



3D Printing
Consumer vs Professional

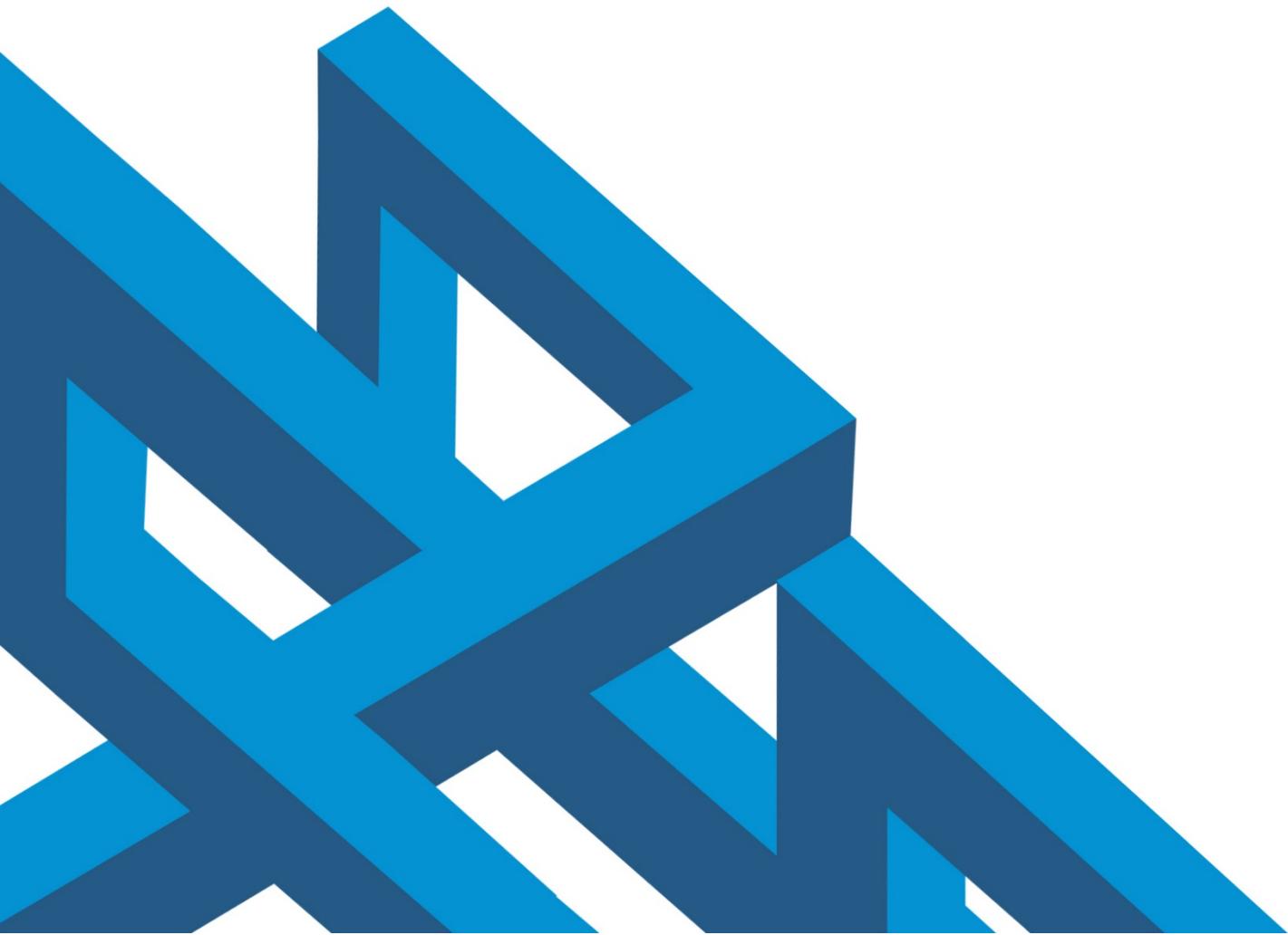


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Introduction

3D printing is the process of manufacturing three-dimensional objects by depositing successive layers of material via a 3D printer. By using an additive manufacturing technique, 3D printing departs radically from conventional subtractive manufacturing processes. As a result, 3D printing enables fast prototyping, saves material and labor costs, and finds applications in a number of commercial and consumer endeavors. It is, as the Harvard Business Review puts it, a technology that “will change the world.”

