

Trending Applications of 3D Printing: A Study

Rakesh Kumar¹ and Santosh Kumar²

¹Assistant Professor, Department of Mechanical Engineering, Chandigarh Group of College Landan, Mohali, India & Research Scholar, Department of Mechanical Engineering, Chandigarh University, Mohali, India

²Assistant Professor, Department of Mechanical Engineering, Chandigarh Group of College Landan, Mohali, India & Research Scholar, Department of Mechanical Engineering, IKG Punjab Technical University, Punjab, India.

E-mail: rk05691@gmail.com, santoshdgc@gmail.com

Abstract - The popular name which is known by the most people and the market is 3D printing. It is an emerging manufacturing technology used to fabricate, real life parts using CAD data by adding material in layer fashion in distinct form (solid, liquid and powder). 3D printing technology is the reverse of conventional/subtractive manufacturing, owing to its design flexibility, customization, material complexity, size range, waste minimization, tool less and the ability to manufacture complicated shapes. This review paper aims to provide a comprehensive overview of distinct 3D printer applications in different sector. In addition, this review paper summarizes the merits, demerits, future and challenges, so that this review paper could become the torch bearer for the futuristic researchers working in the area of 3D printing.

Keywords: 3D Printing, Computer Aided Design, Applications, Challenges, Future Scope.

INTRODUCTION

Additive manufacturing is also known as 3D printing/rapid prototyping/desktop manufacturing/solid free form fabrication technique used for the manufacturing of intricate shapes and structure from 3D CAD model data [1, 2]. This process was 1st started by Charle Hull, in 1980s called "stereo lithography" (SL) [3]. After several experimental investigations he starts writing the code, which understand the printer and later on (in 1988) he sold 1st 3D printing machine for \$100,000. After that, several distinct companies such as Solidscape etc. manufactured 3D printing machine for commercial application. With the advancement in technology, recently, 3D printing machine is utilized for production of implants, automobile parts, bridges, rocket engine components, jewelry, food items, and houses etc. [4-8]. This process consist of three basic steps as depicted in Fig. 1

Recently, 3D printing has been extensively utilized in many countries, for the manufacturing of distinct types of open source designs relevant to the aerospace industries, recently, 3D printing has been extensively utilized in many countries, for the manufacturing of distinct types of open source designs relevant to the aerospace industries, aviation industries, automotive industry and healthcare

industries etc. [9, 10]. In spite, there are still some drawbacks for the selection of 3D printing technology (high printer cost, slow built rate and increase unemployment etc.

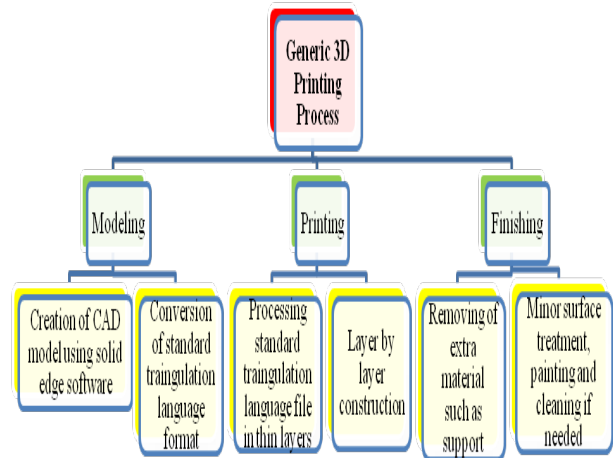


Fig.1 General Steps Involves In 3D Printing [5]

TABLE I THE EVOLUTION OF 3D METHODS

Year of Inception	Technology
1770	Mechanization
1946	1 st Computer
1952	1 st NC Machine Tool
1960	1 st Commercial Laser
1961	1 st Commercial Robot
1963	1 st Interactive Graphics System
1988	1 st Commercial RP System

But current R & D have diminished the 3D printing machine cost. So that increasing its use in colleges, labs, and homes etc. [11]. The features of distinct 3D technology are illustrated in Table 2

