International Journal Of Advance Research, Ideas And Innovations In Technology

IJARIIT

**ISSN: 2454-132X**
**Impact Factor: 6.078**
***(Volume 10, Issue 3 - V10I3-1170)***
Available online at: https://www.ijariit.com

# APPLICATIONS OF 3D PRINTING IN A MULTITUDE OF INDUSTRIES

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## ABSTRACT

***3D printing, also called Additive Manufacturing (AM) is the most rapidly growing industrial technique, fostering inventive, economical, and eco-friendly solutions. It can produce complex-shaped products using the data provided by computer-aided design (CAD) software, layer by layer, with high precision resulting in minimal material wastage. The main agenda of this paper is to portray the various applications of this technology in different everyday industries which include the aerospace, automotive, medical, construction, and fashion industries respectively. It aims to show the countless advantages of AM over conventional methods as well as its relevance in the upcoming years.***

**Keywords:** *Additive manufacturing, 3D printing, Applications, Industries*

## I. INTRODUCTION

3D printing, an additive manufacturing process that produces objects layer by layer has been able to transform the working of several industries due to its vast variety of applications. The terms additive manufacturing (AM) and three-dimensional (3D) printing are general terms that encompass numerous techniques for producing three-dimensional models and structures from digital files provided to the 3D printer software. “The geometry of the object is designed using computer-aided design (CAD) software using commercial industry standard programs such as SolidWorks or AutoCAD. On the other hand, the creation of 3D models is usually performed using programs such as Blender, FreeCAD, Meshmixer, and SketchUp, which are available in free versions. The designed object is saved in the appropriate file format that can be read by the 3D printer software” (Oleksy, Dynarowicz, and Aebisher 2023). The solid modeling component of CAD is the foundation of additive technologies. Additive models use this solid modeling data to build layers of incredibly thin cross-sectional areas, enabling the manufacturing of complex and intricate shapes and surfaces that are very challenging to achieve with conventional methods (Jandyal et al 2022).

The adaptable architecture of this process facilitates the production of multiple components in a single process cycle and reduces human errors during prototyping. (Oleksy, Dynarowicz and Aebisher 2023). Reductions in product weight, transportation costs, and material losses, together with enhanced functionality and the ability to print spare parts, are a few advantages of putting the technology into practice (Böckin and Tillman 2019). Many techniques can be associated with AM namely powder bed fusion, binder jetting, material extrusion, Materials jetting, Sheet lamination, and VAT photopolymerization (Shahrubudin, Lee, and Ramlana 2019). The ability to work with a wide range of materials such as metals, polymers, ceramics, and composites, as well as continuous advancements in technology are the main reasons for the growth of AM. The demand for customized products, quicker product development cycles, lower manufacturing costs and lead times, a stronger emphasis on sustainability, and innovative business models are what are driving the development of the technology (Pérez et al 2020). Since the beginning, AM has not only served as a rapid prototyping method for cost-effective and quicker product development but it has also had a profound impact on designing products, directly manufacturing individual parts, and assembling and repairing parts in different industries (Fouzan et all 2023). This paper aims to portray the effectiveness and importance of AM in prominent everyday industries such as aeronautics, medicine, automotive, and construction and show where it stands as a technology in the future, contributing towards sustainability and efficiency as a whole.

## II. AIRCRAFT AND AEROSPACE

A unique flexibility in the production and fabrication of different components is provided by 3D printing technology. AM originated in the aerospace industry as a mere prototyping technology. The practice of creating non-functional parts that can be used to validate simulation models of aircraft parts and components is known as prototyping. Prototypes help uncover flaws in the design and malfunctions that are only visible in actual models (Alami et all 2023). In addition to producing lightweight parts that can contribute towards the increase of efficiency and lower the energy and resource requirements as well as reduce the fuel consumption and emission levels of gases by aircraft, 3D printing technology can improve the quality of complex geometries thus making it extremely advantageous in the aircraft industry (Karkun and Dharmalingam 2022). Another noteworthy benefit of adopting 3D-printed components in the aircraft sector includes better-reduced warehousing costs. Aerospace components that prioritize aesthetics above functionality, including power wheels, door handles, light housings, full interior dashboard designs, and so forth, are frequently manufactured with 3D printing. By utilizing cutting-edge techniques such as Stereo Lithography and material jet-ting in the aerospace industry, 3DP technology makes it possible to create scale models that are incredibly precise and informative. These models are useful for testing and communication of designs. (Mohanavel et al 2021). Selective laser melting is an AM technology that allows the manufacture of complex lightweight structures that are not possible to manufacture with conventional methods (Uhlmann et al 2015).

