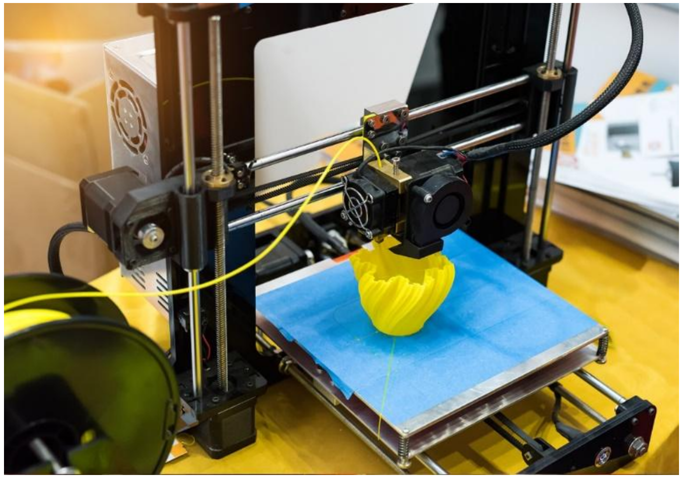
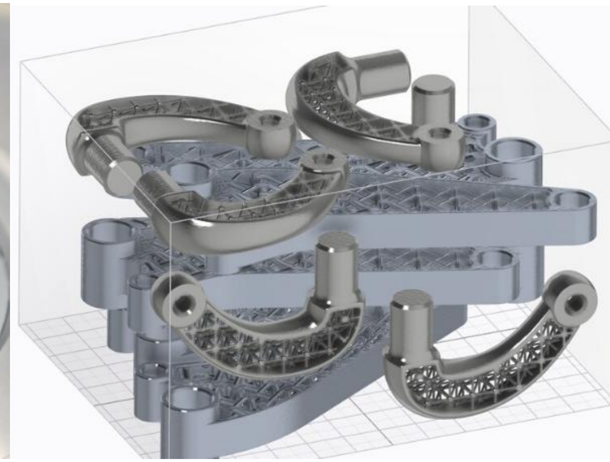
Innovative Technologies

