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Analysis Of Different 3d Printing Technologies In Various Industrial Applications.

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ABSTRACT

Industrial adoption of 3D Printing has been increasing gradually from prototyping to manufacturing of low volume customized parts. The need for customized implants like tooth crowns, hearing aids, and orthopedic- replacement parts has made the life sciences industry an early adopter of 3D Printing. Demand for low volume spare parts of vintage cars and older models makes 3D printing very useful in the automotive industry. It is possible to 3D print in a wide range of materials that include thermoplastics, thermoplastic composites, pure metals, metal alloys and ceramics. Right now, 3D printing as an end-use manufacturing technology is still in its infancy. But in the coming decades, and in combination with synthetic biology and nanotechnology, it has the potential to radically transform many design, production and logistics processes. 3D printing encompasses a wide range of additive manufacturing technologies. Each of these builds objects in successive layers that are typically about 0.1 mm thin. In basic terms there are four categories of 3D printers. Firstly, we have printers that extrude a molten or otherwise semi-liquid material. Secondly, there are printers that solidify a photo curable resin. Thirdly, there are printers that bind or fuse the granules of a powder. And finally, there are printers that stick together cut sheets of paper, plastic or metal.

Key words: Stereo-lithography (SLA); Fused Deposition Modeling (FDM); Laminated Object Manufacturing (LOM); Selective Laser Sintering (SLS) & Direct Metal Laser Sintering (DMLS); Ink Jet Printing &Poly-jet printing.

1. INTRODUCTION

3D printing is an evolution of printing technologies, capable to produce or reproduce freestanding sophisticated structures in one piece. 3D Printing is one of the Additive layer fabrication processes (Vojislav et al., 2011). The 3D printing process happening inside the machine consists of two stages, (1) The direct transfer from software data to printed structures, (2) by repeatedly positioning the print head in all three directions in space in order to print layer by layer the whole object. (Lu et al., 2008) More in detail, Lu et al., (2008) mentioned how the printing process is carried out, first the design is made by a CAD system, and then the areas are printed through a compilation of two-dimensional slices representing the 3D object to consequently print layer by layer until the object is completed. The second stage of the manufacturing process can also be subdivided in two basic steps "coating and fusing", throughout these steps, the material is laid over a surface and by the action of a source of energy the layers are created. The source of energy and the raw materials vary depending on the used technology (Vojislav et al., 2011) [1].

2. TECHNOLOGIES

The technologies that can be used to build a part one layer at a time are quite varied and in different stages of development. In order to accommodate different materials, as well as improve build times or part strength, numerous technologies have emerged. Some technologies are commercially available methods of fabricating prototypes, others are quickly becoming viable forms of production manufacturing, and newer technologies are continuously being developed. These different methods of additive fabrication can be classified by the type of material that is employed.

2.1. Liquid-based processes

The first category of 3D printer creates object layers by selectively solidifying a liquid resin known as photopolymer that hardens when exposed to laser or other light source. Some such photo polymerization 3D printers built object layers within a tank of liquid. Meanwhile others jet out a single layer of resin and use ultraviolent light to set it solid before the next layer is added. A few 3D printers based on the latter technology and are able to mix several different photo polymers in the same print job, so allowing them to output objects made from multiple materials.

2.2. Powder-based processes

A second and very broad category of 3D printing hardware builds object by selectively sticking together successive layers of a very fine powder. Such powder adhesion or granular materials binding can be achieved by jetting an adhesive onto each powder layer, or by fusing powder granules together using a laser or other heat source. Yet other technologies melt and then fuse the granules of a powdered built material as it is deposited onto a built surface. Various forms of powder adhesion are already commonly used to 3D print in a wide range of materials. These include nylon, bio-plastics, ceramics, wax, bronze, stainless steel, cobalt chrome and titanium.

2.3. Solid-based processes

There are 3D printers that create objects by extruding a molten or otherwise semi liquid material from a print head nozzle. Most commonly this involves extruding a molten thermoplastic that very rapidly sets after it has left the print head. Other extrusion based 3D printers manufacture objects by outputting molten metal, or by extruding chocolate or cake frosting (icing) to 3D print culinary creations. There are even 3D printers that extrude concrete or clay.

