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# Module 7: Application areas of 3D Printing

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# Contents

# 7.1. Automotive Industry

## 7.1.1. AM[1] in the automotive industry

Additive manufacturing (AM) is a broad term for a group of processes that construct parts in an additive rather than subtractive manner. This essentially means that instead of removing material from a block, parts are built up layer by layer. This manufacturing method employs a variety of platforms associated with the technology, including stereolithography, fused deposition modeling, selective laser sintering, and others and applies in the following procedures [1]:

- **Communication.** In the automotive industry, designs frequently begin as scale models displaying the form of a vehicle which are frequently used for aerodynamic testing. High detail, smooth scale models of car designs are produced using SLA and material jetting. Accurate models enable design intent to be effectively represented while also displaying the general form of a notion.
- **Validation.** Prototyping with additive AM is increasingly standard in the automotive sector. There is an AM technology for every prototyping need, from a full-size wing mirror printed rapidly using low-cost FDM to a high-detail, full-color dashboard. Also, AM engineering materials permit comprehensive testing and validation of prototype performance.
- **Pre-production.** One of the areas AM has been most disruptive is the production of low cost rapid tooling for injection molding, thermoforming and jig and fixtures. This allows for tooling to be quickly manufactured at a low cost leading to produce low to medium runs of parts.
- **Production.** Because the automotive industry's production quantities are often quite high (more than 100,000 pieces per year), AM has been employed mostly as a prototype solution rather than for end component manufacturing. Because to advancements in the size and speed of industrial printers, as well as the materials available, AM is now a realistic alternative for many medium-sized production runs, particularly for higher-end automobile manufacturers that limit manufacturing quantities to far less than the average.
- **Customisation.** When the cost of highly complex one-off components is justified by a significant improvement in vehicle performance, AM has had a significant impact on the competitive automotive industry. Parts can be customized for a specific vehicle or driver (helmet or seat). AM has also enabled the consolidation of parts and the optimization of the topography of many custom automotive components.

[1] In bibliography, 3D printing is also known as additive manufacturing (AM) and direct digital manufacturing (DDM) (DDM). The industrial production term for 3D printing is additive manufacturing (AM) or additive layer manufacturing (ALM).

### 7.1.2. AM requirements [1]

**Weight - final parts.** Weight reduction of components is one of the most significant features of the automotive industry. Advanced engineering materials and complicated geometries are used in automotive applications to save weight and improve performance. AM is capable of creating parts from a wide range of lightweight polymers and metals used in the automotive sector.

**Complex geometries - prototypes and final parts.** The geometry of a part influences its weight and aerodynamics (and thus its performance). Internal channels in automotive parts are frequently required for conformal cooling, hidden features, thin walls, fine meshes, and complex curved surfaces. AM enables the creation of incredibly intricate structures while remaining exceedingly light and sturdy. It allows for a high level of design freedom, the optimization and integration of functional elements, the production of small batch sizes at low unit costs, and a high level of product customization even in serial production.

**Temperature - testing and final parts.** Many automotive applications necessitate high heat deflection minimums. Several additive manufacturing technologies provide materials that can resist temperatures considerably over the normal 105&#8451 sustained engine compartment temperatures. High-temperature applications are appropriate for SLS nylon and some photo-cured polymers.

**Moisture - testing and final parts.** Most components used in the manufacture of automobiles must be moisture resistant, if not completely moisture proof. One significant advantage of additive manufacturing is that all printed pieces may be post-processed to form a waterproof and moisture-resistant barrier. Furthermore, many materials are, by definition, suitable for wet and moist settings.

**Part consolidation - prototyping and final parts.** By rebuilding an assembly as a single complicated component, the number of elements in the assembly can be decreased. Part consolidation is an important consideration when examining how AM might improve material use reduction, hence decreasing weight and, in the long run, cost. Part consolidation also minimizes inventory and allows assemblies to be replaced with a single part if repairs or maintenance are required; another key issue for the automotive industry.

### 7.1.3. 3D Printing advertences

AM provides much more advantages than traditional manufacturing technologies [1, 2, 3, 4] such as[2]:

1. **Design freedom.** Because 3D printing builds parts layer by layer, it allows for unparalleled design freedom, which offers many potential for part

[2] https://www.rapiddirect.com

optimization and lightweighting. When attempting to enhance fuel efficiency in the automotive industry, the capacity to lower the weight of a component (and thus the overall weight of the vehicle) is critical. 3D printing enables the redesign and creation of automobile parts with complex internal geometry, reducing weight and material utilization without sacrificing quality.

2. **Flexibility.** 3D printer assisted design in the automotive industry allows designers to try multiple options of the same detail and iterations during the stages of new model development. It brings more flexibility, which results in efficient designs and flexibility in making changes in design throughout the process of model evaluation. This, helps auto manufacturers stay up to date with market needs and be ahead of the field. Especially when dealing with the manufacturing of complex bodies[3].
3. **Part Consolidation.** In the automotive sector, 3D printer assisted design allows designers to test various possibilities for the same detail and revisions during the development stages of a new model. It provides additional flexibility, resulting in more efficient designs and the ability to make design modifications during the model review process. This, in turn, assists automakers in staying current with market demands and staying ahead of the competition. Especially when it comes to the production of complicated bodies.Customization. When one thinks of automotive production, one often thinks of mass manufacturing: sophisticated production lines turning out millions of the same parts before assembling them into cars. With the proliferation of 3D printing, however, the automotive industry is now seeing new degrees of customizability for cars at a viable cost. For low-volume or specialty vehicles especially, it is now possible to integrate custom interior features into cars at a reasonable cost. Auto brand MINI, for example, lets customers choose from a range of personalized 3D printed interior parts. [4]
4. **Rapid turnaround times**. 3D printing has the potential to accelerate all stages of car manufacture. For example, during the prototyping stage, 3D printing can be used to swiftly generate functioning parts for testing, allowing automotive designers and engineers to quickly assess whether a component's design is viable. 3D printing is utilized in the production stage for quick tooling, which results in lower prices. Ultimaker and Volkswagen Autoeuropa, two of the most mainstream brands in their respective industries, have demonstrated that it is feasible to get far more mainstream than sub £4,000 3D printers being used on a daily basis in the assembly of over 100,000 automobiles per year [5].
5. **Cost savings.** Printing solutions for the automotive industry offer advantages that are easily quantifiable in terms of performance characteristics which replace costly and time-consuming CNC production[5]. 3D printed plastic parts

[3] https://cprimestudios.com/blog/how-3d-printing-used-automotive-industry

[4] https://www.rapiddirect.com/

[5] CNC 101: "The term CNC stands for 'computer numerical control', and the CNC machining definition is that it is a subtractive manufacturing process which typically employs computerized controls and machine tools to remove layers of material from a stock piece—known as the blank or workpiece—and produces a custom-designed part" https://www.thomasnet.com/articles/custom-manufacturing-fabricating/understanding-cnc-machining/

are less expensive and take less time to produce in-house leading to lower production costs. With a 98 percent cost savings and an 89 percent time savings, 3D printing is a no-brainer for use on an assembly line.
It was designed, printed, and fitted to surround the wheel nut cavities, allowing the assembler to quickly guide and tighten the bolts with familiar heavy-duty tools without scuffing the wheel [5]. Volkswagen Autoeuropa's assembly line process, which has implemented 3D printing, saved €150,000 in costs in 2016, achieved a 100 percent return on investment (ROI) within two months of implementing 3D printing, and is expected to save €250,000 in costs in 2017. Traditional manufacturing costs up to €400. The same tool can be produced in four days using 3D printing for the low cost of €10 [5]. Volkswagen is said to have saved nearly €325,000 in tooling costs by using 3D printing.

6. **Reducing material waste.** When it comes to manufacturing, material waste is extremely essential. Additive manufacturing is ideal for minimizing material waste. It is a very environmentally friendly procedure. When 3D printing a product, you just need to utilize the exact amount of material required to complete it. 3D printing in vehicle design reduces material consumption and waste, which benefits all phases of manufacturing.[6]
7. **Eco-friendly solutions**. One of the most pressing challenges in the automobile industry is the development of new environmentally friendly vehicles. Cars are responsible for 75 percent of carbon monoxide emissions in the United States, according to the Environmental Protection Agency[7]. The car sector now has new options thanks to digital manufacturing. The EU has actually launched a 2.7 million euro programme for recycled 3D printer materials in the automotive and construction industries. It was created to support research and the development of greener materials for construction and automobile manufacture, such as biodegradable materials. The car industry is concerned about the environment, but 3D printing could be a viable alternative.
8. Because everything is manufactured on-site, in-house 3D prototyping can also help to control Intellectual Property (IP) infringements or information leaks.

### 7.1.4. Necessary equipment

**1. Software**

**Software to work on automotive designs**

- Alias[8] is an Autodesk product that includes a variety of tools for drawing industrial designs and modeling automobile projects. Alias is also useful for concept modeling because this software includes many design tools and allows for good project visualization. Aston Martin uses this Alias for its cars design.

[6] https://cprimestudios.com/blog/how-3d-printing-used-automotive-industry
[7] https://www.epa.gov/
[8] https://www.autodesk.com/products/alias-products/overview

- 3Ds Max [figure 1] is the greatest solution on the market for working on car designs. This is a precise tool that is mostly used by expert designers to produce high-end representations. This application can also be used in Virtual Reality. This is an excellent software for shape modeling, which is why it may be used to create a fantastic car body. 3Ds Max can help automobile makers generate realistic car designs, which can be a big benefit to your design process.
- Blender [7] is a free and open-source 3D modeling program. This application provides a plethora of capabilities that could be quite beneficial, particularly for your car ideas. It has simulation tools and can work with polygon meshes and NURBS surfaces. It is really complete, but if you are a more sophisticated user, you may even create your own feature! Furthermore, because this software has a large community, there are numerous tutorials and manuals available.

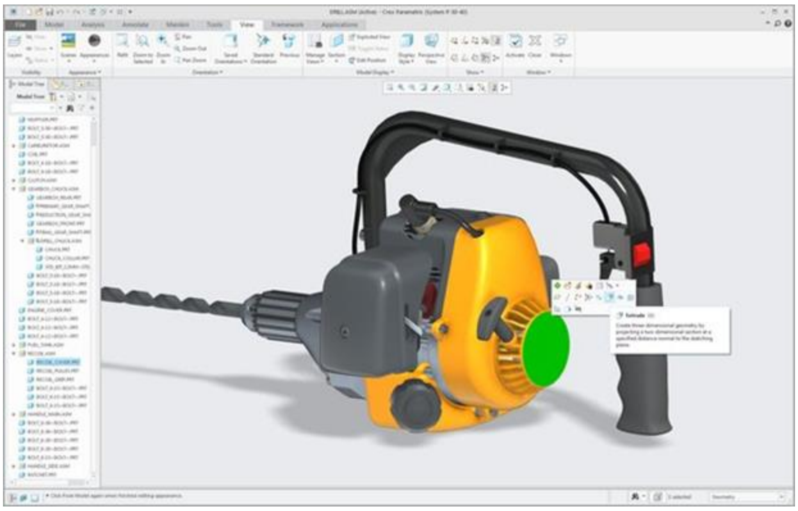

**Figure 1:** 3Ds Max
https://www.ptc.com/en/products/creo/parametrichttps://www.ptc.com/en/products/creo/parametric

## 2. AM materials suited for automotive applications

The table [figure 2] below lists a variety of materials used in the automobile industry, as well as their respective applications [1].

| ***Application*** | ***Process*** | ***Material*** | ***Features*** | ***Example part*** |
|---|---|---|---|---|
| *Under the hood* | SLS | Nylon | Heat resistant functional parts | Battery cover |
| *Interior accessories* | SLA | Resin | Customized cosmetic components | Console prototype |

| | | | | |
|---|---|---|---|---|
| *Air ducts* | SLS | Nylon | Flexible ducting and bellows | Air conditioning ducting |
| *Full scale panels* | Industrial SLA | Resin | Large parts with a surface finish comparable to injection molding that allow for sanding and painting | Front bumper |
| *Cast metal brackets & handles* | SLA & cast | Wax | Metal parts made from 3d printed patterns | Alternator mounting bracket |
| *Complex metal components* | DMLS | Metal | Consolidated, lightweight, functional metal parts | Suspension wishbone |
| *Bezels* | Material jetting | Photopolymer | End use custom screen bezels | Dashboard interface |
| *Lights* | SLA | Resin | Fully transparent, high detail models | Headlight prototypes |

**Figure 2:** Materials used in the automobile industry [1]

### 7.1.5. Common automotive applications **[1]**

- Bellows. AM (particularly SLS) can be utilized to create semi-functional bellow parts where some flexibility in assembly or mating is required. In general, this material/process is best suited for situations in which the part will be subjected to only a few repetitive flexing actions. Other Polyethylene-based SLS materials, such as Duraform "Flex," are better suited for tasks that require extensive flexing.
- Complex Ducting [figure 3]. You may design highly optimized, very complicated single piece structures by employing SLS to build non-structural low volume ducting, such as environmental control system (ECS) ducting for aerospace and performance racing. Through the use of structurally optimized surface webbing, it is possible to engineer in varied wall thicknesses and boost the strength to weight ratio with SLS. Using typical manufacturing techniques, this is a highly expensive detail to implement. There are no costs associated with complexity in SLS, and pieces are printed without support and at a high level of accuracy.