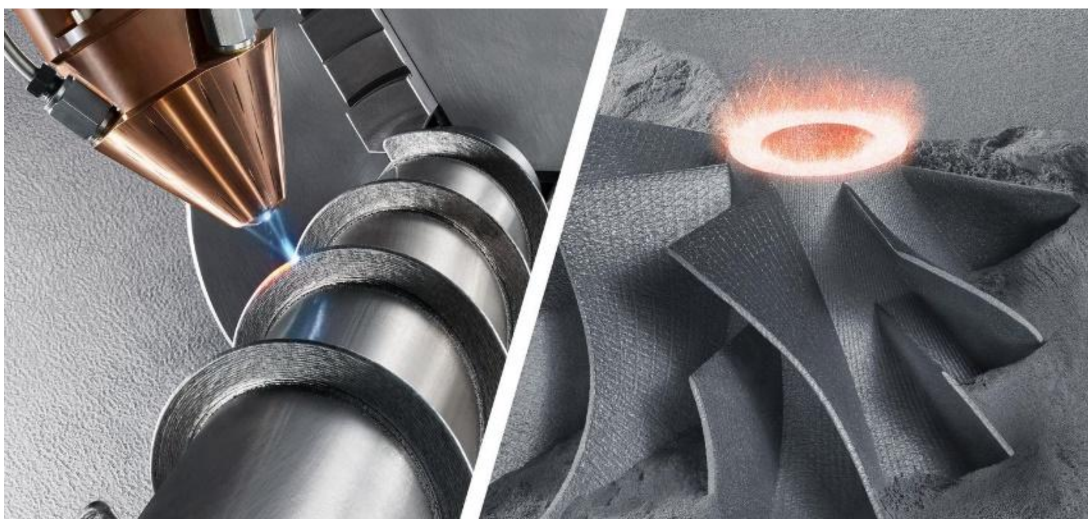
Additive Manufacturing

Innovative technologies

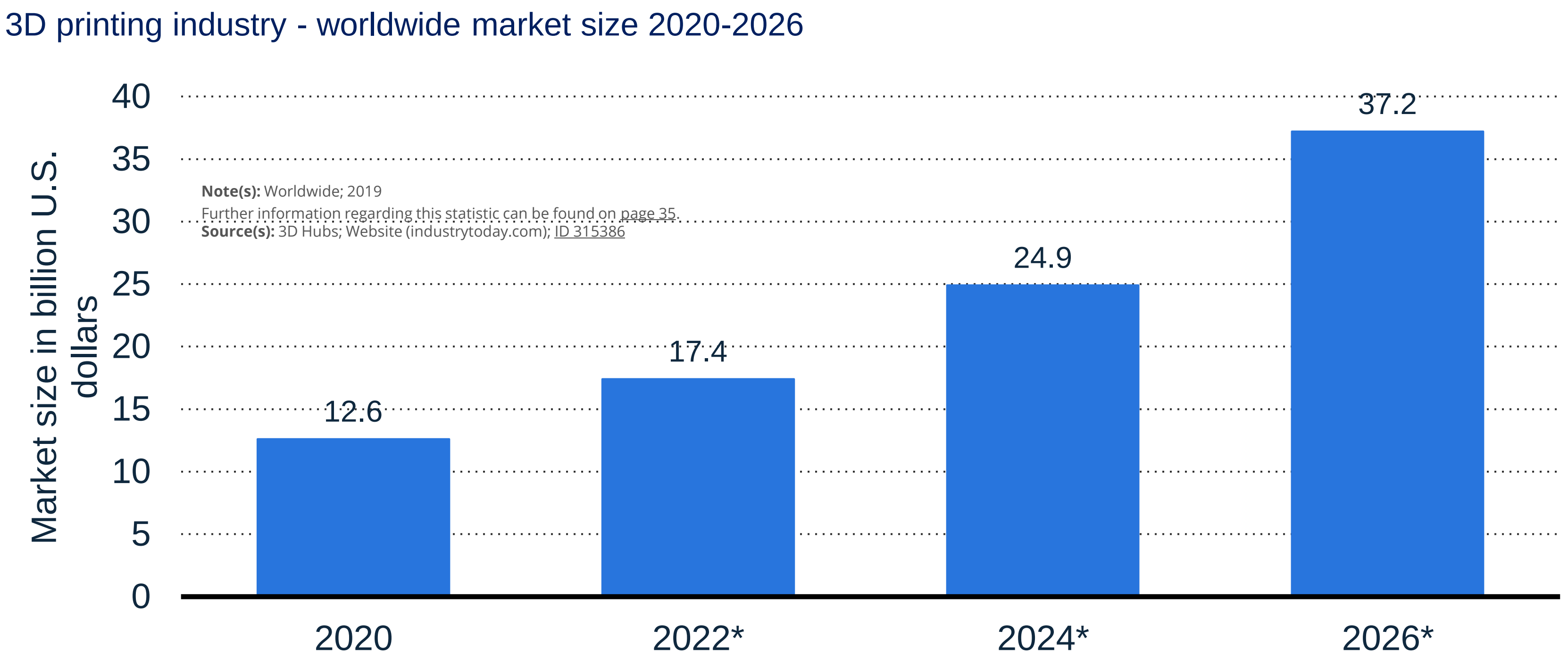


Innovative technologies



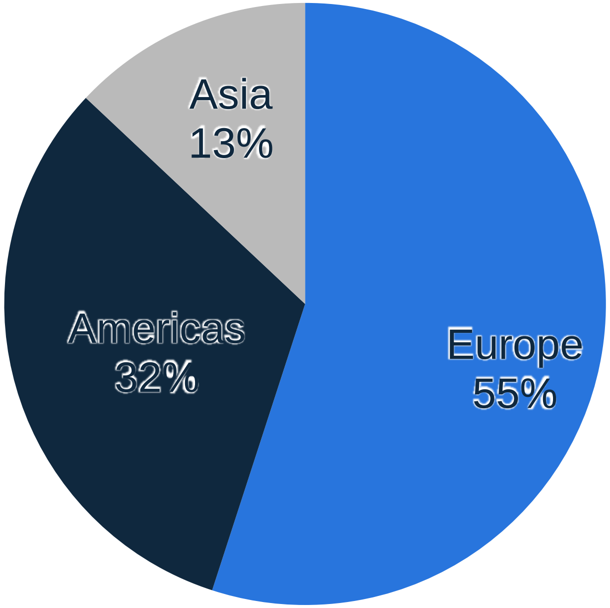


Global 3D printing products and services market size from 2020 to 2026 (in billion U.S. dollars)