2.4. Paper based processes

A final category of 3D printer is based on lamination. Here, successive layers of cut paper, metal or plastic are stuck together to build up a solid object. Where sheets of paper are used as the build material, they are cut by blade or laser and glued together. They may also be sprayed with multiple inks during the printing process to create low cost, full colour 3D printed objects. [2]

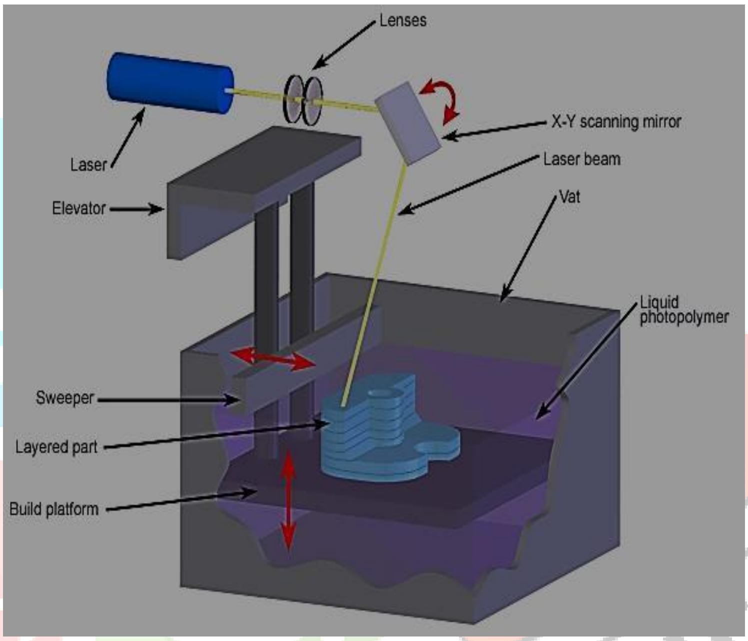
3. TYPES OF 3D PRINTING TECHNOLOGIES

3.1. Stereo-lithography (SLA)

It is the most widely used rapid prototyping technology. It can produce highly accurate and detailed polymer parts. It was the first rapid prototyping process, introduced in 1988 by 3D Systems, Inc., based on work by inventor Charles Hull. Stereo-lithography is the most widely used rapid prototyping technology. Stereo- lithography builds plastic parts or objects one layer at a time by tracing a laser beam on the surface of a vat of liquid photopolymer, inside of which is a movable stage to support the part being built. The photopolymer quickly solidifies wherever the laser beam strikes the surface of the liquid. The platform is lowered by a distance equal to the layer thickness (typically 0.003-0.002 in), and a subsequent layer is formed on top of the previously completed layers. The self-adhesive property of the material causes each succeeding layer to bond to the previous one and thus form a complete, three-dimensional object out of many layers. Objects which have overhangs or undercuts must be supported during the fabrication process by support structures. These are either manually or automatically designed with a computer program specifically developed for rapid prototyping. Once complete, the part is elevated above the vat and drained. Excess polymer is swabbed or rinsed away from the surfaces. In many cases, a final cure is given by placing the part in a UV oven. After the final cure, supports are cut off the part and surfaces are polished, sanded or otherwise finished. [3]

Table 1 Capabilities of SLA

Material type	**Liquid (photo polymer)**
Material	Principally photo curing polymers which simulate polypropylene, ABS, PBT, rubber; development of ceramic-metal alloys.
Maximum part size	59.00 x 29.50 x 19.70 in.
Min feature size	0.004 in.
Min layer thickness	0.0010 in.
Tolerance	0.0050 in.
Surface finish & Build speed	Surface finish is smooth and build speed is Average
Applications	Rapid tooling patterns, Snap fits, very detailed parts.