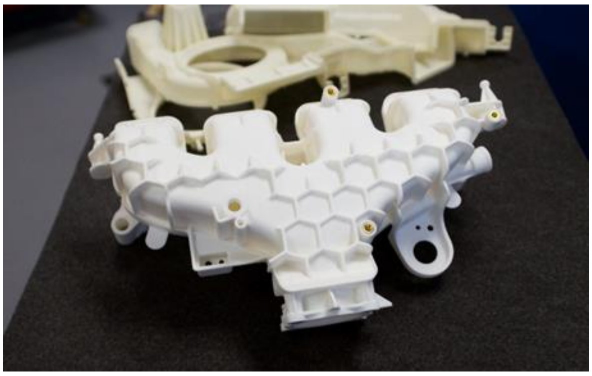

**Figure 3**: Complex Ducting [8]

- High detail visual prototypes. Some AM technologies, unlike traditional prototype approaches, may produce multicolor designs with a surface polish comparable to injection molding. These models enable designers to have a better knowledge of a part's form and fit. Because the surface smoothness that can be achieved is often representative of a finished product, this very exact approach of prototyping is also suitable for aerodynamic testing and analysis. AM is frequently used to build vehicle components that prioritize aesthetics over functionality, such as wing mirrors and light housings, as well as steering wheels and whole interior dashboard designs. The two most common methods of printing are material jetting and SLA printing.
- Functional mounting brackets. The ability to make a sophisticated, lightweight bracket in a matter of hours is a hallmark of the AM industry. Not only can organic shapes and patterns be made with AM, but it also requires relatively little operator input, allowing engineers to quickly get a design from a computer to assembly in a short period of time. Traditional production techniques such as CNC machining, which require a highly experienced machine operator to make parts, do not allow for this. Powder bed fusion methods like as SLS nylon and metal printing are ideal for practical parts and come in a variety of materials (from PA12 nylon to titanium).

### 7.1.6. Main applications

**3D printing can be a key to car model evaluation and cost-saving for automakers [1, 4]. The following table [figure 4] summarizes the main applications in the field [9]:**

| | |
|---|---|
| Design and concept of communication | High detail, smooth and accurate 3D printed scale models are very often used in the automotive industry to demonstrate designs and concepts of new vehicles. The reason is simple – using CAD[9] models alone is not effective enough to define possible design |

[9] CAD – Computer Aided Design. 3D Computer-aided design (3D CAD)

| | |
|---|---|
| | problems. Such models are also used for the aerodynamic testing of new models. |
| Prototyping validation | Like in many other industries, prototyping is a very important part of the manufacturing process in the automotive sector. 3D printing allows for rapid prototyping in the pre-manufacturing stage. Using AM now is one of the most popular ways to validate a prototype – from a small quickly printed detail to a high detail full-scale part suitable for performance validation and testing. |
| Preproduction sampling and tooling | The specialists of 3D hubs regard this application as the most promising. 3D printing can be used to make molds and thermoforming tools, rapid manufacturing of grips, jigs, and fixtures. This allows automakers to produce samples and tools at low costs and to eliminate future losses in production when investing in high-cost tooling. |
| Customized parts | Additive manufacturing is used by automotive enterprises to tailor the parts to specific vehicles (making them custom and lightweight) or even drivers (e.g. seats for racing cars). This is especially useful when the cost of such unique components is justified by a substantial improvement in vehicle performance. |

**Figure 4:** Main applications [9]

### 7.1.7. Advantages and Disadvantages of 3D printing **[figure 5] [4, 10]**

| **Process** | **Advantages** | **Disadvantages** |
|---|---|---|
| Binder Jetting | Large number of potential materials<br>Able to create ceramic molds for metal casting<br>Support structures are included automatically in layer fabrication<br>Low-imaging specific energy | Rough or grainy appearance<br>Poor strength<br>Post-processing required to remove moisture or improve strength |
| Direct Energy Deposition | High material deposition rate and high material utilization<br>High efficiency for repair and | Low to medium part complexity<br>Poor surface finish and |

| **Process** | **Advantages** | **Disadvantages** |
| --- | --- | --- |
| | add-on features<br>Mainly metal and suitable for large components<br>Deposition of thin layers wear resistant metals on components | resolution<br>Poor dimensional accuracy<br>Limited materials for production purposes |
| Material Extrusion | Low cost of the entry-level machines<br>A variety of raw materials are available<br>Versatile and easy to customize | Low level of precision and long build time<br>Unable to build sharp external corners<br>Anisotropic nature of a printed part |
| Material Jetting | No waste of model material<br>High resolution and accuracy<br>Multiple materials and multiple colors | Post-processing may damage thin and small features<br>Support materials cannot by recycled thus wasted |
| Powder Bed Fusion | Support is not required for polymer powder<br>Both polymer and metal powder can be recycled<br>High part complexity and wide range of materials<br>Good accuracy and resolution for metals | Rough surface finish for polymer<br>Relatively slow build rate<br>Small to medium parts only<br>Expensive machines |
| Sheet Lamination | High fabrication speed<br>No support structures are needed<br>Low warping and internal stress<br>Multi-materials and multi-colors are possible | High material waste<br>Difficult to remove support trapped in internal cavities<br>Thermal cutting produces noxious fumes<br>Possible warpage of lamination as a result of heat of laser |
| Vat Photopolymerization | High-resolution and accuracy, good surface finish<br>High fabrication speed | Require support<br>Require post processing to remove support |

| **Process** | **Advantages** | **Disadvantages** |
|---|---|---|
| | Low-imaging specific energy<br>Wide range of materials | Require post curing for enhanced strength |

**Figure 5:** Advantages and Disadvantages of 3D printing [4, 10]

AM has potential environmental and resource benefits, but it also has drawbacks that need to be addressed. As a result, it can be stated that new functionality in designs must be properly investigated in order to fully use the vast potential available. In terms of cooling, laser sources, and material losses, most 3D-printing systems are not currently designed with energy efficiency in mind, but as the technology grows and matures, it is realistic to expect some reduction in electricity use. When it comes to implementing AM, material selections and their environmental repercussions are crucial. Nickel alloys should be avoided whenever possible, and AM technology should ideally be developed to be able to print with lower-impact materials such as low-alloy steel [11].

### 7.1.8. Future projects involving 3D Printing technology

- Wheels of the future. Additive printing is a fantastic way to improve not just the design of your product but also the product itself. Indeed, it is the ideal production approach for working on designs and experimenting with intricate concepts that would be difficult to experiment with using standard manufacturing procedures. For wheels, it enables the testing of new tires with elegant and futuristic designs that are ideally adapted for the road and linked with car manufacturers' eco-friendly aims. As you can see, additive manufacturing is revolutionizing the transportation business by producing promising tire prototypes [3].
- Electric and self-driving cars are already a part of our lives, as are cloud-to-car mapping systems and driver behavior monitoring systems, which are appreciated by both drivers and insurance companies. Because of the volatile economic environment and increasingly demanding consumers, automakers are looking for new prospects and materials to keep up with other industries. In this climate, necessity breeds inventiveness [1].
- Ford pledges that in the future, it will incorporate 3D printing in a variety of methods, potentially growing additive manufacturing to be an integral production process [12].
- Porsche [figure 6] intends to 3D print 40 prototype seats for use on European race tracks, with user feedback used to produce the final street-legal models [1].

**Figure 6:** Porsche 3D prints multiple spare parts [14]

### 7.1.9. Conclusion

3D printing has significant advantages in the automobile sector in terms of overall product robustness, precision, and response speed. The linking of numerous 3D printing devices can also drastically cut product development costs, which are now comparable to the old technique. It is projected that as industrialisation becomes more common, the cost of equipment and raw materials would fall dramatically. As market competition heats up and product life cycles shorten, businesses are becoming more conscious of the necessity of R&D speed and cost control, making the use and application of 3D printing in the industrial sphere more popular [1].

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# 7.2. Prosthetic Industry

**Contents**



A new technology that is booming and brings the future to everyday life, comes to relieve sufferers even in the poorest countries. The three-dimensional printing of organs, tissues, bones, vessels, implants, artificial parts, medical equipment is evolving into a revolution in healthcare. Because it dramatically reduces production time and the cost of organs, prosthetic limbs and tools, speeding up treatment and at the same time reducing inequalities. At the same time, it improves the result as each product is designed with extreme precision on the individual patient, even in the developing world, where until recently it was impossible to adopt new techniques.

**Why we should use 3D Printing-Advantages?**

A lot of new development in the area of 3D printing is available in the interest of patients!
The biggest advantage of 3D printing in medicine, is the quick and cheap construction of prosthetic limbs, anatomical parts, and also medical tools for each patient individually. Each part of the human body is shown in three-dimensional imaging (jaw, knee, skull, vessels, heart, etc.) "can be reconstructed and printed immediately with impressive accuracy, for preoperative or intraoperative use. Preoperatively the three-dimensional printing is applied in every field of medicine, dentistry, maxillofacial surgery, orthopedic surgery, neurosurgery, cardio surgery, vascular surgery, oncology etc.
Data obtained from the CT or magnetic resonance imaging a three-dimensional anatomical model, is showing clearly, everything inside and outside the organ or member, tissues, nerves, arteries, vessels, vascular roots, teeth roots, etc.
The model facilitates diagnosis and then design, with absolute accuracy, even extremely complex interventions

Firstly, better fitting, as every prosthetic, can be personalized to patient needs (even mimic bone stiffness!). Usually other limb is used as specimen, it is scanned with a 3D-scanner. Also cosmetic “add-on” can be manufactured, according to needs!

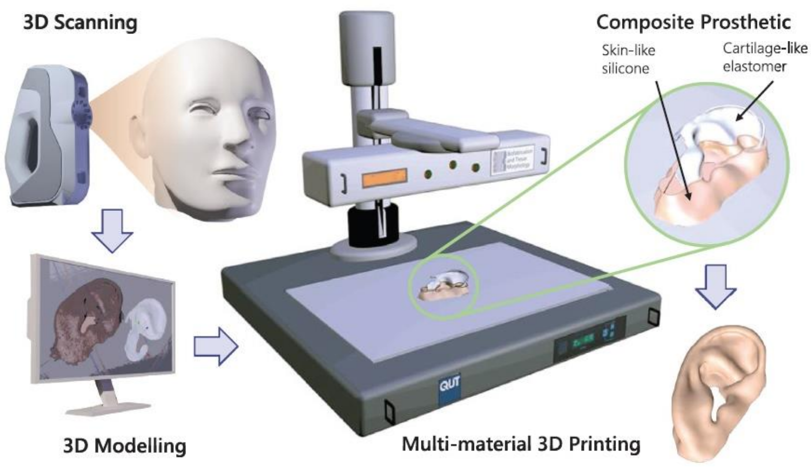


**Figure 1:** Top: Timeline showing significant innovations in the materials science of prosthetics past, present, and future Bottom: the typical advanced manufacturing pipeline for producing prosthetics. Newer techniques include the ability to fabricate multimaterial prosthetics during the single printing process.[9]

Secondly, need for "logistics" significantly reduced as creation can be done at the point of care, reducing thus the need for factory & specialized personnel, the need for transportation, storage and reduces the energy and recourses needed.
All these advantages make 3D printing, an ideal solution for remote areas. Every room can be, literally, transformed to "prosthetics factory".
Also the use of modern technics and materials allows new features such as trabecular structures and the use of modern materials significantly reduces surgery & rehabilitation duration giving, reduced risk of implant failure, improved Osseo-integration & increased lifespan, (compared to conventional implants).
Finally, constant improvement and research, regarding 3D printing materials can further improve implants and reduce cost.

### 7.2.1. Other necessary equipment, beyond 3D-printer.

The necessary equipment to use a 3D printer, is a computer with the necessary software, including software for drawing and modeling in 3D (e.g. Autocad).
Also it is important to have a 3D-scanner, according to specific needs (e.g. there is a different scanner for dental use, and different for orthopedic use). For this reason, there are different type of consumables (metals, polymers, ceramics, and hydrogels), we use to fabricate something, according to needs and 3D printer type.

### 7.2.2. Equipment can be manufactured using 3D printing

The 3D printing industry has expanded rapidly over the last few years. Nowadays we can make orthopedic implants for damaged bones support or replacement them (e.g. joint, bone etc.).

**Figure 2**: Image credit: Arcam, [10]

Also we can produce prosthetic limbs to replace a missing body part (e.g. hand, finger, leg).

**Figure 3**: Woman with transradial amputation. She lost her arm because of a snakebite for which a traditional healer was consulted. A 3D printed prosthesis was made for her, with an extra belt to prevent slipping. She uses the prothesis for domestic activities, supporting her dominant hand, cooking, and esthetic purposes [11]

Another use of 3D printing is make orthopedic aids like devices, which used to protect, immobilize, or restrict motion in a body part and orthotics (e.g. splints, supports), are externally applied devices which used to influence the structural and functional characteristics of the neuromuscular and skeletal system.

**Figure 4**: 3D-printed splints for hands and arms to prevent burn scar contractures after skin transplantation.[12]

Moreover, researchers in the laboratories are experimenting on printing live human skin and blood vessels, while envision the creation of kidneys, liver, heart and other organs and tissues (living cells), so that a patient who needs a transplant does not seek a donor.

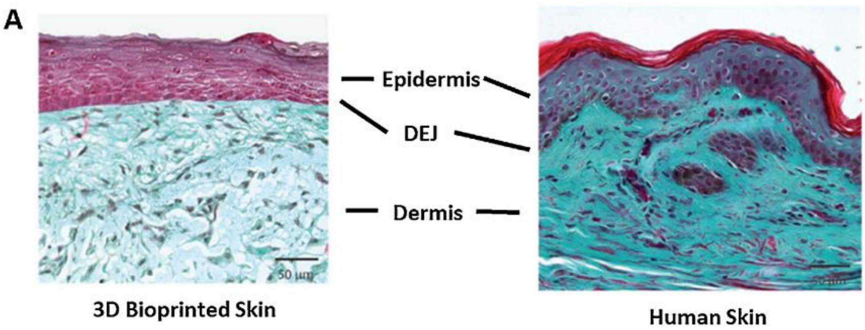


**Figure 5:** Histological and morphological characterization of the bioprinted skin. Optical microscopy images of normal human skin and bioprinted skin after 26 d of culture. Tissues were stained with Masson's Trichrome[13]

Additionally, 3D printing used to make parts to conceal wounds, scars, deformations. (skin-like silicone, prosthetic eye).

