



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

# IJIRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 10, October 2021

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

Impact Factor: 7.569

# Review on 3D Printing and its Applications in Engineering

Priyank Kothari<sup>1</sup>, Gaurav Parate<sup>2</sup>, Chinmay Kulkarni<sup>3</sup>, Nilakshi Soitkar<sup>4</sup>, Girish Khot<sup>5</sup>

Dept. of Mechanical Engineering, Vishwakarma Institute of Information Technology, Pune, India<sup>1-5</sup>

**ABSTRACT:** 3D printing application in manufacturing techniques play an important part in our daily lives. Over the years different advanced manufacturing technologies have been established. Lately, three-dimensional (3D) printing also known as Additive Manufacturing has been used in an extensive variety in industry. The 3D printing process is comparatively less time consuming than traditional manufacturing processes. In this process, components are manufactured layer by layer from basic material. Nowadays, this process is widely used in manufacturing and fabrication of many parts.

**KEYWORDS:** 3D printing, Additive Manufacturing.

## 1. INTRODUCTION

3D printing which incorporates various methods, materials and equipment, has evolved over the years and has been capable of transforming production and logistics processes. Additive production is widely applied in different industries including defence industry, aviation industry, construction, prototyping and biomechanics.

The evolution of 3D printing has been a 4-step process, at first it was used for making models of prototypes, second was allowing parts to be tested in systems, also called as “functional prototyping”, third was making complex tool and the last one was making of functional parts. This method contributes to the reduction of material wastage, the cost of disposing of waste material, the costs of material transportation, the reduction of stock costs for raw materials and the direct production of the final product, which reduces overall costs. Thus, the damage that may occur due to design changes or disappointing sales will be reduced because less stock is kept. In addition, manufacturers can facilitate their purchase. Because the evaluation of the ordered part will have more flexible parameters than the mass production parts. Normally, a machine operating with a single add-on manufacturing system that fulfils the function of all the different machine types required to process a product during its production will be sufficient.

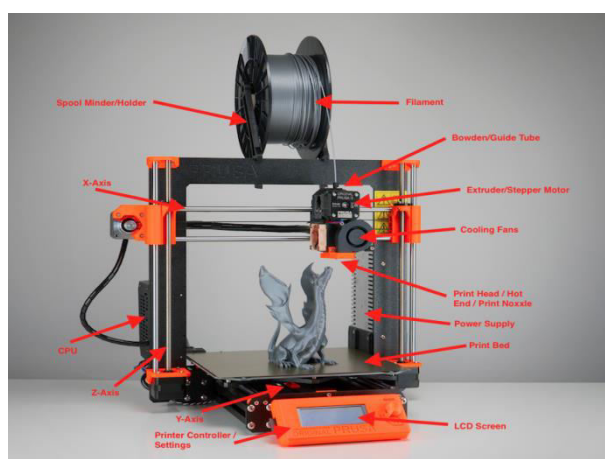


Fig 1: 3D Printer

## II. THEORY

Manufacturing of a mirror, bumper is commonly done by using a process of 3D printing, with higher precision. Overall cost is the biggest benefit of 3D printing. It is a viable option of small and medium businesses by looking at the

development and the increase in the size of the printers. 3D printing has a considerable impact on the consumers in the competitive market. Customised parts can be made from user to user. Photo curable resin was the first material to 3D print. There are even different types of 3D printing for different purposes. Variety of products can be manufactured without the help of a large facility using 3D printing technology, it can manufacture large and at the same time much more complex designs. Recently few parts of the electric prototype were fabricated with the help of 3D printing. Many companies also use 3D printing and modelling to manufacture spare hand tools for assembly of vehicles. While use of prototyping has been very successful in 3D printing but some large manufacturers have also advanced new stages of this technology, these manufacturers have reached new levels of 3D printing technologies manufacturing jigs, hand tool figures etc. and also using innovative and new material. The technology capable of replacing complicated processes like CNC is 3D printing. Economical parts which result in reduction of production cost. It can also help in protecting Intellectual Property (IP) or information leaks because everything manufactured is exactly the company requires.

### III. GENERAL PRINCIPLES

#### 3.1) Modelling.

The first step in 3D printing is modelling wherein the machine takes 3D model in form of CAD. Then the CAD is sliced into various digital cross section, which will guide machine for printing. The machine which is used will determine the amount of material to be on printing platform. This is done until binder layering is achieved. This stage ends once the complete model is printed.

#### 3.2) Printing.

The second step of 3D printing involves printing, or building, the object. Assuming there are no errors in the STL or AMF file, the file is uploaded to the 3D printer. The machine scans the file and adds layers upon layers of liquid, melted plastic, dry powder, or sheet material. This is often done by building the model from a series of cross sections. They're then fused to reveal the final shape of the image. With this system it is possible to make almost any shape or geometric feature from bottom to the highest.

#### 3.3) Finishing.

The final step of 3D printing is finishing. Finishing involves the final touches on the printed object. Solvents, for instance, could also be added to the printed object to eliminate any superficial imperfections while also creating a smoother surface finish.

### IV. PROCESSES

#### 4.1) Stereolithography (SLA)

SLA is unlike any other regular printer, instead of extruding layers on a surface it starts with a tank full of liquid plastic and then some of this liquid is cured or hardened to form solid object.

SLA has 4 major parts:

1. A tank that can be filled with liquid plastic (photopolymer).
2. A perforated platform that is lowered into the tank.
3. An ultraviolet (UV) laser and a computer controlling the platform.
4. The laser.

In the initial step of the SLA process, a thin layer of photopolymer (usually between 0.05-0.15 mm) is exposed above the perforated platform. The UV laser hits the perforated platform, "painting" the pattern of the object being printed. The UV-curable liquid hardens instantly when the UV laser touches it, forming the first layer of the 3D-printed object. Once the first layer is complete the platform lowers, and the laser is traced along the path forming the section of the object being printed. And so, the second layer is printed, this process is followed till the whole object is complete. The platform is then raised to expose a 3D object, this object is then rinsed and baked to further cure the plastic. The objects made from plastic are usually of very smooth surface, but this finish depends on the printer used. The time required for this type of printing also depends on the printer used and size of objects, which can be in hours or even days.

SLA methods are used to make prototypes as it creates a very accurate model and can be also used to produce complex shapes which cannot be produced using conventional prototypes.

