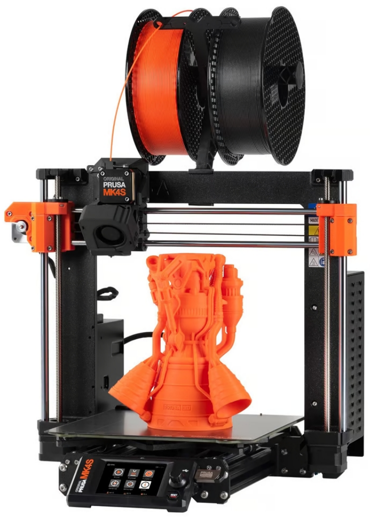
Introduction to additive manufacturing
ME-413

Presentation Report

Domestic 3D Printing



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1 Introduction to Domestic 3D Printing (Maxime)

Declared by some as a full-fledged industrial revolution, additive manufacturing processes have brought significant changes to the industry, particularly in prototyping and the creation of complex geometries that were previously impossible to produce quickly, easily and at low cost. However, they have also succeeded in captivating the consumer market, finding their way into households and even under the Christmas tree during the holiday season. This document will therefore provide an overview of domestic 3D printers, the kind you might find in any home.

1.1 History of Additive Manufacturing

1.1.1 The Birth of Different Technologies

The 3D printer was initially a concept of science fiction, envisioned as a "replicating machine" by Arthur C. Clarke in 1960 or a "three-dimensional photocopier" invented by Professor Calculus in the animated film "Tintin and the Lake of Sharks" in 1972[1]. The story began in 1980 in Japan, when Dr. Hideo Kodama conducted rapid prototyping experiments at the Nagoya Municipal Industrial Research Institute, laying the groundwork for stereolithography. This process involves the polymerization of a photosensitive resin under UV-light. The first patent was filed on July 16, 1984, by French researchers Jean-Claude André, Olivier de Witte, and Alain le Méhauté, acting on behalf of the company CILAS ALCATEL. However, it was abandoned due to a lack of commercial opportunity[3]. Three weeks later, on August 1, 1984, the patent for stereolithography (SLA) was filed in the United States by Chuck Hull, co-founder of 3D Systems. He also introduced the .stl file format (STereoLithography)[4]. In 1987, 3D Systems became the first company to market a 3D printer, the SLA-1[5].

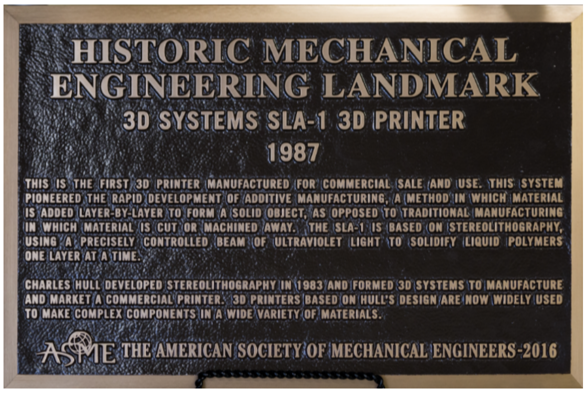


Figure 1: Plate recognising the SLA-1 as a Historic Mechanical Engineering Landmark[2].

Next came the selective laser sintering (SLS) process, patented in 1988 by Carl Deckard at the University of Texas and introduced the previous year by DTM Corp. In 1989, Scott Crump founded Stratasys and developed fused deposition modeling (FDM), also known as fused filament fabrication (FFF) (FDM being a trademark of Stratasys). This technology became the foundation for most 3D printers used in households today.

In 1995, Direct Metal Laser Sintering (DMLS) was introduced—a technology similar to SLS but adapted for metals. Below is a non-exhaustive list of additional key dates[1]:

- 1993: Binder Jetting technology developed by MIT and marketed by Z Corporation
- 1993: the Material Jetting process is introduced by Sanders Prototype Inc, which will be renamed Solidscape
- 1996: Selective Laser Melting developed by the Fraunhofer-Gesellschaft
- 2005: ZCorporation presents the first colour printer to use four-colour printing, with pigments bonded by glue to a mineral material
- 2009: Patent expiry for FDM
- 2014: Patent expiry for SLS
- 2017: Patent expiry for SLM

1.1.2 The RepRap Project and the Maker Community

The RepRap project is one of the cornerstones of the democratization of 3D printing for everyone and serves as a symbol of Maker culture. RepRap, short for "Replicating Rapid Prototyper," was initiated in 2005 by Dr. Adrian Bowyer at the University of Bath[6]. The goal of the project was to create an open-source 3D printer capable of replicating itself by printing many of its own components, enabling someone with an existing printer to build additional ones. All designs, software, and documentation are freely available, allowing anyone to use, modify, and improve the technology[7]. This significantly reduced the cost of accessing 3D printers, democratizing a technology that was previously expensive and confined to industry. Today, many 3D printers trace their origins to the pioneering RepRap models, such as:

- RepRap Darwin
- RepRap Mendel
- Prusa i3
- Hangprinter
- RepRap Fisher
- RepRap Snappy
- RepRap Morgan
- RepRap Ormerod

The history of RepRap began on March 23, 2005, with the launch of its blog. In September 2006, the RepRap 0.2 prototype successfully printed its first self-replicated part, which was used to replace an identical component initially created by a commercial 3D printer. On February 9, 2008, the RepRap 1.0 "Darwin" was completed, with at least half of its parts being rapid-prototyped.

Figure 2: Prusa I3[8].

Later that year, on April 14, what is believed to be the first user-made object was printed by a RepRap: a clip to hold an iPod on the dashboard of a Ford Fiesta. By May 2008, the first "child" machine produced its first "grandchild" component. On November 30, 2008, the first complete replication for another individual was documented by Wade Bortz, a user outside the development team.

On April 20, 2009, the project team announced the automated production of the first electronic circuit board using a RepRap. This was achieved using an automatic control system and an interchangeable head capable of printing both plastic and conductive connectors. By October 2009, the second-generation model, "Mendel," was completed[6].

The Maker culture, which emphasizes the principles of DIY (Do It Yourself) and hands-on learning with an engineering focus, has played a significant role in the adoption of 3D printers in households[9]. This community thrives on sharing knowledge and resources that align with the objectives of the RepRap project. Makers use 3D printers to create prototypes and share their creations with their own experiences.

Domestic 3D printers, popularized by the RepRap project, enable people to become creators rather than mere consumers. They offer access to free design software and vast online libraries of 3D models. This makes it possible to produce objects tailored to specific needs, promoting sustainability by encouraging repair over replacement (see Section 4).

2 Domestic 3D Printing Technologies and Processes (João)

2.1 Types of 3D Printing Technologies

2.1.1 Fused Deposition Modeling

Fused Deposition Modeling (FDM), also known as Fused Filament Fabrication (FFF), is the most well-known and widely used type of domestic 3D printer. It works by melting a filament of thermoplastic material, fed from a spool into the extrusion head, and depositing it layer by layer onto the part being produced. Although the specifications and printing methods differ from one printer to another, most of them share common parts and principles.

The Bed: The bed is the name of the printing surface on which the first layer of plastic is deposited. Its surface is often rough to facilitate layer adhesion and is sometimes heated, depending on the material, to temperatures of up to 120°C.

The Extruder: Filament, rolled on a spool, is fed into the extruder either by an external motor or pulled into the extruder by a motor integrated into the extruder assembly. Stepper motors are commonly used as they provide excellent control over the feeding rate. Inside the extruder assembly, the filament is heated until it reaches a semi-molten state, at which point it flows smoothly through the nozzle. This temperature can reach up to 280°C for some types of materials. The semi-molten plastic is then fed through the nozzle and deposited onto the part being built.

Filament Feeding Mechanism: To hold the filament, some printers have a simple spool holder positioned above or next to the machine, while others feature more complex systems that include motors for feeding the filament into the extruder.

The Casing: Most 3D printers don't have a casing, which leaves the print exposed to the environment. However, some materials require a specific atmosphere to function properly or emit toxic gases that are harmful to humans. For this reason, some printers include a casing that encloses the printing area, allowing control of the temperature and humidity within the printing environment.

Additional Features: All FDM 3D printers include the above-mentioned components, but the facility for customization allows some printers to have many additional features. One of these is multi-color or multi-material printing. For basic printers, a big disadvantage is that one spool of filament only has one color and one material, which means prints have to be monochromatic. However, some printers can change the color of the filament. There are two main methods: one is having multiple extruder heads, each with one filament. The printer can exchange the extruders to change color or material. Another way is to have several filaments feeding into the same extruder, with a system inside that can switch from one filament to another.