Today, AM technology is being used to produce an increasing number of parts for tooling and aircraft. Boeing and Airbus, the two biggest companies in the industry have both incorporated AM techniques for the manufacturing and maintenance of several parts. For instance, Boeing has used AM technology to produce more than 20,000 parts. Recently, Boeing saved about $2–3 million per aircraft by using AM-fabricated titanium alloy parts (Alami et al 2023). Additionally, Boeing decided to include 3D thermoplastic printing for prototypes and components for 737, 747, 777, and 787 aircraft (Weller, Kleer, and Piller 2015). GE Aviation switched to 3D printing the fuel nozzles of certain jet engines. A nozzle that was formerly put together from 20 individually cast parts may now be produced in one piece resulting in a 75% reduction in manufacturing costs (D'Aveni 2015) and Airbus replaced the traditional interior components, such as brackets or cable routing plates (Ntouanogloub, Stavropoulosa and Mourtzis 2018). Currently, space agencies like NASA and SpaceX are also investigating whether using AM igniters, injectors, and combustion chambers on their rocket engines is feasible. Unmanned Aerial Vehicles (UAV) or drones are the newest sector in which AM technology has been implemented in the aerospace industry. Utilizing AM in UAV manufacturing reduced the number of materials while maintaining and even improving the strength of the structure. Additionally, it helped reduce the time required to manufacture the drones in comparison to conventional processes (Alami et al 2023).

## III. AUTOMOTIVE

Recently, the automotive industry has been taking steps to reduce greenhouse gas emissions and fuel consumption of ground vehicles. To accomplish this, replacing materials with lighter ones, redesigning components, or even combining the two have been identified as a solution. This is where AM proves to be extremely useful. In several industrial domains AM can be utilized to technologically support or perhaps replace conventional manufacturing (Priarone et al 2023). AM is closely related to prototyping and tooling in the automotive industry. Rapid prototyping shortens the design and development life cycle in the manufacturing of automobiles. Conventional prototyping techniques like injection molding or machining are expensive and time-consuming, taking much longer to produce prototypes as compared to AM (Stratasys 2023). The majority of commercial vehicle companies use AM technologies for prototyping to gain a quick, cost-efficient, and environmental solution to evaluate the performance of concept ideas and new upcoming designs. This is particularly useful in the case of recalls in which AM techniques can be used to create prototypes to substitute defective parts

(Alami et al 2023). 3D printing allows automobile engineers to develop and alter complex, organic structures that would be extremely difficult to produce using conventional production techniques. Moreover, it gives them the freedom to innovate beyond the boundaries of traditional automotive designs. It also provides the ability to create highly customized parts which is crucial to the automotive industry; whereas traditional manufacturing techniques rely on mass production, long lead times, and higher costs, which prevent such customization. Furthermore, by utilizing lightweight materials such as engineered plastics and composites. 3D printers also help in the overall weight reduction of parts and designs (Stratasys 2023).

3D printing has been used in various aspects of the automotive industry. For instance, a team at Powertrain Engineering in Lyon did a design study with metal 3D printing of a prototype DTI5 four-cylinder Euro 6-step C engine. The process helped reduce the weight of a four-cylinder engine by 120 kg or 25% thus saving time, money, and labor (Volvo Group 2017). Stratasys, an industry leader in PolyJet 3D printers has enabled the rapid creation of prototypes in a matter of hours, thus making the testing, iteration, and design changes of automobile components and assemblies much faster and more efficient (Stratasys 2023). Porsche has unveiled a revolutionary concept for seating in sports cars. Their "3D-printed body form full-bucket seat" makes use of lattice design and 3D printing techniques through which parts of the cushion and backrest surfaces are created. With three rigidity grades to choose from, the seat can be custom-made to the customer's exact specifications (newsroom The Media Portal by Porsche 2020). The 2020 Shelby GT500 included two structural 3D-printed brake components in addition to using 3D-printed prototypes for functional testing and design validation. These components were created using Carbon's Digital Light Synthesis 3D printing technology and have successfully cleared all of Ford's performance criteria (AMFG 2019).

## IV. MEDICAL AND HEALTHCARE

3D printing has great potential within the healthcare sector. As highlighted in a report by market research firm, SmarTech Analysis, the market for medical 3D printing is estimated to be worth $1.25 billion and set to grow to $6.08 billion by 2027. In 2022 the dental 3D printing market alone generated $4 billion in revenue, accounting for nearly one-third of the overall additive manufacturing market (Additive Manufacturing Research Previously SmarTech Analysis 2023).