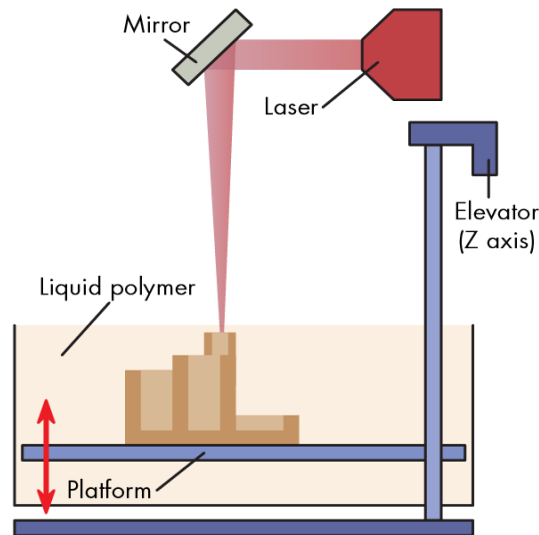


Fig 2: Stereolithography Process

#### 4.2) Selective Laser Sintering (SLS)

This process starts with converting the CAD file into a sliced STL file, which is then sent to the machine for printing. An additive manufacturing layer technology, SLS involves the use of a high-power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal, ceramic, or glass powders into a mass that has a desired three-dimensional shape. The laser selectively fuses powdered material by scanning cross-sections generated from the sliced view on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of the material is spread across and again fused together, this process is continued until the whole part is completed.[1] These parts are further post-processed, if required, as they are porous.

A SLS machine typically uses a pulsed laser as the finished part density depends on peak laser power, and not on the laser duration. The SLS machine preheats the bulk powder material in the powder bed somewhat below its melting point, to make it easier for the laser to raise the temperature of the selected regions the rest of the way to the melting point.

SLS is a very common process in industries as it is very easy to produce complex parts using this process. This process is mostly used to produce prototype parts early in the design cycle such as for investment casting patterns, automotive hardware, and wind tunnel models.

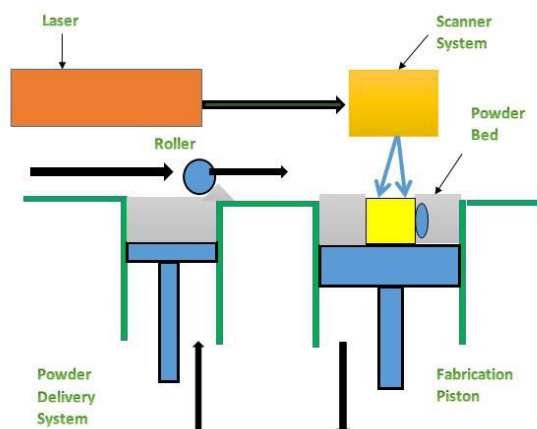


Fig 3: Selective Laser Sintering Process



#### 4.3) Fused Deposition Modelling (FDM)

Technology of 3D printing layer-by-layer that melts plastic. Affordable for average customer and business. 3D plastic filaments can be used for printing for example, ABS, PLA.

Rapid prototyping can be done by FDM. There are 2 types of extrusion configurations:

1. Direct drive
2. Bowden

1. **Direct Drive** allows for the better Stable material control, when using specialty filaments. The extruder sits directly on top of the hot end. However, the vibrations are more as compared to Bowden. The vibration can cause imperfections in the design.

2. **The Bowden** printers can print faster than direct drive and have less vibration, as the extruder doesn't sit directly on the top of the hot end. The disadvantage is that the printer needs to be fine-tuned to print the filaments successfully.

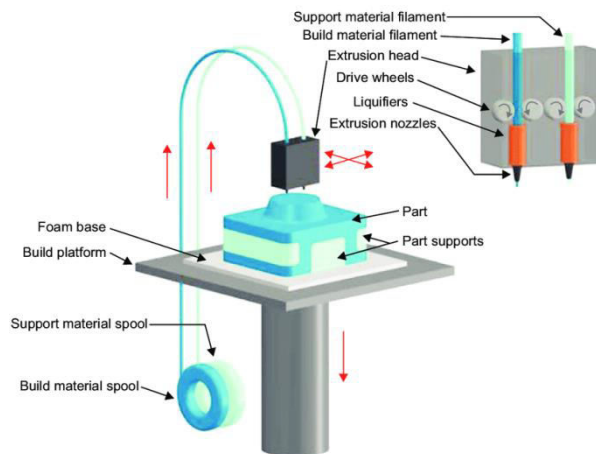


Fig 4: Fused Deposition Modelling Process

#### 4.4) Digital Light Process (DLP)

DLP similar to SLA but deals with photopolymers. DLP produces highly refined and accurate parts but needs support structures and post-curing. A shallow vat of resin is required to facilitate the process which means less waste and less production cost. A photopolymer is a resin which hardens when exposed to light. When the process is used, each layer is exposed to a light pattern, thus hardening the product layer-by-layer. Used for functional testing prototypes, visual prototypes for photo shoots and marketing. The surface finish obtained is smooth, but some layers are visible. Post-processing includes basic processes like curing, smoothing and advanced processes include primer coating and painting.

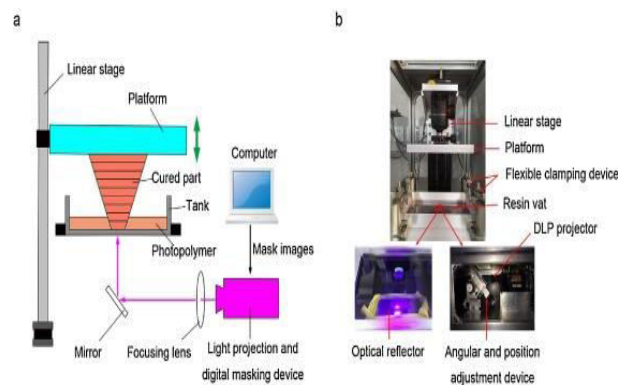


Fig 5: Digital Light Process

#### 4.5) Multi Jet Fusion (MJF)

Multi jet fusion is process which manufactures nylon prototypes. Through multi jet fusion parts can also be created in less than one day. The reason behind using multi jet fusion is that it offers great surface finish, consistent mechanical properties of components and can be built faster at lower cost. Multi jet fusion uses two carriages which are set perpendicular to each other. One carriage goes on adding material to work area, while other carriage goes on printing the added material. In this way operation goes on continuously. This process has high production speed. but the major disadvantage is that, currently no ceramic materials are available yet commercially.