(a) Stereo lithography (SLA) working

(b) Component printed using SLA

Figure 1

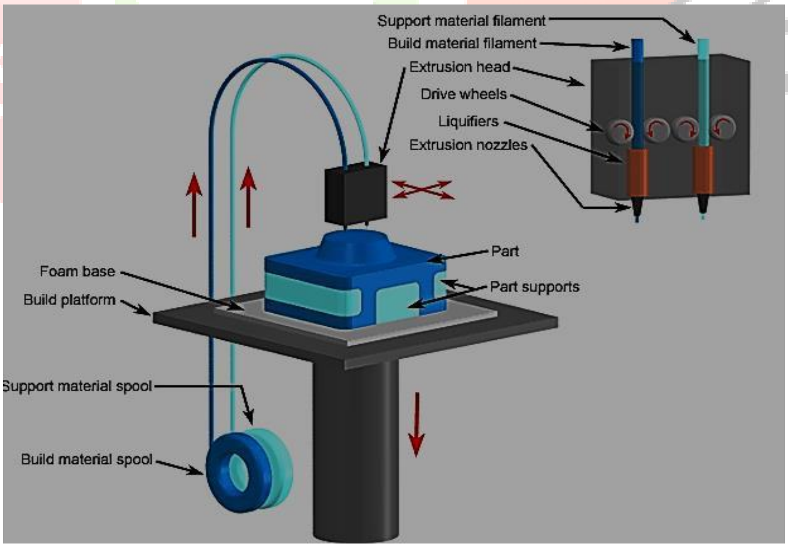
3.2. Fused Deposition Modeling (FDM)

It was developed by Stratasys in Eden Prairie, Minnesota. In this process, a plastic or wax material is extruded through a nozzle that traces the parts cross sectional geometry layer by layer.FDM is the second most widely used rapid prototyping technology, after stereo lithography [5]. A plastic filament is unwound from a coil and supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off. The nozzle is mounted to an X-Y plotter type mechanism which traces out the part contours, There is a second extrusion nozzle for the support material (different from the model material). As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer. The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. The object is built on a mechanical stage which moves vertically downward layer by layer as the part is formed. The entire system is contained within a chamber which is held at

a temperature just below the melting point of the plastic. Support structures are automatically generated for overhanging geometries and are later removed by breaking them away from the object. A water-soluble support material is also available for ABS parts. A range of materials are available including ABS, polyamide, polycarbonate, polyethylene, polypropylene, and investment casting wax. [4]

Table 2 Capabilities of FDM

Material type	**Solid (Filaments)**
Material	Thermoplastics such as ABS, Polycarbonate, and Poly-phenylsulfone; Elastomers
Maximum part size	36.00 x 24.00 x 36.00 in.
Min feature size	0.005 in.
Min layer thickness	0.0050 in.
Tolerance	0.0050 in.
Surface finish & Build speed	Surface finish is rough and build speed is slow
Applications	Rapid tooling patterns, Small detailed parts, Presentation models, Patient and food applications, High heat applications



(a) Fused Deposition Modeling (FDM)

(b) Component printed using FDM

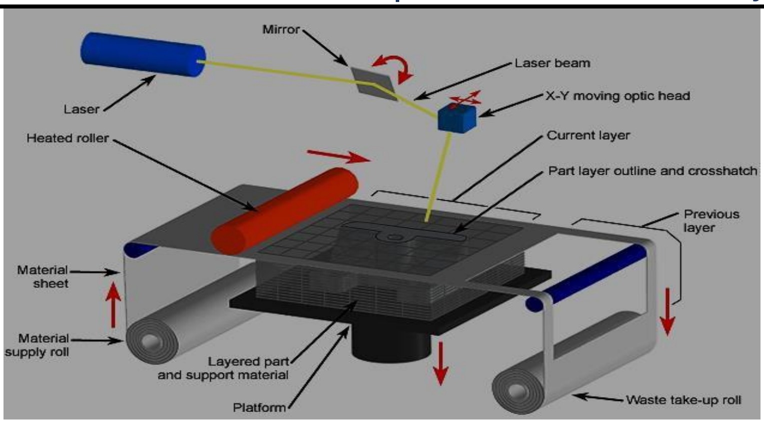
Figure 2

3.3. Laminated Object Manufacturing (LOM)

The first commercial Laminated Object Manufacturing (LOM) system was shipped in 1991. LOM was developed by Helisys of Torrance, CA. The main components of the system are a feed mechanism that advances a sheet over a build platform, a heated roller to apply pressure to bond the sheet to the layer below, and a laser to cut the outline of the part in each sheet layer. Parts are produced by stacking, bonding, and cutting layers of adhesive-coated sheet material on top of the previous one. A laser cuts the outline of the part into each layer. After each cut is completed, the platform lowers by a depth equal to the sheet thickness (typically 0.002-0.020 in), and another sheet is advanced on top of the previously deposited layers. The platform then rises slightly and the heated roller applies pressure to bond the new layer. The laser cuts the outline and the process is repeated until the part is completed. After a layer is cut, the extra material remains in place to support the part during build. [5]

