printing

3.1 Binder jetting

Binder jetting is a type of 3D printing that works by building objects layer by layer using powdered materials like sand, metal, ceramics, or concrete. It starts with a digital model of the object, which is sliced into thin layers. A layer of powder is spread out on a platform, and then a printer head sprays a liquid binder onto certain parts of the powder to make it stick together, following the shape of the design. Once a layer is done, the platform lowers slightly, and a new layer of powder is added on top. This process repeats until the whole object is formed. When the printing is finished, the loose powder is removed, leaving behind a fragile version of the object, called a "green" part. To make it strong and ready to use, it often goes through extra steps like heating, hardening, or adding materials like resin or metal. Binder jetting is popular because it’s fast, uses materials efficiently, and can create complex and detailed designs. It’s great for making prototypes, moulds, architectural models, and construction parts.

3.2 Fused Deposition modelling

3D printing is a process that carefully creates complex objects using powdered materials. It starts with preparing the right type of powder—metals, ceramics, or polymers—with specific properties to ensure it spreads smoothly in thin, even layers. A liquid binder, chosen to work well with the powder, is used to stick the particles together. The design of the object is created in CAD software and sliced into layers, which guide the printer during the process. A layer of powder is spread on a platform, and the printer head applies the binder in specific areas to build the object one layer at a time. When printing is done, the loose powder is removed, and the printed part is strengthened with additional steps like heating or adding other materials. This technique is perfect for making high-precision items like metal casting moulds, ceramic components, or architectural models.

Fused Deposition Modelling (FDM), on the other hand, uses a simpler approach with thermoplastic filaments like PLA, ABS, or composite materials. The filament is loaded into the printer and fed into a heated nozzle, where it melts and is precisely deposited onto the print bed. As the nozzle moves across the X and Y axes and the platform moves up and down, the object is built layer by layer. Once printing is finished, the object may need some finishing touches, like removing supports or smoothing the surface. FDM is popular for being cost-effective, easy to use, and great for creating functional prototypes or everyday products.

3.3 Comparing two methods

Fused Deposition Modelling (FDM) and Binder Jetting are two popular ways of 3D printing, each designed for specific needs and applications. While they both build objects layer by layer from a digital 3D model, the techniques they use and the results they deliver are quite different.

FDM is one of the easiest and most common types of 3D printing. It uses thermoplastic materials like PLA, ABS, or other composites that are melted in a heated nozzle and then deposited onto a print bed. As the material cools, it solidifies, forming the object layer by layer. This straightforward process makes FDM affordable and beginner-friendly, which is why it’s so popular with hobbyists, educators, and small-scale manufacturers. It’s great for making functional prototypes, simple products, or models for educational purposes. However, FDM isn’t as precise as other methods, so it’s better for less intricate designs. Post-printing, the parts might need some extra work, like removing supports, sanding rough surfaces, or adding paint for a better finish.

Binder Jetting, on the other hand, is a more advanced and precise method. It uses powdered materials like metal, ceramics, or sand. Instead of melting the material, Binder Jetting uses a liquid binder to glue the powder particles together layer by layer. This method can produce highly detailed and complex shapes that would be difficult for FDM to handle. Once the printing is done, the loose powder is removed, leaving behind a fragile "green" part. To make it stronger, the part usually goes through additional steps like heating (sintering) or being infused with resin or metal. Binder Jetting is perfect for industrial and architectural applications, such as creating moulds for metal casting, ceramic parts, or intricate models.

When you compare the two, FDM stands out as a cost-effective and simple option, ideal for quick prototypes and straightforward designs. Binder Jetting, however, excels at creating high-detail parts with a wider variety of materials. It is more expensive and requires more effort in post-processing, but it’s unmatched when precision and complexity are essential.

FDM and Binder Jetting each have their own strengths. FDM is a go-to choice for beginners or those working on a budget, while Binder Jetting is the tool of choice for professionals needing detailed, intricate parts. Together, these techniques showcase the incredible flexibility and potential of 3D printing for different industries and needs.