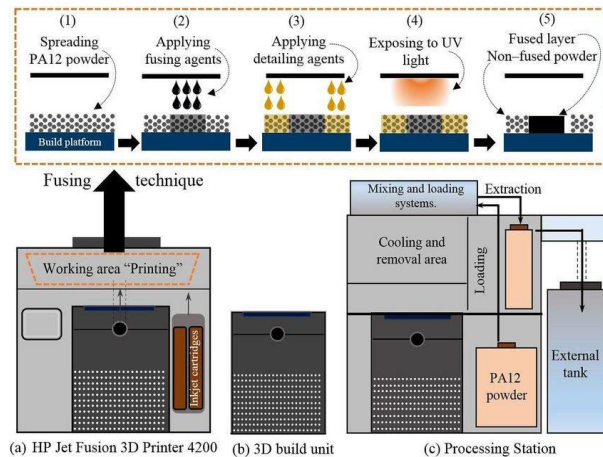


Fig 6: Multi jet fusion process

#### 4.6) Polyjet

Polyjet technology is similar to traditional inkjet printing, instead of plotting ink in the paper it jets liquid photopolymer into build tray. Firstly, from the 3D CAD file software determines the arrangement of photopolymers automatically. By using UV, polyjet printers quickly cure the droplets of liquid photopolymer. Once the material is prepared, its easily removed by hand in solution bath. We can create complex shapes and can obtain detailed parts such as realistic teeth and gums.

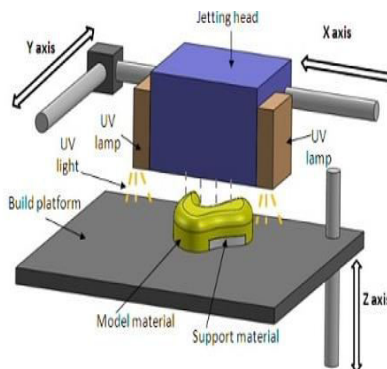


Fig 7: Polyjet Process

#### 4.7) Direct Metal Laser Sintering (DMLS)

It is a 3D printing process which uses high-power laser beam to melt and fuse layers of metallic powder together controlled by computer.

Direct metal laser sintering (DMLS) is an industrial 3D printing process for building fully functional - rapid metal prototypes and production parts. It takes approximately 7 days for manufacturing. Final parts of different applications of metals are produced by this process.

The DMLS machine begins the 3d metal printing process by sintering each layer first the support structures to the base plate, then the part itself with a laser aimed onto a bed of metallic powder. After a cross-section layer of powder is

micro-welded, the build platform shifts down and a recoater blade moves across the platform to deposit the next layer of powder into an inert build chamber. The process is repeated layer by layer until the build is complete.

When the build finishes, an initial brushing is manually administered to parts to remove most of the loose powder, followed by the appropriate heat-treat cycle while still fixtured in the support systems to relieve any stresses. Parts are removed from the platform and support structures are removed from the parts, then finished with any needed bead blasting and deburring. Final DMLS parts are near 100 percent dense.

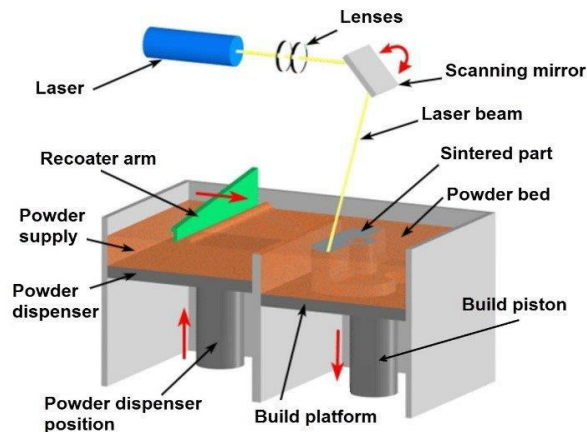


Fig 8: Direct Metal Laser Sintering Process

#### 4.8) Electron Beam Melting (EBM)

It is a 3D manufacturing process in which a powdered metal is melted by a high-energy beam of electrons. An electron beam produces a stream of electrons that is guided by a magnetic field, melting layer upon layer of powdered metal to create an object matching the precise specifications defined by a CAD model. Production takes place in a vacuum chamber to guard against oxidation that can compromise highly reactive materials. Electron Beam Melting is similar to Selective Laser Melting (SLM), as they both print from a powder from the 3D printer's powder bed, but EBM uses an electron beam instead of a laser.

EBM builds high-strength parts that make the most of the native properties of the metals used in the process, eliminating impurities that may accumulate when using casting metals or using other methods of fabrication.

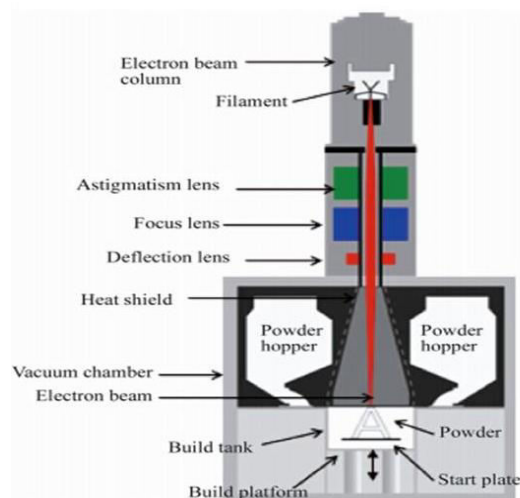


Fig 9: Electron Beam Melting Process

**V. MATERIALS USED IN 3D PRINTING****5.1) Acrylonitrile Butadiene Styrene [ABS]**

Products printed using ABS are suitable for use between range of 20-80°C. The initial melting temperature for ABS is 105°C but softening and deformation can occur at temperatures above 80°C. ABS is mostly used in 3D printing because of its high resistance and impact resistant. Although there is a risk of distortion during printing of large parts due to high temperature of ABS material.