TABLE II FEATURES OF DISTINCT 3D PRINTING TECHNOLOGIES

Method	Process Available	Temperature needed	Principle	Support structure	Merits	Demerits	Energy Used
SLA	1887	Very low	Photo curing	Required	Fine resolution & High quality	Limited materials utilization, Slow printing and costlier.	Laser
LOM	1990	Low	Paper/sheet lamination	Required	Decrease tooling as well as manufacturing time, Used distinct range of materials, low cost and Manufacturing of big size structures	Surface quality as well as dimensional accuracy are not good, complex shapes cannot built.	Laser
FDM	1991	Low	Melted extrusion	Required	Extremely low cost, simplicity and high speed	Low mechanical characteristics, Limited materials utilized.	Extrusion
SLS	1991	Low	Sintering/heating of powders	Not required	Fine resolution, Product of high quality	Layer by layer finishing,	Laser
LENS	1997	Low	laser cladding	Required	Build complex objects	Low strength	Laser
EBM	2001	High	Sintering/heating of powders	Not required	Produce less stresses in components	Costlier and slow process	Electron laser beam
SLM	2004	High	Laser melting of powders	Required	High quality	Slow printing	Laser

II. CLASSIFICATION OF 3D PRINTERS

On the basis of feedstock material used the 3D printers are divided into following three categories such as solid based (FDM), liquid based (SLA, IJP) and powder base (SLM, SLS, EBM) are illustrated in Fig 2.