4. BENEFITS

4.1 Enhanced Functional Performance

Works with Many Materials: It's ability to print with a variety of materials—metals, ceramics, even sand. This means it can handle everything from detailed prototypes to strong, industrial-grade parts.

Faster Production: Binder jetting is built for speed. It prints material and binder simultaneously, which helps get things done quicker. This makes it perfect when you need to meet tight deadlines or produce a lot of parts in a short amount of time.

Endless Customization: If you need something with a complex design or shape, binder jetting is up to the task. It can create detailed, intricate pieces that would be tough to make using traditional methods, so you're not limited to the usual shapes.

Perfect for Large Projects: Binder jetting isn't just for small parts. It's also capable of printing large, custom components for construction projects, or even entire structures. So it's not just versatile—it's scalable too

5. Applications:

Construction

Building Materials: Binder jetting can print large-scale materials like concrete and sand, making it ideal for creating walls, facades, and other structural elements. It's a game-changer for the construction industry.

3D Printed Homes: Some companies are even using binder jetting to print entire homes or building parts, drastically cutting down both the time and cost of construction projects.

Manufacturing:

Metal Parts: Binder jetting is used to create metal parts for industries like aerospace and automotive. It's perfect for producing complex, lightweight, yet strong components that can handle tough demands.

Rapid Prototyping: It's also a go-to method for quickly prototyping parts. Designers and engineers can test ideas and make adjustments before moving into full production, speeding up the development process.

Automotive Industry:

Custom Components: In the automotive world, binder jetting is used to create specialized parts, such as lightweight engine components, which need to meet high-performance standards.

Tooling and Fixtures: The technology also helps make custom tools and fixtures, saving time and reducing costs when manufacturing parts.

Aerospace:

Precision Metal Parts: Aerospace companies use binder jetting to create high-precision, complex parts, like turbine blades, that must withstand extreme conditions while performing at top efficiency.

5. Advantages & Disadvantages

5.1 Advantages

1. Made Just for You : One of the best things about 3D printing is that it allows for total customization. Whether it's a prosthetic that fits perfectly, o a special part for a machine, 3D printing can give you exactly what you need without any of the limits of traditional manufacturing**.**

2. Designs No One Else Can Do: With 3D printing, you can create designs that are too complex or intricate for other methods. It's perfect for exploring new shapes and ideas, whether it's for architecture, engineering, or art.

3. Speedy Prototypes: Need to test an idea? With 3D printing, you can make prototypes quickly, so you can see how a design works and make changes without waiting weeks or spending a lot of money. It's a huge time-saver for designers.

4. Less Waste, More Efficiency: Since 3D printers only use the material they need, there's way less waste compared to traditional methods, where you cut away a lot of extra material. This makes it more eco-friendly and cost-effective**.**

5. Faster Production: 3D printing helps speed up the process of making products. Whether you're printing a part or an entire prototype, it can be done faster than traditional methods, helping you meet deadlines and get things done in record time**.**

6. Flexible Supply Chains: Since you can print parts on demand, 3D printing reduces the need for long shipping times or waiting for parts to arrive from far away. It makes production more flexible and helps avoid supply chain headaches.

Disadvantages:

Limited Materials: Although the variety of materials for 3D printing is expanding, it's still not as diverse as traditional manufacturing. Some materials may not be as strong, durable, or suitable for certain applications, which can limit the technology's use in industries like construction or heavy manufacturing.

Slow Production Speed: For large-scale production, 3D printing can be much slower compared to traditional methods like injection molding or CNC machining. Printing a part layer by layer takes time, so it may not be the best choice for mass-producing items quickly.

Surface Finish and Detail: While 3D printing can create complex shapes, the surface finish might not always be smooth or precise enough for certain applications. Post-processing, like sanding or polishing, may be required to improve the appearance, which adds time and cost.