Other features that printers can have include a camera to monitor the status of the print or take time-lapses of the printing process, automatic bed leveling, which calibrates the motors automatically, and sensors that detect when the printer is about to run out of material and pause the print to avoid failure. High-speed printing is another feature, to achieve faster printing speeds while maintaining good quality, printers use several techniques to minimize vibrations and optimize performance. The key method is optimizing the acceleration and deceleration profiles, which control how quickly the extruder and bed move. By fine-tuning these movements, the printer can reduce the shaking that typically occurs during high-speed printing, resulting in smoother prints.

In more advanced printers, such as the Prusa MK4, additional techniques like vibration damping are used. These printers feature stiffer frames, enhanced motor dampers, and precise motion control systems that reduce the impact of vibrations during fast movements. This helps to maintain print quality even when pushing for higher speeds. Some models also feature active vibration damping, where the printer detects and compensates for vibrations in real-time, further improving print stability.

2.1.2 Stereolithography

The other widely used form of domestic 3D printing is Stereolithography (SLA). It works by selectively curing, or hardening, a liquid resin layer by layer until the product is finished. There are two main methods:

Top-down SLA: In this method, the build platform lowers into a resin vat, and a light source above the vat cures the layers one by one as the platform lowers. This method is more commonly used in industrial settings, as it requires a vat of resin that is as deep as the part is tall, but it can provide greater precision.

Bottom-up SLA: This is the most common variant used in domestic printers (see Figure 3). In this method, the part is printed upside down. The platform starts in a shallow resin vat and ascends, leaving the top of the part being printed inside the vat while light shines from below to cure the resin.

Here are some common components of SLA 3D printing:

The Resin Vat: The resin vat is the container that holds the resin at the bottom of the printer. The type of resin can vary, ranging from standard resin used for prototyping to advanced resins used for medical or engineering applications, where the physical and thermal properties of the resin can differ. At the bottom of the vat is a transparent film that allows light to pass through to solidify the layers one by one. This transparent film is often made from Fluorinated Ethylene Propylene (FEP), a polymer known for its chemical resistance, transparency, and low friction, as the part needs to not stick to the film.

The Build Platform: The build platform is the surface on which the part will be printed. It is initially lowered into the resin until it is one layer thickness away from the film at the bottom, usually around 50 microns. After the layer has solidified, the platform moves up to detach the part from the film and allow more liquid resin to flow in its place. It is then lowered again, ready for the next layer. This allows parts to be very tall while using a relatively shallow resin bath.

The Light Source: The resin cures with UV-light. A light source placed below the vat shines light onto the resin, solidifying the layer. There are different methods for shining the light. A laser can be used to precisely trace out the layer, allowing for great precision as the laser can focus on tiny details. Another method involves a light projector that flashes an entire layer at once, using either an LCD mask or micromirrors, selectively shining light only where the layer needs to be hardened.

The UV Casing: Being sensitive to UV-light, leaving the resin exposed to sunlight is not ideal. For this reason, SLA printers include a UV-blocking casing around the printer, protecting the print from external sources of UV-light.

A disadvantage of SLA 3D printing compared to FDM is the additional post-processing required after the print is finished. With FDM printing, once the part is complete, it typically only requires support removal and is then ready for use. However, SLA printing involves more complex steps. First, the part must be cleaned in isopropyl alcohol (IPA) or an alternative cleaning solution to remove any uncured resin. After cleaning and thoroughly drying, the part undergoes a UV-light curing process to further solidify and strengthen the resin, ensuring it achieves its final mechanical properties. While this post-processing step is crucial for SLA prints, it adds complexity compared to the simpler workflow of FDM printing.

Figure 3: Formalb SLA 3D printer[11].

2.2 Types of Printer Motion Systems

Although SLA printers all move in the same way, where the platform rises up out of the resin, FDM printers have a variety of ways to move the extruder in three dimensions, each with its own advantages and disadvantages. The main trade-off is complexity versus speed. To print faster, it is essential to minimize the moving mass, as less inertia results in better acceleration and fewer oscillations. However, reducing the moving mass often implies more complex mechanisms, which can be more expensive and prone to mechanical issues.

2.2.1 Cartesian Printers

Cartesian printers are the simplest type of 3D printers. They include a gantry that moves in the X and Y coordinates, with stepper motors mounted on the gantry controlling the motion. The Z coordinate is controlled by the bed, which moves in the Z direction. An example of such a printer is the Ender 5 Pro in Figure 4, we can see the stepper motor attached to the right of the gantry on the upper part.

Figure 4: Ender 5 Pro[12].

Advantages: This type of printer is simple to understand and control. It is also inexpensive and easy to repair.

Disadvantages: Because the motors move with the gantry, the moving mass is relatively high, which results in lower printing speeds.

2.2.2 CoreXY Printers

CoreXY printers are a subcategory of Cartesian printers. Instead of having the motors mounted on the gantry, all motors are fixed to the frame and drive the extruder through a belt system. This design makes the moving mass much lighter, allowing for faster movements. A particular case of CoreXY printers is The Voron, which moves the extruder in the X, Y and Z coordinate, leaving the bed stationary.

Advantages: High speed without compromising accuracy. Higher precision, as the more stable movement leads to better quality at high speeds.

Disadvantages: More complex system requiring precise belt calibration. Difficult to troubleshoot, making it harder for beginners to maintain.

2.2.3 Bed Slinger Designs

Bed-Slinger printers are a type of 3D printer where the bed moves in the Y direction, while the extruder handles the X and Z movements (see Figure 5). This system is very simple and compact, as it does not require a gantry above the entire printing area, making it cheaper and ideal for entry-level printers. Some variants use a conveyor belt system for the bed, allowing for an "infinite" print size in the Y direction. One example is the Prusa MK4S from Figure 5.

Figure 5: Prusa MK4S[13].

Advantages: Low cost and simple design, which make it easier to repair and troubleshoot due to fewer moving parts.

Disadvantages: The movement of the entire bed and part limits printing speed, and for tall, slender prints, moving the bed can introduce shaking and vibrations, which can reduce precision and quality.

2.2.4 Delta Printers

Delta printers are a unique type of 3D printer based on the concept of delta robotics. The extruder is attached to three arms, or rods, that move vertically. By precisely controlling the vertical position of each arm, the X, Y, and Z positions of the extruder can be accurately manipulated. The bed remains stationary at the bottom of the printer. Motors that drive the movement of the three arms are located in the base of the printer, with motion transmitted via a belt system, enabling rapid and precise movement (see Figure 6).

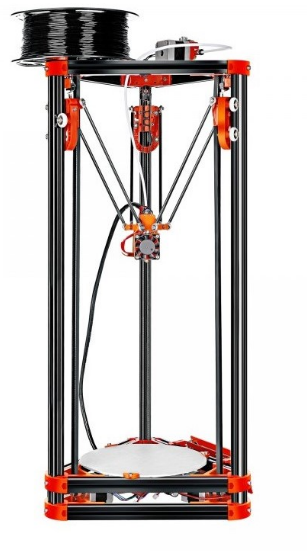


Figure 6: Delta Printer[14].

Advantages: Due to the very light moving mass, Delta printers can achieve higher speeds and greater precision when well-calibrated. Additionally, they are capable of printing taller objects, as the vertical rails provide ample height for large prints.

Disadvantages: Delta printers are notoriously challenging to calibrate properly. The arms must be perfectly aligned, and even small misalignments can significantly impact print quality.

2.2.5 Polar Printers

Polar printers are an uncommon type of 3D printer that utilize a polar coordinate system to control movement. In these printers, the print bed rotates around a fixed central axis to control angular movement (θ), while the print head handles the radial (R) and vertical (Z) movements. This configuration eliminates the need for linear X and Y axes, allowing for a simpler mechanical setup (see Figure 7).

Advantages: Polar printers can offer unique benefits due to their design. The rotating bed simplifies the mechanics and can make circular and arc-shaped patterns easier to execute. Additionally, the polar approach can be more compact which results in a smaller printer footprint.

Disadvantages: Precision can be more challenging to achieve with polar printers. Translating complex geometries into a polar coordinate system requires sophisticated software, and inaccuracies in rotation or radial movement can lead to errors. The rotating bed may also limit the stability of tall or heavy prints, as the motion could introduce wobble.

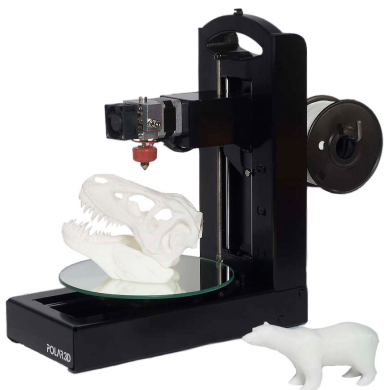


Figure 7: Polar 3D printer[15].

