

# 3D Printing Builds Manufacturing Innovations

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## Introduction

In the thirty years since stereolithography (SLA) arrived on the scene, 3D printing capabilities have evolved from simple model and mold production to product manufacturing. Deciding whether, and how, to leverage and integrate 3D printing – also called additive manufacturing (AM) – with existing design, development, and manufacturing processes requires an understanding of the types of printers, materials used, and printer software. This white paper discusses two printer technologies, Fused Deposition Modeling (FDM) – for which Stratasys holds the original 1992 patent – and PolyJet printing, printing material options, and software choices and how they aid in fostering innovation.

## Printer Technologies

The majority of 3D printers are used for rapid prototyping, component duplication, and small-scale production runs rather than large-volume manufacturing. Notably, 3D printing is enabling a new era of creative engineering, mass customization, product personalization and unique manufacturing solutions with greater design options.

Take an average consumer product: a yoyo is an excellent example. It has a distinct shape, with large plastic sections on the exterior and small functional components inside. Making a yoyo with traditional manufacturing requires molding, machining and then assembly. But fabricating a yoyo with additive technologies is remarkably simpler. A yoyo and all its parts can be built in a single run with a 3D printer.

Many internal moving parts, such as gears, knobs and bearings, can be built and integrated with a 3D printer. It is also possible to construct objects with negative draft angles or pieces that overhang beyond 45°. By printing soluble and non-soluble support structures, virtually any shape can be produced.

## *FDM 3D Printing*

### How FDM works

FDM printers work by extruding a small filament from a nozzle that is similar to a micro sized hot melt glue gun. The filament is extruded layer upon layer from a single point. A new layer is bonded to the previous layer from the heat of the plastic being extruded; it cools down shortly after.

### Materials

FDM machines can use a variety of materials.

- **Acrylonitrile butadiene styrene (ABS)** is mechanically strong and stable enough for many final products. ABSplus is up to 40% stronger than traditional ABS and can be offered in custom colors.
- **Nylon and polycarbonate** are also common, and acrylonitrile styrene acrylate

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(ASA) is resistant to outdoor conditions.

- Most **thermoplastic** materials used in moldings are acceptable for 3D printing.

Some products require use of specialty substrates.

- **Sanitary materials** are useful for medical and food applications. PC-ISO thermoplastic can be gamma or EtO sterilized and is commonly used for food or drug packaging.
- **PPSF/PPSU thermoplastic** can withstand very high heat, making it perfect for automotive applications, medical sterilization and demanding tooling.
- **Translucent and transparent materials** are useful for optical applications.

Stratasys FDM machines utilize heated chambers that allow a larger number of materials to be printed when compared to other FDM machines. Some high quality materials, such as polyetherimide, require such high temperature chambers. Further materials development will help diversify the uses for FDM machines.

### Limitations

**Production volume:** One of FDM's current limitations is production volume. Generally, additive manufacturing is economical when production runs call for 1,000 parts or less. Plastic molding has high capital costs, but that cost is a worthwhile investment when manufacturing many thousands of parts. The main advantage of 3D printing is eliminating this high upfront cost.

**Part size:** Another common challenge is part size. The majority of printers are benchtop models with a printing envelope roughly the size of a basketball. This is adequate for most current jobs. Yet manufacturers increasingly seek to print larger objects. The Stratasys Fortus model line of 3D printers comes with print envelope dimensions up to 36 in. x 24 in. x 36 in an enormous area by commercial 3D printer standards. Novel engineering solutions don't need to be constrained by a small printing envelope. A larger envelope also allows multiple smaller objects to be printed in a single production run.

**Post-production:** Specific post-production processes might be necessary to finish a job properly. Vapor smoothing can remove lines or ridges from the part for a finished appearance. If support material was used in the printing process, it needs to be mechanically or chemically removed. Nonetheless, FDM technologies result in less waste and material use than tradition manufacturing.

### *PolyJet 3D Printing*

PolyJet 3D printing uses a different technique to fabricate components. The jetting head uses piezoelectric pumps to deposit layers of photo-curable resin. Printer heads contain multiple nozzles to create fine resolutions. This technique

is notable because it allows multiple materials and colors to be used in a single build. These new composite materials are known as Digital Materials™.

### Materials

Composite or digital materials are significantly harder to process via traditional manufacturing methods, requiring a multi-step, successive process. A PolyJet 3D printer can fabricate a strong and lightweight composite material much more efficiently. The liquid resin is hardened by exposure to an integral LED UV light, so in this sense it is comparable to stereolithography (SLA). Typically, support materials for PolyJet printing are gel-like and water soluble; a water bath or water jet easily removes excess material. As with FDM, PolyJet is able to create unique and exclusive shapes.

### Format

PolyJet printers are available both in benchtop and industrial-scale configurations. Their exceptional resolution eliminates the need for finishing processes in many cases. Wall thickness can be as small as 0.6 mm and layers as small as 16 microns. After washing away support materials, PolyJet-printed components are "print-and-plug."