Size Limitations: The size of the object you can print is constrained by the size of the 3D printer itself. While some industrial printers can handle large components, there are still limitations when compared to traditional manufacturing methods, which can produce much larger parts more easily.

Strength and Durability: Parts made using 3D printing can sometimes be less strong or less durable than those made with traditional manufacturing processes. This is particularly true for objects made from plastics or other lightweight materials, which might not withstand high stresses or harsh environments as well as metal or other conventional materials.

Cost for Mass Production: While 3D printing is great for prototyping and low-volume production, it can become expensive for large-scale manufacturing. The cost per part can be high, especially for complex designs, making it less cost-effective than traditional methods when mass-producing items.

6. Case Studies

GE's Use of Binder Jetting in Aerospace

Company: General Electric (GE)

Industry: Aerospace

Technology: Binder Jetting 3D Printing

Application: Production of metal parts for jet engines

Challenge:

GE needed a way to create complex, lightweight, and durable jet engine parts while reducing production costs and lead times. Traditional methods like casting and forging were slow, expensive, and limited in design flexibility.

Solution:

GE partnered with ExOne to adopt binder jetting for producing metal parts like turbine blades and fuel nozzles. Binder jetting works by layering metal powder and binder to form solid parts, which are then heat-treated for strength.

Benefits:

Cost Efficiency: Reduced costs by eliminating expensive moulds and tooling.

Faster Production: Parts are produced much faster than traditional methods.

Design Freedom: Complex geometries, like internal cooling channels, could be easily printed.

Results:

By adopting binder jetting, GE was able to quickly prototype and produce high-performance components, improving both speed and efficiency. The technology enabled lighter, stronger parts for jet engines, contributing to better fuel efficiency and lower operational costs.

7. Future Research Direction

Expanding Materials: Right now, binder jetting is mostly used with a limited selection of materials. Researchers are working on expanding the range to include more metal alloys, ceramics, and even composite materials. This would make binder jetting useful for more industries like aerospace, automotive, and medical devices, where performance and material variety are key.

Stronger and Smarter Binders: The binders used in binder jetting can sometimes limit how strong or durable the final product is. Future research is aiming to develop better binders that can work with a wider variety of materials and improve the overall strength and quality of the printed parts.

Post-Processing Improvements: After a part is printed, it often needs extra steps like curing or sintering to reach its final strength. Researchers are working to make these post-processing steps quicker and cheaper, so the overall production process becomes more efficient and cost-effective.

Faster Printing for Larger Runs: Right now, binder jetting can be slow for large-scale production. Improving the speed of printing without sacrificing quality is a key research focus. By refining the technology, it could compete with traditional manufacturing methods for mass production, making it even more practical for industries that need high volumes.

Better Precision and Surface Quality: While binder jetting excels at creating complex shapes, the surface finish and resolution of printed parts could still use some work. Future developments will aim to improve the quality of the printed surface and the precision of the final product, which is especially important for industries like aerospace or healthcare where high accuracy is essential.

8. Conclusion

In conclusion, both Binder Jetting and Fused Deposition Modeling (FDM) are game-changing 3D printing technologies, each with its own strengths that make it valuable for different industries. Binder jetting stands out for its ability to work with a wide range of materials, like metals, ceramics, and composites, making it perfect for industries such as aerospace, automotive, and construction. Its ability to create lightweight, complex structures with minimal waste is a key advantage, especially for large-scale production. While it’s still improving in areas like binder strength, post-processing, and speed, the potential for innovation is huge.

On the other hand, FDM is widely recognized for its simplicity and cost-effectiveness, making it a go-to technology for rapid prototyping and creating functional parts in industries like consumer products and education. While it’s affordable and versatile in terms of material options, it does face some limitations in terms of precision and surface finish. However, ongoing advancements are addressing these issues, and as both technologies continue to evolve, they’ll offer even more efficient, customizable, and sustainable manufacturing solutions, transforming how products are designed and produced across various sectors.