One of the most active uses of 3D printing in dentistry today is the production of clear aligners. Due to their high speeds and accuracy, the key technologies used for the same include Stereolithography (SLA) and Material Jetting as well as HP's powder-based technology called Multi Jet Fusion. Since clear aligners are inherently individualized products, the cost-effective customization provided by 3D printing is the main reason for its utilization in their manufacturing. A great example of a company using 3D printing for clear aligners in Align technology is Invisalign, which in 2019, reportedly produced over half a million unique 3D-printed parts per day (AMFG 2019). 3D printing has also majorly contributed to the biomedical field and is being applied in various areas. This includes the clinical application of lumbar spine and long bone prosthetics in orthopedics, oral jaws and skulls for neurosurgery, dental implants, and other special medical prostheses. Currently, living tissues and organs, including blood vessels, skin, bones, cartilage, kidneys, the heart, and the liver have been successfully printed using 3D printing technologies. The unique advantages of 3D printing technologies for organ manufacturing have greatly raised the bar for conventional medicine. (Oleksy, Dynarowicz and Aebisher 2023). With this technology, new organs that function biologically in the same way as the original organs can be created. The printing of organs and tissues is a technological advancement that will benefit a great number of patients (Bozkurt and Karayel 2021).

3D printing technology can be used to replicate the natural structure of the skin at a lower cost, which is useful in the testing of pharmaceutical, cosmetics, and chemical products and helps gain accurate results. Highly controllable cancer tissue models can be formed using this technology showing great potential to accelerate cancer research. 3D printed models can also be used to train surgeons hands-on, as the 3D model is a simulation of a real patient's pathological condition. This may improve their overall accuracy and efficiency (Shahrubudin, Lee, and Ramlana 2019). 3D-printed drugs can be manufactured in different forms and sizes and subsequently be modified to control drug release (Javaid et al 2022). For instance, "it enables very porous pills to be manufactured, allowing for high drug doses in a single pill. Such a pill dissolves quickly and can be ingested easily." The first 3D-printed drug Sprintam (levetiracetam, for epilepsy treatment) manufactured by Aprecia Pharmaceuticals has gained U.S. Food and Drug Administration (FDA) approval. According to a report authored by Phil Reeves regarding the 3D printing industry, over 10 million 3D-printed hearing aids were in use globally in 2013. The manual, labor-intensive industry was replaced by an automated patient-focused one through this technology. Earlier, the production of hearing aids required more than a week, however, currently, the entire manufacturing process can be completed in less than a day (Dodziuk 2016). Chinese researchers from the National Rehabilitation Aids Research Centre in Beijing in collaboration with German MD and orthopedic surgeon Dr. Hans-Rudolph Weiss, have also used 3D printing to produce personalized scoliosis braces which were sturdier, lighter, and less distinct than the current options (Pasricha and Greeninger 2018). Thus, it is safe to say that the use of 3D printing in pharmacy and healthcare is expanding rapidly and is set to transform various aspects of the medical industry in the upcoming years.

## V. CONSTRUCTION

The construction industry accounts for approximately 7~8.5% of all jobs worldwide and contributes to 9% of a country's GDP (gross domestic product), making it one of the primary industries that drives economic development. Despite being a huge economic contributor, the industry has experienced low productivity, little technological advancement, and minimum automation over the past few decades. 3D printing in construction has great potential to automate construction processes and poses several advantages over conventional methods (Hossain et al 2020). Construction sites tend to produce large amounts of waste, however, 3D printers use the exact amount of materials required for the task and thus generate almost zero waste. 3D printing can also use recycled materials in projects and subsequently help the environment. Construction projects can take longer than expected due to restrictions on when they can be completed, such as during the night or in inclement weather whereas 3D printing can happen continuously with little supervision. Furthermore, it can help reduce risky human operations as well as the overall time, money, and labor required to complete a project (Indeed 2023). Due to the notable advancements and success of extrusion-based 3D printing in other engineering fields, the construction industry is moving towards fully automated processes such as additively manufactured cementitious materials (Nodehi et al. 2022). In contrast to conventional construction techniques, the use of 3D printing technology in the production of concrete structures offers a high degree of automation, rapid construction speed, significant reduction in solid waste generation, and minimal labor consumption, all of which can result in lower costs. The formwork used for the construction of traditional reinforced concrete constitutes a major chunk of the overall costs and construction time. However, using 3D printing techniques, "concrete is extruded from a nozzle and automatically deposited layer by layer according to a digitally designed printing route without using any formwork"(Xiao et al 2021). This allows for a high degree of design liberalization and minimal resource consumption.