Table 3 Capabilities of LOM

Material type	**Paper, plastics (Sheets)**
Material	Thermoplastics such as PVC; Paper; Composites
Maximum part size	32.00 x 22.00 x 20.00 in.
Min feature size	0.008 in.
Min layer thickness	0.0020 in.
Tolerance	0.0040 in.
Surface finish & Build speed	Surface finish is rough and build speed is fast
Applications	Less detailed parts, Rapid tooling patterns



(a) Laminated Object Manufacturing (LOM)

Fruit and bowl 3D printed in paper

(b) Component printed using LOM

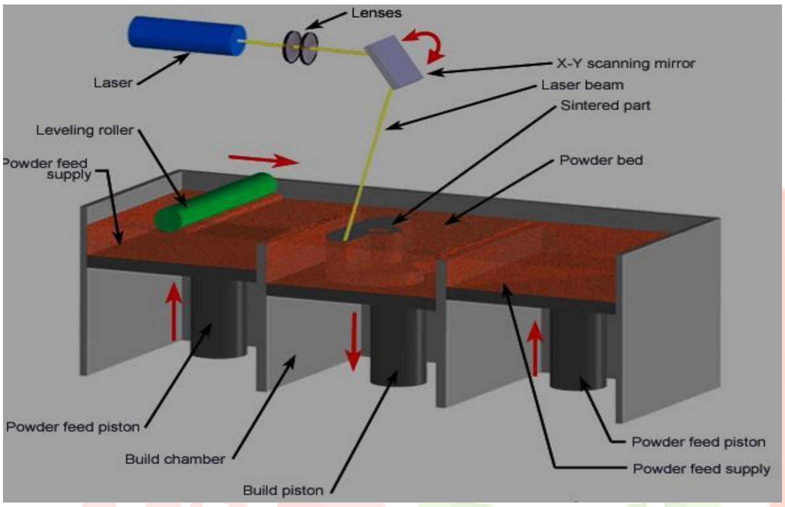
Figure 3

3.4. Selective Laser Sintering (SLS)

It was developed at the University of Texas in Austin, by Carl Deckard and colleagues. The technology was patented in 1989 and was originally sold by DTM Corporation. DTM was acquired by 3D Systems in 2001. Thermoplastic powder is spread by a roller over the surface of a build cylinder. The piston in the cylinder moves down one object layer thickness to accommodate the new layer of powder. A piston moves upward incrementally to supply a measured quantity of powder for each layer. A laser beam is traded over the surface of this tightly compacted powder to selectively melt and join the grains together to form a layer of the object. The fabrication chamber is maintained at a temperature just below the melting point of the powder so that the laser elevates the temperature slightly to cause sintering - the grains are not entirely melted, just their outer surfaces - which greatly speeds up the process. The process is repeated, layer by layer, until the entire object is formed. After the object is fully formed, the piston is raised. Excess powder is simply brushed away and final manual finishing may be carried out. No supports are required with this method since overhangs and under cuts are supported by the solid powder bed. It takes a considerable cool-down time before the part can be removed from the machine. Large parts with thin sections may require as much as two days of cooling. [6]

Table 4 Capabilities of SLS

Material type	**Powder (Polymer)**
Material	Thermoplastics such as Nylon, Polyamide, and Polystyrene; Elastomers; Composites
Maximum part size	22.00 x 22.00 x 30.00 in.
Min feature size	0.005 in.
Min layer thickness	0.0040 in.
Tolerance	0.0100 in.
Surface finish & Build speed	Surface finish is average and build speed is fast
Applications	Rapid tooling patterns, Less detailed parts, Parts with snap-fits & living hinges, High heat applications



(a) Selective Laser Sintering (SLS)

