International Journal of Research in Pharmacology & Pharmacotherapeutics (IJRPP)
IJRPP |Vol.15 | Issue 1 | Jan - Mar -2026
www.ijrpp.com
ISSN: 2278-2648
DOI : https://doi.org/10.61096/ijrpp.v15.iss1.2026.98-109

Multiprocess Approaches for Increasing Component Functionality in 3D Printing

Dhamodhara Prasad*, L. V. Vigneshwaran, Mukesh Kumar C, Shrinidhini R, Dinesh S, Ayeesha H, Roshan V
RKP College of Pharmacy, Krishnagiri, Tamil Nadu
*Corresponding Author: Dhamodhara Prasad.

Published by:
10.02.2026

Futuristic Publications

Abstract: To improve the functioning of manufactured components, multiprocess approaches in 3D printing combine additive manufacturing with complementing methods as subtractive machining, coating, embedding, multi-material integration, and automated digital processes. While sequential, parallel, hybrid, and automated multiprocessing systems enhance accuracy, strength, thermal management, electronic integration, and surface quality, traditional singlematerial 3D printing techniques frequently restrict end-use performance. The categorization of multiprocess systems, appropriate materials, multifunctional fabrication principles, and current technical developments are highlighted in this paper. Applications in engineering, healthcare, aerospace, and pharmaceuticals show how multiprocess techniques are changing component performance and making it possible to create extremely complex, functional, and customizable systems. The move to smart materials and fully automated manufacturing ecosystems is highlighted in the article's conclusion, which also discusses future potential and problems.

Keywords: Multiprocess 3D Printing; Hybrid Manufacturing; Sequential Processing; Parallel Processing; Additive–Subtractive Manufacturing; Multifunctional Components; Automated Manufacturing; Multi-Material Fabrication; Thermal Processes;.

1. INTRODUCTION:

Three-dimensional (3D) printing, also known as additive manufacturing, has transformed modern production by enabling the creation of complex geometries through layer-by-layer material deposition. Unlike traditional subtractive methods, additive manufacturing offers advantages such as design freedom, reduced material waste, rapid prototyping, and mass customization. However, most 3D printing techniques traditionally operate as single-process and single-material systems, which limits the final component's mechanical strength, surface quality, precision, and multifunctionality.

Traditional methods of material processing are not the same as 3D printing technologies. 3D printing, which is sometimes used interchangeably with additive manufacturing, solid freeform fabrication, layered manufacturing, or rapid prototyping, enables the layer-by-layer deposition of printing materials to create three-dimensional things. Accuracy, reproducibility, and dependability are among this method's outstanding qualities [1]. Computer-Aided Design/Computer-Aided

Manufacturing (CAD/CAM) programs are used in 3D printing to plan and manage fabrication procedures. CAD/CAM systems are made up of the following components: a device that uses a particular technology to build the desired thing; software that processes digital data received from the scanner and controls; and a scanner that converts geometric aspects of a 3D object into digital data [2].

In recent years, the fabrication process of layer-by-layer material deposition to create parts— also referred to as additive manufacturing or three-dimensional (3D) printing—has flourished and is now capable of producing intricate geometries for use as models, assembly fixtures, and production molds. The application of this technology for direct manufacturing of production parts has drawn more attention, but it is still mostly restricted to single-material fabrication, which may restrict the structures' end-use functionality.

Three-dimensional printing is currently among the quickest growing field of science, art, and technology, and still broadens the applications [1].This study focuses on the most recent advancements and successes in the field of biomedical and pharmaceutical research from the literature that has been published in the last three years. Though transdermal drug delivery and biomedical applications of additive manufacturing techniques, such as implants, surgical models, bio printed materials, and bio robotics, are also mentioned, the novel approaches in the formulation of solid dosage forms for customized therapy are especially focused.

The process of making three-dimensional items is called 3D printing. Charles Hull invented 3D printing in the 1980s to create plastic devices using photopolymers (Pucci et al., 2017). Later, it was employed for quick prototyping in a number of different industries, such as consumer products, robotics, automotive, and aerospace. The use of 3D printing has received a lot of interest in the pharmaceutical industry since the FDA approved the first 3D printed pill, Spriatam®, in 2015 (Warsi et al., 2018). This article mostly focuses on fused deposition modeling (FDM) 3D printing, despite the fact that there are other 3D printing techniques including stereo lithography (SLA) and inkjet-powder bed[3].Medicine, electronics, aircraft, engineering, and architecture are just a few of the many industries where 3D printing has enormous potential. Sand, metals, ceramics, and polymers are among the materials used in 3D printing [4].

2. CONCEPT AND CLASSIFICATION OF MULTI PROCESS APPROACHES

Multi process approaches in 3D printing refer to the combination of additive manufacturing with other processes, either before, during, or after printing to increase the functionality, accuracy, strength, and surface quality of component.