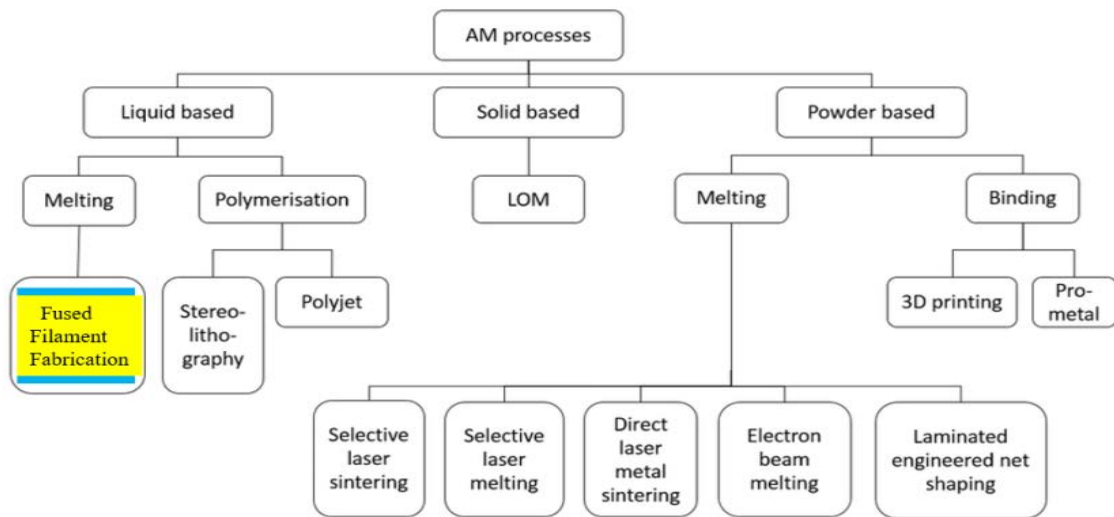
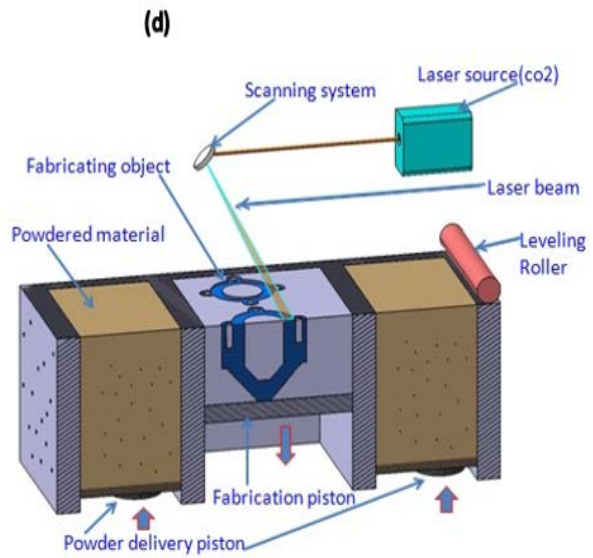
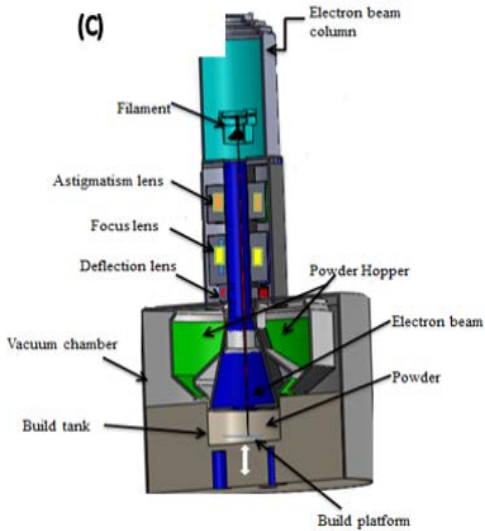
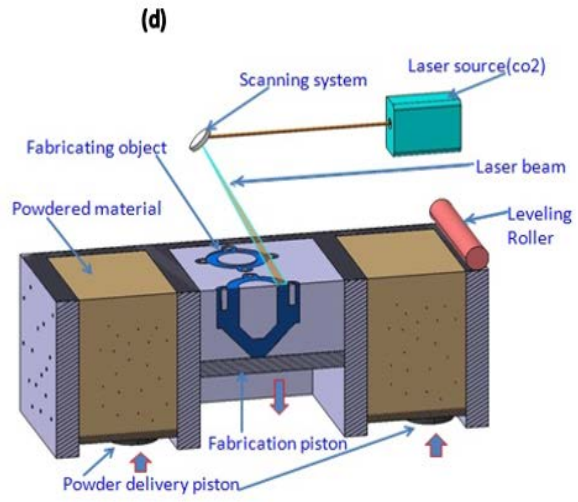
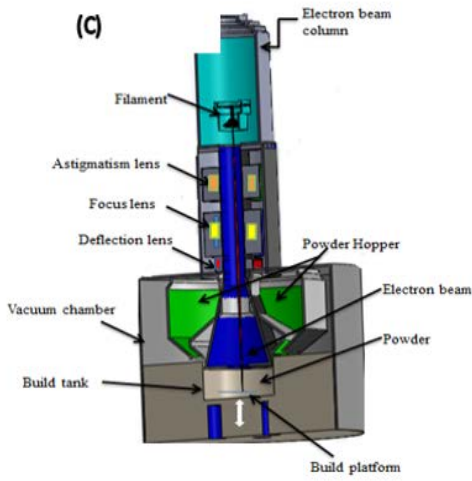
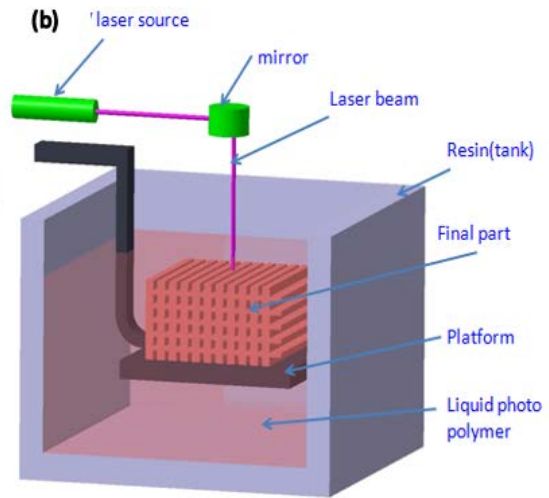
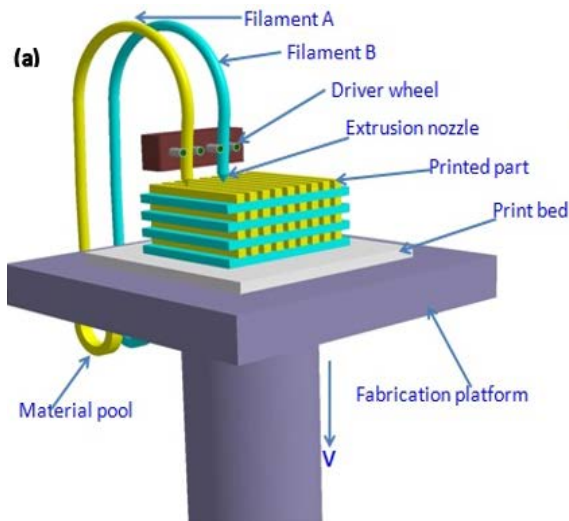


Fig.2 Distinct Types of Additive Manufacturing Methods

The several researchers/authors have used distinct 3D printing methods (SLS, SLA, EBM, FDM, IJP, SLM, etc.) for different applications and all these methods

works on the same principle for manufacturing of final finished parts [27]. The schematic presentation of distinct 3D printer is illustrated in Fig 3(a-f).