2.3 Technical Comparison of FDM vs. SLA 3D Printers

2.3.1 Print Resolution

Resolution in 3D Printing refers to the level of detail and accuracy a printer can achieve, typically measured in microns. It encompasses two aspects: XY resolution, which is determined by the precision of the printer's mechanics (e.g., nozzle size in FDM or laser spot size in SLA), and Z resolution, which is the layer height. In FDM printers, achieving good resolution requires a smaller nozzle size (e.g., 0.2 mm for high precision) and precise control of the extruder's movement. However, FDM prints often have visible layer lines, resulting in a rough surface finish that may require post-processing like sanding or painting. FDM resolutions typically range from 50–200 microns in XY and 10–100 microns in Z. In contrast, SLA printers achieve finer resolution as we can see in Figure 8, offering typical resolutions of 25–100 microns in XY and 25–50 microns in Z. This process results in a smoother surface finish with minimal visible layers, making SLA ideal for high-detail models.

Figure 8: Detailed part made with SLA[16].

2.3.2 Material Choices

Material choice is another key distinction between FDM and SLA printers. FDM offers a broader range of materials, with options suited for various mechanical, thermal, and aesthetic properties, making it highly versatile. SLA, while more limited in variety, focuses on resins that provide exceptional detail and smooth surface finishes, catering primarily to precision applications.

2.3.3 Printing Volume

Print volume refers to the maximum size of an object that a 3D printer can produce, determined by the dimensions of its build area. FDM printers generally offer larger print volumes, making them suitable for creating bigger objects or multiple parts in a single print. Typical entry-level FDM printers feature build volumes around 220 x 220 x 250 mm, while higher-end models can reach sizes of 400 x 400 x 500 mm or even larger, such as the Creality CR-10 Max with a build volume of 450 x 450 x 470 mm. In contrast, SLA printers usually have smaller build volumes, often ranging from 120 x 120 x 150 mm to 200 x 200 x 300 mm, as they prioritize detail over size. This limitation makes SLA printers ideal for small, high-precision objects but less practical for larger-scale prints.

2.3.4 Printing Speed

Print speed is a nuanced metric that varies significantly between FDM and SLA printers depending on the type and size of the object being printed. FDM printers measure speed in millimeters per second (mm/s) of nozzle movement, with typical speeds ranging from 40 to 150 mm/s. This makes FDM relatively faster for printing single, tall objects or simple geometries, as the speed does not depend on the object's complexity within each layer. However, as complexity increases, the time required to trace each layer also rises.

SLA printers, on the other hand, cure entire layers at once, meaning their speed depends on the number of layers, not the complexity within them. For small, individual parts, SLA is often slower than FDM because of longer curing times per layer (e.g., 1–3 layers per minute) and post-processing requirements. However, for larger, flat objects or arrays of multiple parts, SLA can outperform FDM, as the curing time per layer remains constant regardless of the number of parts being printed simultaneously.

For example, printing a small, tall object with a height of 100 mm at a layer height of 0.1 mm would take around 4–6 hours on an FDM printer but 8–10 hours on an SLA printer. Conversely, printing a large, flat array of parts might take the same time on an SLA printer as it does for one part, while an FDM printer would require significantly more time to trace each layer for multiple parts. This makes SLA particularly advantageous for producing intricate or batch prints where consistency and detail are critical.

2.3.5 Summary

In Figure 9 we can see a summary of the different metrics we talked about as well as some additional ones such as ease of use and maintenance.

Metric	FDM	SLA
XY Resolution	50–200 microns	25–100 microns
Z Resolution	10–100 microns	25–50 microns
Build Volume	220 x 220 x 250 mm (entry-level)	120 x 120 x 150 mm (typical)
	Up to 450 x 450 x 470 mm (high-end)	Up to 200 x 200 x 300 mm (high-end)
Print Speed	40–150 mm/s (depending on settings)	1–3 layers per minute (Laser SLA)
		3–4 layers per minute (LCD SLA)
Small Object	1–3 hours (depends on size, complexity)	2–4 hours (Laser SLA)
		1–2 hours (LCD SLA)
Large/Detailed Object	8–12 hours (depends on complexity)	6–10 hours (slower for tall prints)
Array of Small Objects	8–12 hours (depends on part count)	2–4 hours (Laser SLA)
		1–2 hours (LCD SLA)
Surface Finish	Moderate finish, requires post-processing	Excellent finish, minimal post-processing
Material Variety	Wide range of filaments available (e.g., PLA, ABS, PETG)	Limited to resins, with some specialized options
Ease of Use	Generally user-friendly, plug-and-play for entry-level models	Requires more setup (resin handling, washing)
Maintenance	Moderate (cleaning extruder, bed leveling)	High (cleaning resin tank, UV curing station)
Cost of Operation	Generally low cost (filament is cheaper)	Higher material cost (resin) and more frequent maintenance

Figure 9: Comparison between FDM and SLA for various metrics.

3 Materials for Domestic 3D Printing (Maxime)

3.1 Materials for FDM

FDM technology, as previously described, operates on the principle of extruding a melted filament through a nozzle. Here, we will review some of the filaments available on the market, ranging from the most common to the more exotic ones. We will examine their composition, applications, and their respective advantages and disadvantages[18]. See Section Annexes (8) for the tables of properties of all cited materials.

3.1.1 Stiff Materials

PLA (Polylactic Acid): PLA is one of the most popular materials used in desktop 3D printing, because it can be printed at low temperature and does not require a heated bed. It is easy to use, cheap, and the most environmentally friendly. Derived from crops such as corn and sugarcane, PLA is renewable and most importantly biodegradable. As a bonus, this also allows the plastic to give off a sweet aroma during printing.
Pros: Low Cost, Stiff and good strength, Good dimensional accuracy, Good shelf life
Cons: Low heat resistance, Can ooze and may need cooling fans, Filament can get brittle and break, Not suitable for outdoors (sunlight exposure)

ABS (Acrylonitrile Butadiene Styrene): ABS was one of the first plastic used for 3D printing, and still used today thanks to its low cost and good mechanical properties, and its toughness and impact resistance, reasons why LEGO bricks are made of ABS. It also has a higher glass transition temperature. It is then a great choice for outdoor or high temperature applications. ABS also tends to contract as it cools, so controlling the temperature of your build volume and the part inside can have major benefits.
Pros: Low Cost, Good impact and wear resistance, Less oozing and stringing gives models smoother finish, Good heat resistance
Cons: Heavy warping, Needs heated bed or heated chamber, Produces a pungent odor while printing, Parts tend to shrink leading to dimensional inaccuracy

ASA (Acrylic Styrene Acrylonitrile): ASA has the same properties similar to ABS, but was originally developed as alternative that would be more UV resistant. ASA is known for high impact resistance, higher temperature resistance, but increase printing difficulty. It is commonly used in outdoor applications instead of ABS. Warping is still a consistent issue that users need to account for, as well as the potentially dangerous fumes that the plastic emits during printing, due to the presence of Styrene.
Pros: Strong UV resistance, High impact and wear resistance, High glass transition temperature
Cons: Expensive, Requires higher extruder temperatures, Requires ventilation due to potentially dangerous fumes

PETG (Glycol modified version of Polyethylene Terephthalate (PET)): PETG is a semi-rigid material with good impact resistance, but it has a slightly softer surface which makes it prone to wear. It also benefits from great thermal characteristics, and it cools with almost negligible warpage.
Pros: Glossy and smooth surface finish, Adheres well to the bed with negligible warping, Mostly odorless while printing
Cons: Poor bridging characteristics, Can produce thin hairs on the surface from stringing

PC (Polycarbonate): PC is a high strength material made for tough environments and engineering applications. It has high heat deflection, and impact resistance, and a high glass transition temperature of 150°C, meaning it is suitable for high-temperature applications. It can bend without breaking and is used for application with minor flexibility. PC is extremely hygroscopic, and need very high temperature for printing, for both the nozzle and the bed.
Pros: Impact resistant, High heat resistance, Naturally transparent, Bendable without breaking
Cons: Requires very high print temperatures, Prone to warping, High tendency to ooze while printing, Absorbs moisture from the air which can cause print defects

3.1.2 Semi- to Flexible Materials

Nylon (Polyamide): Nylon is known for its toughness and flexibility. Nylon filaments require extruder temperatures near 250°C, but many printers cannot reach so high temperature. However, some brands allow printing at temperatures as low as 220°C. One big challenge with Nylon filaments is that they are hygroscopic, which can lead to several print quality issues, thus filaments storage is important.
Pros: Tough and partially flexible, High impact resistance, No unpleasant odor while printing, Good abrasion resistance
Cons: Prone to Warping, Air-tight storage required to prevent water absorption, Improperly dried filaments can cause printing defects, Not suitable for moist and humid environments