Distribution of additive manufacturing companies in 2019, by region

Additive manufacturing companies by region 2019

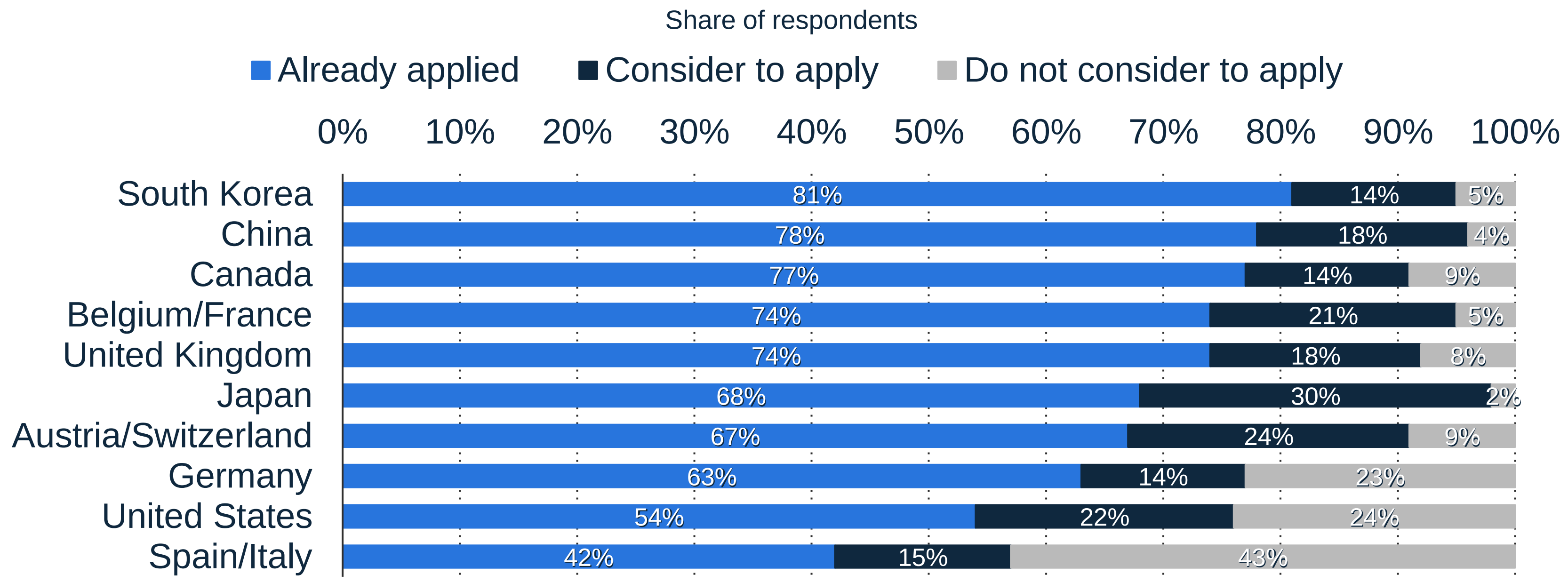


Note(s): Worldwide; 2019
Further information regarding this statistic can be found on page 39.
Source(s): ICTC; EY; ID 1268724