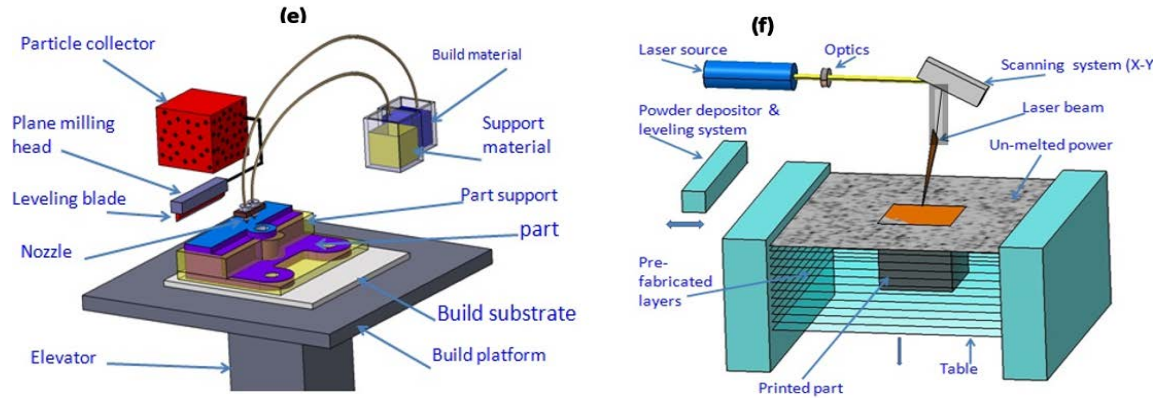


Fig. 3 (a-f) Schematic Diagram of Distinct 3D Printing Methods (a) FDM (b) SLA (c) EBM (d) SLS (e) IJP (f) SLM [27].

TABLE III DESCRIPTION OF DISTINCT 3D PRINTING METHODS

Author/Year	Method	Material	Description	Ref.
Belhabib, S. et al. 2017	FDM	PLA, Nylon, ABS	A thermoplastic material in the form of filament is melted & laid on to the build base in the form of layer until the final part is formed.	[28]
Belhabib, S. et al. 2017	FDM	PLA, Nylon, ABS	A thermoplastic material in the form of filament is melted & laid on to the build base in the form of layer until the final part is formed.	[28]
Liu, T. et al. 2018	SLA	Photopolymers	Laser beam of UV selectively hardens the photo polymer resin in layers. Every layer is solidified and built on top of next until the final part is formed.	[29]
Nakao, Y et al. 2014	EBM	Titanium, cobalt chrome alloy	The EBM 3Dprinting method is similar as that of SLS, except for the high power electron beam (EB) is utilized to fuse the powdered constituent /particles.	[30]
Ligon, S.C. et al. 2017	SLS	Polyamide, nylon	The high powder laser beam fuses the powdered materials in layer fashion pattern to form a component.	[31]
Mandrycky, C. et al. 2016	IJP	Starch or gypsum (powder bed) and water (binding agent)	A liquid binding material is selectively dropped into the powder bed in alternative layers of powder binding liquid powder, until the final component is formed.	[32]
Khan, M. et al. 2010	SLM	metals, PC, Polymers, ABS, powdered plastics	The molten state metal is solidified, as the laser beam moves away from the melt pool. Each layer is melted, enough to fuse it to the underlying layer. Another powder material layer of is then formed and spread onto the earlier melted layer.	[33]

III. APPLICATIONS OF 3D PRINTING IN DISTINCT SECTORS

Additive manufacturing is now being utilized in a several distinct industries such as medical, automotive,

fabric/fashion, aerospace, electronics, food, furniture, architecture, building and construction industry etc. The money spent yearly on final components fabricated by 3D printing worldwide and share of 3DP application in distinct sector are depicted in Fig 4(a&b) respectively.

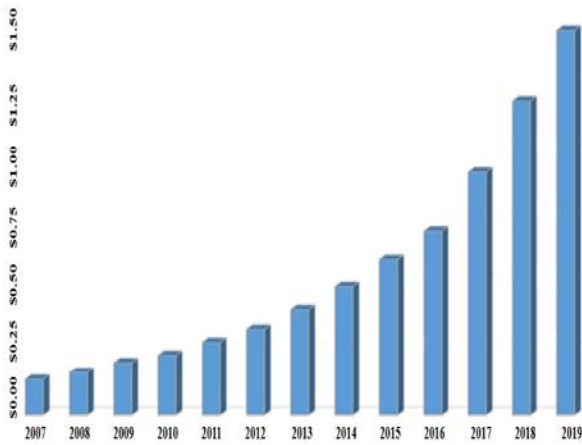


Fig. 4 (a) Money Spent annually on final component production by AM worldwide values are in billions of dollars. (Source: Wohler’s Report 2020).