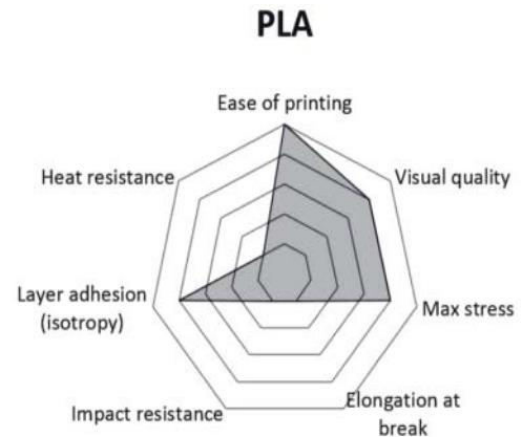
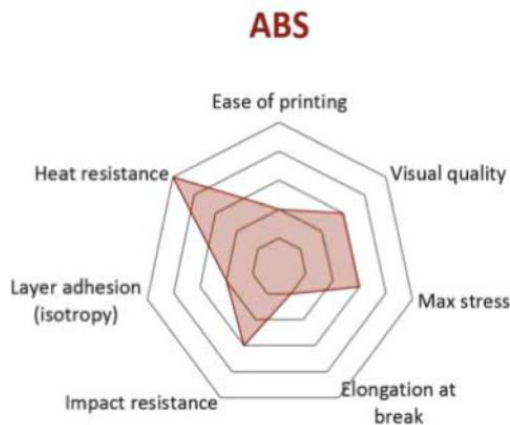


Fig 10: Material and Chemical properties of ABS Fig 11: Material and Chemical properties of PLA

**5.2) Polylactic Acid [PLA]**

This material is most widely used in three-dimensional printer material according to current statics. The main reason this material is preferred because it is easy to use as it works at lower melting temperatures. The PLA material is less likely to be distorted when printing (unlike ABS). Therefore, heater plates are not necessary. Polylactic acid is obtained from materials containing starch while ABS material is obtained from petroleum. PLA material resistance to high temperatures is very low as compared to ABS material.

**5.3) Thermoplastic Polyurethane [TPU]**

This material has high wear resistance and flexibility, has easy processing hence is used in different sectors besides being used in printers. The heat conduction of this material is very low.

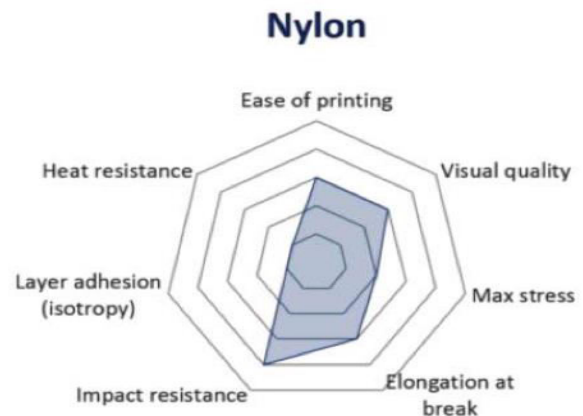
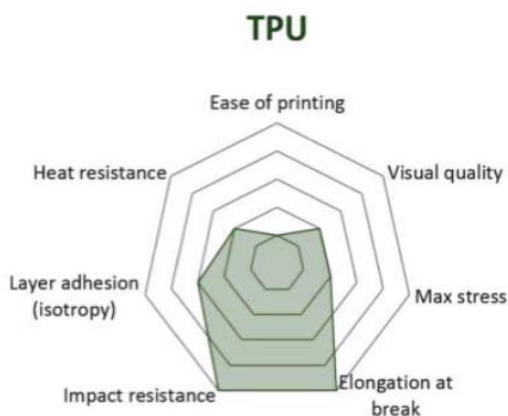


Fig 12: Material and Chemical properties of TPU

Fig 13: Material and Chemical properties of NYLON



#### 5.4) Nylon

Nylon is strong, hard and flexible 3D printing material. As it is very sensitive to moisture, it makes it difficult to print and store. The heat conduction of this material is very low.

#### 5.5) Carbon-reinforced filaments

These filaments have very hard and rigid structure. It can be used in mechanical parts, protective containers and in applications requiring high durability.

It has very low flexibility and breaks when it is stretched but has a higher strength than other materials. The printing temperature is between 195 to 220°C.



Fig 14: Product made of Steel using 3D Printer.

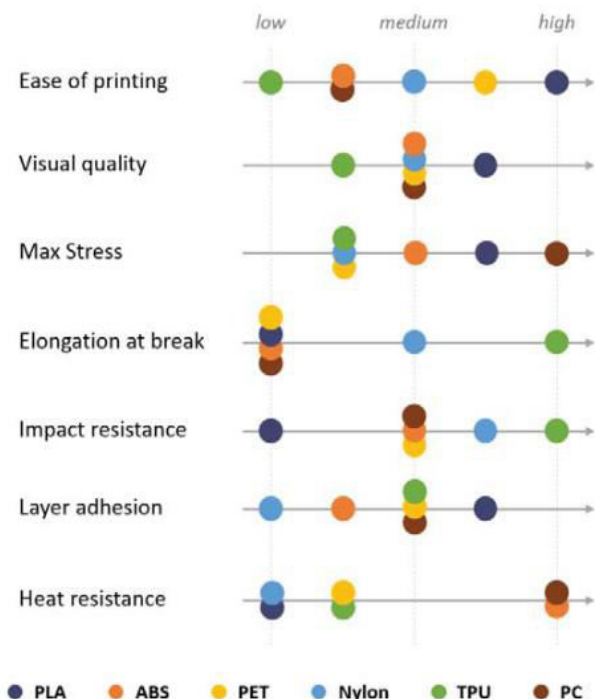


Fig 15: Overall comparisons of different materials.

### VI. 3D PRINTING IN ENGINEERING

#### 6.1) Aerospace engineering

Now-a-days 3D printing is one among the foremost popular way of manufacturing parts for aerospace engineering. this might be used for both civilian also as military purposes. This method is straightforward to manufacture, easy to check and to supply such complex geometries with highest accuracy is feasible. Many companies have started their production using 3D printers. as an example, Boeing has produced various prototype thermoplastic parts using commercially available laser sintering techniques for commercial aircraft 737, 747, 777 and 787. Using this technology, the Boeing company profited \$ 3 million from each 787-Dreamliner aircraft produced. In further stages, layered manufacturing can even be utilized to manufacture energizers, like explosives, solid rocket propellants, which are directly related to the energy of the missiles. Thus, this sort of fabric is usually employed within the foremost efficient and most reliable way. In July 2017, NASA tested the world's first three-dimensional reaction-propulsion engine igniter. The igniter was manufactured using copper alloy and Inconel (chrome and steel alloy). Thus, both the worth and also the time savings were achieved from the manufacture of the igniter. Lockheed is currently using 3D-printed parts for satellite manufacturing. Printed parts are already on-board the solar-powered Juno spacecraft heading to Jupiter.