There are a few key differences between consumer and professional 3D printing. This whitepaper aims to give a brief overview of these two branches of 3D printing.

A Brief History of 3D Printing

Although 3D printing had been a subject of academic debate and scientific postulations for years (consider Star Trek's replicators as an example), it wasn't until 1984 that the first modern 3D printer was developed by Charles Hull. Hull patented a method of 3D printing known as Stereolithography, which is still used in many commercial applications today. The first Stereolithography apparatus (SLA) printer was developed by 3D Systems in 1992. This printer used UV light to cure thin layers of photopolymer deposits onto a build tray. With each layer, the build tray moved a fraction of an inch lower and the process repeated a technique that would become the foundation of much of commercial 3D printing.

The first commercial Fused Deposition Modeling (FDM) printer went on the market in 1992 as well. With rapidly improving technology, 3D printing became a viable alternative to conventional prototyping processes in commercial applications by the mid-1990s. The development of powerful PolyJet and Selective Laser sintering (SLS) printers further enabled the industry's growth. However, cost constraints confined 3D printing to niche industries until the late 2000s. Open-source projects like RepRap, and companies such as MakerBot have helped bring 3D printing to the masses with a range of affordable, easy-to-use 3D printers.

Additive vs. Subtractive Manufacturing

Additive manufacturing is the process of "adding" layers of material on top of each other to create an object. It is obverse of conventional subtractive manufacturing processes. A sculptor chiseling away at a block of marble to create a statue, for example, is a subtractive manufacturing process. A painter dropping layers of paint onto a canvas to create a painting, on the other hand, is an additive process.

The 3D Printing Process

Regardless of the technologies used, all 3D printers employ the following printing process:

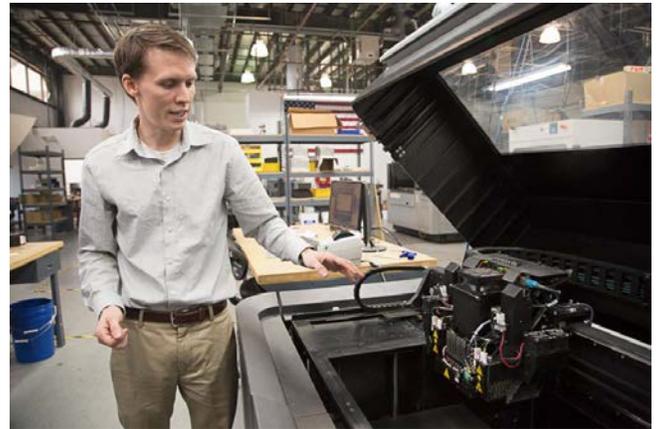
1. **Pre-Processing:** A digital 3D model of the object to be printed is sliced into thin layers via 3D printing software. The software calculates the thickness of each layer and prepares the printer for the printing process. The digital model itself can be created by 3D computer graphics software, downloaded as a digital file, or scanned with a 3D scanner.
2. **Printing:** Pressing "Print" brings the 3D printer to life. The printer lays down thin layers of build material along with a gel-like support material on a build tray. The build tray moves down with each successive layer of build material. Depending on the size and complexity of the printed object, the printing process can take anywhere from a few minutes to several hours.
3. **Post-Processing:** Depending on the type of technology used, post-processing might involve washing away the support material, or sanding to achieve a higher resolution. This is a short process that barely takes a few minutes. Some printers automate this final step.