Experience of selected countries with additive manufacturing technology in 2019

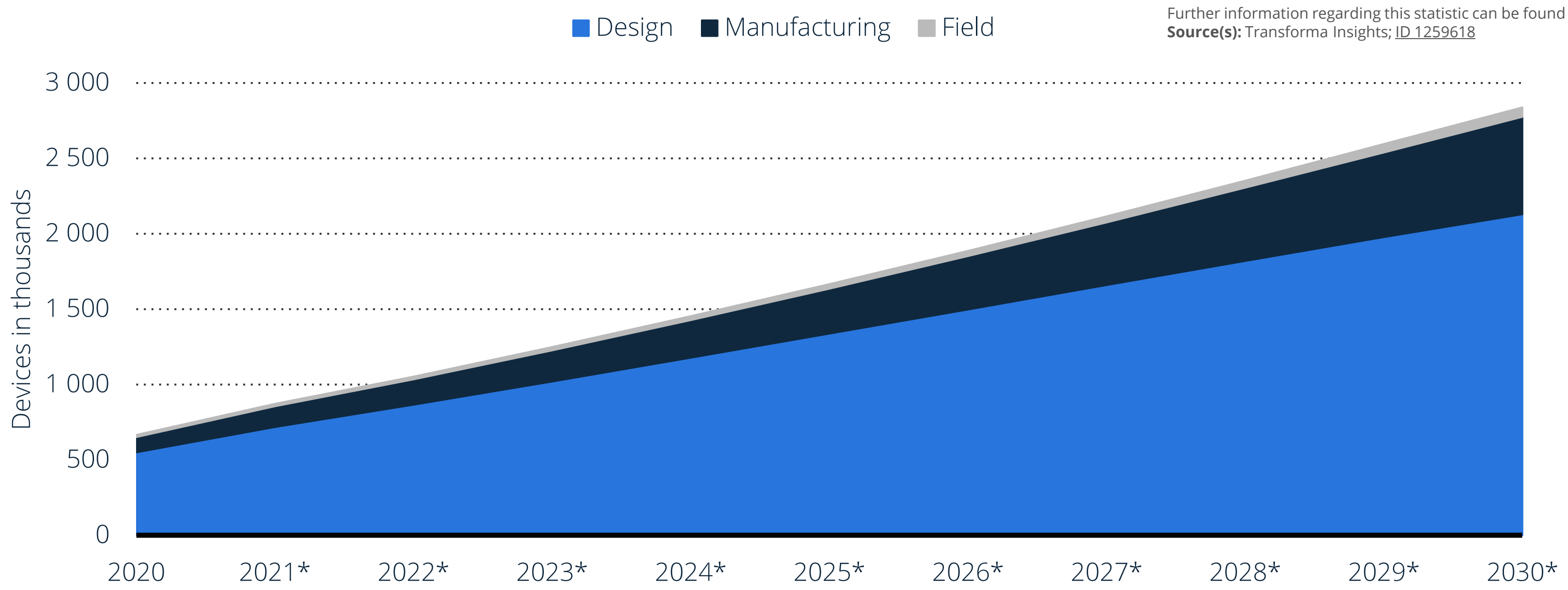
Application of additive manufacturing technology by country 2019

Note(s): Worldwide; 2019; 900 respondents; companies
Further information regarding this statistic can be found on page 38.
Source(s): ICTC; EY; ID 1268735



Number of 3D printing & additive manufacturing devices worldwide from 2020 to 2030, by context (in 1,000s)

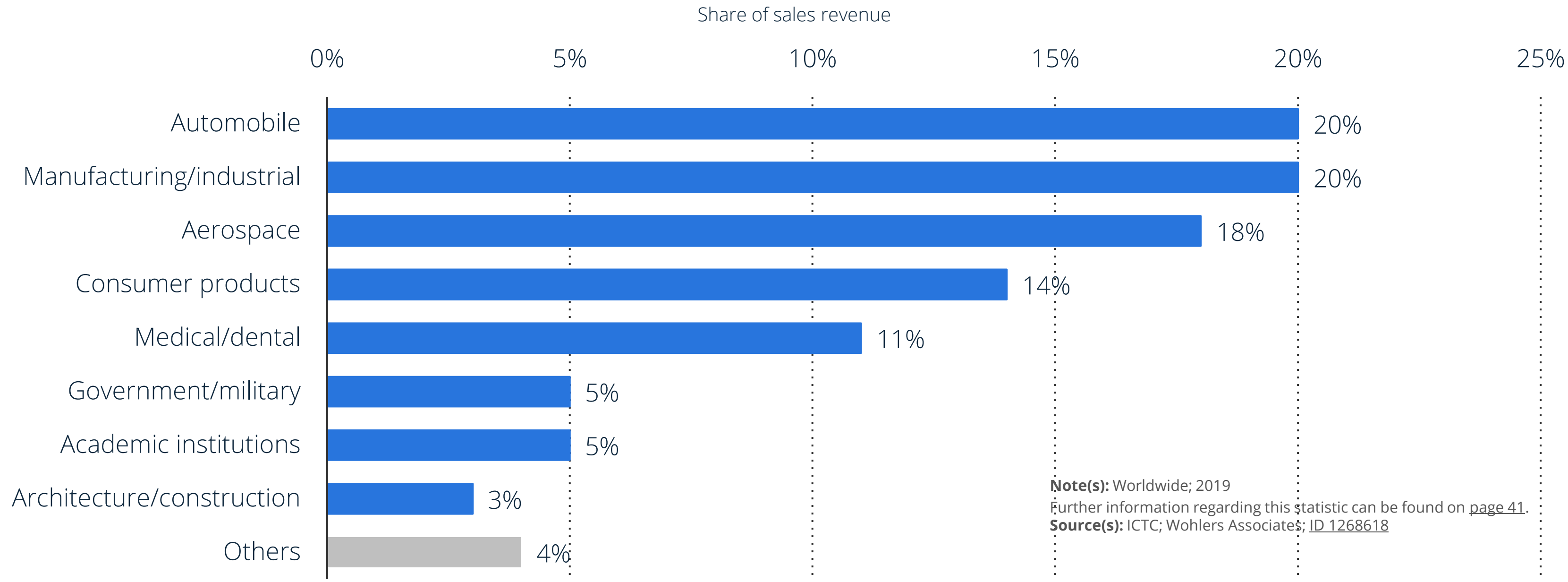
3D printing & additive manufacturing devices worldwide 2020-2030, by context