Flexible filaments: Flexible filaments are made of Thermoplastic Elastomers (TPE), a blend of hard plastic and rubber. This material is elastic, allowing the plastic to be streched and flexed easily. Most used type of TPE is Thermoplastic polyurethane (TPU). The elasticity of the material depends on the type of TPE and the chemical formulation used by the manufacturer.
Pros: Flexible and soft, Excellent vibration dampening, Long shelf life, Good impact resistance
Cons: Difficult to print, Poor bridging characteristics, Possibility of blobs and stringing, May not work well on Bowden extruders

PP (Polypropylene): Polypropylene is a semi-rigid and lightweight material, used in storage and packaging applications. It is a challenge to print it, because of the warping of the parts while cooling. PP is tough and has a good fatigue resistance, ideal for low strength appplications.
Pros: Good impact and fatigue resistance, Good heat resistance, Smooth surface finish
Cons: Heavy warping, Low strength, Difficult to adhere to bed and other adhesives, Expensive

3.1.3 Composite Materials

Carbon fiber filled filaments: In that case, a base material like PLA, PETG, Nylon, ABS or Polycarbonate is filled with some tiny carbon fibers that are infused. These fibers are extremely strong, and increase the strength and stiffness of the part. It also prevent the part to shrink as it cools. Print setting are really similar to the normal settings used for the base material, but due to the added fibers, these filaments are more likely to clog and risk to damage the printer, unless users use appropriate additional equipment.
Pros: Increased strength and stiffness, Very good dimensional stability, Lightweight
Cons: Abrasive and requires hardened steel nozzle, Increased oozing while printing, Increased brittleness of filament, Higher tendency to clog

Metal filled filaments: Metal filled filaments contain very fine metal powder such as copper, bronze, brass, and stainless steel, which makes the filament much more heavier than a standard one, depending on the manufacturer choice of percentage of metal powder infused. Extruding this type of filament, with the same settings as the base material, is really abrasive and will wear the noozle.
Pros: Metallic finish is aesthetically appealing, Does not need high-temperature extruder, Heavier than standard filaments
Cons: Requires a wear-resistant nozzle, Printed parts are very brittle, Very poor bridging and overhangs, Can cause partial clogs over time, Expensive

Wood filled filaments: Wood filled filaments are a composite made of PLA base and wood dust, cork, and other powdered wood derivatives, which represents approximately 30 percents of the composite. The presence of these particules gives the aesthetics of real wood to the parts. It is much less abrasive than carbon fiber and metal filled filaments.
Pros: Wood-textured finish is aesthetically appealing, Does not need any expensive wear resistant nozzles, Aromatic and pleasant smelling
Cons: Prone to stringing, Smaller nozzles can end up with partial clogs over time, May require a larger size nozzle

3.1.4 Support Materials

HIPS (High Impact Polystyrene): HIPS is a dissolvable support material that is commonly used with ABS. Used as support material, HIPS can be dissolved in d-Limonene. It has many of the same properties as ABS. Alone, it is also more dimensionally stable and lighter than ABS.
Pros: Low cost, Impact and water resistant, Lightweight, Dissolvable by d-Limonene
Cons: Heated bed required, Heated chamber recommended, High printing temperature, Ventilation required

PVA (Polyvinyl Alcohol): PVA is a soft and biodegradable polymer, which is really sensitive to moisture. PVA has the property to dissolve in water, making it a useful support structure.
Pros: Great water dissolvable support material, No special solvents required, No additional hardware required
Cons: Moisture sensitive, Airtight storage containers required, Greater chances of clogging if the nozzle is left hot when not extruding, Expensive

3.2 Materials for SLA

SLA technology, as previously described, operates on the principle of curing liquid resin using a light source, such as a laser or a projector, to form solid layers. Here, we will review some of the resins available on the market, ranging from the most common to the more specialized ones. We will examine their composition, applications, and their respective advantages and disadvantages[19]. See Section Annexes (8) for detailed tables of the properties of all cited materials.

3.2.1 Standard Resins

Standard Resins: Standard resin produce high-stiffness, high-resolution parts with a smooth surface finish. They are low cost, ideal for prototyping applications. The color affects its properties: for example, gray resin is better for parts with fine details, and white resin for very smooth surface.
Pros: Fine features and high detail, Smooth surface finish, Very cost-efficient
Cons: Brittle (low elongation at break), Low impact strength, Low heat deflection temperature

Clear resin: Clear resin has similar mechanical properties to standard resin but can be post-processed to near optical transparency, making it useful for showcasing interior features, housing for LEDs and fluidic devices.
Pros: Fine features and high detail, Smooth surface finish, Transparent
Cons: Brittle (low elongation at break), Low impact strength, The optical clarity may change over time, as the part is exposed to UV radiation (sunlight)

3.2.2 Engineering Resins

ABS-Like resin: Similar to ABS, though resin is developed for applications requiring materials that can withstand high stress and strain. This material will produce sturdy, shatter-resistant parts, ideal for functional prototypes and mechanical assemblies.
Pros: High stiffness, Excellent resistance to cyclic loads
Cons: Not suitable for parts with thin walls (recommended minimum wall thickness of 1 mm), Low heat deflection temperature, Relatively brittle (low elongation at break)

PP-Like resin: Durable resin is a wear-resistant and flexible material, with mechanical properties similar to PP. It can be used for parts that require high flexibility, low friction and smooth surface finish.
Pros: High wear resistance, Flexible (relatively high elongation at break), High impact resistance (higher than tough resin)
Cons: Not suitable for parts with thin walls (recommended minimum wall thickness of 1 mm), Low heat deflection temperature, Low tensile strength (lower than tough resin)

PC-Like resin: PC-Like resin is Heat-resistant resin, ideal for applications that require high thermal stability and operation. It has a high heat deflection temperature, made for heat-resistant fixtures, mold prototypes, hot

air and fluid flow equipments, casting and thermoforming tools.
Pros: High heat deflection temperature, Smooth surface finish
Cons: Brittle (low elongation at break), Not suitable for parts with thin walls (recommended minimum wall thickness of 1 mm)

Rubber-Like resin: Rubber-like resin simulate rubber parts that are soft to the touch. It has a low tensile modulus and high elongation at yield, ideal for objects that will be bent or compressed.
Pros: High flexibility (high elongation at break), Low hardness (simulates an 80A durometer rubber), High impact resistance
Cons: Lacks the properties of true rubber, Requires extensive support structures, The material properties degrade over time, as the part is exposed to UV radiation (sunlight), Not suitable for parts with thin walls (recommended minimum wall thickness of 1 mm)

Ceramic-filled resin: Rigid resins are reinforced with glass or other ceramic particles, which produce very stiff and rigid parts, with a smooth surface. They also offer good thermal stability and heat resistance, and a high Young's modulus and lower creep compered to SLA resins, but are more brittle than tough and durable resins.
Pros: High stiffness, Suitable for parts with fine features, Moderate heat resistance
Cons: Brittle (low elongation at break), Low impact strength

4 Applications and Economic Impact of Domestic 3D Printing (Etienne)

This section explores the transformative role of domestic 3D printing in household innovation and small-scale manufacturing. By detailing practical applications and assessing the economic impact, it highlights how this technology empowers individuals and reshapes traditional production paradigms.

4.1 Applications for Domestic Users

4.1.1 Home Improvement and DIY Projects

Domestic 3D printing has revolutionized home improvement by enabling users to create affordable replacement parts and custom fixtures. Items such as curtain hooks, appliance knobs, drawer handles, and wall mounts can be printed to address specific needs, eliminating the need for costly and time-consuming replacements.

Users benefit from accessible tools such as CAD repositories, such as *Thingiverse*, which provide ready-made designs, and free design software like *TinkerCAD*, which allow for the creation of personalized items tailored to unique requirements. For instance, figure 10 shows a broken vacuum caster wheel that has been replaced with a 3D printed alternative for a few dollars, avoiding the much higher expense of purchasing a new part, assuming that the specific part is still in production.

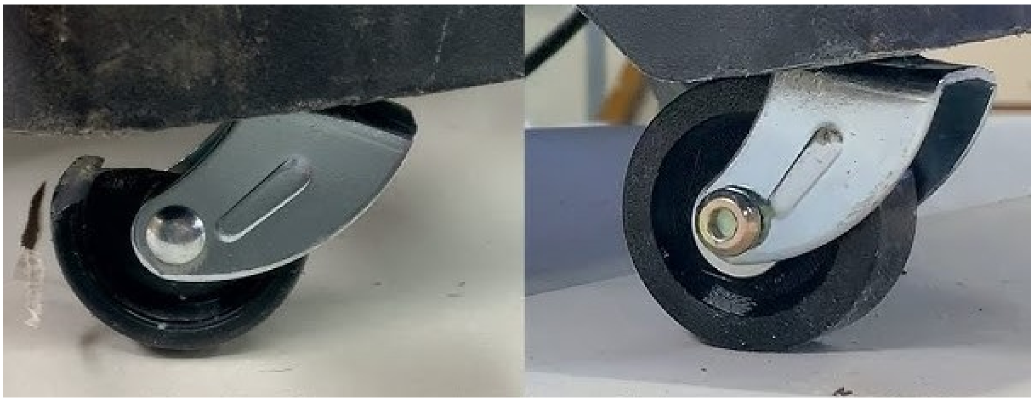


Figure 10: Broken caster wheel (left) and its 3D printed replacement (right)[20].