3D Printing Technologies

The most common technologies used in 3D printers are:

- **SLA (Stereolithographic Apparatus):** SLA printers use vats of liquid photopolymers that can be cured by UV light. A beam of UV light traces patterns on a layer of photopolymer, which solidifies and joins the layer below it. This allows for the creation of complex patterns and designs at relatively high speeds.
- **FDM (Fused Deposition Modeling):** In FDM printers, a thin filament of thermoplastics (i.e., plastics that melt when heated, solidify at room temperature) is fed into a nozzle. The nozzle heats up and melts the plastic, which is then deposited in successive thin layers to build 3D models. The low cost and relative simplicity of the FDM process makes it ideal for use in consumer 3D printers.

- **SLS (Selective Laser Sintering):** In this technology, a high-power laser is used to melt and fuse powdered plastic, ceramics or metals. The laser traces pre-determined patterns around the powdered material, which fuses together to create 3D objects. If the powdered material in question is a metal, the process is called direct metal laser sintering (DMLS). SLS can work with a range of materials, which makes it suitable for use in low-volume manufacturing and advanced prototypes.
- **PolyJet:** PolyJet technology was developed by Israel-based Objet Systems. It borrows elements from SLA and 2D inkjet printing technology. This involves jetting drops of liquid photopolymer on a build tray, which is subsequently cured via UV light. PolyJet technology is fast and can be used with a wide range of build materials.



Example of a PolyJet 3D Printer

Consumer vs. Professional 3D Printing

Based on cost, capabilities, and applications, the 3D printing market can be divided into distinct consumer (desktop) and professional 3D printing.

Consumer 3D Printing

A nascent sub-section of the broader 3D printing industry, consumer or desktop 3D printing, targets hobbyist and amateur home users with small, affordable and easy-to-use 3D printers. Despite giant strides in the last few years, desktop 3D printing remains a niche hobby. Rapidly improving capabilities and decreasing costs are expected to propel this industry to the mainstream within the next decade.

The RepRap project, an open-source initiative launched in 2005 to create a printer that could print itself, was one of the first endeavors at developing a feasible desktop 3D printer. The industry was subjected to a major shot in the arm with the launch of the MakerBot in 2009. MakerBot built on concepts and ideas from the RepRap project and started selling self-

assembled kits by April 2009. The commercial and critical success of MakerBots first printer, the Cupcake CNC, helped spur conversation in favor of desktop 3D printing. Consumers have a number of choices for desktop 3D printers today, including MakerBot Replicator 2, 3D Systems Cube, FlashForge 3D Printer and Solidoodle, among others.

Features

Consumer 3D printing aims to replicate the professional 3D printing experience at a smaller scale and price tag. As such, the key features of consumer 3D printers are:

Price: Desktop 3D printer prices have been falling steadily over the last six years. While high-end printers such as MakerBot Replicator still cost in excess of \$2,000, a number of cheaper competitors such as MakiBox A6 LT and Pirate3D Buccaneer are available at \$200 and \$347, respectively. With a number of patents concerning SLS expiring in 2014, prices are expected to come down further in the next few years. Filament prices have been coming down as well, with a spool of material costing between \$21 to \$50.

- **Size:** Consumer 3D printers are designed for home use. Consequently, they boast a very small footprint compared to their professional counterparts. The MakerBot Replicator 2X, for instance, measures 19.1 x 12.8 x 20.9 inches, which is barely larger than a standard multi-function office inkjet printer.
- **Technology:** Most desktop 3D printers are based on the FDM printing technology. As outlined above, this is a cost-effective, relatively efficient technology that involves squirting heated plastic from a nozzle. Expect 3D printers based on SLS in the next few years as relevant patents expire in 2014.
- **Materials:** Consumer 3D printers use thermoplastics such as ABS or PLA for printing. Thermoplastics melt when heated and solidify at room temperature, making them perfect for the FDM printing process.
- **Standardization:** Increasing popularity has led to broad convergence among manufacturers on issues such as resolution, thermoplastics and filament size. Filament size, for example, is now standardized at 1.75 millimeters in diameter and 0.1 millimeters in height. Most 3D printers sold today are capable of printing at standard 100-micron resolution as well.
- **Aesthetics:** As desktop 3D printers are designed for home use, aesthetics and design are major selling points. For example, the Pirate3D Buccaneer borrows design cues from Apple Power Mac G4 Cube, while competitors like MakerBot favor rougher industrial

design. Color is another design consideration with printers like 3D Systems Cube available in a range of bright colors.

