REVIEW ARTICLE JPAR 2024

Journal of Pharmaceutical Advanced Research

(An International Multidisciplinary Peer Review Open Access monthly Journal)

Available online at: www.jparonline.com

A Review on 3D Printing Technologies in Pharmacy

V.Swathi*, J.N.Suresh Kumar, M.Harika, Sk.Nagurbi, S.Suchitra, V.Tharuni, P.Kethana Kumari

Department of Pharmacy, Narasaraopeta Institute of Pharmaceutical Sciences, Narasaraopet, A.P., India.

Received: 27.09.2024 Revised: 20.10.2024 Accepted: 26.10.2024 Published: 31.10.2024

ABSTRACT:
3D Printing, or additive manufacturing, revolutionized various industries by enabling production of complex geometries with minimal waste and cost. 3D printing has been integrated with digital design and manufacturing process, emphasizing it is potential to accelerate prototyping, customize production, and enhance supply chain efficiency. The current advancements in 3D Printing technologies, including material innovations, process optimizations, and applications across diverse fields such as healthcare, aerospace, automotive industry, innovative industry and consumer goods are focused with future scope for its potential usage in manufacturing products especially in medical sector.

Corresponding author:
Ms. V. Swathi
Assistant Professor
Narasaraopeta Institute of Pharmaceutical Sciences,
Narasaraopet, A.P., India.
Tel: +91-9493388790
E. Mail ID: swathi.pharmabud@gmail.com

Keywords: 3D printers, organ implantation, anticipated, conventional method, operations.

INTRODUCTION:

The idea of 3D printing was initially put forth by American physicist *chuck hull* in 1983. Direct digital manufacturing another name for 3D printing, is the process of turning digital data into tangible models. Using computer aided design (CAD) software or a 3D scanner, geometric structure parameters are gathered to create successive layers of material that create 3D objects [1]. At present, 3D printing is mostly utilized to create artificial heart pump, jewellery collections, cornea, steel bridges in Amsterdam and other items for the food and aviation industries [2]. Emerging technology and 3D printers [3] affect every industry, including medicine.

TECHNOLOGIES INVOLVED IN 3D PRINTING:

There are 7 different types of technologies operated in 3D printing according to American Society for Testing and Material (ASTM) [2].

- Powder bed fusion.
- Material jetting.
- Sheet lamination.
- Directed energy deposition.
- Material extrusion.
- Vat photopolymerization.
- Binder jetting.

Powder bed fusion:

With power bed fusion, a spreader distributes thin layers of material powder across the build sites, and the thermal energy received from a heat source-such as a heated printing head, laser, or electron beam consolidates the layers. Subsequently the build site is covered with a fresh coating of material powder, and the procedure is repeated until a 3D part is created. The entire supply chain is impacted by PBF's use of multiple commodities [4].

Material jetting [5]:

- Material jetting uses a printhead that moves back and forth, similar to an inkjet printer.
- The printhead deposits tiny droplets of material, usually a photopolymer resin or wax, on to the build platform.
- The droplets are selectively deposited based on the design data sent to the printer.
- Each layer is cured with UV light or heat, depending on the material.
- The process is repeated layer by layer, building the part.

Sheet lamination [6]:

- During sheet lamination, the coated material is sliced on building platform using a controlled laser.
- A laminated sheet of material is spread using a roller mechanism in laminated object manufacture (LOM) technology.
- A computer-controlled laser to give the item the correct shape slices the coated material [6].

Directed energy deposition (DED):

- The DED technique, also referred as 3D welding, uses a laser light source to create near -net form samples from wire or powder.
- DED is used in a wide number of industries, including automotive (gear, knob, bumpers) & aircrafts (blade, engine) because of its capabilities to reduce assembly components in order to make metal parts. Metal parts like nickel alloys can be created or damaged [7].

Material extrusion:

- At temperature 165 to 300°C material extrusion is carried out.
- Acrylonitrile butadiene styrene, poly lactic acid, polycarbonate, poly methyl methacrylate polyvinyl acetate, polyether ketone, polystyrene are some of the materials used in material extrusion [8].

Vat photopolymerization:

- The first commercially viable 3D printing was created in 1986 when *Charles w. hull* submitted a patent for stereo lithography (SLA), a type of photopolymerization.
- An eye-wash cup was the first printed model ever created. Every technique is unique in the way that it applies, the way that it cures and the way that the material is in its initial state.
- In this article, vat photopolymerization the oldest AM process in history is discussed [9].