**6.1.1) Wind tunnel 3D printed model:** Some work on the aerodynamic properties of a 2 m-long model (1:8 scale) of the European Tiltrotor aircraft was built and tested at speeds up to 50 m/s (CRP Technology web site, 2010) ILAS and CERBERUS.

## 6.2) Automobile Engineering

Many automobile companies use 3D printing and modelling to manufacture spare hand tools for assembly of vehicles. They use various technologies such as stereo lithography (SLA) and selective laser sintering (SLS), etc. Wide variety of side rear view mirrors are manufactured by Chrysler using 3D modelling.

### 6.2.1) Requirements in automobile industry:

1. Weight reduction: Reduction in weight without compromising the strength can be achieved by additive manufacturing methods like 3D printing.
2. Complex geometries: The most important thing for an automotive part is the cooling, also thin walls and meshes in the design, which make the design complex. But by Additive manufacturing, the part design can be made complex by making sure that the part is lightweight and also stable.
3. Temperature Testing: To withstand high temperature, hybrid materials and customised metals can be processed so that the parts are intact in high temperature.
4. Moisture Testing: As the vehicles are used in all the weathers, the parts manufactured should be moisture-proof, also waterproof, moisture resistant materials can be made.
5. Part consolidation Prototyping: The number of components can be reduced by using additive manufacturing, and making the assembly into a single component, thus reducing the production cost in the long run. Also helps in reducing the weight.

### 6.2.2) Common Automotive Applications:

1. Bellows: Generally, making bellows is considered where the part will be exposed to repetitive flexing motions. E.g. Duraform
2. Complex Ducting: For using ducting operations like ECS (Environmental Control System) for performance racing, you can design optimized and single piece structures.
3. High detail visual prototypes: The additive manufacturing processes can produce multicolour designs with decent surface finish. This method of prototyping is highly accurate. This type of manufacturing is used in the automotive industry, where aesthetics plays a major role than functioning like interiors, steering wheel, mirrors. Photo-activated resin is used to make such parts.
4. Functional mounting brackets: Manufacturing the parts quickly is a trademark of additive manufacturing. The main advantage is that it requires very little input from an operator meaning that the engineers can update the designs in a very short period, which is not possible in other manufacturing processes.

### 6.2.3) 3D Printed Automobile Parts.



Fig 16: Exhaust made by 3D Printer.



Fig 17: 3D printed titanium wheel.

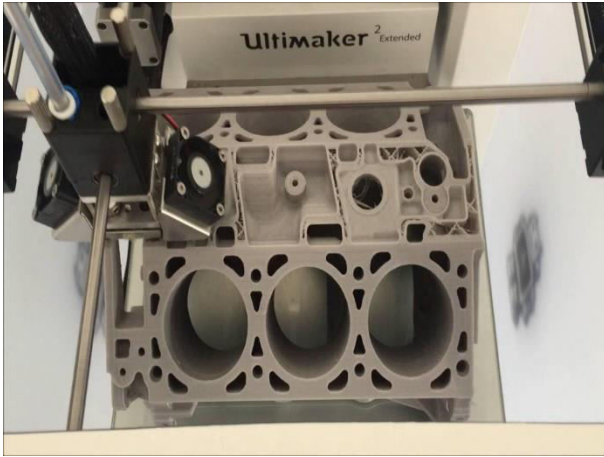


Fig 18: 3D printed engine block.



Fig 19: 3D Printed Bugatti Brake Calliper.

### 6.3) Marine Engineering

Recently the 3D printing process has started implanting their roots in the marine industry too. A survey was conducted a few years back in 2014 by Wohler's among manufacturers of printers to determine the market shares for printer sales of industrial sectors. Marine sector falls under the category "other" which is less than 5%, while aerospace has a market share of 12%.

#### 6.3.1) Building a 3D-Printed Submersible

There was a need to create a 30 feet prototype of hull made from carbon fibre composite material. The U.S navy made the hull within 4 weeks. They gained good knowledge and research in Big Area Additive manufacturing (BAAM). According to the U.S Navy, usually building a traditional hull can cost about \$600,000 to \$800,000 and this process takes about 3-5 months to complete. Using BAAM hull production cost was reduced by 90% and also the time period was reduced a lot. So, with the help of this technology time, money and energy can be saved.



Fig 20: 3D Printed Submersible Hull

#### 6.3.2) 3D printed Marine parts

##### Propeller:

This part was manufactured with the help of 3D printing, and it cost around 5000 to 7000 Euros. 3D printing was carried out on machine DMG Mori. Production time for AM was approximately 4 weeks. While comparing it with traditional methods, there isn't much difference in cost. But production time is reduced marginally through AM.

Compared to traditional manufacturing methods (assembling and welding) the quality of the propeller will increase. And less material is required for Am than the traditional methods.



Fig 21: 3D Printed Ship Propeller

#### 6.4) Civil Engineering

##### 6.4.1) Machines used for 3D printed buildings.

###### Robotic Arm Extruders

1) **The Contour Crafting method** involves the building material being deposited to create a large-scale 3D model with a smooth surface finish. Rails are installed around the building ground that will act as a structure to direct the robotic arm. It moves back and forth to extrude the concrete, layer-by-layer. Trowels placed on the side and above the nozzle to flatten the extruded layers and ensure the model's strength.

2) **Sand layers** machine relies on the binding of powder which makes it possible to solidify a layer of material with a binder. Layers of sand are deposited according to the desired thickness before a print head pours droplets (the binder) to harden the sand. This 4 x 4 metre machine can create large structures of up to 6 cubic metres in size.



Fig 22: Robotic Arm Extruder



#### 6.4.2) 3D Printed Buildings

##### 1) Dubai municipality office building, UAE.

In December 2019, 3D printing robot firm Apis Corp made world's largest 3D printed building. The office is built in UAE and is 9.5 metres in height and has a floor area of 640 m<sup>2</sup>.



Fig 23: 3D Printed Dubai municipality office.

##### 2) Office of the Future, UAE.

The Office of the Future is a unique structure which is home for Emirate's Future Foundation.



Fig 24: 3D Printed Dubai Office of future.

### 3) 3D printed houses by WinSun, China.

The Chinese firm has created home designs, including an apartment building and a villa.