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References

[1]. Iacopo Bianchi , Stelladriana Volpe , Francesco Fiorito , Archimede Forcellese, Valentino Sangiorgio , Journal of Cleaner Production, journal homepage: www.elsevier.com/locate/jclepro

[2]. Adam Hutyra , Magdalena Ba ´nkosz 1, and Bozena Tyliszczak , Technology for Automated Production of High-Performance Building Compounds for 3D Printing, Materials 2024, 17, 3829. https://doi.org/ 10.3390/ma17153829

[3]. Shahrukh Khan Lodhi , Ahmad Yousaf Gill2 , Ibrar Hussain, International Journal of Multidisciplinary Sciences and Art, E-ISSN : 2962-1658 Volume 3, Number 3 , July , 2024 https://doi.org/10.47709/ijmdsa

[4]. Meruyert Sovetova , John Kaiser Calautit, Design, calibration and performance evaluation of a small-scale 3D printer for accelerating research in additive manufacturing in construction, journal ofCleaner Engineering and Technology

[5]. Miguel-Angel Pardo-Vicente a , Pablo Pavón-Domínguez a, Daniel Moreno-Nieto a , Miriam Herrera-Collado , Evaluation of printing parameters in additive manufactured samples using fractal geometry of computed tomography images, journal of additive manufacturing, Published: 10 october 2024

[6]. Marco Valente, Abbas Sibai and Matteo Sambucci, Extrusion-Based Additive Manufacturing of Concrete Products: Revolutionizing and Remodeling the Construction Industry v,journal of composites science, Published: 4 September 2019

[7]. Tariku Sinshaw Tamir Gang Xiong , Zhen Shen , Jiewu Leng , Qihang Fang , Yong Yang f , Jingchao Jiang , Ehtisham Lodhi b, Fei-Yue Wang b, 3D printing in materials manufacturing industry: A realm of Industry 4.0, helyon journal homepage: www.cell.com/heliyon

[8]. Çağatay Takva , Semahat Merve Top , Berru İzel Gökgöz , Şeyma Gebel , Zeynep Yeşim İlerisoy , Hüseyin İlcan , Mustafa Şahmaran [e] , journal of buiding engineering, Volume 98, 1 December 2024, 111257

[9]. Dylan Bender, Ahmad Barari, Integrated Digital Design and Manufacturing for 3D Printing Technologies, ScienceDirect, IFAC PapersOnLine 52-10 (2019) 248–253

[10]. Jaebum Sung , Yeongu Choi , Hongyun So · Fabrication of functional surfaces using layer height method in material extrusion type 3D printing, Journal of Materials Research and Technology Volume 33, November–December 2024, Pages 749-757

[11]. Hongyu Zhao , Yufei Wang , Xianda Liu , Xiangyu Wang , Zhaohui Cen a , Zuxiang Lei , Yiyi Zhou , Amardeep Singh , Review on solid wastes incorporated cementitious material using 3D concrete printing technology, Case Studies in Construction Material , journal homepage: www.elsevier.com/locate/cscm

[12]. A. Derossi , M.G. Corradini , R. Caporizzi a,, M.O. Oral a and C. Severini a, Accelerating the process development of innovative food products by prototyping through 3D printing technology, Food Bioscience, journal homepage: www.elsevier.com/locate/fbio

[13]. M. Slepicka ∗ , A. Borrmann, Fabrication Information Modeling for Closed-Loop Design and Quality Improvement in Additive Manufacturing for construction, Automation in Construction, journal homepage: www.elsevier.com/locate/autcon

[14]. Valentina Tomeia,, Ernesto Grandea , Maura Imbimboa , Michele A. Caponero, 3D-printing technology for integrating the rehabilitation and monitoring of civil structures with fiber optics,science direct , Procedia Structural Integrity 64 (2024) 901–907