Binder jetting:

- It is expected that binder jetting will become the preferred technique for creating a wide range of materials.
- In 1993, binder jetting was developed at the Massachusetts institute of technology.
- Binder jetting is a quick prototyping and 3D printing technique where powder particles are joined by selectively depositing a liquid binding agent.
- In order to create a layer, the binder jetting technology spares chemical binder over the dispersed powder as increasing interfacial strength, mechanical and biological qualities, oxidation resistance, biocompatibility, etc [10].

LIST OF MATERIALS USED IN ADDITIVE MANUFACTURING:

The widely used materials in 3D printing are Smart materials, Ceramics, Fiber-reinforced polymer Composites, Metals, and Polymers [2].

Smart materials:

- When a material has the ability to change an objects shape and geometry in response to outside factors like heat and water, it is said to be smart. One more category for smart materials is 4D printing materials.
- Form memory alloys and form memory polymers are two instance of group smart materials. (The concept of 4D printing, where time of fourth dimension, is centred on the 3D printing of

programmable smart materials has emerged as the industry's most important issue [11].

Ceramics:

- Heat cannot fuse individual powders to their melting point, materials like ceramics and concrete cannot be manufactured with 3D.
- Important functional materials that can realize the transfer of mechanical energy to electrical energy are piezoelectric materials. ceramic is resilient, fire proof, and robust.
- The objects prepared used ceramics doesn't have big pores or cracks [12].

Fiber-reinforced polymer Composite:

- *Ozcan* and colleagues revisited the short fibre - reinforced ABS (acrylonitrile-butadiene-styrene) composite and found that the porosity for the composites is investigated with tensile strength.
- The alterations in fibre orientation, dispersion and void formation were used by them to prepare objects [13].

Metals:

There are numerous metal 3D printing techniques in use today that make use of different energy sources and feedstock materials. There are four types of direct metal printing techniques that are Ultrasonic welding, Electron Beam, Arc based, and Laser based.

Ultrasonic welding:

- Ultrasonic is a novel method that combines intermittent machining and ultra sonic seam welding to create complex structures using thin (150 mm) metallic tapes as feed stock.
- By expanding its machining envelope and boosting the ultra-sonic horns power the UAM (ultrasonic additive manufacturing) techniques has been scaled to large diameters and challenging to join materials with embedded sensors and smart materials.

Electron beam:

- The feed stock material for a 3D printing technique based on electron beam melting is supplied by wire feed or powder bed.
- An electron beam has low power. A wire is continually fed into the melt pool in wire feed version of EBM in a high vacuum chamber while an electron beam is focussed.
- With over 100 % material utilization and about 95 % power efficiency the process is extremely competitive.

Arc based:

- An arc formed between a base material and a consumable rod made of the feed stock material, DED (direct energy deposition) is applied to arc-based metal 3D printing techniques.
- The rod is fully melted and fed into the melt pool to form a weld deposit. There are several types, such as gas metal arc welding, shielded metal arc welding, plasma arc welding, 3D micro welding, and shaped metal deposition.

Laser based:

The different types of laser-based 3D printing methods are laser metal deposition, Laser sintering and Laser melting.

- One method of direct energy deposition is laser metal deposition (LMD).
- In LMD, the material may be wire or powder. In a powder-based LMD, a pressurized gas delivery system directs the powder into a melt pool that is formed on a substrate by a laser beam using one or more nozzles.
- Instead of a powder, a wire is continuously fed into the lasers path with a wire-feed LMD. Core materials are used in the tip of nozzle as wire and is constantly heated to form deposits on a substrate and almost all of the wires are consumed [14].

Polymers:

- The advancements in 3D printers resulted in utilization of polymer in polymer 3D (three-dimensional) printing.
- The benefit of polymer printing is that it makes it possible to print inexpensive functioning parts with a variety of characteristics.
- Resin extrusion and powder 3D printing techniques enable polymer printing and offer a wide range of material options for designs that support a variety of architectural responses and layouts.
- The products prepared using polymers had wide scope in medical disciplines.
- Medical models and biodegradable scaffolds are mostly made of polymer materials that includes both natural and synthetic biomaterials.
- Three often utilized natural medicinal polymeric materials are fibrin, collagen and chitosan.
- Furthermore, the process of 3D printing antimicrobial polymers can be simply extended to other nonmedical fields, like the production of kid's toys, food manufacturing and water purification.

- The relative molecular mass, shape and degradation time of synthetic materials improve printing resolution, biocompatibility, prolonged drug release, and biochemical qualities [15].

METHODS INVOLVED IN ADDITIVE MANUFACTURING:

The methods involved in manufacturing objects employing 3D printing are Three dimensional bioprintin, Stereolithography (SLA), Fused deposition modelling **(**FDM**)**, and Other forms of additive manufacturing.