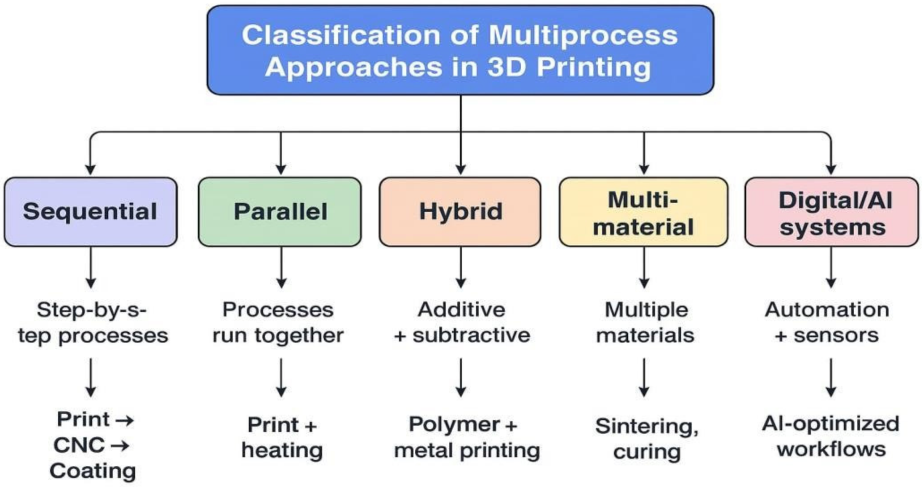

Fig 1: Classification of Multiprocess Approaches in 3d Printing.

2.1 Sequential Multiprocess System:

In the context of hybrid/higher-functionality manufacturing, “sequential” refers to processes where one type of manufacturing (e.g. additive) is completed, and then the part is moved (manually or automatically) to a different process (e.g. subtractive, coating, plating, secondary treatment), rather than doing both “simultaneously” or in fully integrated “hybrid heads.”[5] Sequential multiprocessor gives flexibility: it allows combining the strengths of different manufacturing methods — e.g. additive for complex geometry, then subtractive or finishing for high accuracy/surface quality or addition of functionality (coatings, embedded components etc.)[6].

2.2 Parallel Multiprocess System:

Parallel processing in 3D printing refers to two or more fabrication processes operating simultaneously within a coordinated manufacturing system. Unlike sequential multiprocessing (process-1 then process-2), parallel processing enables real-time cooperation between tools, print heads, robots, or manufacturing modules. This approach increases speed, efficiency, multi-material capability, structural performance, and enables fabrication of complex or functional parts not possible through single-process printing [7].

2.3 Hybrid Multiprocess System:

Additive manufacturing (AM) and subtractive manufacturing (SM) technologies, which are at very different stages of development and maturity, are integrated in hybrid additive/subtractive manufacturing (AM/SM). Although it has experienced a significant boom over the past ten years, AM is the most recent arrival and still has a lesser level of growth. AM allows for the production of items with extremely complicated geometries using a variety of materials, including plastics, metals, ceramics, and composites, either separately or in combination. This is accomplished by successively adding layers of material. [8]

2.3.1 Evaluation of concept:

A dual perspective is crucial when examining the development of the Hybrid Manufacturing AM/SM paradigm. On the one hand, it is a hybrid process that combines and optimizes both additive and subtractive manufacturing processes in a supply and production chain; on the other hand, it combines both types of technologies in a single machine [9].

Hybrid additive manufacturing, according to academics, is an integrated set of AM procedures connected to one or more nonadditive manufacturing processes, ideally machining to improve the products' outcome. The creation of an integrated supply chain is the setting for hybrid manufacturing. The fabrication of metal parts with high added value is its most advantageous field, according to the authors. OEMs are particularly interested in metallic parts since they are profitable and can be produced in small quantities or even uniquely [10]. The fact that assembly is not required, that it may be produced on demand, that waste production is eliminated or at least minimized, and that the complexity and variety of the parts do not raise the cost are all highlighted by certain authors as advantages of additive manufacturing [11]. Other advantages include shorter supply chains, faster production periods, and lower prices for skilled labour and logistics [8].

2.4 Multi Material:

By flipping the print system, we have previously suggested a technique that would enable multi material SLS printing [12]. By fusing a thin layer of powder through a glass substrate, Inverted Laser Sintering (ILS) enables us to sinter powdered material to a substrate layer by layer from the top down. The material powder is sintered onto the substrate by directing a laser up through the glass. After that, the substrate is elevated using the sintered material and transferred to a glass slide using a secondary substance. The secondary material is fused to either the substrate or the previously sintered material powder by exposing it to either the same laser or a different laser. After that, this procedure can be carried out repeatedly until a solid part is produced. In this study, we offer a method that extends the ILS the most advanced level of integration in contemporary additive manufacturing is represented by automated or digital multiprocess chains. Robotic systems, sensors, and digital process control are used to coordinate the entire workflow, from printing to finishing, in place of human intervention between processes. This makes it possible to produce high-precision, multipurpose parts with less flaws, better repeatability, and increased output [13].

2.5 Automated 3D printing:

The most advanced level of integration in contemporary additive manufacturing is represented by automated or digital multiprocessing chains. Robotic systems, sensors, and digital process control are used to coordinate the entire workflow, from printing to finishing, in place of human intervention between processes. This makes it possible to produce high precision, multipurpose parts with less flaws, better repeatability, and increased out.