Fig 25: 3D Printed Apartments



Fig 26: 3D Printed Villa

### 6.5) Electronics and Electrical Engineering

Different physical properties can be recorded or indicated by means of sensors like force, displacement, pressure, and strain etc. For the same various sensors are being produced. Different sensors like pressure sensor, strain sensor, temperature sensor etc. have been produced in large scale with traditional methods like lamination, coating, and lithography all over the world. As additive manufacturing provides ease and time saving over traditional processes, many sensors are being fabricated using this technology. The applications of this 3D printed sensors and the material used as shown in tables below:

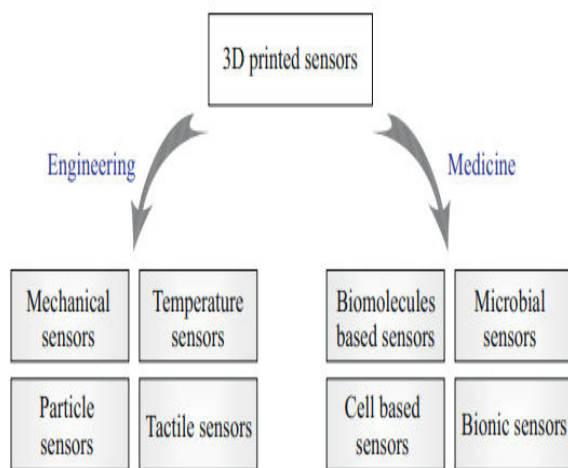


Fig 27: Types 3D Printed Sensors

### 6.5.1) 3D Printed Sensors

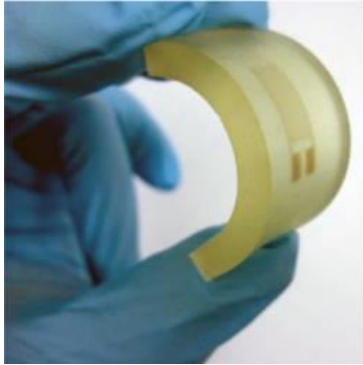


Fig 28: 3D Printed Stain sensor

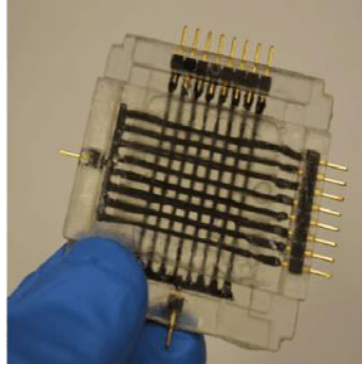


Fig 29: 3D Printed Tactile sensor

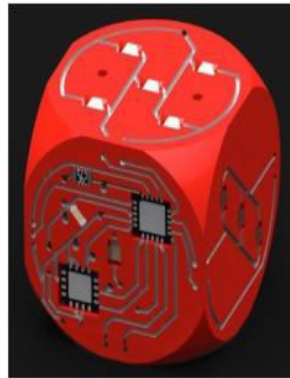


Fig 30: 3D Printed Acceleration sensor

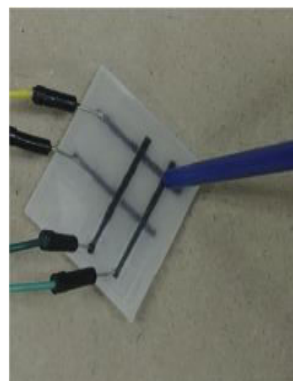


Fig 31: 3D Printed Pressure sensor

## 6.5.2) 3D printed and non-printed parts of sensors.

AM Process	Measured Parameters	Materials	3D-Printed parts	Non-Printed part
BJ	Force Strain	Nanoparticle silver Ceramic	Sensor patches Sensing Part	Silicon layer Fiber cladding
ME	pH Liquid	ABS Polyethylene	Platform Fluidic device	Micropipette Electrode
MJ	Pressure pH	Polymer Photo resin	Light travels Platform	Accelerometers Microcontroller
SL	Strain Temperature	Steel foil Copper	Sensing part Sensing part	Housing Ceramic shield
PBF	Force pH	Ceramic Metallic particle	Housing Electrode	Electrode Housing
VP	Gas Viscosity	Acrylic resin Transparent resin	Gas cell Micro viscometer	Container Pump

Table 1:3D Printed and Non-Printed parts of sensors

Type of sensor	AM Process	Material	Transduction Mechanism
Strain	SL FDM	Silicon rubber Polymer Composite	Resistance Resistance
Force	FDM FDM	Nanocomposite PLA	Piezoresistive Piezoresistive
Accelerometer	VP VP	Photopolymer Resin Photopolymer Resin	Capacitance Capacitance
Pressure	FDM FDM	Polyvinylidene Fluoride ABS	Capacitance Optical Absorbance
Temperature	BJ DIW	Exfoliated graphite Graphene Composites	Resistance Resistance
Biomolecular	FDM FDM	Graphene/PLA Biomimetic material	Electrochemical Electrochemical
Biosensor	VP DIW	Liquid Resin Hydrogel	Chemiluminescent Resistance
Cell based	FDM VP	PLA Photopolymer resin	Electrochemical Electrochemical

Table 2: Information of 3D-Printed sensors.



## VII. ADVANTAGES AND DISADVANTAGES


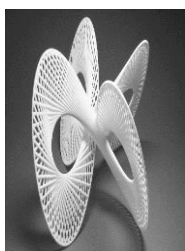




	<b>Fused Deposition Modelling (FDM)</b> <b>Advantages</b> 1. Large build volumes 2. Cost effective 3. Strong Materials <b>Disadvantages</b> 1. Anisotropic 2. Surface Finish 3. Slow		<b>Stereo Lithography (SLA)</b> <b>Advantages</b> 1. Excellent surface finish (top surface). 2. Efficient use of materials. 3. Transparent/translucent materials <b>Disadvantages</b> 1. UV degradation 2. Low mechanical properties 3. Expensive materials.
	<b>Selective Layer Sintering (SLS)</b> <b>Advantages</b> 1. Good mechanical properties. 2. Mature process. 3. Good environmental resistance <b>Disadvantages:</b> 1. Build volume 2. Material selection.		<b>Direct Metal Laser Sintering (DMLS)</b> <b>Advantages</b> 1. Better surface finish 2. Fine features 3. Wide selection of materials <b>Disadvantages</b> 1. Slow 2. Small build volumes 3. Support structures required 4. heavy post processing
	<b>Electron Beam Melting (EBM)</b> <b>Advantages</b> 1. Fast 2. Lower residual stresses <b>Disadvantages</b> 1. Rough surface finish 2. Internal passages are a challenge		<b>Direct Metal Deposition</b> <b>Advantages</b> 1. Repair capability 2. part size 3. Gradients 4. Coatings <b>Disadvantages</b> 1. Slow 2. Expensive machines 3. Column shapes

Table 3: Advantages and Disadvantages

## VIII. CONCLUSION

Compared to the increasing sales every year, and 3D printing still under development, it cannot be considered as a substitute to the traditional methods, but for sure can be considered as a lending hand to the traditional methods. The skills required to carry out the processes must be addressed if people look at additive manufacturing as a replacement to the traditional methods. These skills are vital and should be nurtured, partnerships from universities and workshops and training programmes are one of the few ways to make sure that the skilled and talented group of people is built.