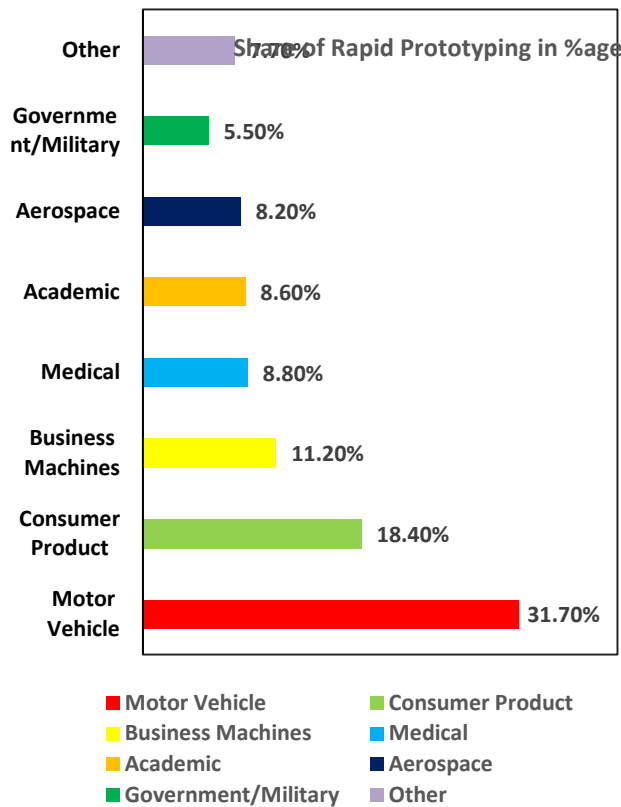


Fig. 4 (b) Share of Rapid Prototyping in Distinct Sectors [Wohler’s Report 2020].

A. Medical Industry

The use of 3D printing is growing regularly, mainly in the medical field. The study reveals that about eleven

percent of medical industries revenue comes from 3D components, whether medical device or implants [34]. The data obtained from web of science printing for biomedical applications has been published from 2011 to till June, 2020 years. The distinct authors used distinct 3D printing methods in areas of medical for different applications such as custom made implant & prosthetics, surgical tool, anatomical models, bio printing tissues and origins etc.[35-38]. The powder based process (SLS) process, facilitate/helps the fabrication of bone scaffolds, dental implants and medical devices while, solid based process (FDM) enable to fabricate surgical guides and bone models etc. respectively[39-42]. 3D printing provides greater customization as per the individual patient data which is obtained from laser scanning, ultrasound etc. and need for medical use. [43,44]. Now a day, 3D printing was used for the separation of Siamese twins by performing a correct pre surgical planning on 3D printer fabricated models, skull model and prosthetic leg respectively [44-47] as depicted in Fig.5.



Fig. 5 Medical Applications: (a) Pre-Surgical Planning (b) Skull Model (c) Prosthetic Leg [44-47].

B. Automotive Industry

In the automotive industry, additive manufacturing has made miracle to bring new shines, robust designs, lighter, stronger and safer product in the short time [48, 49]. In this industry 3D printing applications are mainly found in an assembly line to assemble, light weight parts, replacement spare parts and prototypes [50]. Many car companies like BMW, Mercedes-Benz, Bugati, Honda, Toyota and Ford etc. are embracing 3D printing. The popularity of 3D printer is automobile industry has increased so rapidly over the past decade and the graph is expected to increase in oncoming financial years. The market value of 3D in this industry is predicted to reach USD 2391 million by 2022.

Most of the car manufacturers that are using 3D printer have heightened the profitability and have secured the other revenue too [50]. According to the report of smart tech., only in 2019 the global automotive AM revenues is USD 1.4 billion and is predicted to increase to USD 5.8 billion by the year 2025 and have a 31.7% share in motor vehicles. There is a lot of benefits of using a 3D printer in the automotive industry such as weight reduction, part consolidation and enhance the quality via rapid prototyping etc. Currently the main uses of automotive rapid prototyping are to manufacture valves, wind breakers, cooling vents, bumpers, and pumps, etc. The 3D printing is expected to be employed soon for fabrication of corrosion resistant super alloys [51, 52]. In addition, the 3D printing method can minimize the wastage materials, material consumption. Furthermore, 3D printing method can decrease time and cost. Hence, it provides to testing new designs in a fast timely. The application of 3D printing in automotive sector is depicted in Fig.6 [53-55].



Fig. 6 Automotive application: (a) Toyota's i-Road vehicle (b) Toyota four Cylinder engine [55].

C. Fabric and Fashion Industry

The fusion of fashion and 3D printing may not sound like natural fit, but it is going to be part of everyday wears. Today 3D printing not only limit to the core of fashion industry, i.e. textile industry, its application is extending day by day, now it can print leather goods, accessories and many other [56]. 3D printing is utilized in the fashion industry to fabricate one-off complex design [58]. This technique has a great importance in many industries such as clothing, shoes, and jewellery industries.