Three dimensional bioprinting:

Three-dimensional bioprinting is a cutting-edge technology that combines 3D Printing and biomaterials to create living tissues and organs models. Living cells, biomaterials and growth factors are combined to create a bioink. This bioink is extruded through a printed nozzle, depositing layers of living tissue. Layers are built up to form a 3D structure. Printed tissue is incubated to promote cell growth and differentiation.

***Advantages*:**

- Customizable tissue structures.
- Reduced animal testing.
- Increased drug efficacy testing.
- Potential for organ replacement.

***Limitations*:**

- Limited biomaterial options.
- Material degradation and stability.
- Limited control over material properties.
- High equipment and material cost.

Stereolithography (SLA):

Stereolithography is a 3D Printing technology that uses resin and laser light to create models. Photosensitive resin is poured into the printing chamber. UV laser beam traces the objects cross-section onto the resin. The laser light solidifies (cures) the resin, layer by layer. The build platform rises or falls, creating space for the next layers. The process is continued until the object is complete [16].

***Advantages*:**

- Smooth surface finish.
- Accurate and precise.
- Fast printing speeds.
- Wide range of materials available.

***Limitations*:**

- Expensive equipment and materials required.
- Resin can be brittle.
- Support structures required.

Fused deposition modelling (FDM):

Fused deposition modelling (FDM) is a popular 3D Printing technology that uses melted plastic to create objects layer by layer. FDM uses a thermoplastic filament, typically ABS(acrylonitrile butadiene styrene), PLA(polylactic acid) or PETG(polyethylene terephthalate glycol). The filament is fed through a heated extruder, melting the plastic, that extrudes through a nozzle, depositing it onto the build platform. The extruder moves in X and Y axes, depositing plastic according to the design. The build platform lowers or rises, creating layers forming objects [17,18].

***Advantages*:**

- Affordable and accessible.
- Wide range of materials available.
- Easy post processing.
- Fast printing speeds.

***Limitations*:**

- Layer adhesion can be weak.
- Warping or shrinkage possible.
- Layer lines visible.

OTHER FORMS OF ADDITIVE MANUFACTURING:

- Stencil printing.
- Digital light processing (DLP).
- Embedded 3D printing (e-3DP).
- Semisolid extrusion printing (EXT)and ink jet printing (IJP).
- Selective laser sintering (SLS).

Stencil printing:

Stencil printing is a 3D Printing technique that involves depositing material through a stencil-like mask to create patterns or images on a substrate. A thin, flexible stencil is created with the desired pattern. A paste like material (e.g., conductive ink, biomaterial) is prepared. This stencil is placed on the substrate, and the material is squeezed through the stencil's openings and thus material forms the desired pattern on the substrate.

***Advantages*:**

- High resolution and accuracy.
- Low cost and simplicity.
- Environment friendly.
- Suitable for small-scale production.
- Flexibility in material choices.

***Limitations*:**

- Limited layer thickness.

- Difficulty with complex geometries.
- Material viscosity constraints.
- Limited scalability.

Digital light processing:
Digital light processing (DLP) is a 3D printing technology that uses digital light to cure liquid resin layer. A photosensitive resin is poured into the printing chamber and the digital light projector (DLP) displays images on to the resin then the projected light cures the resin layer by layer then build platform rises or falls, creating layers forming objects.

***Advantages*:**
- High resolution
- Fast printing
- Smooth surface finish
- Low material waste
- Affordable price.

***Limitations*:**
- Limited build size.
- Support structure required.
- Expensive materials.

Embedded 3D printing:
Embedded 3D printing is a technique that involves printing objects within a surrounding material, creating complex internal structures and geometries. Choosing the surrounding material and embedded object material. Designing the internal structure, object and printing the surrounding material and embedding the object removing excess material and refining the embedded object.

***Advantages*:**
- Complex internal geometrics.
- Reduced material waste.
- Increased structural integrity.
- Improve thermal and electrical conductivity.
- Enhanced aesthetic appeal.

***Limitations*:**
- Material compatibility issues
- Difficulty in removing excess material
- Potential for damage during post -processing
- High equipment and material cost

Semisolid extrusion printing& ink jet printing:
Semisolid material (e.g., paste, gel) is extruded through a nozzle material is deposited layer by layer, forming the desired shape layers are fused together creating a solid structure. The advantages are High viscosity materials can be printed, Good for printing complex geometries, Fast printing speeds, and Low material waste.
The limitations are Limited resolution, Difficulty in achieving uniform layer thickness, and Material properties may vary.