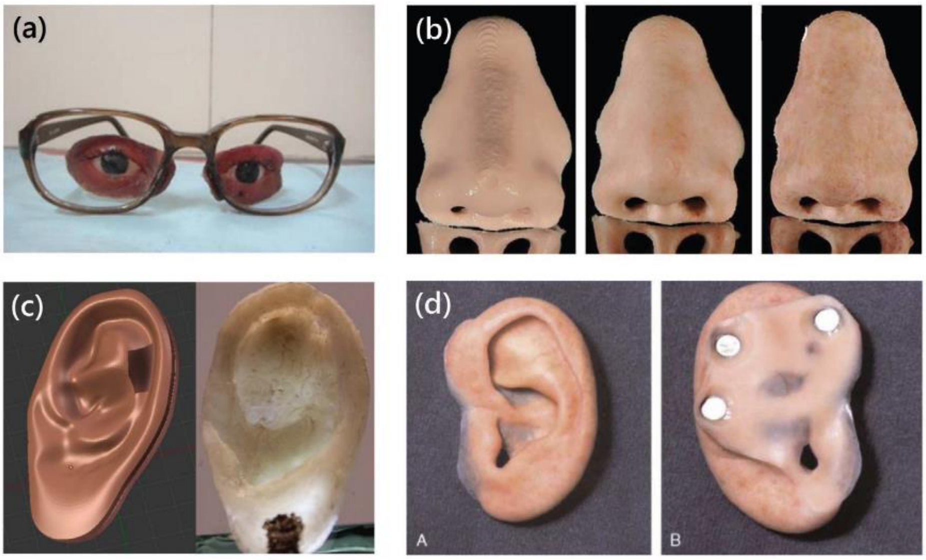


**Figure 6**. a) Facial prosthesis attachment to spectacles. Reproduced with permissionb) 3D printed prosthetic nose before post processing (left), colored and sealed with silicone coating (mid), and polished, sealed with silicone, and colored (right) c) An ear prosthesis 3D printed from electroactive poly (vinylidene fluoride); computer model (left), and 3D printed ear (right). Reproduced under the CC-BY Creative Commons Attribution 4.0 International License d) Auricular prosthesis (left), placement of retaining magnets (right).

Finally, the possibility of 3D scanning and printing dentures, orthodontic models and devices helps the dentist to work accurately and apply new techniques and new dental equipment (dental bridge, implants, aligners) for the best possible result, reducing the healing time and cost. [14]


**Figure 7:** Conventional orthodontic treatment (a) and thermoformed clear aligner with its 3D printed mold [15]

### 7.2.3. Disadvantages of 3D printing.

As with everything, this technology has disadvantages that should be carefully examined. For the time being, most 3D-printers can produce small dimension objects. Moreover, the high cost of buying a 3D-printer, a 3D-scanner and consumables is also problem. Also the need for dedicated consumables according to 3D-printer type or manufacturer.
Some materials have disadvantages (e.g. humidity absorption, excessive weight, reduced strength when exposed to high temperature or osmotic pressure or UV radiation) and some of them, require some kind of processing after printing.
Finally, ethical issues relating to experimental testing on human and lack of regulatory directives (for 3D-bioprinting).

### 7.2.4. Future projects involving 3D printing technology

Currently as the feedback is necessary in order to improve this technology, one of the first thoughts is attaching sensors to prosthetics that will provide feedback, helping to enhance this technology and will help the creation of a fully operational prosthetic hand, palm or fingers.

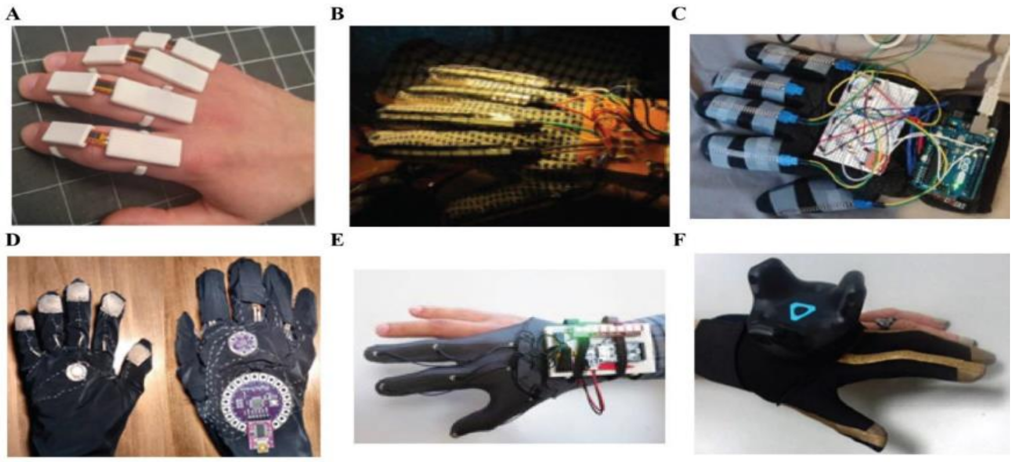


**Figure 8:**. Examples of Do-It-Yourself prototypes of wearable sensor gloves with different sensors. [16] A., B. Image courtesy of Instructables.com, C. Image courtesy of Instructables.com, D. Image courtesy of Instructables.com, E. Image courtesy of Instructables.com, F. Image courtesy of Instructables.com.

Furthermore, in order to make this technology available to every person in need, it is necessary to train practitioners in digital technologies to encourage the adoption of new innovations. Furthermore, we should reduce costs so everyone can buy and use it. Also we should make more research and improvement of materials for better results and finally we must create legal framework regarding 3D-bioprinting.

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# 7.3. Medical devices Industry

**Introduction**

The healthcare industry is constantly evolving, with traditional 'one-size-fits-all' treatment approaches quickly becoming obsolete. As a result the healthcare industry must adapt and embrace new platforms for the development of personalized therapies. Three-dimensional (3D) printing, a type of additive manufacturing, improves the ability to personalize medical implants and devices while also allowing for more complex geometries. With the utilization of additive manufacturing technologies, medical applications such as regenerative medicine, implants, cardiology, orthopedics, and dentistry are making significant progress. [1]

There are five primary types of current 3D printing applications in healthcare (figure 1). Dentistry is the first category which consists of 3D-printed transparent orthodontic devices that straighten teeth without the usage of traditional metal braces. The second category includes the anatomical 3d models, such as in chemotherapy-impregnated mesh devices that can be built to fit a given tumor that would otherwise be impossible to remove surgically and would have previously spelled the death for affected patients. The pharmaceutical industry is the third category. 3D printing has the potential to have a significant influence on world health by allowing for the creation of amorphous solid dispersions of pharmaceuticals within dosage forms, which are particularly useful for improving the release of poorly soluble substances. 3D printing can also be used to produce bespoke medical devices which we will analyze below. Finally, 3D printing offers a potential solution in bio printing of tissues and organs.

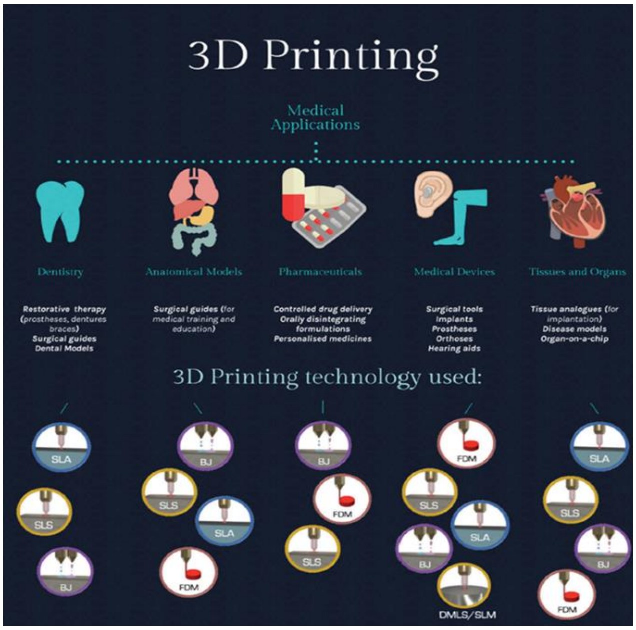


**Figure 1**: Categories of 3D printing [1]

Advances in 3D printing technology have entered the field of regenerative medicine, making the printing of biological materials a reality rather than a fantasy. [2].

• With 3D printing technology, the natural structure of the skin can be replicated at a lesser cost. As a result, they don't test their products on animals' skin. By utilizing a skin duplicate, researchers will be able to obtain reliable results.

• 3D printing technology can be used to replace bony holes in the cartilage or bone caused by trauma, medical implants and orthopedic medical devices (e.g. knee and hip joint devices).

• Similar organ failure caused by essential problems such as disease, accidents, and birth deformities can also be printing using 3d printing technology.

• 3D printing can be used to create highly controllable cancer tissues models, which has the potential to speed up cancer research. Patients can acquire more reliable and accurate data by employing 3D printing technology.

• 3D printable models can be used in the learning process to assist neurosurgeons practicing surgical techniques. Because the 3D model is a simulation of a genuine patient's pathological condition, it can increase accuracy, save time for the trainer when performing clinical procedure, and provides possibilities for hands-on training surgeons.

Unlike other production processes, 3D printing provides a simple, low – cost manufacturing method with final products that are personalized precisely for the patient.

### 7.3.1. Applications of 3D printing in medical devices

3D printing can be used in orthopedic surgery, for surgical planning, customized instruments and prosthetics. [3] Prosthetic limbs that fit perfectly provide better comfort and lower the risk of infection and other difficulties. Furthermore, personalized knee or hip replacements can result in a significant reduction in operating time and medical expenses, as well as encourage rapid recovery with an aesthetic appearance. 3DP's early achievements are numerous.

Three 3D printers at the Medical 3D Printing Center on the Washington University Medical Campus [4] are capable of generating medical/surgical modeling (through direct CT image modeling), robotically driven prosthetic forearms (including hands), research equipment, and custom parts for study. Designers collaborate with surgeons and other health-care professionals to create bespoke models of patient anatomy. Model precision and accuracy display the details and anomalies that allow doctors to personalize treatment regimens to each patient. Custom surgical guides, templates, and other equipment, in addition to patient anatomy models, may be made for use in the University.

They produced models for: Craniofacial for facial trauma, craniosynostosis, orbital dysmorphology and tumors, cardiology for multiple complex cardiovascular disorders, from newborns to adults with congenital and structural heart disease, nephrology for tumors and orthopedics. By allowing a clinician to understand the anatomy of a surgical area, make more appropriate diagnoses, and practice surgery, 3D printing minimizes operating time. Doctors can also use printed models to test different solutions.

But 3D printing in medicine can also be a lifesaver – as it saved a life of a baby in the U.S. Kaiba Gionfriddo was born prematurely in 2011 and suffered from tracheobronchomalacia – a congenital disability that causes the windpipe to collapse. He was treated with a tracheostomy and placed on a ventilator—the standard treatment. Despite this, Kaiba would stop breathing on a near-daily basis. His heart would stop beating as well. His doctors 3D created a bioresorbable device that allowed Kaiba to breathe more easily straight away. After the operation, Kaiba's trachea has gradually reconstructed itself. His body reabsorbed the inserted splint. A year later, the tube was also removed without causing any harm.

Australian scientists 3D printed a set of microneedles for effective diabetes monitoring. These minimally invasive and minimally painful needles offer an effective way for continuous glucose monitoring – and opens up the path towards personalized medicine and drug intake itself.

Both Chinese and American researchers have developed 3D printed models of cancerous tumors to aid in the discovery of novel anti-cancer medications and to better understand how cancers develop, grow, and spread. Bioprinted cancer models can even "mimic the 3D heterogeneity of real tumors".

Organ models can be printed using 3D printing in medicine. These could also be useful for surgeons' pre-operative planning and patient education. Scientists have lately begun to use a mix of MRI and ultrasound imaging, as well as 3D-printing techniques to aid surgeons in preparing for infant procedures. Doctors can more readily identify potential impediments and minimise the risk of surgery on babies with spina bifida, a congenital impairment, using the 3D printed model. [5]

Over 30 million people need mobility devices such as prosthetics. Researchers at the University of Toronto used 3D printing to quickly produce cheap and easily customizable prosthetic sockets (figure 2) for patients in the developing world. [6]

**Figure 2**: Rosaline and her 3D printed prosthetic leg [7]

Personalized medical implants could also be 3D printed. For implants (including internal prosthesis, orthosis, splints, and fixators), proper surface properties and mechanical strength are essential to allow optimum performance. This is especially important in complex and rare cases. Back in 2014, Dutch surgeons replaced the entire top of a 22 year–old woman's skull with a customized printed implant made from plastic. The patient was suffering from a rare condition that caused the inside of her skull to grow extra bone, which squeezed her brain. The growth was discovered after she reported severe headaches and then lost her sight and motor control. If untreated, the extra bone would have killed her. [7] A synthetic material called hyperelastic bone is another option for mending skull deformities caused by 3D printing. The structure of hyperelastic bone is a lattice network that permits new bone material to develop. Although autologous bone is reccomended, it is difficult to come by, hence hyperelastic bone is a convenient and cost-effective alternative. Experiments have shown that the three-dimensional printed substance can be a good substitute for matching bone and bone material that is currently available on the market. [3]

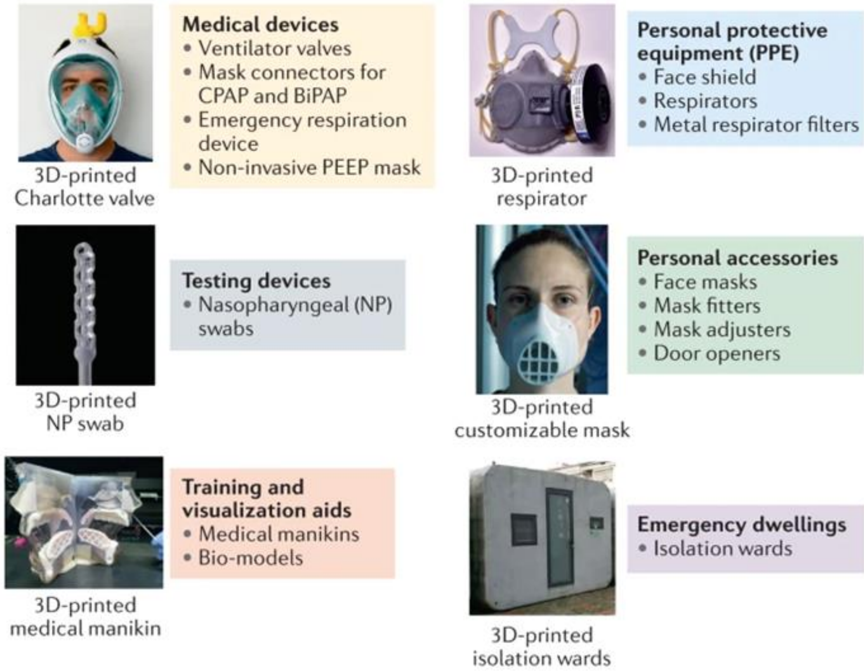


**Figure 3**: 3D printing applications for COVID-19 [8]

In the midst of the COVID-19 pandemic, 3D printing has emerged as a critical tool for bettering healthcare and our overall response to the emergency (fig. 3). The 3D-printing community is aiming to build even more printable devices, with the safety and well-being of users remaining a top priority. It is critical to assure the technological compatibility and accountability of new approved designs and certified materials to exploit the benefits of 3D printing in order to retain a high degree of confidence in this technology. [8]

The ability of 3D printing to mass customize products when combined with the use of 3D scanning. Customized 3D-printed face masks with a comfortable fit. [9] Furthermore, 3d printing provides potential solutions to address environmental concerns about medical waste generated by disposable PPE by supporting recyclable materials and reusability of respirators and filters.