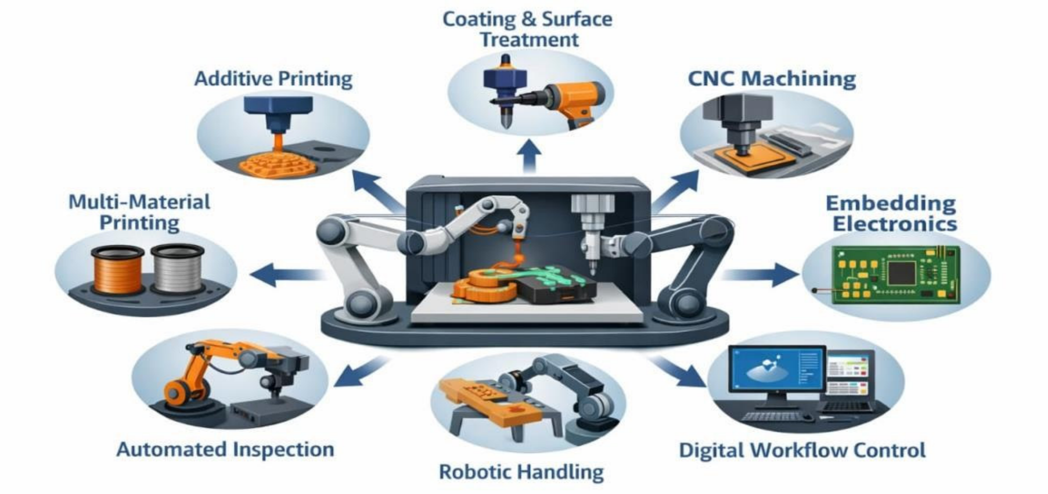

Fig 2: Automated 3d printing for increasing component functionality.

3. MATERIALS USED FOR 3D PRINTING TECNOLOGY:

To produce consistently high-quality products, 3D printing requires premium materials that adhere to uniform criteria, just like any other manufacturing process. Procedures, specifications, and material control agreements are set up between the material's suppliers, buyers, and end users to guarantee this. A variety of materials, such as ceramic, metals, polymers, and their mixtures in the form of hybrid, composites, or functionally graded materials (FGMs), can be used to create completely functioning parts using 3D printing technology [14].

3.1 Metal:

The aerospace, automotive, medical, and manufacturing industries are paying close attention to metal 3D printing technology because to its benefits [15]. Metal has exceptional physical qualities and can be employed in sophisticated manufacturing processes, such as printing human organs or aeronautical components. Aluminum alloys [16], cobalt-based alloys [17], nickel-based alloys [18], stainless steels, and titanium alloys are a few examples of these materials. An alloy based on cobalt can be used in 3D printed dental applications [20]. This is due of its high specific stiffness, robustness, elongation, high recovery capacity, and heat-treated conditions [19]. Additionally, nickel base alloys can be used in 3D printing technology to create aeronautical parts [18]. It is possible to use 3D-printed items made of nickel base alloys in hazardous settings. This is due to its strong resistance to corrosion and its ability to withstand temperatures as high as 1200 °C [17]. Finally, titanium alloys can be used to build the thing utilizing 3D printing technology. Exclusive characteristics of titanium alloys include low density, high corrosion resistance, oxidation resistance, and ductility. It is utilized in high-stress and high-temperature applications, such as the biomedical industry and aerospace components [21].

3.2 Polymers:

Polymer components, from prototypes to functional constructions with challenging geometries, are produced extensively using 3D printing technology [22]. By depositing consecutive layers of extruded thermoplastic filament, such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polypropylene (PP), or polyethylene (PE), a 3D printed object can be created using fused deposition modelling (FDM).Thermoplastic filaments with higher melting temperatures, including PMMA and PEEK, can now be utilized as materials for 3D printing technology [23]. The 3D printing industry makes extensive use of liquid-state or low-melting-point polymer ingredients because of their affordability, light weight, and processing flexibility [24]. The majority of the time, polymers were used in biomaterials and medical device goods, frequently as inert materials, to help the devices operate effectively and to provide mechanical support for many orthopedic implants [17].

3.3 Ceramics:

By optimizing the conditions and setting up the right mechanical qualities, 3D printing technology can now create 3D printed objects from concrete and ceramics that have no significant pores or cracks [25]. Ceramic is robust, long-lasting, and fireproof. Because ceramics are fluid before they solidify, they can be used in almost any geometry and shape, which are ideal for building and construction projects in the future [26]. Ceramic materials are important in dentistry and aerospace applications, according to [27]. These materials include zirconia, bioactive glasses, and alumina [28].

3.4 Smart materials:

Smart materials are those that can change an object's shape and geometry in response to environmental factors like water and heat [29]. Self-evolving structures and soft robotics systems are two examples of 3D printed objects made with smart materials. 4D printing materials can also be categorized as smart materials. Shape memory alloys [30] and shape memory polymers [31] are two instances of group smart materials. Certain shape-memory alloys, such as nickel-titanium [30], have use in microelectromechanical devices [26] and biomedical implants. Transformation temperatures, density, and microstructure repeatability are crucial factors in the creation of 3D printed goods made of nickel-titanium. In the meantime, a type of functional material called shape memory polymer (SMP) reacts to stimuli like light, electricity, heat, various chemical kinds and so forth. The intricate shape of shape memory polymer might be produced with ease and convenience by utilizing 3D printing technology. Surface roughness, part density, and dimensional accuracy are used to assess this material's quality [32].

4. MULTIPROCESS TECHNIQUES TO ENHANCE COMPONENT FUNCTIONALITY:

In order to focus on production rather than prototyping, 3D printing is now sometimes referred to as additive manufacturing [33]. Increasing the functionality of the created components is one potentially disruptive stage in the growth of 3D printing. The process of 3D printing can be initiated and halted to include alternative fabrication processes or embed subcomponents made using conventional techniques, but up until recently, 3D printing was often limited to single-material structure prototyping for form and fit assessment [34]. Multiprocess (or hybrid) 3D printing is described here as additive manufacturing augmented by complementing procedure. Traditional manufacturing techniques including machining, cutting, dispensing, robotic placement, and more can be included in these complimentary processes. The objective of this new method, which represents a paradigm shift, is to create multifunctional end-use devices in a non-assembly process, possibly combining electronic, electromagnetic, optical, fluidic, actuation, chemical, and thermal features all at once—all with the built-in geometric advantages of 3D printing. Furthermore, these cutting-edge 3D printing technologies continue to take advantage of mass customization without the need for tools [35].