- **Software:** Software is an important consideration for consumer 3D printers. As the target market is amateur home users, the software must be easy to use and accessible from multiple devices. While it is possible to use any 3D graphics software capable of exporting STL/OBJ/3DS files with a 3D printer, most manufacturers have their own printer-specific design software (MakerBots MakerWare, Cubify Invent/Sculpt, Pirate3D SmartObjects, etc.). This software is geared towards novice users and boasts intuitive controls, user-friendly UI and dozens of existing templates and designs.
- **Cloud Printing:** Cloud printing via Wi-Fi expands a 3D printer's functionality and is a major selling point for home users. Most 3D printers sold today support some form of cloud printing. Files can either be uploaded by users through online platforms or downloaded directly from existing libraries.
- **Community:** Consumer 3D printing has developed a strong community of enthusiastic users who like to share their designs with others under open-source licenses. Platforms like MakerBots Thingiverse boast thousands of designs created by a dedicated community of users. These designs can be easily customized using 3D graphics software.
- **Applications:** Most desktop 3D printers are neither powerful nor efficient enough to be used for rapid prototyping in industrial applications. The target market is hobbyists and home users looking to create spare parts, customized items, toys and decorative objects. The printing process is usually slow; a complex design can take several hours to print and often requires user oversight. Limitations in terms of print materials and speed means that consumer 3D printers are best used in homes.

Limitations and Challenges

- **Build Volume:** The build volume of desktop 3D printers rarely exceeds 10 x 10 x 10 inches. This limits the printer's applications to small-scale objects.
- **Resolution:** Desktop 3D printers usually print at 100 microns. This is significantly lower than the lowest resolution available on professional printers.
- **Materials:** Consumer 3D printers can use only a handful of plastic materials for printing, which, once again, limits the printer's applications.

- **Speed:** Slow printing speed and frequent printing errors are major challenges to the widespread adoption of 3D printing.
- **Accuracy:** Although accuracy is gradually improving with each generation of desktop 3D printers, it remains sub-par when compared with professional 3D printers. This limits the complexity of objects that can be printed.

Professional 3D Printing

Professional 3D printing (also called advanced additive manufacturing) is the industrial-grade counterpart to consumer 3D printing. It is primarily used for concept modeling, manufacturing tooling, creating functional prototypes and even end-use parts. Professional printers are significantly more expensive, powerful and efficient than desktop printers. To use a familiar analogy, professional 3D printers are the MS Word to desktop printers Notepad.

Features

The chief features of professional 3D printers are:

- **Price:** Professional 3D printers are used by design firms and hardware manufacturers for making molds and prototypes. Consequently, these printers have to adhere to very strict quality standards. They must also be capable of printing large objects efficiently, all of which contribute to the price tag. A standard professional 3D printer can cost upwards of \$100,000.
- **Size:** Professional 3D printers vary significantly in size. Most printers are the same size as large office copy machines and weigh anywhere from 30 to 150 kilograms. Typically, the higher the resolution, accuracy, and speed of the printer, the larger the size. Production quality printers tend to be even larger, weighing in at a thousand or more kilograms (3D Systems Phenix PXL, for example, weighs 5,000 kilograms).
- **Technology:** Technologies employed range from FDM, SLS, SLA and PolyJet. This differs from manufacturer to manufacturer. Stratasys printers, for instance, primarily employ FDM and PolyJet. 3D Systems, on the other hand, offers printers that use DSLM, SLS and SLA technologies.
- **Build Volume:** Build volume is a significant consideration in professional 3D printers as it determines the largest part that can be built at once. Again, this varies from model to model and manufacturer to manufacturer. For example, build size for Stratasys Dimension Elite is 8 x 8 x 12 inches. The same for Stratasys Objet1000 is 39.3 x 31.4 x 1119.6 inches.