Note(s): Worldwide; 2020
Further information regarding this statistic can be found on page 40.
Source(s): Transforma Insights; ID 1259618

Distribution of sales revenue of the additive manufacturing market worldwide in 2019, by industry

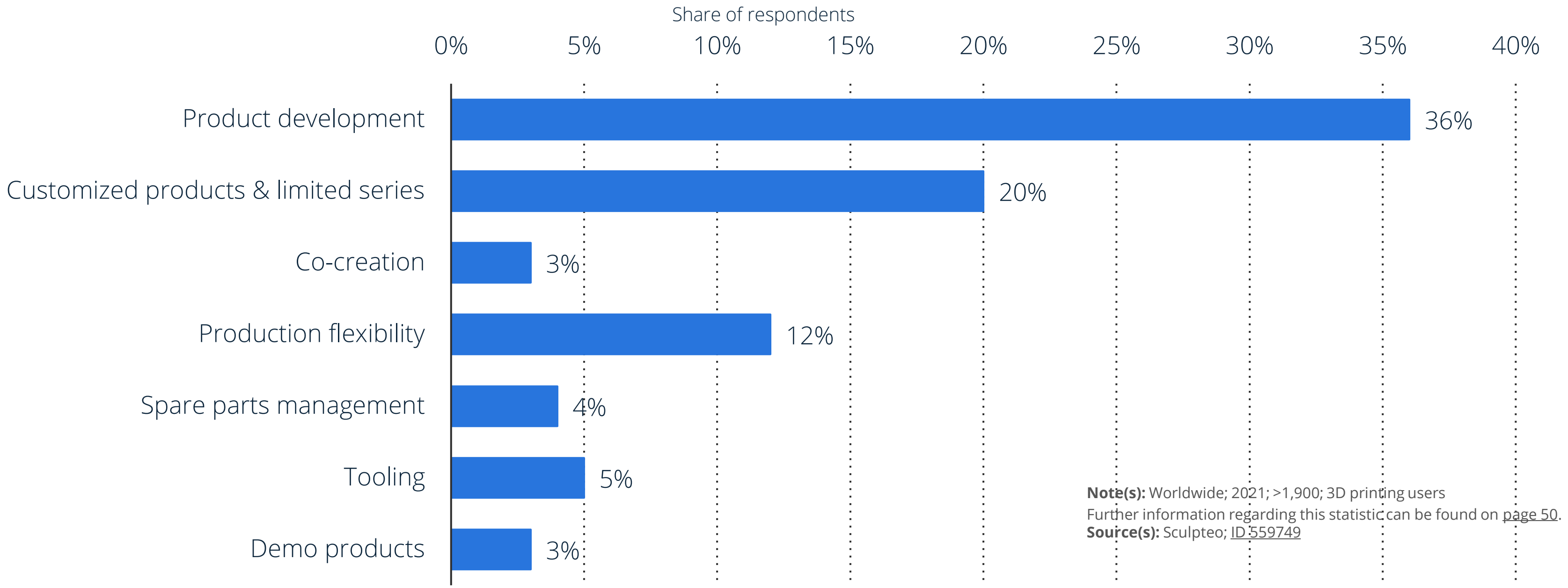
Share of sales revenue of the global additive manufacturing market by industry 2019