4.1 Multifunctional fabrication process:

The layer-by-layer manufacturing process is the foundation of 3D printing, which allows manufacturing flexibility with the provision of interrupting the process to leverage complementary processes. The ASTM(American society for Testing and Materials)F42 subcommittee was established in 2009,to provide standards for common terminology, testing techniques, file formats, and more additive manufacturing concepts, and has identified a taxonomy of seven basic 3D printing processes[36].Multiprocess additive technologies, which are based on 3D printing, typically have lesser throughput than traditional methods. However, new 3D-printed geometries are now feasible, and additive manufacturing has its own benefits. For instance, the non assembly methodology reduces labour requirements, and the removal of tooling enables mass customization, allowing each production part to be customized [37]. While more recent technologies, especially the powder bed fusion of metals using lasers or electron beams, offer many of the same properties as conventional cast and even wrought materials, the mechanical performance of the structures created by some of the additive processes struggles in the area of anisotropic strength [38].

- A vat of liquid photo-curable polymer is selectively cured using an energy source, such as a laser beam or a lamp with a projection system, in a process known as vat photo polymerization. Usually, a platform that falls after each layer has been selectively cured is used to produce the fabricated part layer by layer.

- The process of selectively dispensing material through an extrusion nozzle is known as material extrusion. Thermoplastics that require heated extrusion are the most frequent utilize material usually the procedure entails extrusion and/or layer-by-layer production using a moving platform.

- Powder bed fusion is the process of employing a thermal energy source, like a laser or electron beam, to fuse specific areas of powder in a bed. A rake or roller dispenses more powder to produce the subsequent layer as a platform supporting the bed drops by a layer thickness.

- Binder jetting joins powder feedstock in a bed supported by a platform by selectively dispensing a binder. Similar to powder bed fusion, the platform drops by a layer thickness, and more powder is dispensed by a rake or roller. The majority of parts need to be post processed using a furnace cycle and an infiltrate.

- Droplets of the construction material, usually photo-cured, are selectively deposited using material jetting. For every layer, deposition and curing are repeated.

- Sheet lamination is the process of bonding individual sheets of material together to create a structure. In order to precisely produce the 2D shape for each individual layer, it is usually necessary to machine or cut between layers.

- Both a material deposition (usually wire or powder) and an energy source (usually a laser or an electron beam) at the construction site. Improvements that allow for the printing of structures with more functionality would be advantageous for each of these operations. In order to incorporate functional components and conductive traces into a building, the first documented research from the 1990s used the layered technique of 3D printing by stopping the process [39].

- This is an early example of multiprocess 3D printing, where 2D sheets are essentially piled together to create a 3D item made with two processes. Robinson and associates stopped the ultrasonic consolidation method, which combines material extrusion with conductive and thermoplastic ink to insert basic circuits [40].

Any additional capability beyond rendering is referred to as multifunctionality in additive manufacturing. A simple form. For example, a structure can have many colours and densities graded throughout, which qualifies as multifunctionality (although marginally). These structures can be made using a variety of common commercial 3D printing techniques. Actually, multi-coloured processes have been on the market for years [41]. Additional instances of multifunctionality with mechanical metamaterials used in commercial 3D printers create negative stiffness to dampen vibrations and lessen noise in the cabin or that enable pneumatic actuation, as illustrated in Fig. 1. Associated though not the same as multipurpose 3D printing, Multiprocess 3D printing: the cooperative application comprising several processes often but not always produces item with several uses

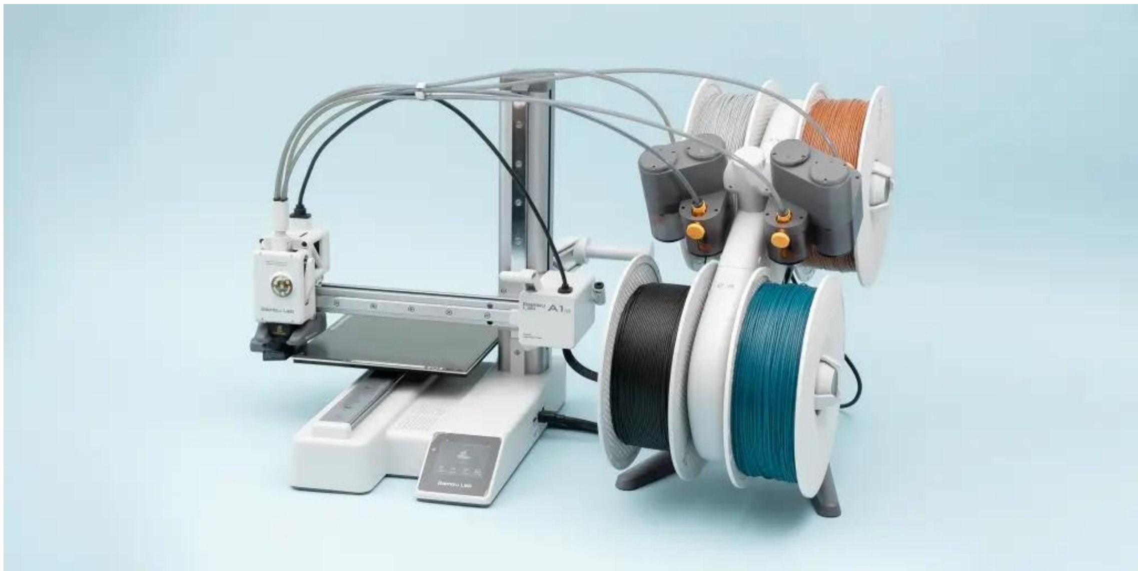

Fig 3: Example of 3D printing.