An Italian company (WASP), [10] has developed an open-source process that, starting from the 3D scan of the face, allows to customize and produce a tailored mask for every user. In the second half of March 2020, Czech Institute of Informatics, Robotics and Cybernetics CTU (CIIRC CTU) in Prague, developed and certified the prototype of the advanced respirator “CIIRC RP95-3D” in just one week. (fig. 4)

The idea is of a 3D printed mask that can be sanitized and used many times. [11] The goal was to make the 3d printed face mask perfectly ergonomic, following the facial features as a second skin. The filter is located in a central front slot, where it can be replaced. (fig. 5)

foto: CARDAM

**Figure 4**: “CIIRC RP95-3D” [12]

**Figure 5**: Technology Agency of the Czech Republic under the GAMA 2 Program [12]

The capacity to 3D print life-sized medical manikins to supplement training materials and allow healthcare workers to practice COVID-19 swap testing procedures with regular medical-grade swabs is enabled by the ability to duplicate complicated human anatomy in very accurate models. The internal features of the nasal cavity, throat and mouth are revealed by printing translucent materials on some portions of the manikin. A front-line training organization approached Creatz3D, a Singapore-based 3D printing solutions provider, to produce life-sized 3D medical manikins [13]. Along with the current training materials and arrangements, the 3D printed manikins presented chances to train more successfully (training slides, hands-on sessions, etc.). Compare to the available general manikins (such as those used for airway simulation), the 3D printed manikins were designed specifically for collecting respiratory swabs. (figure 6)

Internal structures of the nose, mouth and throat that would otherwise be impossible to see with an actual person being swabbed.

Allowing the trainers to clearly illustrate the techniques and emphasize additional concerns to ensure that swab collection, is done safely with standard medical-grade swabs.

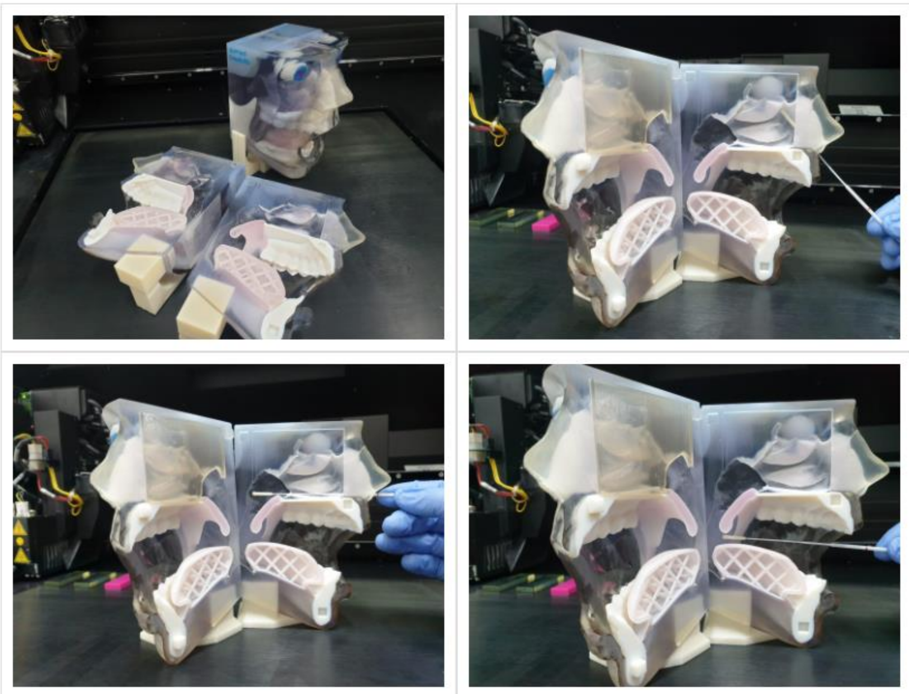

**Figure 6:** 3D printed manikins [13]

## 7.3.2. Conclusion and future work

This study provided a thorough review of the medical uses of 3D printing. Because it gives for patient-specific design, high complexity, on-demand and cost-effective fabrication, and high productivity, 3D printing is becoming a widely accepted production approach in medicine. Implantable and non-implantable items such as bone tether plates, hip cups, spinal cages, knee implants, denture bases, craniofacial implants and surgical tools are some of the more 85 medical device products made by 3D printing which are currently available in the market. Although 3D printing has been found to be particularly effective in a variety of medical applications, there are still challenges that must be overcome. Materials, techniques, software, and applications are being developed daily. This will ensure that additive manufacturing will continue to be fundamental to help humanity fight the next coming pandemics [14]. Table 1, summarizes the main challenges and prospects that future research focus for each application area. In short, 3D printers' main performance aspects, such as fabrication speed, resolution and reproducibility, must be further optimized.

| Area | Future research focus |
|---|---|
| Dentistry | Improve printing quality, accuracy and speed<br>Develop new techniques allowing sintering of pure ceramic powders<br>Prevent thermal distortion or cracks in SLS and SLM processes<br>Incorporate multiple materials in one step (aesthetic and mechanically strong)<br>Eliminate lengthy and potentially dangerous post-processing steps |
| Tissue engineering and regenerative medicine engineered tissue models | Improve printing resolution, speed and repeatability<br>Increase cell interactions and migration<br>Integrate vascular and innervation structures<br>Create fully functional and human-size organs<br>Combine cell printing with other biofabrication methods<br>Develop *in vivo* bioprinting to directly repair tissues/organs at defect sites<br>Maintain high cell viability and phenotype<br>Enable heterocellular printing<br>Develop more advanced bioinks (e.g. use dECM)<br>Develop proper cleaning and sterilization protocols |
| Engineered tissue models | Use patient-derived cells to create personalized tissue models and personalized treatments<br>Improve 3D-printed microfluidic devices (organ-on-a-chip, organ-to-organ connection)<br>Online services for high-throughput testing |
| Medical devices | Further improve printing accuracy and durability<br>Decrease cost and fabrication time<br>Evaluate long-term follow-up of patients with 3D-printed implants<br>Develop clinical and design interface for each specific application<br>Develop proper cleaning and sterilization protocols<br>Integrate 3D printing in remote areas<br>Online services for custom-made medical devices |
| Anatomical models | Improve resolution and accuracy<br>Better mimic the biomechanical, modulus and colors of real human tissue<br>Develop soft-tissue models<br>Online services for patient-specific surgical models |
| Drug formulation | Prevent variation in product qualities (shrinkage, warping, residuals, etc.)<br>Improve mechanical stability and reduce friability<br>Increase drug loading<br>Explore right combination of API and excipient materials<br>Investigate relationships between drug release profiles and internal structures<br>Minimize post-processing cycles |

**Figure 7:** Future research focus for each medical application [14]

In addition, a large amount of research is now focused on the development of novel biomaterials for 3D printing. When exposed to an external stimulus, 3D printing of stimuli responsive materials, for example, allows for temporal changes in the shape of the constructions after printing. 4D printing is the word used to describe this concept.

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## 7.4. Aviation Industry

### 7.4.1. Design communication

Designs in the aerospace industry often begin with conceptual models showing an aircraft component. They are frequently used for aerodynamic control, which is of vital importance to aerospace. SLA and Material Jetting are used to create detailed, smooth and scale models of aerospace designs. Accurate patterns help to clearly communicate design intent and represent the overall shape of a concept. [1]

Stereolithography (SLA) is an additive manufacturing process in the photosynthetic family. In SLA, an object is created by selectively curing polymeric resin layer by layer using an ultraviolet (UV) laser beam. Materials used in SLA are photosensitive thermoset polymers in liquid form. [2]

SLA is known as the first 3D printing technology: its inventor patented this technology in 1986. When very high precision parts or smooth surfaces are required, SLA is the most cost effective 3D printing technology. The best results are achieved when the designer takes advantage of the advantages and limitations of the manufacturing process. SLA shares many features with Direct Light Processing (DLP), another 3D printing technology based on the photopolymerization of the ladle. For the sake of simplicity, both technologies can be considered equal. [3]

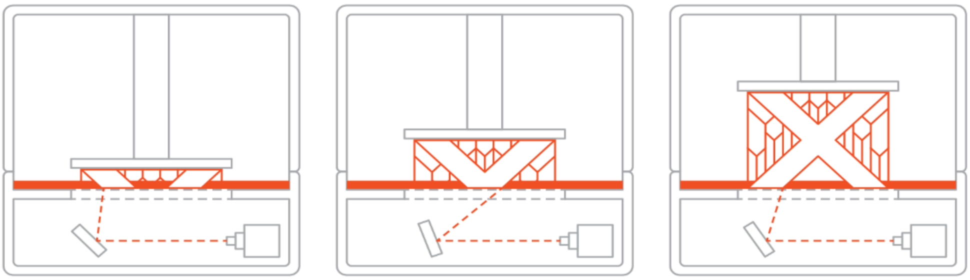

**Figure 1:** The SLA 3D printing process [11]

An SLA always requires a supporting structure. Support structures are printed from the same material as the part and must be manually removed after printing. The orientation of the part determines the position and amount of the support. It is recommended to orient the parts so that visually important surfaces do not come into contact with the supporting structures. [4]

SLA ingredients are available as a liquid resin.The price per liter of resin varies widely, ranging from around 50 € for normal resin to 400 € for specialist resins like castable or dental resin. Industrial systems can print a wider choice of materials than desktop SLA printers, giving the designer more control over the printed part's mechanical qualities. SLA materials (thermosets) are more brittle than FDM or SLS (thermoplastics) materials, and as a result, SLA parts are rarely utilized for functional prototypes that will be subjected to severe loading.

**Post Processing**

Various post-processing procedures, like as sanding and polishing, spray coating, and mineral oil finishing, can be used to finish SLA parts to a very high degree. SLA's Advantages and Drawbacks. The following are the technology's main advantages and disadvantages:

**Advantages:**

• SLA parts have an extremely smooth surface quality, making them perfect for visual prototypes.

• SLA materials with unique properties, such as transparent, flexible, and castable resins, are available.

**Disadvantages:**

- SLA pieces are fragile in general, making them unsuitable for practical prototypes.
- When SLA parts are exposed to sunlight, their mechanical qualities and appearance deteriorate over time.

### 7.4.2. Material Jetting (MJ)

Material Jetting (MJ) is a type of additive manufacturing that works similarly to 2D printers.

A printhead (similar to those used in normal inkjet printing) sprays droplets of a photosensitive substance that solidifies under ultraviolet (UV) light, layer by layer, to form a part.The thermoset photopolymers (acrylics) utilized in MJ are liquid thermoset photopolymers. [1] Material jetting works in a similar way to a two-dimensional ink jet printer in that it makes objects. A continuous or Drop on Demand (DOD) technique is used to jet material onto a build platform.[5]

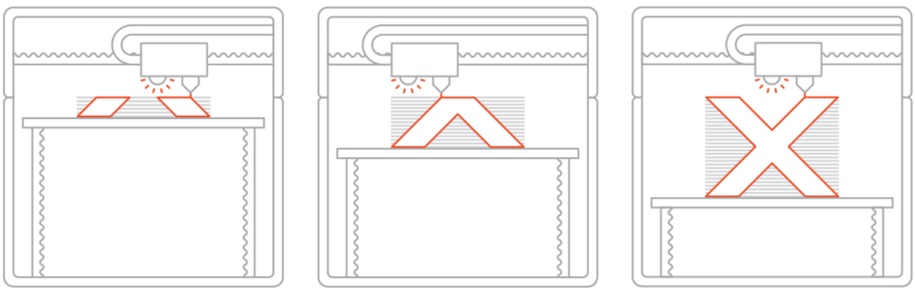

**Figure 2**: The Material Jetting 3D printing process [12]

Almost all process parameters in Material Jetting are pre-set by the machine manufacturer. Due to the complicated physics of droplet generation, even the layer height is tied to each individual material. Material Jetting typically uses layer heights of 16 to 32 microns.

There are a few important sectors in the aircraft industry where 3D printing is having an impact:

3D printing provides placeholder parts that act as surrogates for training purposes

It is used to manufacture metal brackets that perform a structural function inside aircraft

Prototypes are increasingly 3D printed, allowing designers to refine the form and fit of finished components.

**Conclusions**

Material jetting is perfect for making visually and haptically realistic prototypes with exceptionally smooth surfaces that look like injection molded parts. Material Jetting provides technical materials for tooling and injection molding applications.