## REFERENCES

- [1] A.K.Matta,R.UmamaheswaraRao,V.Rambabu, "Preparation and characterization of ternary blends composed of polylactide, poly( $\epsilon$ - caprolactone) and MWCNT", ICEMAP-2013,23rdMay2013.
- [2] A.K.Matta, A.S.Kranthi "Fabrication of a six- Legged robot with crank and slotted lever mechanism using RF communication ", IJAER,ISSN 0973-4562 Volume 10, Number 13, pp 33170-33174 (2015).
- [3] A.K.Matta, "Optimization of operation parameters on a Novel internally ventilated cross drilled disc brake by using Taguchi Method" IJESTA ISSN 2395-0900 Volume 1, Number 5 (2015).
- [4] A.K.Matta, Dr.D.RangaRaju, Dr.K.N.S.Suman, "The integration of CAD/CAM and RapidPrototyping in Product Development A review",elsevier, procedia material science pp.3438- 3445,vol.2,2015.

- [5] <https://www.3dhubs.com/knowledge-base/fdm-3d-printing-materials-compared>
- [6] H. Topcuk, 3D Yazıcı, Karabuk Üniversitesi, 2016.
- [7] <https://3dprinting.com/materials>, 2018.
- [8] <https://www.artiboyut.com/index.php/tr/bilgi-bankasi/39-3d-yazici-filament-ozellikleri>, [Accepted: May 28, 2018]
- [9] <https://www.3dhubs.com/knowledge-base/fom-3d-printing-materials-compared>, 2018.
- [10] N. Sandalci, Türkiye'de Endüstriyel Tasarımcıların 3 Boyutlu Yazıcıları Kullanımları Hakkında Bir İnceleme, Haziran 2016.
- [11] 3D Printing Promises to Revolutionize Defense, Aerospace Industries <https://www.jstor.org/stable/10.2307/27020306> March 2014, Vol. 98, No. 724 (March 2014), pp. 20-23
- [12] Weller C, Kleer R, Piller FT. Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited. International Journal of Production Economics; 164: 43-56, 2015.
- [13] <https://www.techcentral.ie/boeing-turns-3d-printed-parts-save-millions-787-dreamliner/>. Boeing turns to 3D-printed parts to save millions on 787 Dreamliner. In. 04.12.2018.
- [14] [http://www.lanl.gov/discover/publications/1663/2016march/\\_assets/docs/1663\\_26\\_explosive-3d-design.pdf](http://www.lanl.gov/discover/publications/1663/2016march/_assets/docs/1663_26_explosive-3d-design.pdf) (2018).
- [15] Berman B., "3-D Printing: The New Industrial Revolution." Bus Horiz, vol.55(2): pp.155-62, 2012.
- [16] Stansbury JW, Idacavage MJ. 3D printing with polymers: challenges among expanding options and 2016;32(1):54-64. opportunities. Dent Mater
- [17] Wu P, Wang J, Wang X. A critical review of the use of 3-D printing in the construction industry. AutomConStruct2016;68:21-31.
- [18] S. Agarwala, G.L. Goh, Y.L. Yap, G.D. Goh, H. Yu, W.Y. Yeong, T. Tran, Development of bendable strain sensor with embedded microchannels using 3D printing, Sens. Actuators A 263 (2017) 593–599.
- [19] J. Oliveira, V. Correia, H. Castro, P. Martins, S. Lanceros-Mendez, Polymer-based smart materials by printing technologies: improving application and integration, Addit. Manuf. 21 (2018) 269–283.
- [20] C. Liu, N. Huang, F. Xu, J. Tong, Z. Chen, X. Gui, Y. Fu, C. Lao, 3D printing technologies for flexible tactile sensors toward wearable electronics and electronic skin, Polymers 10 (2018) 1–31.
- [21] Y. Wang, Y. Wang, W. Liu, D. Chen, C. Wu, J. Xie, An aerosol sensor for PM concentration detection based on 3D printed virtual impactor and SAW sensor, Sens. Actuators A 288 (2019) 67–74.
- [21] A. Zolfagharian, M.R. Khosravani, A. Kaynak, Fracture resistance analysis of 3D-printed polymers, Polymers 12 (2020) 1–18.
- [22] W. Su, B.S. Cook, Y. Fang, M.M. Tentzeris, Fully inkjet-printed microfluidics: a solution to low-cost rapid three-dimensional microfluidics fabrication with numerous electrical and sensing applications, Sci. Rep. 30 (2016) 1–12.
- [23] M.N. Jahangir, J. Cleeman, H.J. Hwang, R. Malhorta, Towards out-of-chamber damage-free fabrication of highly conductive nanoparticle-based circuits inside 3D printed thermally sensitive polymers, Addit. Manuf. 30 (2019) 100886.
- [24] F. Zhang, E. Saleh, J. Vaithilingam, Y. Li, C.J. Tuck, R.J.M. Hague, R.D. Wildman, Y. He, Reactive material jetting of polyimide insulators for complex circuit board design, Addit. Manuf. 25 (2019) 477–484.
- [25] M. Borghetti, M. Serpelloni, E. Sardini, S. Pandini, Mechanical behavior of strain sensors based on PEDOT:PSS and silver nanoparticles inks deposited on polymer substrate by inkjet printing, Sens. Actuators A 243 (2016) 71–80.
- [26] Y.H. Chang, K. Wang, C.W. nd, Y. Chen, C. Zhang, B. Wang, A facile method for integrating direct-write devices into three-dimensional printed parts, Smart Mater. Struct. 24 (2015) 65008–65015.
- [27] M. Vatani, Y. Lu, E.D. Engeberg, J.W. Choi, Combined 3D printing technologies and material for fabrication of tactile sensors, Int. J. Precis. Eng. Manuf. 16 (2015) 1375–1383.
- [28] A. Frutiger, J.T. Muth, D.M. Vogt, Y. Mengüç, A. Campo, A.D. Valentine, C.J. Walsh, J.A. Lewis, Capacitive soft strain sensors via multicore-shell fiber printing, Adv. Mater. 27 (2015) 2440–2446.
- [29] H. Zang, X. Zhang, B. Zhu, S. Fatikow, Recent advances in non-contact force sensors used for micro/nano manipulation, Sens. Actuators A 296 (2019) 155–177.
- [30] A. Nag, S. Feng, S.C. Mukhopadhyay, J. Kosel, D. Inglis, 3D printed mould-based graphite/PDMS sensor for low-force applications, Sens. Actuators A 280 (2018) 525–534.
- [31] L.-M. Faller, W. Granig, M. Krivec, A. Abram, H. Zang, Rapid prototyping of force/pressure sensors using 3D- and inkjet-printing, J. Micromech. Microeng. 28 (2018) 1–11.
- [32] M.A. Hossain, J. Canning, S. Ast, P.J. Rutledge, T.L. Yen, A. Jamalipour, Lab-in-a-Phone: smartphone-based portable fluorometer for pH measurements of environmental water, IEEE Sens. J. 15 (2015) 5095–5102.
- [33] G.W. Bishop, J.E. Sattewhite, S. Bhakta, K. Kadimisetty, K.M. Gillette, E. Chen, J.F. Rusling, 3D-printed fluidic devices for nanoparticle preparation and flow-injection amperometry using integrated prussian blue nanoparticle-modified electrodes, Anal. Chem. 87 (2015) 5437–5443.