4.2 Thermal Processes:

The insertion of electrical and thermal interconnects enables for subsystem communication or the transmission of energy or heat throughout a structure [44]. Inks that are conductive and pastes have been used in conjunction with 2D printing because of the manufacturing flexibility of direct writing (e.g., the ability to print conform ally, no tooling required). The combination has been studied for more than ten years using micro dispensing, ink jetting, and aerosol jetting [43-44]. The inks have typically been applied to the exterior surfaces of completed constructions, although there have only been a few instances of stopping and starting over. A 3D printing method to incorporate interconnect functionality completely. Conductive inks have improved over the past two decades but still suffer from high resistance relative to traditional printed circuit boards manufactured with a bulk copper plating process. Reliability is still an issue, and higher resistance conductors cause performance declines with voltage drops and power loss [45].

Low-temperature metal alloys have been printed using modified thermoplastic extrusion heads and through injection into polymer structures to provide connectivity with increased conductivity relative to inks. When compared to bulk plated copper used in conventional electronics, connectivity still falls short, despite the fact that these alloys typically have better conductivity than conductive particle-loaded inks [46]. Although selective plating on 3D printed substrates has been shown to be possible with laser direct structuring, which offers bulk characteristics and is an interesting discovery, it does necessitate an additional chemical bath process [47]

4.2.1 Thermal management:

Researchers have been investigating sophisticated geometrically complex heat exchangers for years because to the design flexibility provided by 3D printing. Metal 3D printing methods have been used to construct complicated large-surface-area structures having excellent thermal conductivity [48] for applications such as fluidic heat transfer devices [49], 3D-printed plastic injection moulds [50], and even thermonuclear reactors [51] Thermal management applications, such as sophisticated designs with integrated heat pipes and phase reservoirs, will develop along with multiprocessor 3D printing. Changing material, leading to enhanced thermal management in 3D constructions [50]

4.3 Additive and Subtractive manufacturing:

By constructing structures layer by layer utilizing a variety of 3D printing technologies, additive manufacturing (3D printing) is a new and promising method that can fabricate titanium and zirconia components [52]. The additive fabrication of zirconia has also gained substantial interest in dentistry research because of its intriguing potential for creating complicated ceramic restorations [52-53]. In these methods, the slurry is cured layer by layer using light to form a green (pre-sintered) part [54]. After printing, the part is dried and then subjected to post-processing through sintering at high temperatures to achieve the necessary strength and durability for clinical dental applications. A significant benefit of 3D printing of zirconia is its material efficiency, as only a small amount of ceramic suspension is required to create the intended object, which helps reduce material waste [52]. Research has demonstrated the efficacy of 3D printing of zirconia for dental restorations [54].

5. APPLICATION OF MULTIPROCESS APPROACHES:

In many applications, such as high-demand servers, scientific simulations, and sophisticated software like video editing and big databases, multiprocessor techniques are utilized to increase performance and efficiency. Additionally, they are essential for embedded systems, which enhance energy efficiency and real-time performance in gadgets like supercomputers and cell phones. They essentially make it possible to divide and carry out activities in parallel, which improves scalability, responsiveness, and processing speed.

Pharmaceutical Formulations:

3D printing technology can make loose and porous preparations, thus, assisting them to consume medication; for patients who take multiple drugs at the same time, separate pharmaceuticals can be partitioned and mixed into a single pill to avoid errors or missed medications, which can promote the safety and effectiveness of medication; in addition, particularly shaped preparations can be printed or unique symbols can be printed on the surface of the preparation to provide convenience for patients with visual impairment [55]. The advantages of 3D printing technology for tailored medication delivery give technical support for patients to accomplish personalized medicine, and some 3D printed drug businesses are progressing towards the aim of personalized medicine, such as FabRx in the UK, which makes tailored medications for children with maple diabetes, and has deployed SSE printers in the pharmacy of a Spanish hospital and conducted clinical research on the issue [56].

Aerospace Industry:

Unmatched freedom in component and production design is made possible by 3D printing technology. In aircraft industry, 3D printing technology has potential to manufacture lightweight parts, better and complicated geometries, which can minimize energy need and resources [57]. At the same time, by adopting 3D printing technology, it can contribute to fuel savings because it can reduce the material necessary to make aerospace's parts. Additionally, the production of spare parts for certain aircraft components, such engines, has made extensive use of 3D printing technology. Engine parts must be replaced frequently because they are easily damaged. Therefore, 3D printing technology is a good alternative to the acquisition of such spare parts [58]. Nickel-based alloys are increasingly favoured in the aerospace sector because of their damage tolerance, oxidation/corrosion resistance, and tensile qualities.