The feasibility of producing buildings with concrete and construction 3D printing technology has been shown by several development projects. For instance, In 2014 China-based WinSun Decoration Design Engineering Co. constructed 10 homes that were almost entirely 3D printed with recycled concrete material (Stevenson 2019). In 2017, Apis Cor was the first to 3D print an entire home on-site in just 24 hours in Russia. Furthermore, an open dome formwork structure was also 3D printed on-site in less than 13.5 hours, and a volumetric fabrication rate of about 0.375 m3/h was achieved in concrete extrusion for a project by them. With the use of concrete and a 3D printer with a robotic arm, 3D Printhuset created the first on-site 3D-printed house in Copenhagen in 2019. The Royal BAM group and researchers from TU Eindhoven constructed the world's first concrete 3D-printed bridge in the Netherlands in 2017 (Technology Cards, 2019).ICON, a Texas-based company, printed a 500-square-foot building in roughly 27 hours and a 350-square-foot house in about 47 hours. (Ayyagari et all 2023) Branch Technology, a Tennessee-based company that is a pioneer in the 3D printing industry prefabricated interior walls and partitions with their patented Cellular Fabrication technique. This AM method uses a robot arm to create intricate and exotic components. XtreeE is a French company that specializes in concrete printing and has utilized the technology to print 7' x 7' x 8' storm water drains which are prefabricated in a warehouse and then placed at the location. In just nine hours, these drains are printed and completed (Kidwell 2017).

 

## VI. FASHION

3D printing is frequently being used in the fashion industry. It has several benefits over conventional manufacturing techniques, such as a quicker design process, shorter production times, and cheaper inventory, warehousing, packaging, and shipping expenses (Vanderploeg, Lee, and Mamp 2017). Due to its extensive capacity to customize size and shape, 3D printing has recently garnered a lot of interest from the textile and fashion sectors. By using 3D scanning to create customized garments based on the body of the person who wears them, 3D printing technology surpasses traditional cloth production in customization capabilities and enables the creation of highly complex structures (Xiao and Kan 2022). For instance, It is possible to create a brace, accessory, or garment to the exact shape of the body such that it fits the body precisely and doesn't require any alterations (Pasricha and Greeninger 2018). "3D printing on textile substrates provides the ability to decorate the fabric's surface without the need for adhesives."(Xiao and Kan 2022). However, a strong adhesion of the 3D printed part cannot be obtained from every textile material. A study conducted by Malengier et al. contrasted three different test arrangements – a perpendicular (vertical) test, a shear test, and a peel test to determine the adhesion properties and process parameters of 3D prints on textiles that yield the best results (Malengier et al. 2017).

Prominent clothing companies, like Nike and Adidas, have integrated 3D printing into their manufacturing processes, using it to create components like soles and garments (Yang et al 2024). Camper, a popular Spanish shoe company, uses BCN3D printers to build prototypes and concept models for each new shoe collection they create. The switch from outsourcing the production of these models to in-house production using 3D printers led to a reduction in the time and money spent on the overall design process and also gave their designers the freedom to take more design risks allowing them to quickly assess the viability of their designs (BCN3D Technologies 2020). Unfortunately, due to the limitations of raw materials that can be used, the production of products with the same properties as traditional textiles in terms of flexibility, scalability, and pore structure is extremely challenging (Xiao and Kan 2022). Notably, the majority of the materials used in textile printing center around flexible polylactic acid (PLA), acrylonitrile-butadiene-styrene (ABS), nylon, thermoplastic polyurethane (TPU), and photopolymer resins. However, printed fabrics and clothing are less comfortable to wear and are typically reserved for fashion shows due to the intrinsic properties of these materials (Yang et al 2024). To address this limitation, numerous research endeavors have been conducted that aim toward manufacturing printed textiles with increased flexibility and softness to compete with traditional textiles. For example, Beecroft used the selective laser sintering technique to convert nylon powder into weft-knit structures, allowing the demonstrated product to be easily compressed, expanded, stretched, and folded. The study shows the potential for 3D printing tubular knit-based structures that display the mechanical properties of the material used in conjunction with the stretch and extensibility of conventional knitted textile structures (Beecroft 2019).

## VII. CONCLUSION

Additive Manufacturing and 3D printing technologies have completely revolutionized engineering techniques through their diversified applications. It has developed into a technology that is employed in almost every facet of the production process today. Apart from just prototyping, AM can be used for the fabrication, repair, and restoration of different parts, tools, and components with flexible designs and minimum wastage. Additionally, the parts can be rapidly printed on demand, enabling an economical and sustainable production method. AM can enable the creation of heavily complex structures, design customizations, and lightweight components, which are otherwise extremely difficult to achieve through conventional production methods. It proves to be a promising technology with great potential to change the working of several industries in the future.

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