- [34] D.D. Willis, E. Brockmeyer, S.E. Hudson, I. Poupyrev, Printed optics: 3D printing of embedded optical elements for interactive devices, in: Proceedings of the Annual ACM Symposium on User Interface Software and Technology, Cambridge, MA, USA, 2012, pp. 1–10.
- [35] M. Yafia, A. Ahmadi, M. Horfar, H. Najjaran, Ultra-portable smartphone controlled integrated digital microfluidic system in a 3D-printed modular assembly, *Micromachines* 6 (2015) 1289–1305.
- [36] A. Hehr, M. Norfolk, J. Wenning, J. Sheridan, P. Leser, P. Leser, J.A. Newman, Integrating fiber optic strain sensors into metal using ultrasonic additive manufacturing, *JOM* 70 (2018) 315–320.
- [37] A. Bournias-Varotsis, S. Wang, D. Hutt, D.S. Engstrom, The effect of ultrasonic additive manufacturing on integrated printed electronic conductors, *Electron. Mater. Lett.* 14 (2018) 413–425.
- [38] M.S. Hossain, J.A. Gonzalez, R.M. Hernandez, P. Morton, J. Mireles, A. Choudhuri, Y. Lin, R.B. Wicker, Smart part fabrication using powder bed fusion additive manufacturing technologies, in: Proceedings of Annual International Solid Freeform Fabrication Symposium, Texas, USA, 2017, pp. 1–14.
- [39] A. Ambrosi, J.G.S. Moo, M. Pumera, Helical 3D-printed metal electrodes as custom-shaped 3D platform for electrochemical devices, *Adv. Funct. Mater.* 26 (2016) 698–703.
- [40] R. Bauer, G. Stewart, W. Johanstone, E. Boyd, M. Lengden, 3D-printed miniature gas cell for photoacoustic spectroscopy of trace gases, *Opt. Lett.* 39 (2014) 4796–4799.
- [40] P.S. Venkateswaran, A. Sharma, S. Dubey, A. Agrawal, S. Goel, Rapid and automated measurement of milk adulteration using a 3D printed optofluidic micro viscometer (OMV), *IEEE Sens. J.* 16 (2016) 3000–3007.
- [41] Y.L. Park, B.R. Chen, R.J. Wood, Design and fabrication of soft artificial skin using embedded microchannels and liquid conductors, *IEEE Sens. J.* 12 (2012) 2711–2718.
- [42] D. Xiang, X. Zhang, E. Hakin-Jones, W. Zhu, Z. Zhou, Y. Shen, Y. Li, C. Zhao, P. Wang, Synergistic effects of hybrid conductive nanofillers on the performance of 3D printed highly elastic strain sensors, *Composites A* 129 (2020) 105730.
- [43] S. Hampson, W. Rowe, S.D.R. Christie, M. PLatt, 3D printing of multi axial force sensors using carbon nanotube (CNT)/thermoplastic polyurethane (TPU) filaments, *Sens. Actuators A* 263 (2017) 493–500.
- [44] F. Wassefall, N. Hendrich, F. Fiedler, J. Zhang, 3D-printed low-cost modular force sensors, in: Proceedings of International Conference on Climbing and Walking Robots and the Support Technologies for Mobile Machines, Porto, Portugal, 2017, pp. 1–8.
- [45] V. Zega, C. Credi, R. Bernasconi, G. Langfelder, L. Magagnin, M. Levi, A. Corigliano, The first 3-D-printed z-axis accelerometers with differential capacitive sensing, *IEEE Sens. J.* 18 (2018) 53–60.
- [46] V. Zega, M. Invernizzi, R. Bernasconi, F. Cuneo, G. Langfelder, L. Magagnin, M. Levi, A. Corigliano, The first 3D-printed and wet-metallized three-axis accelerometer with differential capacitive sensing, *IEEE Sens. J.* 19 (2019) 9131–9138.
- [47] E. Suaste Gomez, G.R. Roldan, H. Reyes Curz, O.T. Jimenez, developing an ear prosthesis fabricated in polyvinylidene fluoride by a 3D printer with sensory intrinsic properties of pressure and temperature, *Sensors* 16 (2016) 1–11.
- [48] Y. Lin, T. Hsieh, L. Tsai, S. Wang, C. Chiang, Using three-dimensional printing technology to produce a novel optical fiber Bragg grating pressure sensor, *Sens. Mater.* 28 (2016) 389–394.



**Impact Factor:  
7.569**



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 **9940 572 462**  **6381 907 438**  **ijirset@gmail.com**



[www.ijirset.com](http://www.ijirset.com)

Scan to save the contact details