Healthcare and Medical Industry:

3D skin, medication and pharmaceutical research, bone and cartilage, replacement tissues, organs, printing for cancer research, and models for visualization, teaching, and communication are all possible with 3D printing technology [59]. The technology of 3D printing has numerous benefits for biomedical products which are:

- The skin's natural structure can be more affordably replicated using 3D printing technology. Skin that is 3D printed can be used to test pharmaceutical, cosmetics, and chemical products. Therefore, it is unnecessary to use the animal skin to test the items. As a result, the researcher will be able to obtain precise results by using imitate the skin [60].
- By employing 3D printing technology to print drug can increase efficiency, accurate control of dropped size and dose, high repeatability and able to construct dosage form with complex drug-release profiles [61].
- Cartilage and bone can be printed using 3D printing technology to fill up bony holes in the cartilage or bone that brought on by

illness or trauma. This treatment is distinct choices from employing auto-graft sand all or grafts since this treatment focuses on to manufacture bone, maintain, or improve its function by employing in vivo

- Additionally, the function of tissues can be improved, maintained, restored, or replaced using 3D printing technology. The replacement tissues made using 3D printing technology feature a network of interconnected pores, are biocompatible, have the right surface chemistry, and have good mechanical properties [60].
- 3D printing technology also can be utilized to build up identical organ failure caused by essential difficulties such as disease, accidents, and congenital deformities.

6. FUTURE PROSPECTIVE:

One advantage of 3D printing is that it can manufacture intricate structures more quickly than traditional methods. Numerous industries, including aerospace, automotive, electronics, medical, food packaging, construction, and home appliances, have demonstrated the productivity of this technique. However, to further cater to the demand for particular and customized parts, 3D printing technology is taken to another level known as 4D printing. 4D printing uses shape memory polymers for more customized applications.

Also, certain disadvantages need urgent attention for improved technical growth. The drawbacks are anisotropic mechanical qualities, limited applications due to limited materials, and high-cost limiting uses in big constructions. Material and methodology study and development have helped to avoid some of these challenges. However, there are still a few issues that need to be resolved in order to expand additive manufacturing (AM) to a wider range of industries and applications.

7. CONCLUSION:

Multiprocess approaches in 3D printing represent a transformative advancement that significantly expands the functional capabilities of additively manufactured components. By integrating additive, subtractive, thermal, electronic, and automated processes, it becomes possible to fabricate complex, high-performance, multifunctional structures beyond the limitations of single-process printing. These technologies support the development of next generation components with enhanced mechanical, thermal, biomedical, and electronic functionality across various industries. While challenges such as high cost, material constraints, and process complexity persist, ongoing innovations—including 4D printing and smart materials—promise to further elevate the potential of multiprocess manufacturing. Overall, multiprocess 3D printing is poised to play a crucial role in future industrial production, personalized medicine, aerospace engineering, and advanced manufacturing ecosystems.

REFERENCE:

1. Prosthetic models produced by traditional and additive manufacturing methods. The Journal of Advanced Prosthodontics, 2015; 7(4): 294- 302.
2. Torabi K, Fariood E, Hamedani S, Rapid prototyping technologies and their applications in prosthodontics, a review of literature. Journal of Dentistry, 2015; 16(1): 1-9. Park J-Y, Kim H-Y, Kim J-H, Kim J-H, Kim W-C, Comparison of
3. Ligon SC, Liska R, Stampfl J, Gurr M, Mülhaupt R, Polymers for 3D printing and customized additive manufacturing. *Chemical Reviews*, 2017; 117(15):10212-10290
4. L. J. Love, R. F. Lind, J. F. Jansen, "Mesofluidic actuation for articulated finger and hand prosthetics," in 2009 IEEE/RSJ Conference on Intelligent Robots and Systems [Institute of Electrical and Electronics Engineers (IEEE), 2009]pp. 2586–259
5. B. P. Conner et al., Making sense of 3-D printing: Creating a map of additive manufacturing products and services. Addict. Manuf.1–4, 64–76 (2014). doi: 10.1016/j.addma.2014.08.005
6. Vijaya Venkataraman S, Fuh JYH, Lu WF, 3D printing and 3D bioprinting in pediatrics. Bioengineering, 2017; 4(3): 1-11.
7. Park J-Y, Kim H-Y, Kim J-H, Kim J-H, Kim W-Comparison of prosthetic models produced by traditional and additive manufacturing methods. *The Journal of Advanced Prosthodontics*, 2015; 7(4): 294-302