### 7.4.3. 3D Printing Benefits

The aerospace sector uses additive manufacturing for a large portion of its production due to the normally limited runs of aircraft parts.When compared to traditional methods, the technology can make complicated pieces that are more robust and lightweight, which is an obvious benefit.In reality, according to EOS, a leader in industrial 3D printing of metals and polymers, additive manufacturing can result in weight savings of 40-60%.[6]

The average business aircraft travels 75,000 miles each month, to put this in perspective.

Air drag is reduced by 2.1 percent when a single component is developed and made via 3D printing (and therefore lighter).

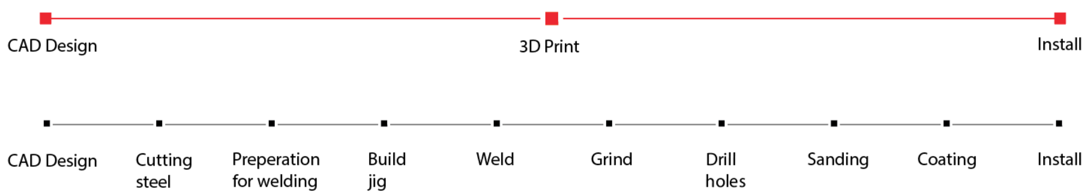


**Figure 3**: The 3D printing process (red) compared to the traditional manufacturing process (black). [13]

**Validation stage**

In the aircraft sector, 3D printing prototyping is already prevalent. There is a 3D printing technology for any prototyping need, from a full-size landing gear enclosure printed quickly with low-cost FDM to a high-detail, full-color control board concept model. [1]

**Pre-production**

The manufacture of low-cost quick tooling for injection molding, thermoforming, and jigs and fixtures is one of the areas where 3D printing has proved most disruptive and valuable.This permits tooling to be swiftly made at a minimal cost and then utilized to produce low to medium quantities of parts in the aerospace sector. [1]

**Production**

Because the aerospace industry's production quantities are so high (more than 70,000 pieces per year), 3D printing has primarily been employed for prototyping rather than end-part manufacturing in the past. 3D printing is now a realistic choice for many medium-sized production runs, particularly for high-end interior build-outs, thanks to improvements in the size of industrial printers, their printing speed, and the materials available.

**Customization**

When the cost of highly complex one-off components can be justified by a significant improvement in aircraft performance, 3D printing technologies have a significant impact on the aerospace industry: the average corporate aircraft travels 75,000 miles per month, and a single component designed and manufactured with 3D printing reduces air drag by 2.1 percent, saving 5.41 percent in fuel costs. [7]

### 7.4.4. How 3D printing is Influencing the Aerospace Industry

**Jigs & Fixtures**

Some of the more ordinary 3D printing uses, such as the creation of jigs and fittings, have significant advantages. Hundreds of fittings, guides, templates, and gauges are 3D printed for each specific aircraft, resulting in cost and lead time savings of 60 to 90 percent when compared to traditional production methods. [8]

### Surrogates

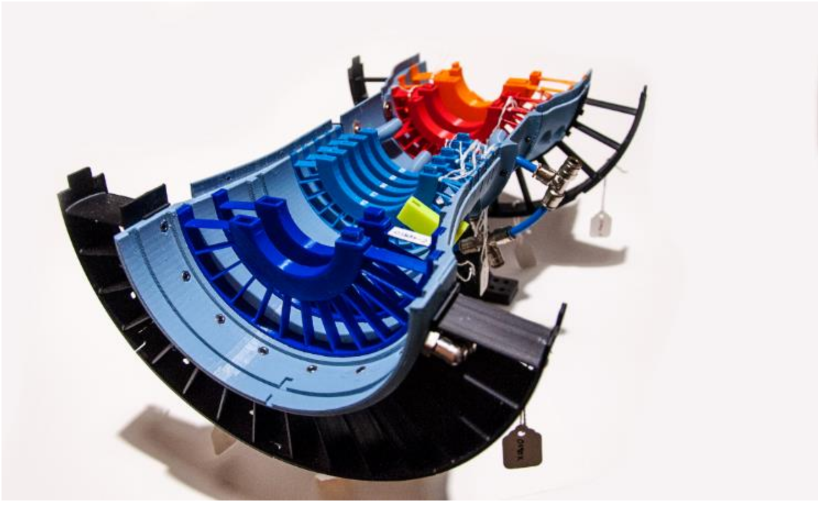

**Figure 4:** A model of a jet engine for educational purposes. [14]

Surrogates are placeholder pieces that are used throughout the manufacturing process to simulate components that will be added later in final assemblies. Surrogates are mostly employed for the purpose of training. Surrogate parts are routinely used on the manufacturing floor at NASA and numerous Air Force stations.[1]

### Mounting brackets

The manufacturing of structural, low-volume metal brackets (with DMSL/SLM) that mount sophisticated life-saving equipment to the inside wall of a plane is a popular application of 3D printing.[1]

**Figure 5**: A metal bracket before support removal [15]

**High detail visual prototypes**

Material Jetting allows 3D printing to make multicolor designs with a surface polish that is comparable to injection molding. Designers can gain a better knowledge of a part's form and fit with these aesthetically appealing models before making production decisions.[9]

### 7.4.5. 3D Printing Materials for aerospace applications

The table below summarizes the recommended materials for applications specific to the aerospace industry:

| Application | Example part | Requirements | Recommended Process | Recommended Material |
|---|---|---|---|---|
| Engine compartment | Tarmac nozzle bezel | Heat resistant functional parts | SLS | Glass-filled Nylon |
| Cabin accessories | Console control part | Customized functional knobs | SLA | Standard Resin |
| Air ducts | Air flow ducting | Flexible ducts and bellow directors | SLS | Nylon 12 |
| Full size panels | Seat backs & entry doors | Large parts with smooth surface finish | SLA | Standard Resin |

| Application | Example part | Requirements | Recommended Process | Recommended Material |
|---|---|---|---|---|
| Casted metal parts | Brackets and door handles | Metal parts casted using 3D printed patterns | SLA & Material Jetting | Castable Resin or Wax |
| Metal components | Suspension wishbone & GE Jet Engine | Consolidated, lightweight, functional metal parts | DMLS/SLM | Titanium or Aluminum |
| Bezels | Dashboard interface | End use custom screen bezels | Material Jetting | Digital ABS |
| Lights | Headlight prototypes | Fully transparent, high-detail models | Material Jetting & SLA | Transparent Resin |

**Figure 6**: 3D Printing Materials for aerospace applications [14]

### 7.4.6. The future

3D printing is used in the aerospace sector to produce end-use parts, prototypes, alleviate supply chain restrictions, minimize warehouse space, reduce storage costs, and eliminate waste production materials.[10] It's also utilizing the technology to test out ground-breaking ideas including lowering commercial airline emissions, building in space, and even printing biomaterials in space.[7]

We can expect more corporations to create on-site 3D printing operations and invest in the technology as the aerospace sector continues to understand the potential of 3D printing. On-site printing capabilities, in fact, allow for unprecedented real-time design, processing, testing, and implementation of customized components.[7] 3D printing software is also fast evolving, which will have even more of an impact on aircraft manufacturing processes.

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## 7.5. Entertainment Industry

The 3D printing and scanning technologies for creating high-precision 3D models of real-world objects have ushered in a revolution in the fields of entertainment design. Although, there are several questions that should be answered before a film studio company, a director, an artist etc. starts using 3D printers in the field. For instance [1]:

- Is 3D printing/scanning this product going to save you time or money?
- Will this object require many copies?
- Does this product necessitate a high level of detail that could be difficult to achieve?
- Will 3D printed materials outperform traditional materials in terms of durability?
- Will this artefact be mistreated, necessitating the creation of replicas?
- Do you have to make many copies of a rare or fragile item?
- Do you need to copy something you cannot buy, such as a well-known product?
- Is this an organic, creative, or trinket-like object?

### 7.5.1. Film Industry

The primary use of 3D printing in the film business is to swiftly construct props, which are then post-processed to appear realistic on screen. While special effects in movies have grown standard, filmmakers have already employed 3D printers to manufacture props including customs, guns, food, statues, sculptures or machinery in order to enhance the filming experience. Additive manufacturing appears to be gaining traction and filmmakers have already employed 3D printers to facilitate the development of animated films or design the iconic costumes of our favorite superheroes. For example, in the film "Guardians of the Galaxy," prop specialists employed 3D printing to create Star-mask Lord's, a fully 3D printed costume and the armor suit for the character Korath. The team used an Objet500 Connex printer to create some of the classic weapons as well as ship pieces [2]. At another stop-motion movie, Paranorman, the production team wanted to create different facial emotions but for the same character and they used 3D printers to create all of them at once. This solution appeared to be a cost-effective alternative option as if they were using injection molding instead, it could be more expensive and too slower process [3].

In addition, Jason Lopes, who he worked on Iron Man 2 for the Legacy Effects studio, designed a suit that perfectly fits the actor by using 3D printing instead of Computer-Generated Imagery (CGI) [3]. Similarly, the costume designer Michael Wilkinson relied heavily on this technology when he created the metallic undersuit structure of Superman's Kryptonian costume as worn by scanning the actor's entire body so that the suit could be designed using CAD software and include several 3D printed features [4].

**Figure 1:** Iron Man 2 [14]

#### 7.5.1.1. Scenic Design

Elektra, Richard Strauss' operatic tragedy, was performed in Canada in 2015 at the Opéra de Montréal under the direction of Alain Gauthier. The set featured a 25-foot (over 7-meter) tall, rotatable and 3D printed statue of Agamemnon – a replica of a piece commissioned by the opera's artistic director, Michel Beaulac, by sculptor Victor Ochoa [1]. This sculpture weighted 2,400 kg and was made up of 2,900 parts of 3D-printers which are joined and glued together to form the sculpture's skin, which wrapped around an interior aluminum frame. Undo Prototipos, a spanish company specialists in 3D printing, made this sculpture after a hard work of seven months by a total of 100 workers in the various teams participating in the project phases to complete the sculpture. They used ten 3D printers that had been running 24 hours a day for five months that they had consumed around 400kg of 3D printer filament [5].

Furthermore, Colorzenith, an Italian 3D printing provider, printed a life-size reproduction of the legendary Italian car (La Scala Flying Car), Lancia B24, for the Don Pasquale opera, which was played at Europe's greatest opera theatre, La Scala in Milan, Italy. This 4.23 meters long and 1.3 meters high car was 3D printed in four parts in under four days [6].

**Figure 2:** La Scala Flying Car [15]

3D printing is also an excellent method for making tiny, detailed items like model furniture and other architectural aspects which is used in theatrical scenic models.

**Figure 3:** Agamemnon statue [16]

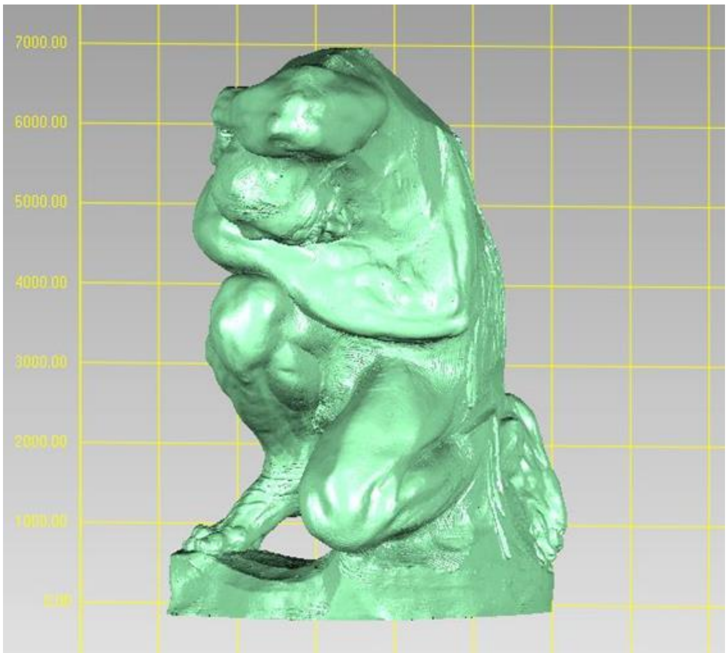


**Figure 4:** Agamemnon statue - 3D Model [17]

Kacie Hultgren, a scenic designer working for Broadway productions, prefers 3D printing miniature models items for the productions in which she is involved. She uses 3D printing for fine features such as model furniture, and other intricate architectural details such as fireplaces, staircases, and windows [1].

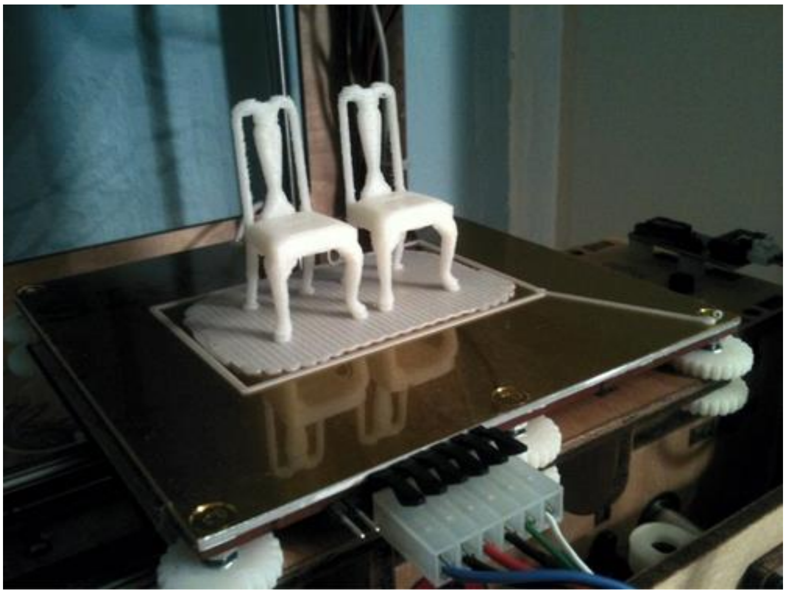

**Figure 5:** Kacie Hultgren's Model [18]

### 7.5.1.2. Costume Design

In the film industry and the theatrical productions, 3D printing is also used to manufacture custom-made costumes in accordance with the 3D printed clothes that becoming an asset to the fashion field. Julia Koerner, the designer, and Ruth Carter, the costume designer, worked together to develop Queen Ramonda's style in the film “Black Panther” where they produced visually appealing and accurate parts that truly reflected the character's personality [3].