Note(s): Worldwide; 2019
Further information regarding this statistic can be found on page 41.
Source(s): ICTC; Wohlers Associates; ID 1268618

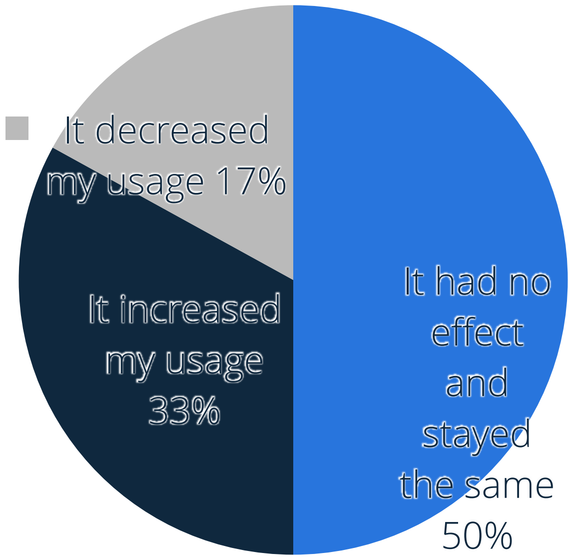
What is your top focus related to 3D printing in 2021?

Top 3D printing priorities for organizations worldwide 2021



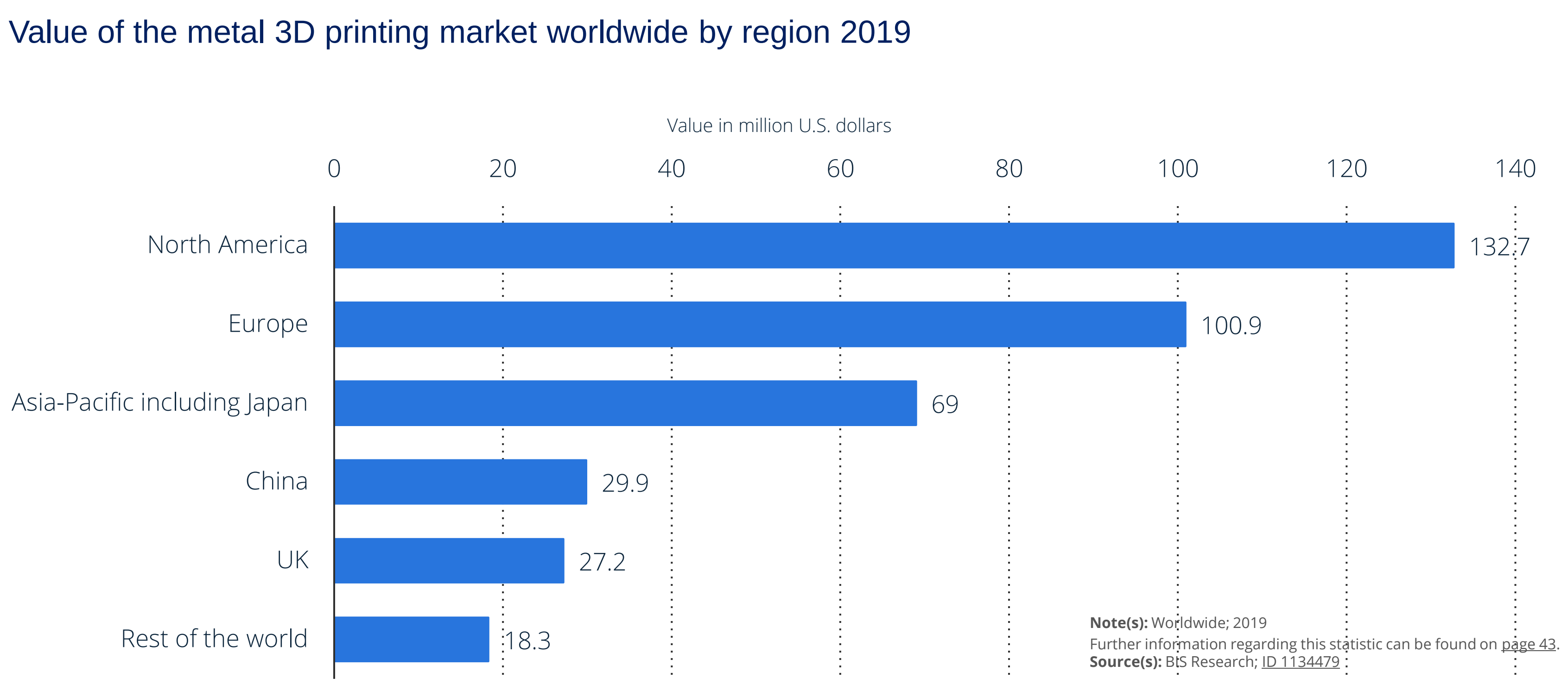
How did COVID-19 affect your 3D printing usage?