(b) Component printed using SLS

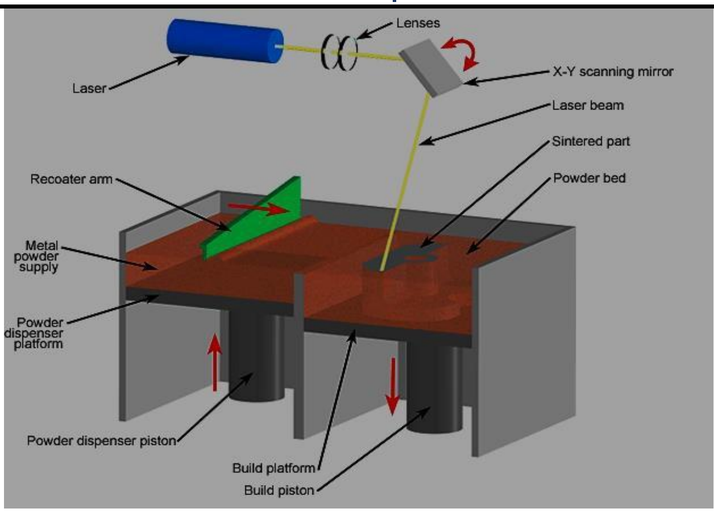
Figure 4

3.5. Direct Metal Laser Sintering (DMLS)

It was developed jointly by Rapid Product Innovations (RPI) and EOS GmbH, starting in 1994, as the first commercial rapid prototyping method to produce metal parts in a single process. With DMLS, metal powder (20-micron diameter), free of binder or fluxing agent, is completely melted by the scanning of a high-power laser beam to build the part with properties of the original material. Eliminating the polymer binder avoids the burn-off and infiltration steps, and produces a 95% dense steel part compared to roughly 70% density with Selective Laser Sintering (SLS). An additional benefit of the DMLS process compared to SLS is higher detail resolution due to the use of thinner layers, enabled by a smaller powder diameter. This capability allows for more intricate part shapes. Material options that are currently offered include alloy steel, stainless steel, tool steel, aluminum, bronze, cobalt-chrome, and titanium. In addition to functional prototypes, DMLS is often used to produce rapid tooling, medical implants, and aerospace parts for high heat applications. The DMLS process can be performed by two different methods, powder deposition and powder bed, which differ in the way each layer of powder is applied. In the powder deposition method, the metal powder is contained in a hopper that melts the powder and deposits a thin layer onto the build platform. In the powder bed method (shown in fig.5 (a)), the powder dispenser piston raises the powder supply and then a re-coater arm distributes a layer of powder onto the powder bed. A laser then sinters the layer of powder metal. In both methods, after a layer is built the build piston lowers the build platform and the next layer of powder is applied. The powder deposition method offers the advantage of using more than one material, each in its own hopper. The powder bed method is limited to only one material but offers faster build speeds. [6]

Table 5 Capabilities of DMLS

Material type	**Powder (Metal)**
Material	Ferrous metals such as Steel alloys, Stainless steel, Tool steel; Non-ferrous metals such as Aluminum, Bronze, Cobalt-chrome, Titanium; Ceramics
Maximum part size	10.00 x 10.00 x 8.70 in.
Min feature size	0.005 in.
Min layer thickness	0.0010 in.
Tolerance	0.0100 in.
Surface finish & Build speed	Surface finish is average and build speed is fast
Applications	Rapid tooling, High heat applications, Medical implants, Aerospace parts



(a) Direct Metal Laser Sintering (DMLS)