**Figure 6:** 3D Custom of Queen Ramonda [19]

## 7.5.2. Musical Instruments

Even for relatively simple instruments like flutes, the manufacture of musical instruments involves a multi-step process. Regarding the influence of materials on the sound of instruments, musicians, acousticians, and musical instrument makers have differing opinions. Digital fabrication technology could play a significant role for musical instrument designs.

Even though many instruments require additional parts, such as strings, the 3D printing instruments are quite reliable. For example, the Black Widow is a great 3D printed guitar that is easy to be made. The Black Widow guitar is entirely configurable and available to adjustments and touches, with a printing time of 100+ hours and plenty of options to customize the design to your satisfaction [7].

A firm, dedicated to the production of electric violins, created also in 2015 the 3Dvarius and now the company has developed its own range of 3D printed violins with unique designs [8].

**Figure 7:** Black Widow guitar [20]

Also, a completely 3D printed alto recorder tuned in F can be made at home with the use of a Reprap Prusa i3 3D printer. But, as its designer states, this instrument requires post processing to work properly such as filing, sanding and smoothing [9].

Emiliano Brignito also created the 3D printed Maracas that can produce variety of sounds if someone fills them with dried beans, stones, and seeds [10].

3D printing could inspire new designs as well as contribute to new acoustic and ergonomic advancements in musical instruments development. While 3D printing technologies still have significant drawbacks, such as resolution, material quality, and stability, which lead the way to a limited use for manufacturing, new technologies for digital fabrication could contribute to new acoustic instrument designs [11].

### 7.5.3. Conclusions

Dark Cell, a pilot for a French science fiction series starring Juliette Tresanini, was printed with a cluster of eight Zortrax 3D printer which enabled the producers to meet tight schedules for filming the pilot while staying within a constrained budget [12].

Mass customization, scalability, cost savings, speed, even on a tight schedule, and fine detail are just a few of the reasons why 3D printing technology is becoming increasingly popular in the film industry and the theatrical productions [1] [3] [12] [13]. In the past each mock-up would have been built by hand, but virtual models or quick 3D prints allow the creative process to progress more quickly.

Each 3D scanning and printing technology comes with its own limitations, advantages, and costs and also necessitates the development of new skill sets for the designers, such as 3D digital sculpting, which will provide new jobs to the design line of work.
It is also critical to recognize that 3D design and printing process will not replace traditional design or construction approaches, but will surely improve and reform the creative process.

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# 7.6. Arts, Design and Sculpture

3D printing technology has been used in a variety of fields, and it has continued to improve and expand in recent years. This technology is slowly making its way into the cultural and creative industries.

One of the most significant advantages of 3D technologies is the ability to tap into fresh sources of inspiration. This has resulted in the emergence of previously unknown techno-artists or bio-artists who have now actually emerged from the hand of 3D technologies.

## 7.6.1. 3D printing in art: first developments

The first creative shows using 3D printed items appeared after the first decade of the twenty-first century. Originally displayed as potential for future technology advancement rather than as works of art. They didn't display 3D printed objects as real works of art until 2015. Exhibitions with a new perspective on 3D printing have appeared in the previous two years.

Gilles Azzaro, a French artist known as "Voice Sculptor," has distinguished out from the start for offering a unique perspective on the use of 3D technology in art. 3D printing of sounds, phrases, and speeches is one of his specialties. It made headlines in 2013 when it 3D printed a sculpture with the sound of Barack Obama's address on 3D printing, which was then digitally replicated (figure 1).

**Figure 1**: Gilles Azzaro and one of his voice sculptures [1]

Neri Oxman, an MIT Media Lab researcher, architect, and visual artist, was introduced to explore the juxtaposition of material characteristics to produce new forms inspired by nature using additive manufacturing in the same years. It was already voted "Top among the most influential designers and architects who create the future" by ICON magazine in 2009.

New artists have arisen as a result of these advancements, ranging from Neri Oxman's biological vision to Amy Karle's newest vision, which employs additive printing techniques. [1]

### 7.6.2 Advantages of 3D printing in Arts

**Impossible Designs Can Be Realized**

One of 3D printing's most valuable advantages is its ability to represent complicated designs properly. It is already transforming the jewelry industry. And that's only the beginning. Actuators, LEDs, and audio devices may all be included into the fabric of 3D printed art works, giving them new levels of responsiveness. Direct manufacturing and freeform modeling make it possible to develop and produce highly personalized items with fewer constraints than previous approaches.

**Breaking Free from Size Constraints**

Issues of scale have frequently held artists back in terms of conception and execution, both in making extremely small and very big pieces. Small art works can only have so much detail, while attempts at extremely huge ones might be unfeasible without a lot of money. Some of these limitations are removed by using a digital process.

**Raising Prototyping and Production Standards**

Whether they work with tiny or large media, artists who use digital technology are altering their approach to experimentation and production. The production process is less expensive because of the simplicity of maintaining, retrieving, and iterating via digitally saved designs. Digital prototyping is a very empowering manufacturing approach for artists wanting to make multiple copies of tiny pieces because to its accessibility and speed.

**Getting Rid of the Lines Between Artistic Disciplines**

Because 3D printing is so flexible and has so many applications, it is also being used to create extraordinary multidisciplinary pieces. Even their most odd geometric designs have structural integrity and longevity when made with a 3D printer, free of the constraints imposed by traditional design and production processes. Digital technologies are the foundation of their endeavor, demonstrating that 3D printing may affect both the ethos and the production technique of an artistic endeavour.

**The Art Restoration Process is Being Revolutionized**

Digital technologies aren't simply for coming up with fresh ideas and manufacturing them. They make it possible to restore old artworks that were previously unachievable. Prior to restoration, art restorers employ 3D scanning to assess antiques. To reduce the danger of interpretation, they use digital modeling software to reconstruct missing components by utilizing extant sections of the sculptures as a basis for further restorations. After that, restorers utilize 3D printing to make prototypes for quality control and pre-visualization, as well as final material repairs. [2]

### 7.6.3. Disadvantages of 3D printing in Arts

**3D art software can be costly.**

Free 3D art software is not available. Some offer free access to the most basic functions.

**Mastering 3D art methods is not simple.**

Learning 3D art is a difficult process. You must be familiar with numerous 3D creative technology as well as the many tools accessible. It takes a long time to do this.

**In 3D art, you can't see the texture of the material.**

The textures of the design or model cannot be touched since 3D art is digital. Even if you print it, the work will lack the original subject's vibe. In certain situations, this may be extremely inconvenient.

**3D art is not acceptable in all situations**

Even if the world is more technologically advanced than ever before, some situations may need the use of non-digital models and designs. Many initiatives ask participants to create their work using any physical media, which presents a challenge for artists making 3D art, especially if 3D printing is not an option. [3]

### 7.6.4. 3D printing in Jewellery

It is important to prepare for 3D printing after 3D models of planned jewelry are generated. It's also crucial to create the models in accordance with the specifications of the selected 3D printing technique, as well as to consider the weight of each finished piece of jewelry, since it shouldn't be too heavy to wear, especially if it's made of metal.

Different 3D printing methods are used to produce the jewelry. Fused deposition modeling technique is utilized to print the majority of the jewelry (FDM). Stereolithography (SLA) is utilized and produced for items with exceptionally flat surfaces. Furthermore, selective laser melting technology, or SLM, is another technique utilized in this sector.

For printing utilizing FDM technology, two distinct PLA thermoplastic filaments were utilized. The first was constructed of colored metal, while the second was composed of a biocomposite including wood fibers. The picture below (figure 2) shows jewelry that has been printed using bronze filament. The filament in question was chosen for its shine, warm color, and smooth texture, all of which improve the look of printed objects. [5]


Figure 2: Jewellery collection “Hlebci” (Loafs), printed with FDM technology, author Tina Dovjak [5]

A piece of jewelry produced with SLA technology is seen in the next image (figure 3). It came in three parts, each of which was printed separately. Individual parts were completed with spray painting after the printing process, which added color and gloss to the result, and then joined using adhesive, as seen on the left image.

Figure 3: Bracelet from the collection “Tri dobe življenja” (Three Phases of Life), printed with SLA technology on the right and assembled and spray painted on the left. [5]

The SLM technology allows for the creation of fully functional jewelry. A laser metal printer, L and a metal powder were utilized for the next project (figure 4). Post-processing is required. Sandblasting and, in certain circumstances, polishing were employed.

**Figure 4**: Ring printed with SLM technology [5]

### 7.6.5. 3D printing in Ceramics

In the next application (figure 5) is the Olivier van herpt's 'useful 3D printed ceramics' collection. Van Herpt's copper and earth-toned vases were initially shown at Ventura Lambrate at Milan Design Week.

The goal of the research was to create a novel technology for 3D printing medium and large-scale ceramics. The textures, surfaces, forms, and sizes of the custom 3D printer may be changed by fine-tuning the settings. The unique collection (figure 5) is a continuous investigation of past and present processes, mimicking traditional craftsmen' work while generating today's thinnest 3D-printed ceramic layers.

**Figure 5**: Olivier van herpt's 'useful 3D printed ceramics' [6]

### 7.6.6. 3D printing in Sculpture

Danny van Ryswyk has created an incredible collection of 3D printed sculptures that are both beautiful and terrifying (figure 6). Each item was created using 3D software. He used cutting-edge technology with tried-and-true ways to achieve his goals. He commissioned a professional 3D printer to build a physical sculpture from his computer file, which will subsequently be hand-painted using acrylics. He uses his imagination instead of drawing.

Figure 6: Finished sculpture under antique glass dome.[7]

### 7.6.7. 3D printing in Painting

In partnership with Fujifilm12, the Van Gogh museum in Amsterdam has produced a Relievo collection of 3D printed replicas of some of Van Gogh's most renowned paintings. One, seen in the next image (figure 7), is of his Sunflowers, which was printed using the reliefography process, in which the painting is duplicated layer by layer to resemble the color and brushstrokes of Van Gogh's work in high-quality.

Figure 7: A 3D printed replica of Van Gogh's Sunflowers

## 7.6.8 Future projects involving 3D printing technology

The connection between 3D printing and art is well established. 3D technologies are being used creatively by everyone from kids to seasoned artists. Aside from the preservation of numerous historical works, which has been a fascinating area for some years, 3D methods have provided a window into the world of art.[8]

In the world of art, 3D printed art came to be used as a tool for repairing damaged artworks (for example, the artist Morehshin Allahyari uses 3D technology to recreate art destroyed by ISIS in Iraq). [9] But, recently, the number of artists using 3D printing is constantly increasing.

3D printing has become an important component of modern art. Probably in conjunction with other mediums (conventional sculptures or paintings), 3D Printed Art will surely become part of many art collections.

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# 7.7. Architecture

The use of 3D printers in architecture and construction is on the rise, and many architects and designers are already convinced that the adoption of 3D printing on a larger scale will be a true revolution. A conceptual model is the starting point for any architectural project. It's a crucial tool for architects, clients, and the general public to visualize the architect's concept for their project. However, the road from concept to real model is long and winding. Creating a handcrafted, detailed, and scaled concept model takes a lot of time and effort. When complex geometries are involved, the task becomes significantly more challenging. 3D printing technology offers the possibility of creating functional end products - decorations, furniture and gadgets, or even buildings.

3D Floor Plans, 3D Product Modeling, 3D Architectural Modeling, 3D Architectural Rendering, 3D Bird's Eye View Rendering, 3D Elevation Design, 3D Exterior Concept Design, 3D Interior Concept Design, 3D Walk-through, Landscape Design are some of the most common applications for true 3D designs and architectural rendering projects.[1]

## 7.7.1. Advantages of 3D printing in Architecture Industry

**Design Freedom and Complex Geometries**

The freedom of design is the most significant benefit of using 3D printing in architecture projects. The potential to construct new complicated geometries comes with additional design freedom.

**Sustainability**

Although some 3D printing materials are not "green," 3D printing is proven to be more sustainable than most other traditional construction methods in many aspects. Furthermore, because this technique does not require transportation, it has a low carbon footprint.

**Customization**

It's critical to be able to offer highly customizable products. Traditional processes make customization difficult to obtain. 3D printing offers for more visual freedom in design renderings and makes it easier for architects to design, produce, and modify high-quality architectural models than earlier technologies. It also enables architects to create a library of 3D designs that may be reused. [6]

**Fast production**

3D printing in the construction industry means greatly reduced production time. This is because the machines themselves are very fast. Some of them are capable of producing houses of 55 to 75 square metres in as little as 24 hours. [2]

3D printers are also fully automated, which eliminates human error. The machine only needs to be monitored, but most of the production process comes without human assistance. In addition, 3D printers do not require any additional tools. They have the design programmed and simply manufacture it. They do not need additional support, different materials, and other aspects to consider that traditional methods require.

**Almost no material waste**

In the construction business, 3D printing offers a significant reduction in manufacturing time. This is due to the fact that the machines are extremely rapid. Some of them can build houses ranging from 55 to 75 square meters in as little as 24 hours. [5] 3D printers are also completely automated, removing the possibility of human error. The machine just has to be watched, but the majority of the manufacturing process can be completed without human intervention. Furthermore, 3D printers do not necessitate the use of any additional instruments. They've already programmed the design and are just waiting to put it into production. They don't require the same level of support, different materials, or other considerations that traditional methods do. There is almost no waste of material. [2]

**Create a Library of Reusable Designs**

You may be more creative with your model creation when you use 3D printing. When working with repeating components, for example, you can print one as a mold, cast it, and then use the cast to injection-mold the required duplicates. [8]

### 7.7.2. Disadvantages of 3D printing

On the other side, the construction sector is currently facing a number of obstacles that must be overcome:

- In general 3D printing is still an expensive technology.