Ink Jeting:
Droplets of ink are ejected from a print head ink droplets that are deposited on to a substrate or previously printed layer. Layers fuse together forming the desired shape.
The advantages are High resolution and accuracy, Fast printing speeds, Wide range of materials can be printed and Low material waste. The limitations are Limited build size and Support structures often required.

Selective laser sintering:
Selective laser sintering is a popular 3D printing technology that uses a laser to fuse powdered material, layer by layer. A thin layer of powdered material is deposited on to build platform, high powered laser selectively fuses the powder, tracing the desired pattern. Then the fused powder forms a solid layer this process is repeated until the object is complete

***Advantages*:**
- High strength and durability.
- Goods thermal and chemical resistance.
- Complex geometries and internal structures.
- No support structure required.
- Fast printing speeds.

***Limitations*:**
- High equipment and material costs.
- Limited build size.
- Powder handling and safety concerns.
- Post -processing required.
- Limited material options.

APPLICATIONS OF 3D PRINTING [2, 20-22]:
- Automotive industry.
- Aerospace industry.
- Health care and medical industry.
- Food industry.
- Fabric and fashion industry.
- Architecture, building, and construction industry.
- Electric and electronic industry.

Automotive industry:
- Geographically, north America is currently the largest market for automotive 3D Printing services and technologies, followed by Europe and Asia-pacific.

- The automotive 3D Printing market is expected to grow significantly, reaching USD 11.26 billion by 2030.Its ability to create complex geometries, reduce production costs, and enable customization,3D Printing play an increasingly vital role in shaping the future of the automotive industry.
- BMW employs 3D Printing to produce custom components for its high-performance vehicles.

Aerospace industry:

- Companies like airbus, Boeing and Lockheed Martin are already leveraging 3D Printing technology to innovate and improve their manufacturing processes.

Health care and medical industry:

- The healthcare and medical industry has witnessed significant advancements and innovations through 3D Printing technology.
- 3D Printing creates customized prosthetics and implants, enhancing patient comfort and mobility.
- 3D Printing models and guides aid surgeons in planning and executing complex procedures.
- 3D Printing technology produces pills and capsules with tailored release rates, improving drug efficacy.
- 3D Printing streamlines production of medical devices, reducing costs and increasing efficiency.

Food industry:

- The food industry has been revolutionized by 3D Printing technology, transforming the way food is designed, manufactured and packaged.
- 3D Printing creates intricate food designs, textures and Flavors, expanding the possibilities for chefs and food manufactures.
- 3D Printing promotes sustainable food systems by reducing food waste, energy consumption and environmental impact.
- These innovations demonstrate the transformative potential of 3D Printing in the food industry, driving sustainability, efficiency and customization.

Fabric and fashion industry:

- The fabric and fashion industry has been revolutionized by 3D Printing technology, transforming design, production and sustainability.
- 3D Printing creates customized prosthetic limbs and orthotics enhancing mobility and comfort.
- Adidas 3D Printed shoes, which are mass production of customized shoes.
- NASA's 3D Printed space suits, which are advanced, functional designs for space exploration.

Architecture, building, and construction industry:

- The architecture, building and construction industry has witnessed significant advancements and innovations through 3D Printing technology.
- 3D Printed homes provide cost-effective, sustainable solutions for low-income families.
- Winsun's 3D Printed houses (China) in which over 100 affordable homes built using recycled materials.
- Dubai's 3D Printed house building it is first fully functional 3D Printed building in the Middle East.
- Apis cor's 3D Printed house (Russia) the fastest 3D Printed house, built in 24 h.
- ICON's 3D Printed homes (USA) are affordable, sustainable for low-income families.

Electric and electronic industry:

- The electric and electronic industry has witnessed significant advancements and innovations through 3D Printing technology.
- 3D Printing enables rapid prototyping and production of complex PCB's (printed circuit boards).
- NASA's 3D Printed electronics which are successfully printed electronic components for spacecraft applications.
- Intel's 3D Printed CPUs demonstrated 3D printed CPU prototypes.

CONCLUSION:

3D Printing stands as a transformative technology with the potential to reshape traditional manufacturing models. Its ability to produce complex structures with precision, customize products, and reduce waste positions as a pivotal tool across various industries. The integration of 3D Printing with digital technologies and innovations suggests a future where manufacturing is more personalized and efficient. As research and development in this field progress, 3D Printing is likely to drive significant changes in production practices, supply chains, and product design, cementing its role as a cornerstone of modern manufacturing.