In addition, the main merits of fabric & fashion industries are lower supply chain cost, on-demand custom fit, deliver and produce products in less quantity with less time [59-61]. In fashion industry more often

fused deposition melting (FDM), selective laser sintering (SLS) and polyjet AM technique are used, along with-it material is also required as input.

Mainly polymer, polymer composites material area used as it is lighter in weight and flexible for movement. For example: ABS plastic, PLA and PETG. These are the polymer having quality like printing durability of ABS material, dimensional accuracy of PLA plastic and PETG have water resistance and smooth surface finishing [62].

3D printing can provide a major tool to the artists and jewellers which will allow them to manufacture different shaped components in a very few hours than days [63].

D. Aerospace Industry

Aerospace Industry is one of the initials adopted of AM technology for prototyping, but now it is used to produce end parts as well as replacement parts [64]. The reason of adoption of 3D Printing in the aerospace industry is; that it has the capability to give support in energy saving and fuel economy idea from lightweight, quick production and reduce supply chain cost, etc. [49]. According to the earlier Wohler report 2017, the use of 3DP in aerospace is in the order of about USD 1 billion [64]. Only Aeronautics sector is responsible for around 3% of global green emission house gas [65].

It is predicated that the percentage would be increased to 70% by 2025 and 300% -700% by 2050 as compared to 2005. The international civil aviation organization and the international air transport has an ambitious reduction goal for air transport that reduction of 50% in net aviation CO₂ emission by 2050, the adoption of additive manufacturing technology is the way to the goal by enhancing aircraft eco-design initiative [65]. Some benefits of additive manufacturing are as follow.

E. Waste Reduction

3D printing produces part by adding material only where it needed by layer on layer as a result, it produces less waste than traditional method. In aerospace industry very expensive material are used like titanium and different alloys which takes a lot of cost, effort, and time to recycle scarp producing during machining in traditional method. AM brings the scarp rate down to 10-20 percentage from 80-90 percentage [64], hence the cost time and effort are also saved by employing AM.

F. Part Consolidation

One of the key benefits of 3D printer is part consolidation. Additive manufacturing has ability to manufacture the multiple components as single component [64]. Part consolidation simplifies the assembly and maintenance process and effort [5].for example: GE additively manufactured its leap engine's fuel nozzle as a single part, ever it was made by

assembling 20 different parts and is found 5 times more durable than the previous part [64].

G. Maintenance and Repair

Making maintenance, repair and overhaul MRO is an important function in the aerospace industry. Sometime MRO Company needs to produce or repair typical parts at a time and in this situation AM is very beneficial, not only this, in some situation MRO's company also have to produce the typical tool for any part that are not available to purchases from OEMs [64]. To do MRO, the MRO's company commonly uses metal 3D printing technologies like direct energy deposition. In addition, this technology provides many merits in aerospace sector, such as decrease fabrication cost ranging from 30% - 35% in the case of low volume service components and decrease up to 70% product introduction lead-time [66]. Other applications of 3D printing are the prototyping complicated gearbox housing (for design examination), manufacturing of the engine block (cast metal) etc. [67]. In aerospace field 3D printing has shown more interest in these owing to fabricate direct metal components such as Ti and manufacture good performance items without the need of tooling [68].

H. Electronics industry

3D printing electronics provides high potential to build various functional 3D objects with complex feature, appearance, and properties. The engineers are working on structural, stretchable, conformal, embeddable and flexible electronics because the interest of persons is turning towards the wearable electronics, soft robotics, machines and human interference [69, 70]. Along with the extending in the application of 3D electronics, different multifunctional fabrication process is evolving like vat photo polymerization, material extrusion, power bed fusion, binder jetting, aerosol jetting, etc. [71].

However, nowadays hybridizing 3D printing process such as the combination of jet printing and extrusion, powder bed-based and aerosol jet printing (mostly used in electronics fabrication field) are in trend [72]. All the above process required certain material like metal nanoparticle ink, adhesives, ceramics, bio-active matter, polymers and conductive inks and wire etc. to manufactures 3D structured object. This industry is interested to deliver something to a new generation, to catch the goal innovative technique and methods are using [73] like as mention above embedded electronics.

It is one of the recent progresses of 3D electronics that added significant functionality in printed structure also reduces the mass and assembly complexity. An embedded electronics circuit is fabricated with the help of stereolithographic (SL) and direct print (DP) together (a hybrid process). Similarly, as embedded electronics,

stretchable and flexible electronics are also one of the recent progresses, which make possible to manufacture wearable electronics and soft robotics.