- The Architecture industry is still unfamiliar with this technology.

- 3D printers for construction, such as concrete construction, can be large, and transportation to the construction site can be costly. [3]

### 7.7.3. Technologies types and materials

3D printers can deal with a number of materials in different states (powder, filament, pellets, granules, resin, etc.). The table below (figure 1) shows 3D printers that work with various materials. This means that any recyclable material, such as glass, plastic, thermoplastic polymers (ABS), metals, ceramics, and so on, can be molded during the printing process. Furthermore, 3D printing reduces manufacturing-related resource consumption by requiring only the amount of material required to construct the printed object with the least amount of waste. The majority of the materials used for support can be reused.

| Classification | Technology | Description | Materials | Developers (Country) |
|---|---|---|---|---|
| Binder jetting | 3D printing<br>Ink-jetting<br>S-print<br>M-print | Creates objects by depositing a binding agent to join powdered material | Metal, polymer, ceramic | ExOne (US)<br>Voxljet (Germany)<br>3D Systems (US) |
| Direct energy deposition | Direct metal deposition<br>Laser deposition<br>Laser consolidation<br>Electron beam direct melting | Builds parts by using focused thermal energy to fuse materials as they are deposited on a substrate | Metal: powder and wire | DM3D (US)<br>NRC-IMI (Canada)<br>Irepa Laser (France)<br>Trumpf (Germany)<br>Sciaky (US) |
| Material extrusion | Fused deposition modeling | Creates objects by dispensing material through a nozzle to build layers | Polymer | Stratasys (US)<br>Delta Micro Factory (China)<br>3D Systems (US) |
| | Ink-jetting<br>Thermojet | depositing small droplets of build material, which are then cured by exposure to light | wax | (US)<br>LUXeXcel (Netherlands)<br>3D Systems (US) |
| Powder bed fusion | Direct metal laser sintering<br>Selective laser melting<br>Electron beam melting<br>Selective laser sintering | Creates objects by using thermal energy to fuse regions of a powder bed | Metal, polymer, ceramic | EOS (Germany)<br>Renishaw (UK)<br>Phenix Systems (France)<br>Matsuura Machinery (Japan)<br>AROAM (Sweden) |
| Sheet lamination | Ultrasonic consolidation<br>Laminated object manufacture | Builds parts by trimming sheets of material and binding them together in layers | Hybrids. metallic, ceramic | Fabrisonic (US)<br>CAM-LEM (US) |
| VAT photopolymerisation | Stereolithography<br>Digital light processing | Builds parts by using light to selectively cure layers of material in a vat of photopolymer | Photopolymer, ceramic | 3D Systems (US)<br>EnvisionTEC (Germany)<br>DWS Sri (Italy)<br>Lithoz (Austria) |

Figure 1: 3D printing technology type and materials [3]

## 7.7.4. Examples of 3D printing applications in Architecture

### 7.7.4.1. Application of 3D-Printed concrete structural components in the Baoshan pedestrian bridge project

For this study, a special composition of fibre-reinforced concrete was developed that can meet both structural strength and printability requirements. In particular, our concrete consists of sulfoaluminate cement (SAC), sand, polyvinyl alcohol (PVA) fibres, water and several additives.

The bridge (figure 2) constructed with the 3D-printed technology is located in the Baoshan District of Shanghai, China. The printing system consists of several parts: the mixer, the pump, the six-axis robotic arm, the printing tool head, the controller, and the programming and control system. [4]

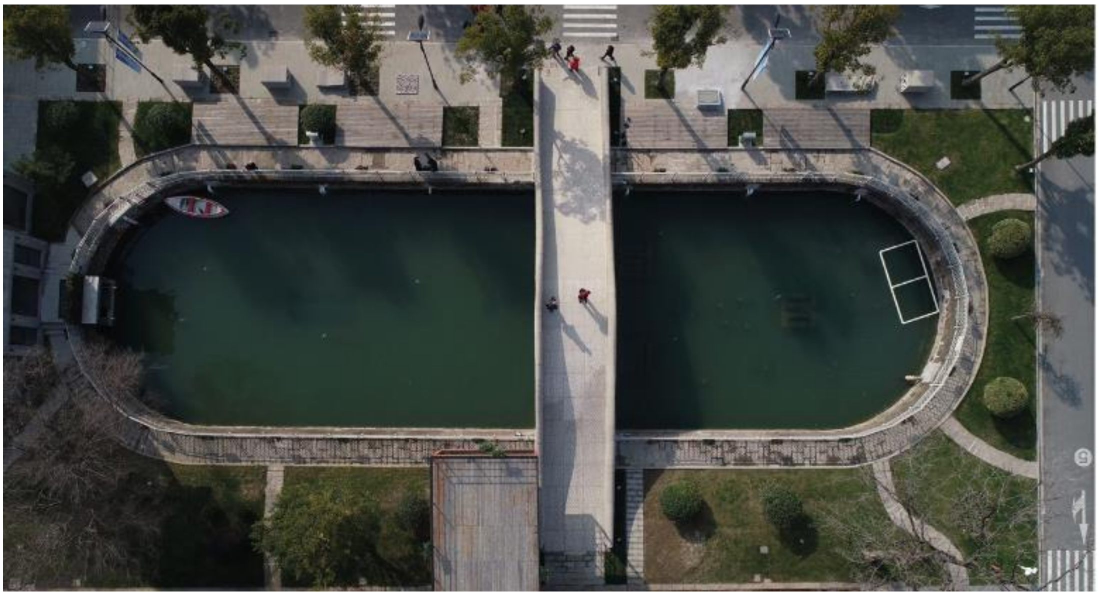

Figure 2: Photo of the completed bridge [4]

Figure 3: Structure test

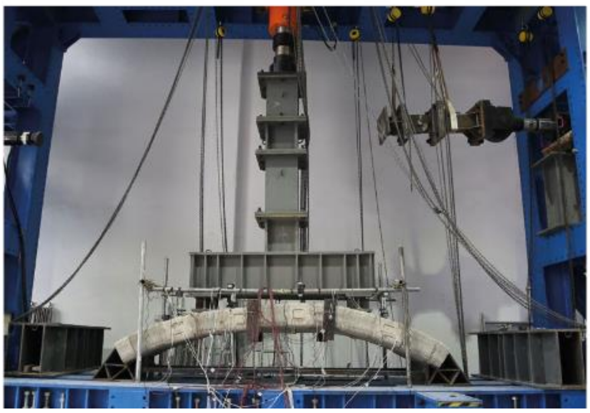

Figure 4: Compressive test

This bridge was the largest concrete bridge made of 3D printed components when it was completed. It attracted the attention of the industry and the media because it demonstrated the possibility of using 3D printing techniques in the construction and architecture industries in the future.

### 7.7.4.2. 3D models historical architectural objects by photo

Graphic reconstruction of historical architectural relics is now possible thanks to advances in 3D graphics, modeling, and design on specialist computer systems. This can be seen in the 1950s model of the Parochial Cathedral of St. Mary of the Perpetual Assistance (figure 5).

The steps of creating 3D models of architectural monuments are based on generic techniques that take into account the jobs' particular qualities, the program selected, and the level of granularity and realism required. The phases of design implementation of the miniature of Parochial Cathedral are the analytical phase, which is the collection of input data, the calculation of sizes and parameters of the object, and the modeling phase, which is the creation of a design of the object shape, accumulation, carving, embossing, and so on). Professionals from the Innovative Centre of 3D handled the process of developing the 3D model. [5]

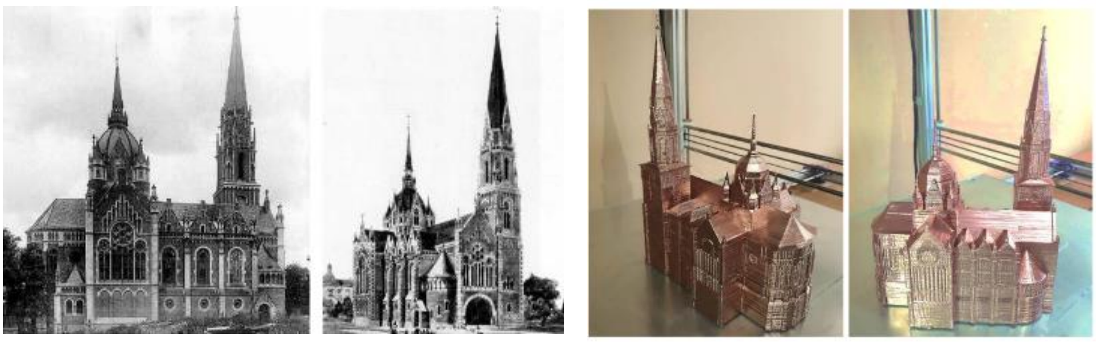

Figure 5: The printed miniature of the Parochial Cathedral of St. Mary [5]

### 7.7.4.3. 3D Canal House, Netherlands

DUS Architects in Amsterdam built the 3D Print Canal House (figure 6) as a research project. The project's purpose is to construct a 13-room show house. In a shipping container beside the canal, a customized 3D printer named "KamerMaker" was installed. Many printed components (figure 7) can be found around the house. Each component is a research update in terms of shape, structure, and material. [3]

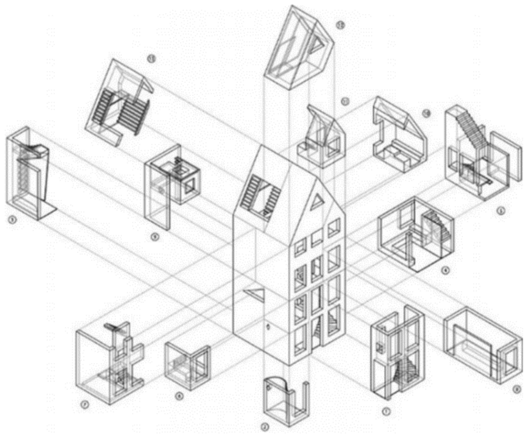

Figure 6: General view of the project [6]      Figure 7: Decomposition of the model [6]

The 3D Print Canal House is made up of sections that measure a maximum of 2.2x2.2x3.5m and is printed on-site. The parts are assembled like Lego construction blocks after printing. Hollow sections in each portion can be filled with reinforcement (concrete) or insulating material. The placement of pipes and wires is another usage of the hollow spaces. This method has the advantage of being easily disassembled and reassembled at a different place. [7]

#### 7.7.4.4. Thinking Huts' 3D Printed School in Madagascar

3D printing can be used to implement projects for a non-profit organization. The next example (figure 8) is an additively manufactured school building in Madagascar. The project is the brainchild of Maggie Grout, which Thinking Huts launched in 2015. In the project, the founders try to preserve flora and fauna as much as possible and adapt the appearance of the building to nature. Inspired by the honeycomb, the building was constructed with a two-meter Hyperion Robotics robot arm made of cement. It is a single-story building that can accommodate 137 students and can be expanded with additional "pods" if needed. [9]

Figure 8: School in Madagascar [9]

#### 7.7.4.5. Stairs to Infinity

In this case study (figure 9), we'll look at how parametric principles enable new ways to build staircases using additive manufacturing: lighter and with recycled materials. To achieve the goal of lightness and resistance at the same time, the structure was created in wire form.

Carmen Baselga and Hector Serrano created this concept for the show PRINT3D at the Cosmocaixa Museum in Barcelona. The goal of the project was to create a 12-meter-long spiral staircase that was solely supported by translucent threads and was as light as feasible. [10]

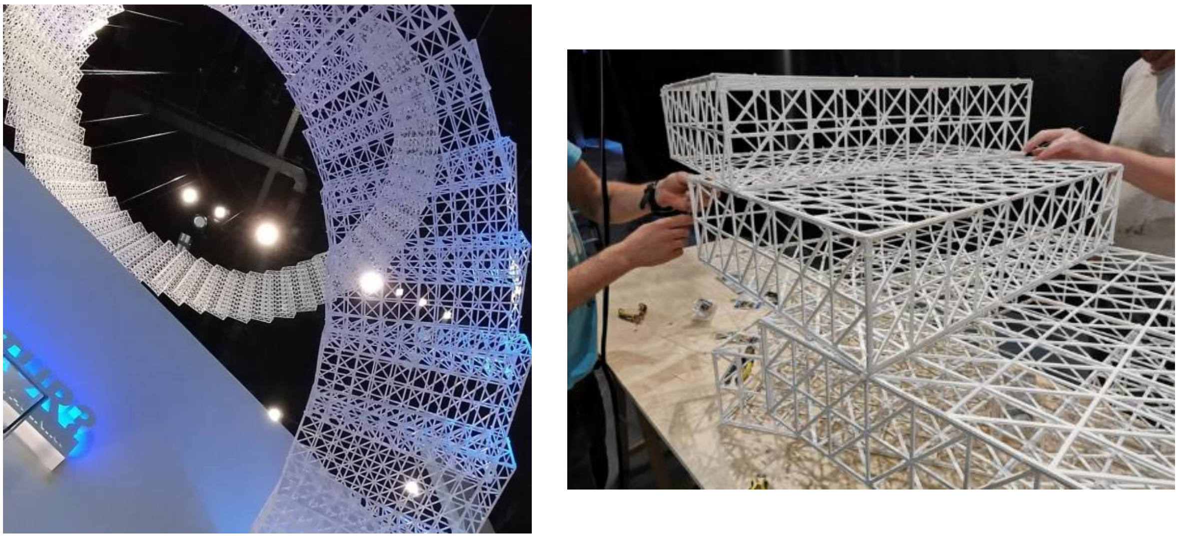

Figure 9: Final look of the stair [10]

### 7.7.5. Future projects involving 3D printing technology

From the start, it appears that 3D construction has the potential to be environmentally friendly. However, more practice and experience are required. On subjects that are still unknown, such as structural and mechanical stability, material durability, toxic effects of materials, and so on, there is still a lot of research to be done. Because 3D printing in the construction business is still in its infancy, the life cycle performance of printed buildings/components is unclear. It might be argued that overcoming these challenges will allow 3D printing to attain its full potential in the construction industry in the near future.