(b) Component printed using DMLS

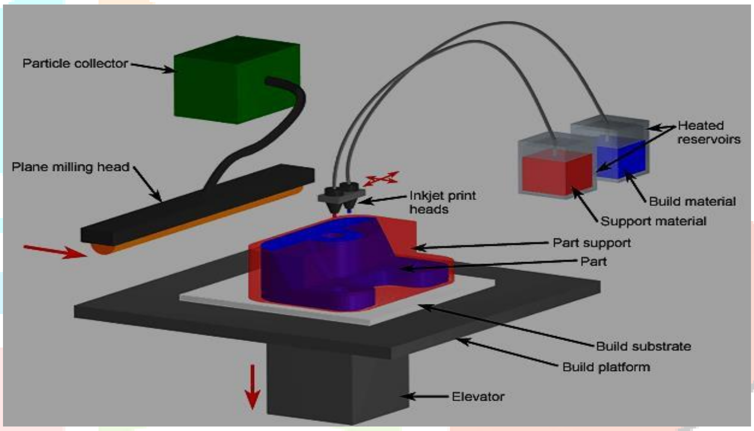
Figure 5

3.6. Ink Jet Printing

This method uses a single jet each for a plastic build material and a wax-like support material, which are held in a melted liquid state in reservoirs. The liquids are fed to individual jetting heads which squirt tiny droplets of the materials as they are moved in X-Y fashion in the required pattern to form a layer of the object. The materials harden by rapidly dropping in temperature as they are deposited. After an entire layer of the object is formed by jetting, a milling head is passed over the layer to make it a uniform thickness. Particles are vacuumed away and are captured in a filter. The process is repeated to form the entire object. After the object is completed, the wax support material is either melted or dissolved away. The most outstanding characteristic of the Solid-scape system is the ability to produce extremely fine resolution and surface finishes, essentially equivalent to CNC machines. The technique is very slow for large objects. Materials selection is very limited. Other manufacturers use considerably different inkjet techniques, but all rely on squirting a build material in a liquid or melted state which cools or otherwise hardens to form a solid on impact. 3D Systems produces an inkjet machine called the Thermo-Jet Modeler (TM) which utilizes several hundred nozzles in a wide head configuration. It uses a hair-like matrix of build material to provide support for overhangs which can be easily brushed off once the object is complete. This machine is much faster than the Solid-scape approach, but doesn't offer as good a surface finish or resolution. [3]

Table 6 Capabilities of Ink jet printing

Material type	**Liquid**
Material	Acrylic based thermo polymeric Plastic, Natural and Synthetic Waxes, Fatty Esters
Maximum part size	12.00 x 6.00 x 6.00 in.
Min feature size	0.005 in.
Min layer thickness	0.0005 in.
Tolerance	0.0010 in.
Surface finish & Build speed	Surface finish is very smooth and build speed is slow
Applications	Very detailed parts, Rapid tooling patterns, Jewelry and fine items, medical devices



(a) Inkjet Printing

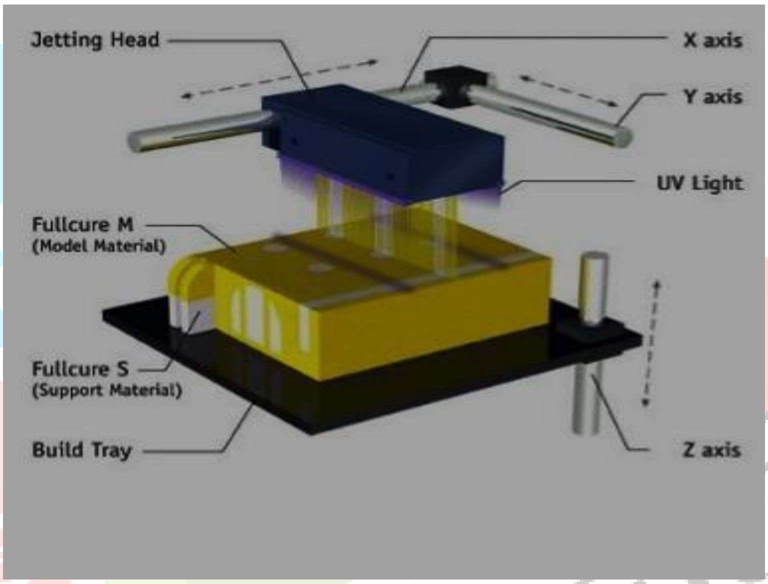
Figure 6

3.6. Poly-Jet 3D printing

Objet Geometries Ltd., an Israeli company, introduced its first machine based on Poly-Jet technology in early 2000. It is a potentially promising replacement for stereo- lithography. Poly jet process is very similar to the ink jet printing done on paper but in this process, instead of jetting drops of ink onto paper, the printer jets layers of liquid polymer onto a tray and then the UV rays instantly cure the model. The process is based on photopolymers, but uses a wide area inkjet head to layer wise deposit both build and support materials. It subsequently completely cures each layer after it is deposited with a UV flood lamp mounted on the print head. The support material, which is also a photopolymer, is removed by washing it away with pressurized water in a secondary operation. The advantage of poly-jet systems over SLA systems is that the resins come in cartridge form (no vat of liquid photopolymer), the machines are clean, quiet and office friendly. There is less post processing cleanup on parts. Disadvantages are that the print heads are relatively expensive and need to be replaced regularly, adding to maintenance costs. [3]

Table 7 Capabilities of Poly-jet printing

Material type	**Liquid (photo polymer)**
Material	Photopolymer resin
Maximum part size	19.30 x 15.40 x 7.90 in.
Min feature size	0.006 in.
Min layer thickness	0.0006 in.
Tolerance	0.0010 in.
Surface finish & Build speed	Surface finish is smooth and build speed is fast
Applications	Very detailed parts, Rapid tooling patterns, Presentation models, Jewelry and fine items