- **Materials:** One of the chief advantages of professional printers over their desktop counterparts is the range of materials they can print in. Most manufacturers have their own specially engineered portfolio of proprietary materials. The wide range of available materials means end users can select the material that fits their printing requirements.

This includes thermoplastics (ABS, PC, ULTEM), photopolymers, SLA materials like 3D Systems Accura and SLS materials like CastForm and DuraForm.

- **Software:** Power and flexibility rather than ease of use are the chief requirements for professional 3D printing software. Most manufacturers have their own range of software options. This includes 3D Systems GeoMagic and Stratasys Objet Studio, CatalyEX and Insight.
- **Aesthetics:** Aesthetics aren't nearly as important for professional 3D printers as they are for desktop printers. Most professional printers offer standard industrial design that can blend in perfectly among copiers and 2D printers in a typical office setting.
- **Resolution:** Resolution refers to the minimum thickness of the build layer. It is a key requirement for professional applications. Professional printers can print at resolutions as low as 16 microns (Stratasys Objet1000). High-end production-grade printers can even print layers just three microns thin (3D Systems sPro 60 HD).

Applications

The range of professional 3D printer applications includes:

- **Concept Modeling:** Concept modeling involves bringing early-stage ideas and concepts to life. Concept modeling is widely used in design, engineering and architecture firms for testing, proofing and fine-tuning raw designs.
- **Rapid Prototyping:** One of the key benefits of professional printers is their ability to make moving parts in different materials. This enables manufacturers to produce fully functional prototypes for testing purposes. Rapid prototyping can dramatically increase productivity and help identify errors early in the design process.
- **Manufacturing Molds:** Professional 3D printers enable manufacturers to make molds and casts for tools, fixtures and jigs in-house within hours, dramatically decreasing production time.

- **Rapid Manufacturing:** Decreasing costs and faster production speeds mean that manufacturers can use 3D printers to create end-use parts directly without tooling. Rapid manufacturing can be a viable alternative to assembly-line production in the coming few years if 3D printing technology keeps progressing at the current pace.

Professional 3D printers are widely used in aerospace, defense, medical, consumer goods, automotive and architecture industries.

Limitations and Challenges

- **Cost:** Mid-range professional 3D printers usually cost in excess of \$100,000. Combined with the high cost of proprietary materials, this can be prohibitively expensive for small manufacturers and startups.
- **Availability:** Huge demand and limited supply have affected the availability of 3D printers. Waiting periods for new printers can often stretch for months.
- **Limited Materials:** Compared to traditional manufacturing, 3D printers can work with a very limited range of materials.
- **Ease of Use:** As a new technology, there is a steep learning curve to using 3D printers, which has affected adoption in many industries.
- **Volume:** 3D printing cannot compete with conventional manufacturing on volume and remains confined to low-scale production and prototyping for now. Reduction in upfront and material costs along with better speeds may offset this in the near future.

Key Takeaways

Based on the benefits, features and limitations outlined above, we can make a comparison between professional and consumer 3D printing:

	Consumer 3D Printers	Professional 3D Printers
Price	Between \$200 and \$3,000	\$50,000 and above
Build Volume	Less than 10x10x10 in.	Greater than 12x12x12 in.
Materials	Choice limited to 2-3 materials	Dozens of materials depending on manufacturer
Resolution	Approx. 100 microns	As low as 3 microns in high-end printers
Ease of Use	Can be used by casual users	Requires significant operational training
Customization	Limited	Most printing parameters can be changed
Software	Easy to use, supports cloud printing, available on multiple devices	Complex, requires trained operators, powerful
Running Costs	Low	High: requires both expensive build materials and trained operators
Applications	Hobbyists and home users	Rapid prototyping/manufacturing, manufacturing tooling, concept modeling in diverse industries

SUMMARY

3D printing has matured incredibly over the last few years. The consumer 3D printing market has exploded with a number of affordable options for hobbyists and amateur home users.

At the same time, professional 3D printers continue to progress in speed, reliability, and quality. Led by these changes, the 3D printing market is expected to continue growing at 20% annually and double in size by 2015.



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