Beyond cost savings, 3D printing promotes sustainability by reducing repair waste. This approach extends the lifespan of household items while minimizing environmental impact, aligning with growing consumer interest in environmentally friendly solutions.

4.1.2 Educational Tools

3D printing plays a transformative role in education, particularly in STEM fields, by providing tangible models that enhance understanding of complex concepts. Teachers can create geometric shapes for math lessons, molecular structures for chemistry, and anatomical models for biology, offering students a tactile learning experience that bridges the gap between abstract ideas and real-world applications.

For example, a teacher can print a DNA model as in figure 11 for less than $10, a cost-effective alternative to purchasing a similar model, which often go for much higher prices. This affordability is especially valuable for under-served schools, where budgets for educational tools are limited.

4.1.3 Hobbies and Crafts

3D printing equips hobbyists and artists with creative freedom and iterative prototyping. Enthusiasts use it to develop figurines for their favorite board game, craft intricate parts for RC vehicles, or create artistic sculptures.

The technology allows users to experiment with designs and refine them in ways previously inaccessible without specialized tools.

For instance, an RC plane enthusiast can print a durable and lightweight wing for a fraction of the cost of purchasing pre-manufactured components, and personalize it for any given application, as seen in figure 12.

By dramatically reducing expenses and providing accessible tools, 3D printing reduces barriers for hobbyists to achieve professional-grade results, fostering innovation and skill development within creative communities.

Figure 11: 3D printed DNA model[21].

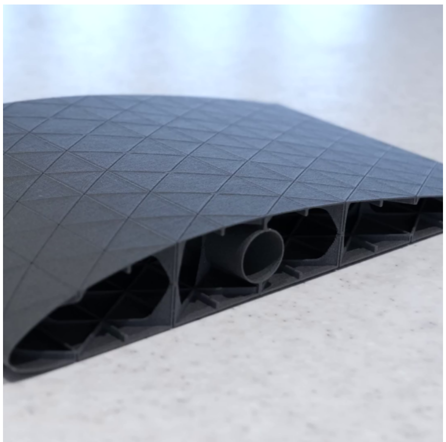


Figure 12: 3D printed wing[22].

4.1.4 Small-Scale Entrepreneurship

3D printing has opened opportunities for small-scale entrepreneurs by enabling custom product creation and rapid prototyping. Home businesses can design and produce personalized items, such as figurines, ornaments, and niche products tailored to customer preferences. Platforms like *Etsy* and *Shopify* provide marketplaces for these creators to reach a global audience.

For example, a business owner can print customized phone stands, as seen in figure 13, and sell them for a higher price, achieving good profit margins with minimal upfront investment.

The accessibility and cost-effectiveness enable people to explore entrepreneurship without requiring extensive manufacturing infrastructure, making 3D printing a key driver of innovation in niche markets.

Figure 13: 3D printed custom iPhone stand[23].

4.2 Economic Impact

The economic implications of domestic 3D printing extend beyond individual cost savings, representing a transformative shift in production economics, market structures, and consumer behavior. This section examines the evolution of 3D printer affordability, the comparative economics of 3D printing versus traditional manufacturing, and its broader influence on market dynamics.

4.2.1 Evolution of Pricing and Market Accessibility

The declining cost of 3D printers over the past decade has been instrumental in their widespread adoption. From common prices around $2,000 in 2010, entry-level models now cost as little as $200. Concurrently, advancements in material affordability have further lowered barriers; in 2010, filaments such as PLA often cost $50–$60 per kilogram, while today, they are widely available for approximately $20 per kilogram,

Figure 14 below shows a comparison between models that came out between 2010 and 2024, illustrating the strides that the industry has taken in print quality (precision), speed and printer pricing. Printing volumes are also included as they have a major impact on the pricing of the machines.

Model	Release Year	Precision	Speed	Original Price	Price Adjusted for Inflation (2024)	Printing Volume (cm)
MakerBot Cupcake	2010	200 microns	20mm/s	$1,300	$1,825	10 x 10 x 15
Ultimaker Original	2011	200 microns	50mm/s	$1,500	$2,053	20 x 20 x 20
RepRap Prusa i3	2012	100 microns	60mm/s	$700	$970	20 x 20 x 20
Robo 3D R1	2014	100 microns	100mm/s	$1,200	$1,500	25 x 22 x 20
Prusa i3 MK3	2017	50 microns	200mm/s	$749	$934	25 x 21 x 21
Creality Ender 3	2018	100 microns	50mm/s	$199	$245	22 x 22 x 25
Creality Ender 3 V2	2020	50 microns	60mm/s	$270	$306	22 x 22 x 25
Bambulab A1	2024	100 microns	100mm/s	$219	$219	24 x 24 x 25
Prusa i3 MK4	2024	25 microns	300mm/s	$1,399	$1,399	25 x 21 x 21

Figure 14: Table comparing printer performance and price.

We can see that a $219 printer today achieves higher accuracy, speed and printing volume than a $2000+ printer from 2011. Today's more expensive Prusa i3 MK4 achieves results that were unthinkable for domestic 3D printers just ten years ago. This trend shows no signs of slowing down: market analysis indicate that the consumer 3D printing sector is expected to grow at a compound annual growth rate (CAGR) of 18% to 25% depending on sources between 2024 and 2030, driven by advancements in software, printer reliability, ease of use, and materials diversity[24][25]. With over two million 3D printers sold each year and the market continuing to grow, innovation and access to high-quality printers are likely to keep getting better.

4.2.2 Cost Analysis: 3D Printing vs. Traditional Manufacturing

Domestic 3D printing fundamentally alters the cost structure of small-scale production by shifting from economies of scale to economies of scope. Traditional manufacturing involves fixed costs such as mold creation, tooling, and bulk production, which are amortized over large quantities. For small production runs or unique items, these fixed costs make traditional methods economically prohibitive.

3D printing, by contrast, eliminates these fixed costs. Production costs are primarily variable, scaling directly with material consumption and print time. To illustrate this, we can take a simple standard example: a 100 gram part that can be produced either through 3D printing or injection molding. We take standard values for the computations: \$20/kg for PLA 3D printing, a \$5000 mold and a production price of \$0.2 per part for the injection costs. Figure 15 shows the price per part as a function of the amount of parts produced.

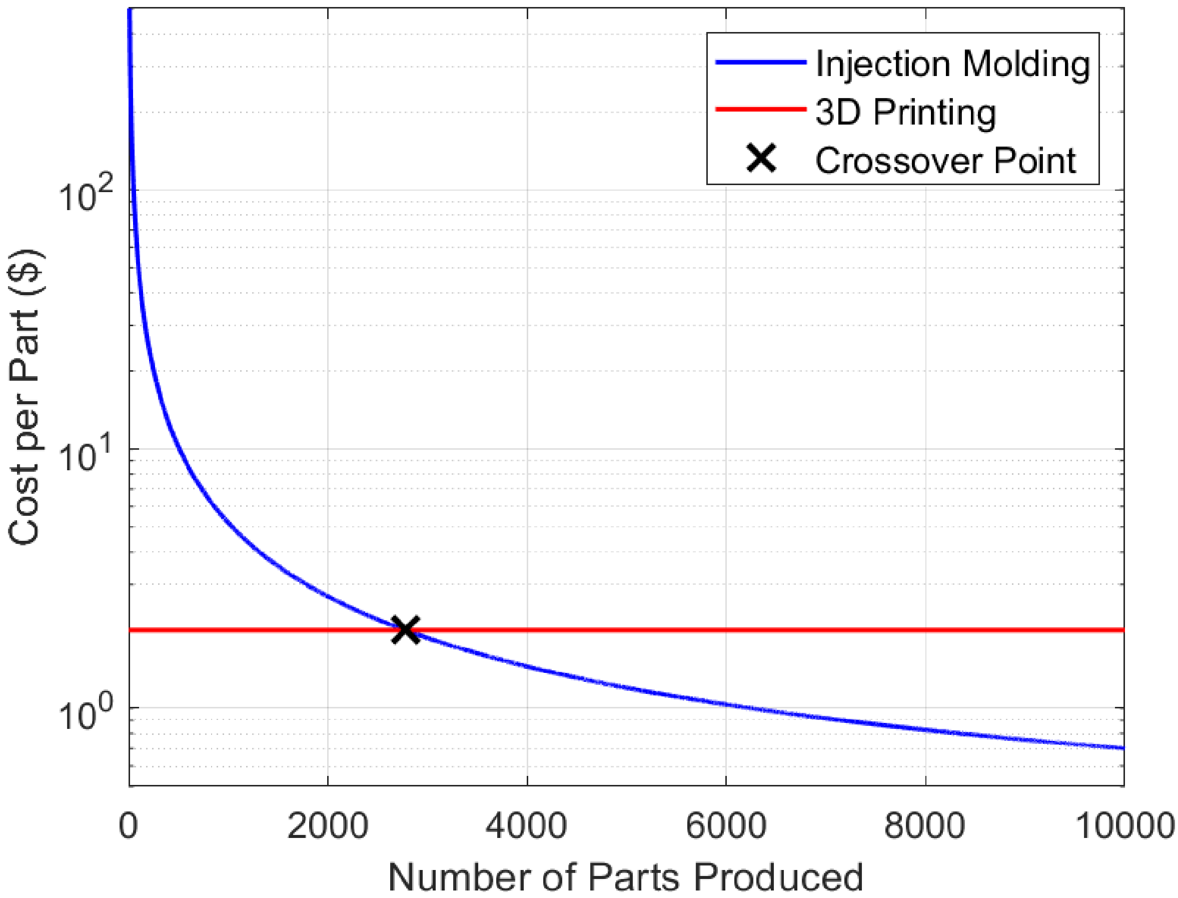


Figure 15: Per part cost analysis, log-scaled, 3D printing vs injection molding.