REFERENCES:

1. Li H, Lu L, Li N, Zi L, Wen Q. Application of Three-Dimensional (3D) Printing in Neurosurgery. Adv Mater Sci Eng, 2022; 2022(1): 8015625.
2. Shahrubudin N, Lee TC, Ramlan RJ. An overview on 3D printing technology: Technological, materials, and applications. Procedia manuf, 2019; 35: 1286-1296.

3. Bozkurt Y, Karayel E. 3D printing technology; methods, biomedical applications, future opportunities and trends. J Mate Res Technol, 2021; 14: 1430-1450.
4. Mehrpouya M, Tuma D, Vaneker T, Afrasiabi M, Bambach M, Gibson I. Multimaterial powder bed fusion techniques. Rapid Prototype J, 2022; 28(11): 1-9.
5. Gülcan O, Günaydın K, Tamer A. The state of the art of material jetting-a critical review. Polymers, 2021; 13(16): 2829.
6. Pilipović A. Sheet lamination. In: Polymers for 3D Printing. New York: William Andrew Publishing; 2022. pp. 127-136.
7. Dezaki ML, Serjouei A, Zolfagharian A, Fotouhi M, Moradi M, Ariffin MK, *et al*. A review on additive/subtractive hybrid manufacturing of directed energy deposition (DED) process. Adv Powder Mater, 2022; 1(4): 100054.
8. Ecker JV, Kracalik M, Hild S, Haider A. 3D-material extrusion-printing with biopolymers: a review. Chem. Mater. Eng. 2017;5(4):83-96.
9. Agac M, Hajnys J, Ma QP, Jancar L, Jansa J, Stefek P, *et al*. A review of vat photopolymerization technology: materials, applications, challenges, and future trends of 3D printing. Polymers, 2021; 13(4): 598.
10. Zhao K, Su Z, Ye Z, Cao W, Pang J, Wang X, *et al*. Review of the types, formation mechanisms, effects, and elimination methods of binder jetting 3D-printing defects. J Mater Res Technol, 2023; 27: 5449-5469.
11. Azlin MN, Ilyas RA, Zuhri MY, Sapuan SM, Harussani MM, Sharma S, *et al*. 3D printing and shaping polymers, composites, and nanocomposites: a review. Polymers, 2022; 14(1): 180.
12. Sun D, Lu Y, Karaki T. Review of the applications of 3D printing technology in the field of piezoelectric ceramics. Resour Chem Mater, 2023; 2(2): 128-142.
13. Tian X, Todoroki A, Liu T, Wu L, Hou Z, Ueda M, *et al*. 3D printing of continuous fiber reinforced polymer composites: development, application, and prospective. Chin J Mech Eng, 2022; 1(1): 100016.
14. Das S, Bourell DL, Babu SS. Metallic materials for 3D printing. MRS Bull, 2016; 41(10): 729-741.
15. Arefin AM, Khatri NR, Kulkarni N, Egan PF. Polymer 3D printing review: Materials, process, and design strategies for medical applications. Polymers, 2021; 13(9): 1499.
16. Devi L, Gaba P, Chopra H. Tailormade drug delivery system: a novel trio concept of 3DP+ hydrogel+ SLA. Jf Drug Deliv Thera, 2019; 9(4-s): 861-866.
17. Patel R, Desai C, Kushwah S, Mangrola MH. A review article on FDM process parameters in 3D printing for composite materials. Materials Today: Proceedings. 2022; 60: 2162-216.
18. Yadav D, Chhabra D, Garg RK, Ahlawat A, Phogat A. Optimization of FDM 3D printing process parameters for multi-material using artificial neural network. Materials Today: Proceedings, 2020 ; 21: 1583-1591.
19. Mathew E, Pitzanti G, Larrañeta E, Lamprou DA. 3D printing of pharmaceuticals and drug delivery devices. Pharmaceutics, 2020; 12(3): 266.
20. Madhav CV, Kesav RS, Narayan YS. Importance and utilization of 3D printing in various applications. Int J Modern Eng Res, 2016: 24-29.
21. Tian Y, Chen C, Xu X, Wang J, Hou X, Li K, *et al*. A review of 3D printing in dentistry: Technologies, affecting factors, and applications. Scanning, 2021; 2021(1): 9950131.
22. Feng Y, Zhu S, Mei D, Li J, Zhang J, Yang S, *et al*. Application of 3D printing technology in bone tissue engineering: a review. Curr Drug Deliv, 2021; 18(7): 847-861.

Conflict of Interest: None
Source of Funding: Nil
Paper Citation: Swathi V*, Kumar JNS, Harika M, Nagurbi S, Suchitra S, Tharuni V, Kumari PK. A Review on 3D Printing Technologies in Pharmacy. J Pharm Adv Res, 2024; 7(10): 2422-2428.