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# 7.8 Education

## 7.8.1. 3D printing in education

New technologies have been used to motivate people to come up with new ideas and foster their creativity. The way materials are handled and things are made is fundamentally altering because of technological advancements. Because of its capacity to handle complex geometries and provide creative freedom, the technology is also being employed for purposes other than quick prototyping including a variety of industrial sectors in the creation of functional parts, including a variety of industrial sectors in the creation of functional parts. [7]

3D printing is a huge revolution, and its influence in education is growing. Learners can acquire more complicated topics faster and with new "tools" thanks to three-dimensional printing and the surrounding environment. Manufacturers of 3D printers are now promoting their equipment as having potential use in education. We looked at how 3D printing technology could be used to improve teaching methods and student learning. 3D printing technology may provide students with a strong tool for discovery and creativity. Technology has been used to motivate people to come up with new ideas and foster their creativity. The way materials are handled and things are made is fundamentally altering as a result of technological advancements. Because of its capacity to handle complex geometries and provide creative freedom, the technology is also being employed for purposes other than quick prototyping including a variety of industrial sectors in the creation of functional parts. [6]

Teachers and trainers must develop specialized skills in order to integrate 3D printing into training programs and utilize printers and related equipment independently. These abilities include not just technology abilities, but also creativity and teaching methods. A 3D printer can be utilized in a variety of disciplines in education. For example, history students can print historical artifacts to examine, graphic design students can print 3D versions of their work, geography students can print topography, demographic, or population maps, chemistry students can print 3D models of molecules, biology students can print cells, viruses, organs, and other biological artifacts, and math students can print out equations. [4]

The primary educational environments in which 3DP are used are schools, universities, that should take the lead in 3D printing-based collaborations involving university–industry–government partnerships, libraries, and special education settings. [9] The main ways of use of 3D printing are to teach students about 3DP, to teach educators about 3D printing, to teach design and creativity, to build artifacts that aid learning and to develop assistive technologies. [1]

## 7.8.2. Process

To start a 3D printing project, users design what they want to print using a 3D modeling program or they select an already constructed design from an online database and feed the 3D printer with suitable material for the needs of the print object. Then, it needs to be uploaded to software, where users can adjust a number of settings such as size, quality, support type, print speed, and temperature. Once the settings are adjusted and the 3D printer is connected to the computer, the user can start the 3D printing process. [3]

### 7.8.3. Advantages

Benefits of 3D printing on education [6]:

- From the study and design phase of the models through the realization phase of the things, the student can be involved, fostering anticipation and active participation
- Students are not a passive consumer of information, but can be a part of creativity and imagination in the creation of lesson's objects
- The level of learning is improved by expanding the quantity of knowledge that can be obtained in a setting without the benefit of visualization, thanks to the ability to "visualize" in 3D the objects mentioned in the courses.
- Students improve their skills of persistence and endurance in overcoming difficulties.
- Capture interest of students
- Stimulate interaction during class
  Any class may be instantly transformed into an interactive learning experience by using a 3D printer. This technique needs inquiry through interaction and promotes the learning process, whether it's printing portions of a skeleton for a biology class or producing prototypes for engineering classes.
- Assessing educational outcomes objectively and on time
- Giving teachers and learners new 21st-century skills: improve observation and concentration, enhance creativity, improve independent learning habits, develop spatial imagination, develop reflective and problem-solving ability and promote cooperation [5]
- Making learning more focused, fresh, novel, and fun
- Promoting critical thinking and exposure to new ideas
- Reducing administrative burdens, e.g. reporting absence
- It enables more authentic exploration of objects and concepts
- It gives the students complete understanding of objects and structures
- It is innovative technology that brings new methods of learning
- Make learning more lively and meaningful [3]

3D printing is changing the way students learn by giving them a hands-on experience that encourages them to pay attention to details, be more creative, and see their work come to life. Because students are challenged to think differently, allowing them to effectively build something makes it real and can ultimately encourage them to take the incremental steps that frequently lead to being the one to design the ‘next big thing.

### 7.8.4 Disadvantages

There are also several barriers to 3D printing's adoption in education:

- Its process is very slow
- It is expensive
- The results of 3D printers often fail because: 1. the printers are new to the market and may have bugs, 2. there are problems of hardware issues and 3. there are incorrect settings or the digital model is not well designed
- Lack of knowledge and specific skills of the trainers [10]
- It is difficult to change educational programs and methodologies
- Lack of educational approaches based on 3D printing
- It is a difficult and time-consuming effort [3]

Access to technology, adequate resources, pedagogical principles, and instructors' attitudes about the use of technology are all important variables in successful technology integration in education. [6]

### 7.8.5 Applications

3D printing technology is a new technology in universities that changes teaching and learning process drastically. 3D printing is a revolutionary and innovative technology that brings new methods of learning. The uses of this technology in educational sector are very wide. Some of the areas that is currently used are the following: mathematics, chemistry, history, graphic design, biology, geography, engineering, architecture.[8]

**i. University of Virginia**

The University of Virginia’s mechanical and aerospace engineering program is one of the best in the U.S., partly due to its emphasis on hands-on learning. UVA's rapid prototyping lab, which runs six 3D printers and a 3D production system on a daily basis, is where theory and imagination become objects that either succeed or fail in the real world. The results are smart machines and students learned about stepper motors, brush motors, limit switches, and software engineering. Employers are increasingly looking for graduates with applied, tested abilities, therefore developing students' design talents beyond the theoretical is crucial. UVA has incorporated a genuine business into its curriculum in order to prepare well-prepared graduates for the business world.

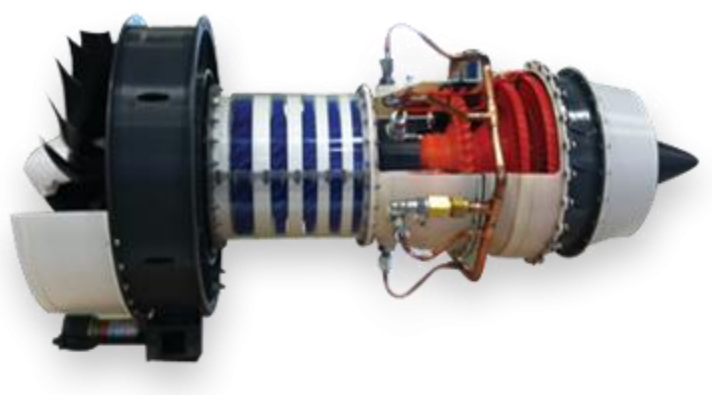

**Figure 1:** Application of University of Virginia, 2021 [11]

**ii. Case Western Reserve University**

Case Western Reserve University enhances and enriches people's lives through research that harnesses the power of collaboration and education that engages the students in meaningful ways. This 3D printed model of a titanium dioxide nanoparticle will be used in the classroom to provide students with hands-on experience with molecules. Shane Parker, a postdoctoral researcher, picked this molecule as a prototype because his research focuses on that substance. As a learning enrichment project, students will design and print their own 3D models of molecules.

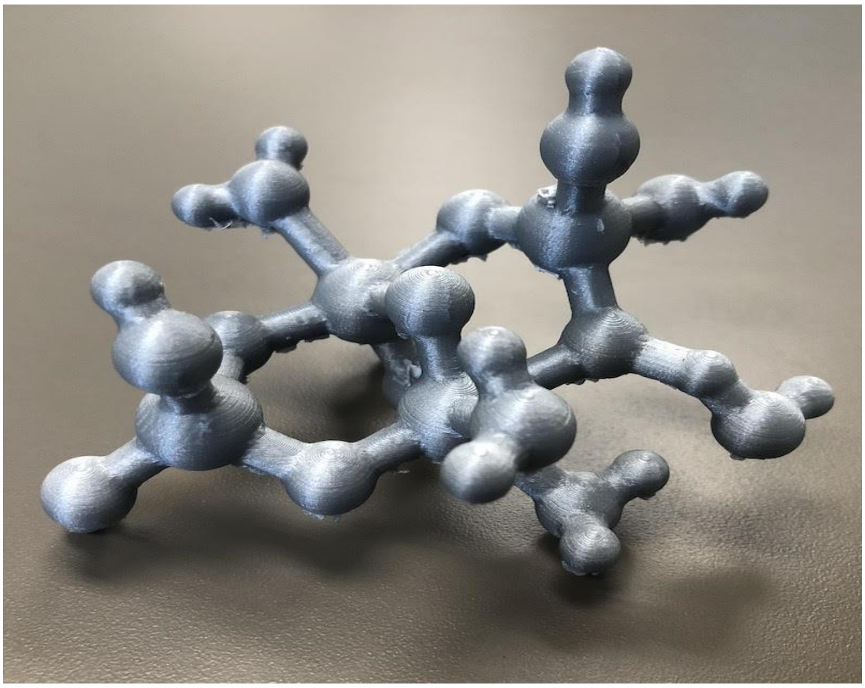

**Figure 2:** Application of Case Western Reserve University, 2021 [12]

### iii. Edge Hill University

A trainee teacher at Edge Hill University, has developed an amazing project which he hopes will allow the bee population to increase. He was able to build and prototype a working device that will pollinate flowering plants, collect nectar, and improve farming using 3D printing and other advanced technology. This incredible piece of work exemplifies the versatility of 3D printing's applications for all types of individuals in all types of businesses all around the world.

This project would assist students in identifying new materials and technologies. This will also teach students about the iterative design process, as they will be required to evaluate and quality test their prototype as it is being built. Pupils will also improve their communication skills by creating 2D and 3D drawings, as well as taking inspiration from and reviewing the work of expert designers while doing so. Teachers covered components of biology when gathering material for this project by explaining the anatomy of bees and the differences in species, as well as the coevolution process of bees and flowers, spectrums of light, the life cycle of plants, and the genetic mutation of cells. [12]

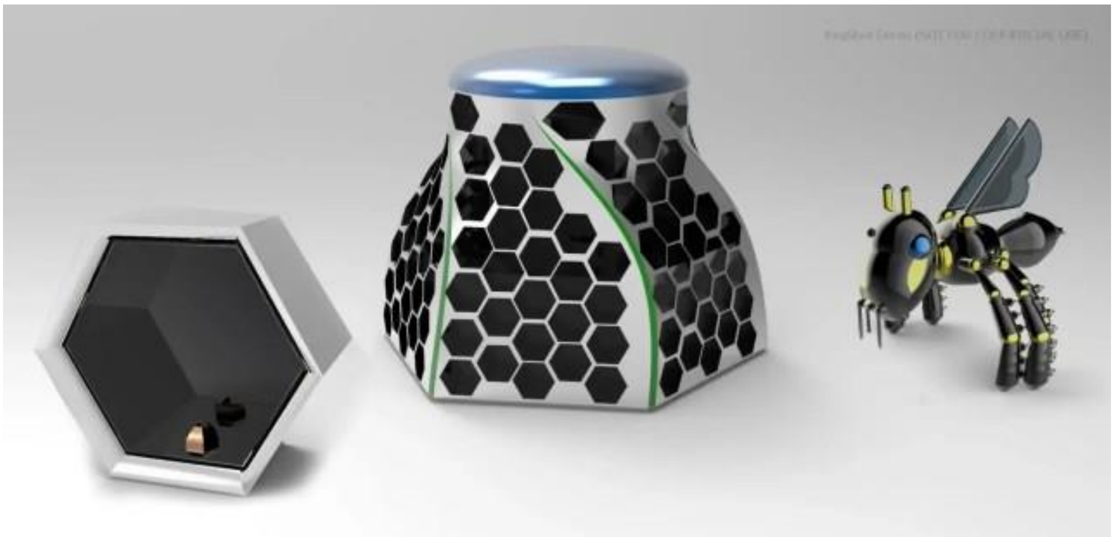

**Figure 3:** Application of Edge Hill University, 2021 [13]

### iv. High School in Krokou Kozanis

The aim of the teachers was to strengthen the interest of the students by providing motivation so that they not only learn but also enjoy the magical world of natural sciences. As an example of application is the teaching of Geography High School in Krokou Kozanis. The aim of the project is the agricultural products correlate with the factors of the natural environmentin a specific area and to distinguish the vegetation zones into which it is divided the European continent. [14]

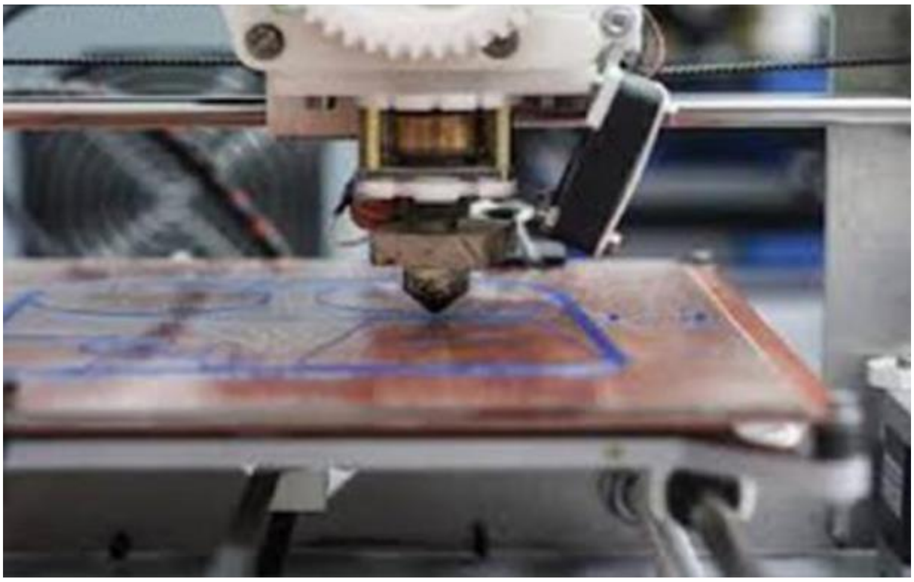

**Figure 4:** Application of High School in Krokou Kozanis, 2021 [14]

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