The plot shows that domestic 3D printers make more sense for low production numbers, the crossover point being at approximately 2800 parts for our simplified example. This figure will vary for each specific case. This highlights the usefulness of domestic 3D printers for small businesses with production numbers much lower than the crossover point where traditional production processes become cheaper. Furthermore, on-demand printing allows for agile production without inventory holding costs, a significant advantage over traditional methods.

4.2.3 Market Dynamics and Decentralized Manufacturing

Domestic 3D printing is revolutionizing manufacturing by enabling individuals to produce and customize products locally, reducing dependence on centralized supply chains. This shift aligns with the broader maker movement, which emphasizes innovation, accessibility, and self-sufficiency through production tools. One emerging trend suggests that companies may transition from selling physical spare parts to offering digital blueprints, allowing consumers to print replacement parts at home[26].

Decentralization and Supply Chain Resilience: The ability to manufacture locally reduces risks associated with global supply chain disruptions. During the COVID-19 pandemic, 3D printing played a critical role in addressing shortages by rapidly producing personal protective equipment (PPE) and essential medical supplies. This demonstrated the agility of decentralized manufacturing in responding to urgent needs.

Beyond emergencies, 3D printing lowers supply chain costs, especially in sectors requiring low production numbers or high levels of customization. By minimizing the need for inventory storage, long-distance transportation, and warehousing, domestic 3D printing provides a leaner, more flexible alternative to traditional methods[27].

Hyper-Localized Production Ecosystems: Decentralized manufacturing fosters the development of hyper-localized production ecosystems. Community makerspaces equipped with shared 3D printing capabilities allow neighborhoods to meet local manufacturing needs, bypassing large industrial processes. For example, initiatives like *Fab Labs* worldwide provide tools, training, and resources for small businesses and individuals, encouraging communities to create and innovate at a local level.

This approach is reshaping both regional and global production systems, reducing reliance on centralized factories and long supply chains[28]. It also supports a circular economy by encouraging sustainable practices and reducing waste through on-demand production.

Implications for Employment: The rise of decentralized manufacturing has significant implications for employment in traditional manufacturing industries, both challenging and creating opportunities in the labor market:

- **Reduction in Low-Skill Manufacturing Jobs:** As production shifts from centralized factories to individuals and makerspaces, the demand for roles such as assembly line workers, logistics personnel, and warehouse operators may decline, particularly for low-volume or customized items.
- **Emergence of Specialized Roles:** Decentralized manufacturing generates demand for new skill sets, including 3D design, printer maintenance, and material science expertise. These roles require advanced training, underscoring the importance of reskilling programs for displaced workers.
- **Localized Economic Opportunities:** Community-driven 3D printing hubs offer new avenues for employment and entrepreneurship. By pooling resources like printers and materials, these hubs lower the entry barrier for small businesses and foster innovation within local economies. For instance, aspiring entrepreneurs can start micro-businesses with minimal upfront costs, selling customized products or providing printing services.

Another interesting development that came with the rise of domestic 3D printing is the business model where a company leverages its user community for innovation, reducing traditional R&D costs while enhancing product quality, exemplified by Prusa. By sharing the designs and software of its 3D printers under open-source licenses, Prusa invites users to modify, improve, and share their innovations, in both software and hardware. This collaborative approach creates a dynamic feedback loop, where the community's contributions directly inform product enhancements, such as the development of the popular PrusaSlicer software. This benefits both the costumer and the company: the user gets a better, cheaper product which he can personalize at will, while the company reaps the innovative ideas of its thousands of users, leading to faster and more cost-effective innovation, more brand loyalty and an enhanced reputation. This rare combination of open-source principles with a commercially viable hardware ecosystem showcases how community-driven innovation can sustain profitability and continuous improvement[29].

4.2.4 Sustainability and Long-Term Economic Benefits

Domestic 3D printing supports the principles of a circular economy by reducing waste and encouraging resource efficiency. Traditional manufacturing often produces surplus or unsold inventory, leading to waste; 3D printing's on-demand model avoids this by producing only what is required. Additionally, the ability to repair and extend the life of products using printed replacement parts reduces waste[26].

Over time, the cumulative economic benefits of customization and reduced waste can outweigh the initial investment in a printer and materials, both economically and ecologically. This depends of course on the use that each individual makes of their 3D printer. For instance, an individual who prints modular furniture components or replacement parts could save hundreds annually while contributing to more sustainable consumption patterns.

5 Challenges Unique to Domestic 3D Printing (Tanguy)

5.1 Common FDM Printing Issues

In this section, common issues of FDM printing will be addressed. They need to be avoided to ensure good printing quality.

5.1.1 Bed Leveling

Bed leveling is a crucial step in 3D printing that ensures the print bed is perfectly aligned relative to the nozzle. Proper leveling creates an even distance between the nozzle and the print surface across the entire bed, enabling consistent extrusion and strong adhesion for the first layer. If the bed is too high or low in spots, prints may fail due to poor adhesion or uneven layers.

There are two main types of bed leveling: manual and automatic. Manual leveling involves adjusting screws under the bed while checking distances with tools like a piece of paper. Automatic leveling uses sensors to map the bed's surface and compensate for any irregularities during printing.

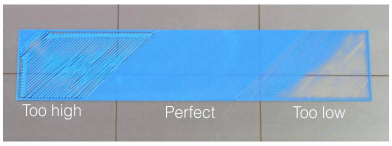


Figure 16: Exemple of bad bed leveling[30].

A well-leveled bed is key to achieving high-quality prints, reducing the risk of warping, and avoiding nozzle clogs. Regular checks and adjustments can help maintain optimal printing conditions.

5.1.2 Warping

Warping is a common issue in 3D printing where the edges of a print lift or curl away from the print bed. This typically occurs due to uneven cooling of the printed material. As layers cool, they contract; if the base layers cool too quickly or do not adhere properly to the bed, the tension causes the edges to bend upward.

Warping is especially problematic with materials like ABS and nylon, which have high shrinkage rates. To minimize wrapping, ensure the print bed is level and heated appropriately, use adhesives like glue or tape for better bed adhesion, and consider using an enclosure to maintain a stable printing temperature. Proper settings and preparation can significantly reduce wrapping and improve print quality.

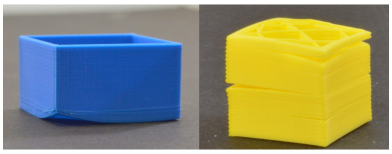


Figure 17: Exemple of warping[31].

5.1.3 Stringing

Stringing occurs in 3D printing when thin strands of filament are left behind as the nozzle moves between different parts of a print. This happens when melted filament oozes from the nozzle during non-printing travel moves, resulting in "strings" that stretch across gaps.

To reduce stringing, users can adjust the retraction settings, which control how much filament is pulled back into the nozzle during travel. Increasing travel speed and reducing printing temperature can also help, as they minimize the chance of filament oozing. Additionally, using a filament with lower moisture content and ensuring your printer is well-calibrated can further reduce stringing for cleaner, more precise prints.

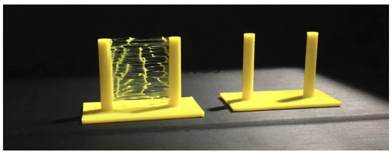


Figure 18: Exemple of stringing[32].

5.1.4 Failed Prints

Failed prints are a common frustration in 3D printing and can result from various issues. Common causes include power interruptions, which halt the print process unexpectedly; filament clogs, where material gets stuck in the nozzle, preventing extrusion; or insufficient knowledge of slicer settings, leading to improper layer heights, speeds, temperatures or not having supports when needed.