Effect of COVID-19 on the use of 3D printing 2021

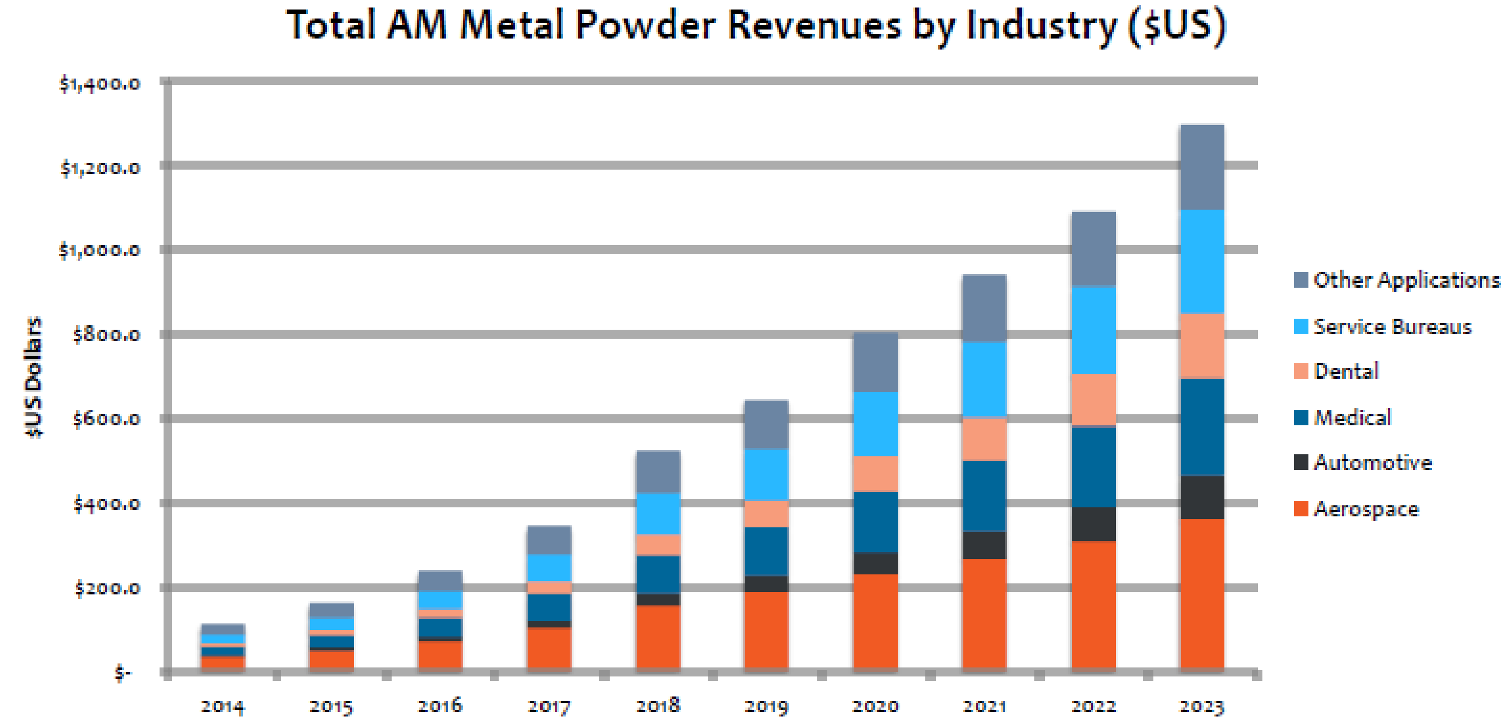


Note(s): Worldwide; February 2021; 1,504 respondents
Further information regarding this statistic can be found on page 46.
Source(s): Website (3druck.com); 3D Hubs; ID 1268830

Value of the metal 3D printing market worldwide in 2019, by region (in million U.S. dollars)



Who uses Additive Manufacturing?