(a) Poly-jet Photopolymer

(b) Adidas shoe printed

Figure 7

4. APPLICATIONS OF 3D PRINTING USING DIFFERENT TECHNOLOGIES IN DIFFERENT

AREAS

4.1. Aerospace

NASA engineers drew on ingenuity and advanced technology. About 70 of the parts that make up the rover were built digitally, directly from computer designs, in the heated chamber of a production-grade Stratasys 3D Printer. The process, called Fused Deposition Modeling (FDM) Technology or additive manufacturing, creates complex shapes durable enough for Martian terrain [7].For its 3D-printed parts, NASA uses ABS, PCABS and polycarbonate materials. FDM, patented by Stratasys, is the only 3D-printing method that supports production-grade thermoplastics, which are lightweight but durable enough for rugged end-use parts. [8]

4.2. Architecture industry

Poly-Jet 3D printing technology produces astonishingly smooth, detailed architectural models in an array of materials, including rigid photopolymers ready for painting. For models that must bear loads or take abuse, FDM Technology builds strong parts in production-grade thermoplastics. [9]

4.3. Automobile industry

One of Ducati's key challenges is to reduce time-to-market for new products by reducing the design cycle. To help meet this challenge, the entire design process is validated using FDM prototyping systems from Fortus. FDM (fused deposition modeling) enables Ducati to build both concept models and functional prototypes from ABS, polycarbonate and poly-phenylsulfone. [9]

4.4. Consumer products

Consumer electronics: Poly-Jet technology can produce models with exceptionally thin walls — 0.6mm or less — ideal for small devices densely packed with minute components. Smooth finish and realistic colors make these models virtually indistinguishable from the end product.

Sporting goods: Prototypes often require a combination of rigid and flexible materials. Think of a helmet's hard shell and padded interior, or a pair of ski goggles with tinted lenses and rubber over molding. Only Poly-Jet technology can produce prototypes with multiple materials and colors in a single, automated build, so it's ideal for sporting goods designers with an eye for aesthetics. FDM Technology works with production-grade thermoplastics to produce parts with high impact strength and great durability. It's perfect for components that need to withstand tough and repeated functional testing.

Toys: To capture the look and feel of your future products, only Poly-Jet can deliver fine details, smooth surfaces, playful textures, varied materials and vivid colors in a single, automated build process. [10]

4.5. Dental industry

APEX Dental Milling Center was one of the early adopters of CAD/CAM technology for producing dental parts straight from CAD design imagery. Instead of outsourcing production to CNC traditional milling techniques, the company then switched to in- house 3D printing. Having brought digital dentistry into the heart of its business, APEX Dental Milling Center has discovered that in addition to lowering prices, it can provide faster delivery times while maintaining its high-quality standards. For APEX Dental Milling Center, any worthwhile 3D printing solution had to provide one or more business advantages, such as better products, shorter processing times or more accuracy. The company found all of these advantages, and more, with the Objet 3D Printer. APEX Dental Milling Center was impressed with the ease and speed of the Objet Eden260V 3D Printing System. The printed models produced on the Objet Eden260V delivered exceptionally fine details and an outstanding surface finish – all necessary for ensuring the high accuracy required by the lab's team and its dentist customers. [9]

4.6. Jigs and Fixtures

Inkjet-based technology and FDM Technology, both available from Stratasys, provide fast and accurate methods to produce and manufacture tools. 3D printing jigs and fixtures with inkjet or FDM can help reduce the backlog for an in-house machine shop and be used as a bridge-to-tooling solution. [10]

4.7. Medical Industry

3D Printer Creates Multi-Material Respirator. Design reality, a UK based design consultancy, uses the Objet260 Connex1 multi-material 3D printer; to prototype gas mask respirators for the UK Ministry of

Defense and US Fire Services –reducing a 5- 6 day prototyping process to just hours.[10]

5. CONCLUSION

3D printers have many promising areas of potential future application. New 3D printing processes have reduced the time it takes for designers and engineers to conceptualize, create, and test prototypes. But for 3D printing to catch on the rapidly changing manufacturing industry, it will have to be seen by companies less as a fascinating technological upgrade and more as an everyday business decision. Some of the most promising areas include medical applications, custom parts replacement, and customized consumer products. As materials improve and costs go down, other applications we can barely imagine today will become possible. Perhaps the greatest area of potential growth for 3-D printing is in the medical field. As mentioned above, researchers are just starting to experiment with the idea of creating artificial bones with 3-D printers.

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