Figure 19: Exemple of a failed print[33].

5.2 Common SLA Printing Issues

Since SLA printers are less common, fewer lines are dedicated to discussing their problems. Resin 3D printing, while offering high precision and detail, can come with its own set of challenges that users need to overcome for successful prints. One common issue is when the print doesn't stick to the build plate. This may happen due to improper plate leveling, insufficient exposure time, or incorrect resin type. Another frequent problem is layer delamination, where printed layers fail to bond properly, leading to weak or fragmented structures. Incorrect print settings, such as inadequate curing times or improper exposure, can be the cause of such problems. Support failures are also a concern, especially when the print collapses mid-way, often due to insufficient support structures or incorrect support settings. Finally, random holes and gaps may appear in a print, creating missing sections or incomplete models. These imperfections can occur due to issues like inconsistent resin exposure, hardware malfunctions, or improper printer calibration. Troubleshooting and fine-tuning print settings are crucial for addressing these common resin printing problems.

5.3 Limits Compared to Industrial Printers

Domestic 3D printers are affordable and accessible, but on the other hand have several limitations when compared to industrial-grade 3D printers. One significant difference is material compatibility; consumer printers are typically restricted to standard plastics like PLA, ABS, and PETG, which are sufficient for basic prototyping but lack the advanced properties needed for specialized applications. In contrast, industrial machines can process high-performance materials such as PEEK, carbon-fiber-reinforced composites, and even metals, making them suitable for demanding sectors like aerospace and automotive manufacturing. Another limitation is print size and resolution; consumer-grade printers generally have smaller build volumes and lower precision, which restricts their ability to create large, complex, or highly detailed objects. Industrial printers, equipped with larger build areas and finer resolution capabilities, can handle intricate designs and larger-scale projects with ease.

Speed and efficiency are also significant differentiators. While domestic printers use mostly either FDM or SLA, Industrial systems employ advanced technologies like multi-laser sintering and optimized deposition processes to produce parts more quickly and efficiently. Moreover, the hardware in consumer printers is designed to prioritize cost over durability and precision, as seen in previous sections some printers can be made out of plastic by other printers, which often results in less reliable performance over extended use. Industrial machines, built with robust components and enhanced with closed-loop control systems, deliver consistent accuracy and reliability over long production runs, as well as more careful maintenance made by professional. Software is another area where domestic printers fall short, as their slicing programs are generally simplified that can be an advantages for new user but it also limits advanced tuning. Industrial-grade printers integrate with sophisticated software for design optimization, simulation, and quality assurance, ensuring they meet strict manufacturing standards.

5.4 Environmental Concerns

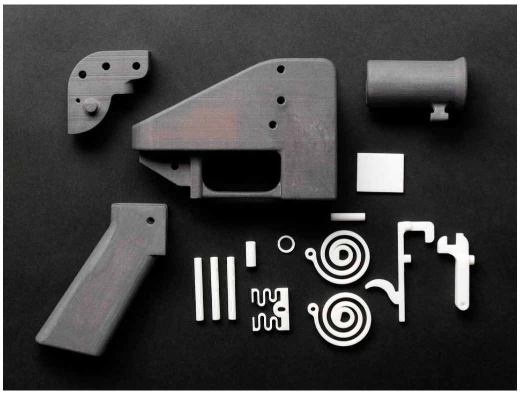
While domestic printers can reduce waste by allowing customers to repair broken parts more easily, it also raises ecological concerns, particularly regarding waste management of failed prints and the use of non-biodegradable materials. The fact that trying and learning by doing is promoted, by the maker community induces, a great number of failed prints, causing waste. In addition, calibration errors, software glitches, or improper filament handling, combined with leftover filament scraps and support structures, contribute to overall waste, posing a challenge for sustainable disposal. Most consumer-grade 3D printers primarily use filaments like PLA, PETG and ABS. PLA is marketed as biodegradable and could be seen as a solution but it requires industrial composting conditions to break down effectively, such recycling conditions are rarely available in many countries. ABS and other non-biodegradable plastics, on the other hand, are derived from petroleum and do not decompose, leading to long-term environmental persistence. Recycling these materials is also difficult for most households, as local recycling facilities often do not accept or process 3D printing waste due to its specific composition and contamination risks. Machines that can recycle failed prints and scraps into reusable filaments are emerging as a potential solution, allowing users to repurpose waste directly at home and reduce environmental impact. Currently, the price remains the main setback, as a good quality machine can cost upwards of $7300, many times more than most domestic 3D printers[34]. Compared to throwing out the waste and buying new filament, recycling does not seem to be an economically viable option for many users. Size is also a concern, as a printer already takes up much space and not every household would want to add another machine. Addressing these environmental concerns requires greater awareness among users, innovations in biodegradable and recyclable filament technology, and the development of efficient systems for managing 3D printing waste within the domestic context.

5.5 Technical Support

Domestic 3D printer manufacturers often let their customers deal with their struggles. Many consumer-grade printers are marketed toward hobbyists and tech enthusiasts and rely on the assumption that users will troubleshoot problems independently. As a result, users often turn to online communities, forums, and social media groups for guidance. While these communities can be incredibly resourceful, the reliance on user-generated advice can lead to inconsistent solutions, varying quality of support, and potential frustration for those unfamiliar with technical troubleshooting. This lack of customer service can make domestic 3D printing challenging for people not used to exploring the Internet for solutions.

5.6 Potential Drifts

In 2013, Defense Distributed, an American organization, released the plans for the "Liberator", a firearm that could be almost entirely 3D printed using a consumer-grade printer. This single-shot pistol, based on a simple Second World War gun and made out of plastic, raised immediate concerns about gun regulation and the potential for individuals to create unregistered, undetectable firearms without traditional oversight. Despite its revolutionary design and the noise its released made, the Liberator was highly impractical; it had a limited lifespan, a range of 2 meters, had a bad accuracy, and carried a significant risk of exploding upon firing[35].



(a) All the parts needed.

(b) Look once assembled.

Figure 20: The Liberator[36].

While the Liberator was a symbolic step, its functional limitations did not stop other "innovators" from improving on the concept. A notable example is the FGC-9 ("F*** Gun Control - 9mm"), a semiautomatic carbine developed in 2020 by an anonymous German designer known as "JStark1809." Unlike the Liberator, the FGC-9 was designed for practicality, ease of assembly and has a whole other firepower. It could be fabricated using regular consumer 3D printers and assembled with accessible off-the-shelf components, including springs and metal pipes purchasable at hardware stores. The FGC-9 represented a significant leap in the DIY firearms movement, combining increased reliability and firepower with the same decentralization of manufacturing that had alarmed regulators with the Liberator.

(a) All the parts needed[37].

(b) Look once assembled[38].

Figure 21: The FGC-9.

The development of 3D printed firearms like the Liberator and FGC-9 has heightened global concerns about the ease to bypass traditional gun control, creating challenges in controlling not just physical firearms but the digital files that enable their production. These advancements underline the tension between technological innovation and the need for public safety, sparking ongoing debates about the implications of decentralized weapon manufacturing in the digital age.

6 Future of Domestic 3D Printing (Tanguy)

6.1 Accessibility

6.1.1 User-Friendly Printer

One of the major barriers to widespread adoption of 3D printing is its perceived complexity. Future 3D printers are likely to address this by becoming significantly more user-friendly. Touchscreen interfaces, step-by-step guided software, and plug-and-play setups will make operating a 3D printer as intuitive as using a smartphone, an app could also replace the use of the computer. Pre-loaded designs with simple customization options could eliminate the need for technical expertise, allowing users to create objects effortlessly.

For example, users might only need to select a desired item from a catalog, choose a few parameters, and press a button to start printing. AI-driven error detection systems could automatically adjust settings or provide clear guidance on how to resolve failure, further lowering the knowledge required to use one of these machine.

6.1.2 Price and Size

Another critical factor in making 3D printers accessible is affordability. Currently, while hobbyist printers are becoming more cost-effective, the balance of price, quality, and functionality remains a challenge. In the future, advances in manufacturing processes and economies of scale are expected to drive down costs. Looking back at section 4.2.1, if the price continues the current trend printers will be affordable for the majority of households.

Compactness is equally important. As living spaces become smaller, 3D printers will need to shrink in size without compromising on functionality. Modular designs or foldable printers could emerge, making them easier to store and use in homes with limited space.

6.1.3 Implementation of AI

Artificial intelligence is assured to redefine the domestic 3D printing experience. AI-powered software could analyze user needs, suggest optimal designs, and automatically generate models based on verbal or visual inputs. Users could simply describe an object and have the AI design and prepare it for printing without requiring users to use complex CAD software or look through the internet for an existing file.