### **Printer material properties or Material types/characteristics**

Printer materials range from opaque to transparent. FDM printers can make translucent products but not optical clear ones. UV-curing resins, such as those used with PolyJet techniques, have a variety of desirable optical properties. Along with improved resolutions offered by PolyJet 3D printers, UV resins can create transparent products with a glass-like appearance. With this technology, eyeglasses could be made in a single print. Viewing windows could be incorporated into a component without the need for a seal, fastener or adhesive to attach a separate pane.

Printing support materials are soluble or insoluble. Soluble materials are composed of acrylic polymers made with high levels of plasticizers, waxes, or water- or caustic-soluble polymers. These can be removed by water or a lye-based solution. Soluble support materials require less labor as the removal process can be automated, but they may take longer to dissolve than it would to remove manually. This technique is useful for printing cores or mandrels for applications such as composite molding and pattern casting where the finished 3D printed part consists of soluble support material.

Insoluble support materials are typically made of the same material as the printed product. The support material is loosely attached and is easily removed via instruments such as water jets, knives or picks.

Gradient materials are those that gradually transition between printed material types. Using multiple print heads, different materials are positioned precisely, layer by layer. Highly stressed zones in printed parts can be printed with

higher-strength materials. Components can be light and efficient, yet also strong and durable.

Take a squeegee, for example. Traditional manufacturing requires the manufacture and assembly of two separate pieces. Manufactured conventionally, the supple rubber blade is mechanically attached to the hard plastic handle; eventually the rubber edge breaks away after repetitive flexing. But a 3D printer could make a squeegee as a single part, significantly increasing its functionality and lifespan.

Using different infill patterns and infill percentages, operators will be able to tailor strength-to-weight ratios. Infill patterns such as honeycomb, lattice blocks, and micro-trusses are common methods for improving component surface rigidity. Conventional composite panels with honeycomb cores are manufactured using adhesives. An adhesive bond can impart vulnerability into part design, but printing an infill pattern could eliminate the adhesive altogether. Internal support coring can be printed in unlimited numbers of shapes and sizes; it is typically chosen to support a specific application. Unique composites, such as layers or sections of TPE elastomer, could be printed to toughen a part and stop crack propagation or dampen vibrations.

### 3D Software – an Overview

In additive manufacturing, the choice of software has an immense impact on the quality of a final product. A comprehensive 3D printing system employs different software packages depending on the process stage.

**Design and modeling software** is used to create the concept. This is normally a CAD package; commercial software like AutoCAD or open source packages such as Google Sketchup are common choices. Print Wizard, a software package included in Stratasys 3D printers, is an excellent application for 3D design.

**Converters:** After the design process the CAD file must be converted to a format suitable for 3D printers. This is generally a two-step process. First the CAD file is converted to a file type such as STL (stereolithography) format. STL files render surfaces in the CAD design as a mesh of triangles. The accuracy of curved surfaces depends on the number and size of triangles generated, which is configurable by the operator.

The second step transitions the STL file to another format, generally called 3D Print, which the printer reads to create the 3D printed structure. At this stage the designer/operator must check several parameters:



- Wall thickness must be correct
- The model should be “watertight”
- Final printing size must be defined.

CatalystEX software, sold as an integral part of Stratasys printers, is an example of a popular and user-friendly program capable of performing both conversions.

**Scanning.** Using a 3D printing system for duplication usually requires scanning the object to create a CAD file.

**Production.** This software controls parameters during production, such as those that determine the look, color, strength and precision of parts, as well as printing speed, use of materials, and build orientation for smoothest surface finish.

**Software based on technology and materials.** Specialty software packages are needed for particular technologies and materials. The primary printing techniques in current use are FDM and PolyJet.

### In Conclusion

3D printing is taking the technology world by storm; it is perhaps the most significant manufacturing innovation since the Industrial Revolution. Exploiting the advantages of this advance in processing requires a manufacturer to understand the pros and cons of different printer technologies, materials, and software, and related costs as they relate to a particular project. Companies who are deciding whether to jump onto the 3D bandwagon, or those who want to test a new process, will probably benefit from tasking a multi-disciplinary team to evaluate options. Companies who haven't yet found the right 3D printing application need only continue to keep up with advances; the correct technology could be on the market soon.

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#### ABOUT STRATASYS

Stratasys Ltd. (Nasdaq:SSYS), headquartered in Minneapolis, Minnesota and Rehovot, Israel, is a leading global provider of 3D printing and additive manufacturing solutions. The company's patented FDM®, PolyJet™, and WDM™ 3D Printing technologies produce prototypes and manufactured goods directly from 3D CAD files or other 3D content. Systems include 3D printers for idea development, prototyping and direct digital manufacturing. Stratasys subsidiaries include MakerBot and Solidscape, and the company operates a digital-manufacturing service comprising RedEye, Harvest Technologies and Solid Concepts. Stratasys has more than 2,500 employees, holds over 600 granted or pending additive manufacturing patents globally, and has received more than 25 awards for its technology and leadership.

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