8. Perez M, Caroe D, Rubio EM, Teti R, Current advances in additive manufacturing, Procedia CIRP 2020;88: 439–444
9. Strong, D, Siri Chakwal I, Manogharan G, Wakefield T. Current State and Potential of Additive - Hybrid Manufacturing for Metal Parts, Rapid Prototyping Journal 2017; Vol.23 Issue 3: 577-588
10. Lipson and M. Kurman, La revolution de la impression 3D. Madrid, España: Multimedia, Anaya, 2014
11. J. Whitehead, H. Lipson, Inverted multi-material laser sintering, Addit.Manuf.36(2020)101440,doi:10.1016/j.addma.2020.10140
12. amp J. Whitehead, H. Lipson, Embedding components during laser sintering, Addit. Manuf. Lett. (2022) 100055, doi:10.1016/j.addlet.2022.100055.
13. A. M. T. Syed, P. K. Elias, B. Amit, B. Susmita, O. Lisa, & C. Charites's, "Additive manufacturing: scientific and technological challenges, market uptake and opportunities," Materials today, Vol. 1, pp. 1-16, 2017.
14. D.J. Horst, C.A. Duvoisin, & R.A. Viera, "Additive manufacturing at Industry 4.0: a review," International Journal of Engineering and Technical Research, Vol. 8, No.8, pp. 1-8, 2018.
15. J.H. Martin, B. D. Yahata, J. M. Hundley, J. A. Mayer, T. A. Scheduler, & T. M. Pollock, "3D Printing of high-strength aluminum alloys," Nature, Vol. 549, No. 7672, pp. 356-369, 2017.
16. L. Hitzler, F. Alifui-Segbaya, P. William, B. Heine, M. Heitzmann, W. Hall, M. Merkel, & A. Ochner, "Additive manufacturing of cobalt based dental alloys: analysis of microstructure and physio mechanical properties," Advances in Materials Science and Engineering, Vol. 8, pp. 1-12, 2018.
17. L. E. Murr, "Frontiers of 3D Printing/Additive Manufacturing: from Human Organs to Aircraft Fabrication," Journal of Materials Sciences and Technology, Vol. 3, No. 10, pp. 987-995, 2016.
18. T. Debroy, H. L. Wei, J. S. Zuback, T. Mukherjee, J. W. Elmer, J. O. Milewski, A. M. Beese, A. Wilson-Heid, A. De, & W. Zhang, "Additive manufacturing of metallic components-Process, structure and properties," Progress in Materials Science, Vol. 92, pp. 112-224, 2018.
19. E. Uhlmann, R. Kersting, T. B. Klein, M. F. Cruz, & A. V. Borille, "Additive manufacturing of titanium alloy for aircraft components," Procedia CIRP, Vol. 35, pp.55-60, 2015
20. F. Trevisan, F. Calignano, A. Aversa, G. Marchese, M. Lombardi, S. Biamino, D. Ugues & D. Manfred, "Additive manufacturing of titanium alloys in the biomedical field: processes, properties and applications," Journals Indexing & Metrics, Vol. 16, No. 2, 2018.
21. M. A. Caminero, J. M. Chacon, I. Garcia-Moreno, & G. P. Rodriguez, "Impact damage resistance of 3D printed continues fibre reinforced thermoplastic composites using fused deposition modelling," Composite Part B: Engineering, Vol. 148, pp. 93103, 2018.
22. J. R.C. Dizon, A. H. E. Jr, Q. Chen, R. C. Ad vincula, "Mechanical characterization of 3d-printed polymers," Additive Manufacturing, Vol. 20, pp. 44-67, 2018.
23. W. Xin, J. Man, Z. Zuowan, G. Jihua, & H. David, "3D printing of polymer matrix composites: A review and prospective," Composites Part B, Vol. 110, p.442458,2017
24. P. A. Gunatillake, & R. Adhikari, "Nondegradable synthetic polymers for medical devices and implants," Biosynthetic Polymers for Medical Applications, Vol. 1, pp.3362, 2016.
25. F. Baldassarre, & F. Ricciardi, "The Additive Manufacturing in the Industry 4.0 Era: The Case of an Italian FabLab," Journal of Emerging Trends in Marketing and Management, Vol. 1, No.1, pp. 1-11, 2017.
26. D. Owen, J. Hickey, A. Cusson, O. I. Ayeni, J. Rhoades, D. Yifan, W. Limmin, P. Hye-Yeong, H. Nishant, P. P. Raikar, Yeon-Gil, & Z. Jing, "3D printing of ceramic components using a customized 3D ceramic printer," Progress in Additive Manufacturing, Vol 1, pp. 1-7, and 2018.
27. A. Zocca, P. Lima, & J. Günster, "LSD-based 3D printing of alumina ceramics," Journal of Ceramic Science and Technology, Vol. 8, No. 1, pp. 141-148, 2017.
28. L. Jian-Yuan, A. Jia, & K. C. Chee, "Fundamentals and applications of 3D

printing for novel materials," Applied materials today, Vol 7, pp. 120-133, 2017.