AI could also help on existing files, optimizing print settings, improving efficiency, reducing waste, and ensuring better quality for even the most inexperienced users. Predictive maintenance features, powered by machine learning, might warn users of potential issues before they arise, reducing downtime and extending the lifespan of printers.

6.2 Technical improvement

6.2.1 Material Diversification

The expansion of printable materials will be key in making 3D printers more versatile and useful in everyday life. While today's domestic printers primarily use plastics such as PLA and ABS, the future will likely see machines capable of handling a broader spectrum of materials, that could include:

- Flexible materials: For wearable items like clothing or accessories.
- Metal filaments: Enabling home users to craft durable tools or small mechanical parts.
- Food-grade materials: Expanding into culinary uses, like printing customized chocolates or pasta[39].
- Bio-compatible materials: For personalized medical devices such as braces or splints.

Such diversification will open up countless applications, transforming 3D printers into essential tools for creativity, utility, and innovation.

6.2.2 Material Reusability and Sustainability

Sustainability is a key aspect in many technological advancements, and domestic 3D printing is no exception. Systems that promote material reusability will be integrated in future printers.

- Recycling mechanisms: Advanced printers could shred and reuse failed prints or obsolete objects, converting them back into usable filament at an affordable price.
- Biodegradable filaments: Enhanced versions of eco-friendly materials like PLA will offer durability during use but biodegrade safely when disposed of.
- Waste-free printing: Smarter AI-driven print optimization will minimize material waste, ensuring that every gram of filament is used effectively.

These innovations have the potential to make 3D printing greener than ever and more ecologically sound than traditional manufacturing.

6.2.3 Speed, Quality, and Energy Efficiency

For 3D printers to become universally adopted, they must balance speed, quality, and energy consumption. Key advancements in this area will likely include:

- Speed: New printing technologies, could drastically reduce print times. A process that once took hours could be completed in minutes, making the technology more practical for everyday use. Keeping FDM but improving current parts could also affect speed.
- Quality: Improvements in layer resolution and extrusion technology will lead to sharper, more detailed prints.
- Energy Efficiency: Low-energy printers will use optimized heating and movement systems to reduce electricity consumption. Solar-powered or energy-storing models might become available, making 3D printing a viable option even in off-grid settings.

6.3 Distributed Manufacturing

As mentioned earlier in section 4.2.3, the concept of decentralized manufacturing, supported by domestic 3D printing, represents an attractive development in production methods. Domestic 3D printers are likely to play an even more significant role in the evolution of distributed manufacturing systems in the years to come. This approach minimizes dependencies on centralized facilities and global supply chains, making manufacturing more resilient to disruptions. In addition, it enables faster response times, reduces carbon footprints by lowering transportation emissions, and supports on-demand production to fit specific consumer needs.

7 Conclusion

Domestic 3D printing has emerged as a transformative technology, reshaping traditional manufacturing patterns by bringing production capabilities into the hands of individuals. From its origins in industrial prototyping, the field has expanded to include diverse applications such as home improvement, education, hobbies, and small-scale entrepreneurship. This democratization has been fueled by advancements in printer affordability, accessibility, and material diversity.

FDM and SLA technologies each offer unique advantages, with FDM excelling in material variety and cost-effectiveness, while SLA provides unmatched detail and precision. However, both face challenges, including environmental concerns, technical limitations compared to industrial printers, and the need for user-friendly advancements. Addressing these issues will be crucial for widespread adoption.

Looking ahead, the future of domestic 3D printing is bright, with promising developments in AI-driven user interfaces, material sustainability, and distributed manufacturing systems. These advancements have the potential to not only enhance accessibility but also contribute to a circular economy and reduced environmental impact. As the technology evolves, it will continue to empower individuals to innovate, create, and contribute to a more sustainable and localized approach to manufacturing. It is important however to nuance these claims, as the ease of production brought by having a 3D printer could also push towards overconsumption and extra waste. Educating users in correct practices is still a necessary step, especially with a technology as recent and rapidly evolving as 3D printing.

By understanding and overcoming the current limitations, domestic 3D printing can fulfill its promise of revolutionizing how we design, produce, and consume in our everyday lives.

8 Annexes

8.1 Tables of properties for FDM materials

	ABS	Flexible	PLA	HIPS	PETG	Nylon	Carbon Fiber Filled
Ultimate Strength	40 MPa	26–43 MPa	65 MPa	32 MPa	53 MPa	40–85 MPa	45–48 MPa
Stiffness	5/10	1/10	7/10	5/10	5/10	5/10	9/10
Durability	8/10	9/10	4/10	7/10	6/10	8/10	7/10
Max. Service Temp.	98 °C	60–74 °C	52 °C	100 °C	73 °C	80–95 °C	52 °C
Coeff. Thermal Exp.	90 µm/m-°C	157 µm/m-°C	68 µm/m-°C	80 µm/m-°C	60 µm/m-°C	95 µm/m-°C	57.5 µm/m-°C
Density	1.04 g/cm^3	1.19–1.23 g/cm^3	1.24 g/cm^3	1.03–1.04 g/cm^3	1.23 g/cm^3	1.06–1.14 g/cm^3	1.3 g/cm^3
Price (per kg)	$10–$40	$30–$70	$10–$40	$24–$32	$20–$60	$25–$65	$30–$80
Printability	8/10	6/10	9/10	6/10	9/10	9/10	7/10
Extruder Temp.	220–250 °C	225–245 °C	190–220 °C	230–245 °C	230–250 °C	220–270 °C	200–230 °C
Bed Temp.	95–110 °C	45–60 °C	45–60 °C	100–115 °C	75–90 °C	70–90 °C	45–60 °C
Heated Bed	Required	Optional	Optional	Required	Required	Required	Optional
Build Surfaces	Kapton Tape, ABS Slurry	PEI, Painter's Tape	Painter's Tape, Glue Stick, Glass Plate, PEI	Glass Plate, Glue Stick, Kapton Tape	Glue Stick, Painter's Tape	Glue Stick, PEI	Painter's Tape, Glue Stick, Glass Plate, PEI
Other Requirements	Heated Bed, Enclosure Recommended	Part Cooling Fan	Part Cooling Fan	Heated Bed, Part Cooling Fan	Heated Bed, Part Cooling Fan	Heated Bed, Enclosure Recommended, All Metal Hotend	Wear Resistant or Stainless Steel Nozzle, Part Cooling Fan

Table 1: Comparison of 3D printing materials for FDM (Part 1).

	ASA	Polycarbonate	Polypropylene	Metal Filled	Wood Filled	PVA
Ultimate Strength	72 MPa	78 MPa	32 MPa	20–30 MPa	46 MPa	78 MPa
Stiffness	7/10	9/10	4/10	3/10	3/10	7/10
Durability	9/10	9/10	9/10	7/10	4/10	4/10
Max. Service Temp.	121 °C	75 °C	100 °C	52 °C	52 °C	75 °C
Coeff. Thermal Exp.	98 µm/m-°C	69 µm/m-°C	150 µm/m-°C	33.75 µm/m-°C	30.5 µm/m-°C	85 µm/m-°C
Density	1.07 g/cm^3	1.2 g/cm^3	0.9 g/cm^3	2–4 g/cm^3	1.15–1.25 g/cm^3	1.23 g/cm^3
Price (per kg)	$38–$40	$40–$75	$60–$120	$50–$120	$25–$55	$40–$110
Printability	8/10	6/10	4/10	7/10	6/10	4/10
Extruder Temp.	235–255 °C	260–310 °C	220–250 °C	190–220 °C	190–220 °C	185–200 °C
Bed Temp.	90–110 °C	85–100 °C	80–105 °C	45–60 °C	45–60 °C	45–60 °C
Heated Bed	Required	Required	Required	Required	Optional	Required
Build Surfaces	PEI, Commercial Adhesive, Glue Stick	PEI, Painter's Tape	Packing Tape, Polypropylene Sheet	Painter's Tape, Glue Stick, PEI	Painter's Tape, Glue Stick, PEI	PEI, Painter's Tape
Other Requirements	Heated Bed	Heated Bed, Enclosure Recommended	Heated Bed, Enclosure Recommended	Part Cooling Fan	Part Cooling Fan	Heated Bed, Part Cooling Fan

Table 2: Comparison of 3D printing materials for FDM (Part 2)[18].

8.2 Tables of properties for SLA materials

	Standard & Clear	Tough	Durable	Heat Resistant	Ceramic Reinforced
IZOD impact strength (J/m)	25	38	109	14	N/A
Elongation at break (%)	6.2	24	49	2.0	5.6
Tensile strength (MPa)	65.0	55.7	31.8	51.1	75.2
Tensile Modulus (GPa)	2.80	2.80	1.26	3.60	4.10
Flexural Modulus (GPa)	2.2	1.6	0.82	3.3	3.7
HDT @ 0.45 MPa (°C)	73	48	43	289	88

Table 3: Comparison of material properties for SLA[19].

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