It is generally produced with the help of syringe extrusion-based 3D printing process [74, 75].

I. Food Industry

The healthy food, especially for pregnant ladies, patients, children, etc. is very essential [76]. By using 3D printing, the materials (high nutrients) can be mixed as well as processed into desired size and shape [77]. The major examples of food items which can be printed by this technology with desired shape are pizza, pasta, chocolate etc. [78]. Very soon a new kitchen appliance will be added in many kitchen rooms of the hotel, restaurant, homes, cafe, etc and the appliance is 3D printer. The 3D printer is so capable that it can now print food from ordinary meals to grow able and personalized nutrition [79]. However, food security and sustainable nutrition are the global agenda that should be considered during printing by 3D printer [80]. The food is printed through different technique and is basically categorized into 3 different categories they are extrusion-based printing, ink jet printing and binder jetting.

J. Furniture Industry

Today's 3D printing is trending around in all the industry. It has grave furniture industry too. In fact, it (3D printing) is making waves across this industry (furniture industry) by producing the novel form of furniture, connectors, replacement parts etc. [81].

As we know, furniture, play great role in decoration of home, hotel, office and etc. with different accessories like beds, coffee table, chairs and etc., to make stylish or to decorate that furniture 3D printing play great role [82]. Not only for decoration, but also save time, cost, etc. by eliminating or reducing has the assembly worked which took lots of time in the traditional method [83].

The material like thermoplastic, metal alloy, aluminium, plastic, PLA, ABS, stainless steel, polymer, etc. are used to make furniture and accessories, apart from this wood polymer, wood chip, saw dust are also used as material [83].

The 4XYZ company uses wood instead of saw dust powder or wood fibre to make product with a précised dimension shape and location. Sawdust; which is wood fiber that acts as raw material for different types of 3D printing technique like FFF. These types of material have great role in environment impact, reducing price, increasing performance and the printed product could be sanded, sainted, and painted like normal product [84].

Architecture, building, and construction industry. This technology is considered as eco-friendly derivative. In case of the construction industry, this technology can be utilized to print whole building of manufacture components [85]. The other merits of this technology are the companies can create/design the visual of the building economically, very less time and pinpoint problem areas. The most common examples of 3D printer buildings are Apis Cor Printed House in Russia and Amsterdam (Canal House) etc. [86, 87].

The architects generally 1st make their models by performing manually, that take more times and cannot fabricate complicated shapes of the object.

If we compare to other processes the SLA is most suitable for architectural modelling owing to its printing materials availability and resolution. In addition, the designs can be enhanced easily by simply amending the computer aided design model [88].

K. Jewellery Industry

Jewellery is one of the ancient and a well-known human art which is also considered as the wealth and aesthetic. Initially, some precious stone and metals are only considered as the material for jewellery, but today many other materials are added like stainless steel, bronze, copper, plastic, metal alloy and other precious metals like platinum, palladium, etc. Similarly, the application of the jewellery is also expanding e.g. Jewellery like bracelets, necklace, etc. are imbedding in fabrics, clothes, etc. for fashion [89].

There are many ways of making jewellery, but in market mostly 2 method are mostly used. i.e. Investment Casting and Direct printing (a 3DP method). Which are briefly explains below.

Today's investment casting begins with the designing through CAD software then it is transfer to the 3D printing machine like SLA, DLP, DOD, etc. According to the properties required of the product these techniques are selected. The machine then prints the pattern, for patterning mostly wax, castle resin is used. Thereafter, it is coated with clay, ceramics, etc. after it the wax is taken out by melting it.

After that, the liquefied metal is poured into it and left for cool. Finally, the coated clay is then removed. The second one is direct printing; in this method SMLS/SLM is used.

Same as IC, this method also starts with designing and transferring the STL to machine. The machine is then prepared for orientation of support, sized, shape, etc. and heated. Then the piece is sintered after it the product made is extracted from the supported, then finally sent to the post processing.

Both the methods have their own pro and cons in this industry. The DMLS technique has given the freedom on concepts and geometries, improve the time-to-market, high quality of output and sustainable design.

But in this method temperature should be preciously maintained, if the temperature is high then there is more chance to get the damage the parts or increase the work of post processing. It is expensive than IC. Similarly, IC has their own benefits like IC have potential to produce very high quality, detailed and minute, intricate feature. It is very beneficial for mass production [90].