29. H. J. Van, "Additive manufacturing of shape memory alloy," Shape memory and super elasticity, Vol. 4, No. 2, pp. 309-312, 2018.
30. Y. Yang, Y. Chen,Y. Wei, & Y. Li, "3D Printing of shape memory polymer for functional part fabrication," The International Journal of Advanced Manufacturing Technology, Vol. 84, No. 9, pp. 2079-2095, 2015
31. Wohler's Associates, Wohler's Report 2014 (Wohler's Associates, 2014).
32. B. P. Conner et al., Making sense of 3-D printing: Creating a map of additive manufacturing products and services. Addit. Manuf. 1–4, 64–76 (2014). doi:10.1016/j.addma.2014.08.005
33. P. Reeves, C. Tuck, R. Hague, "Additive manufacturing for mass customization," in Mass Customization: Engineering and Managing Global Operations, F. S. Fogliatto, G. J. C. da Silveira, Eds. (Springer, 2011), pp. 275–289...
34. ASTM F42 Committee, Terminology for Additive Manufacturing Technologies (ASTM International, 2012).
35. L. E. Weiss et al., Shape deposition manufacturing of heterogeneous structures. J. Manuf. Syst. 16, 239–248 (1997). doi: 10.1016/S0278-6125(97)89095-4
36. C. Robinson, B. E. Stucker, A. J. Lopes, R. Wicker, J. A. Palmer, "Integration of direct-write and ultrasonic consolidation technologies to create advanced structures with embedded electrical circuitry," in Solid Freeform Fabrication Symposium Proceedings (University of Texas at Austin, 2006), pp. 60–69
37. C. Newell et al, Out of bounds additive manufacturing. Ady.Mater. Process, 171, 1519 (2013).
38. L, E. Murr et al, Metal fabrication by additive manufacturing using laser and electron beam melting technologies. J. Mater.sci. Technol. 28, 1-14 (2012).doi:10.1016/S1005-0302(12)60016-4
39. D.Quil, N .A. Langarana Void eliminating toolpath for extrusion based multi -material layered manufacturing rapid prototyping J.8,3845(2002).doing:10.1108/13552540210413 293
40. M. R. Haberman, T. D. Klatt, P. S. Wilson, C. Seepersad, Negative stiffness metamaterials and periodic composites. J. Acoust. Soc. Am. 131, 3372 (2012). doi: 10.1121/1.4708717
41. B. Y. Ahn et al., Planar and three-dimensional printing of conductive inks. J. Vis. Exp. 58, e3189 (2011). pmid: 22214978
42. R. O. Kadara, N. Jenkinson, B. Li, K. H. Church, C. E. Banks, Manufacturing electrochemical platforms: Direct-write dispensing versus screen-printing. Electrochemical. Commun. 10
43. J. L. Zunino III, D. P. Schmidt, A. M. Petrock, B. E. Fuchs, Inkjet printed devices for armament applications. NSTI-Nanotech 2, 542–545 (20110
44. J. P. Swensen, L. U. Odhner, B. Araki, A. M. Dollar, Printing three-dimensional electrical traces in additive manufactured parts for injection of low melting temperature metals. J. Mech. Robotics 7, 021004 (2015). doi: 10.1115/1.4029435
45. A. Wild, Integration of functional circuits into FDM parts. Adv. Mater. Res. 1038, 29–33 (2014). doi: 10.4028/www.scientific. net/AMR.1038.29
46. .T. J. Horn, O. L. Harrysson, Overview of current additive manufacturing technologies and selected applications. Sci. Prog. 95, 255–282 (2012). doi: 10.3184/ 003685012X13420984463047; pmid: 23094325
47. M. Wong, S. Tsopanos, C. J. Sutcliffe, I. Owen, Selective laser melting of heat transfer devices. Rapid Prototyping J. 13, 291–297 (2007). doi: 10.1108/13552540710824797
48. E. Sachs, E. Waylon's, S. Allen, M. Cima, H. Guo, Production of injection molding tooling with conformal cooling channels using the three dimensional printing process. Polym. Eng. Sci. 40, 1232–1247 (2000). doi: 10.1002/pen.11251
49. M. A. García, C. García-Pando, C. Marto, "Conformal cooling in moulds with special geometry," in Innovative Developments in Virtual and Physical Prototyping (CRC Press, 2011), pp. 409–412.
50. Alageel, O.; Alhijji, S.; Alsadon, O.; Alsarani, M.; Gomawi, A.A.; Alhotan, A. Trueness, flexural strength, and surface properties of various three-dimensional (3D) printed

interim restorative materials after accelerated aging. *Polymers* **2023**, *15*, 3040.

51. Wang, Y.; Zhou, Y.; Zhu, H.; Jiang, J.; He, F. Accuracy, fit, and marginal quality of advanced additively manufactured and milled zirconia 3-unit fixed dental prostheses. *J. Prosthet. Dent.* **2025**, *133*, 208.e1–208.e10.
52. Bergamo, E.T.; Zahoui, A.; Ikejiri, L.L.A.; Marun, M.; da Silva, K.P.; Coelho, P.G.; Soares, S.; Bonfante, E.A. Retention of zirconia crowns to Ti-base abutments: Effect of luting protocol, abutment treatment and autoclave sterilization. *J. Prosthodont. Res.* **2021**, *65*, 171–175.
53. van Kampen, E.E.M.; Willemsteijn, L.; Ruijgrok, E.J. 3D Printing of Drugs: Expanding the Options for Child-Tailored Pharmacotherapy. *Arch. Dis. Child* **2021**.
54. Goyanes, A.; Madla, C.M.; Umerji, A.; Duran Piñeiro, G.; Giraldez Montero, J.M.; Lamas Diaz, M.J.; Gonzalez Barcia, M.;Taherali, F.; Sánchez-Pintos, P.; Couce, M.-L.; et al. Automated Therapy Preparation of Isoleucine Formulations Using 3D Printing for the Treatment of MSUD: First Single-Centre, Prospective, Crossover Study in Patients. *Int. J. Pharm.* **2019**, *15*, 118497.
55. S. C. Joshi, & A. A. Sheikh, "3D-printing in aerospace and its long-term sustainability," Virtual and Physical Prototyping, Vol. 10, No.4, pp. 175-185, 2015.
56. W. Yu-Cheng, C. Toly, & Y. Yung-Lan, "Advanced 3D printing technologies for the aircraft industry: a fuzzy systematic approach for assessing the critical factors," The International Journal of Advanced Manufacturing Technology, Vol. 3, No.3, pp. 1-10, 2018.
57. D. Pai, "3D-Printing skin is real: Here's what you need to know," Allure News. 2017. [Online]. Available: https://www.allure.com/story/3dprinting-skin. [Accessed 2019]
58. Y. Qian, D. Hanhua, S. Jin, H. Jianhua, S. Bo, W. Qingsong, & S. Yusheng, "A Review of 3D Printing Technology for Medical Applications," Engineering, Vol. 4, No. 5, pp. 729-742, 2018.
59. C. L. Ventola, "Medical Application for 3D Printing: Current and Projected Uses," Medical Devices, Vol. 39, No.10, pp. 1-8, 2014.
60. L. Yigong, Q. Hamid, J. Snyder, W. Chengyang, & S. Wei, "Evaluating fabrication feasibility and biomedical application potential of in situ 3D printing technology," Rapid Prototyping Journal, Vol.22, No.6, pp. 947 – 955, 2016.