IV. MERITS AND DEMERITS OF ADDITIVE MANUFACTURING

A. Merits

1. 3D printing decreases the part production time and cost.
2. Fabricate customization implant.
3. In-Situ repair and In-Situ manufacturing are also possible with 3DP, which results in minimizing wastage.
4. It gives freedom in geometry, due to which the product with complex design can be easily produced that is moreover impossible with traditional manufacturing.
5. AM makes the product by adding the material so, the only required amount of material is used but with traditional way it just reverses. Hence, more material save, less wastage (in fact, no wastage) is produced, no environmental impact, etc. [91-93]

B. Demerits

1. Poor surface finish.
2. Less mechanical properties
3. In the study of Illinois Institute of Technology, It seems that some 3DP methods emit many harmful, toxic and carcinogen particle, which have a bad effect on health.
4. In future, it might reduce the manufacturing jobs for people, which latter invites many other social problems. Similarly, there will be a great issue of violation of copyrights. If anyone gets blueprint then they will easily counterfeit the product [93, 94].

V. SUMMARY

The results of some of the researchers who already used distinct 3D printing techniques in distinct sectors are summarized in Table 4

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TABLE IV THE SUMMARY OF DISTINCT 3D PRINTING METHODS, APPLICATIONS AND THEIR CONCLUSION

Author	Year	Process	Application	Conclusion	Ref.
Ishack, S. <i>et al.</i>	2020	FDM, powder bed fusion, ink jet printing, etc.	Medical Industry	N95 mask has 3D Printed, face shield property gained by scanning the exact facial parameter, stable & biocompatible material, O2 control ventilator, pills. Hence this 3DP mask in one of the best safety measure for respiratory syndrome like COVID19	[95]
Nerella, V. N. <i>et al.</i>	2016	Extrusion based	Construction Industry	It possess dual process i.e. buildability with the properties of compressive, tensile, durable, etc. of the constructed body.	[96]
Singh, R. <i>et al.</i>	2020	Powder bed fusion	Aerospace, Automotive, Energy Industry, etc.	Despite of some limitation like roughing, cracking, etc. which can be control by some process, it has great benefit over the other AM technique. It is low cost, eco-friendly, some are recyclable, good mechanical properties & material like metal, alloys, plastic, glass, etc. can be used.	[97]
Velázquez, J. S. <i>et al.</i>	2020	FDM	Medical Industry	The patient of Keratoconus is also able to take the benefit of AM by using 3DP cornea with bio compatible material, low cost, custom-made, light weight. Apart from this it gives better and perspective treatment to the patient.	[98]
Beecroft, M.	2019	SLS, FDM	Fabric Industry	It possible for the AM to produce the knitted fabric that has the properties nearly like in traditional fabric i.e. easily stretchable, flexible, etc. Along this, continuous fiber type geometry can be knitted easily.	[99]
Gha S. H. <i>et al.</i>	2018	Robotic arm & extrusion nozzle nearly like ink jet printing method, FDM, SLS, SLA, etc	Construction Industry	Construction with the help this technology gives the gives the facility of customization, design-complexity, flexibility, low cost, socio-economic, eco-innovative, etc. It has also main role in developing model of complex and big project by the help of FDM, SLS, etc. It is future of the construction industry	[100]
Patel, K. D. <i>et al.</i>	2017	DLP	Construction Industry	For DLP, elastomer is very beneficial for printing highly deformable complex 3D structure and fast processing without any material support. Its uses is rapidly increasing in soft robotics.	[101]
Cooper, F. <i>et al.</i>	2016	DMLM/SLM	Jewellery Industry	By using this technology in jewelry manufacturing increases the production precious metals in medium & small sized enterprises to run the efficient business. Plus it has potential for production of hollow profile, complex design, low cost, less weight, etc.	[102]

VI. CONCLUSIONS

3D printing technology has become a competent and advance manufacturing tool in different fields, including, automobile, medical, military, government, and aerospace, etc. Among these sectors, medical sector is an emerging sector in future due to customization, design flexibility, high accuracy, and ability to produce intricate parts. A lot of research in the medical sector to explore its new applications has been done. But some advance medical application such as organ printing is under progress.

VII. FUTURE SCOPE AND CHALLENGES

In the future, researchers can explore the investigation to identify optimum parameter settings for specific 3D printing process and materials to obtain desired properties in the product. In addition, some research on lead time, product cost, and process capability of distinct

type of 3D printing techniques can be performed for comparison and economic benefits.

The main challenges that 3D printing facing are as follows.

1. Intellectual property right of 3D printer user (for example pistol manufacturing)
2. Nearly anything can be printed by 3D printer and this is a troubling prospect, if criminals used 3D printer to create illegal product.

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