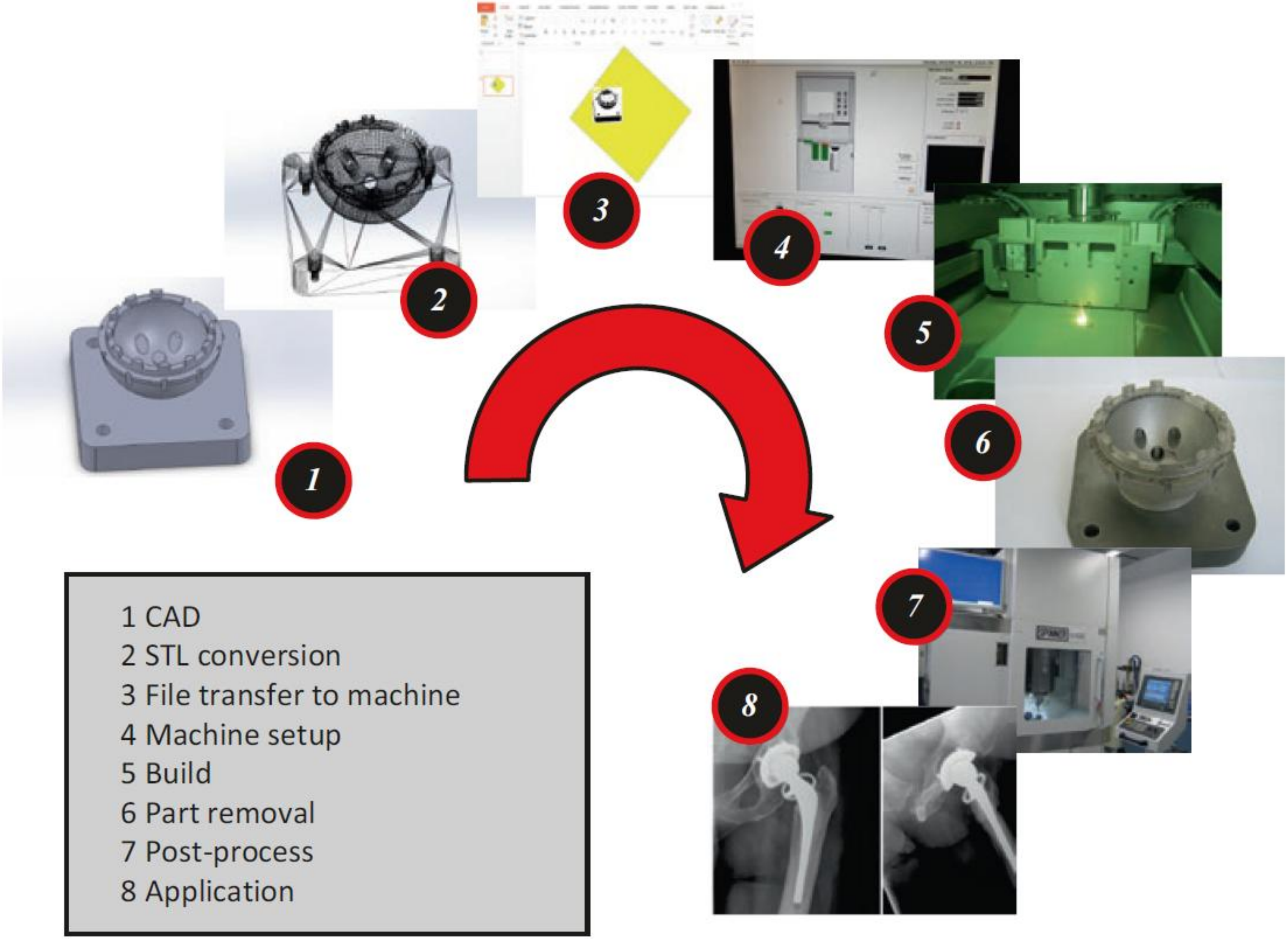


Source: SmarTech Markets Publishing, *Opportunities in Metal Additive Manufacturing*

Open topics
The qualification of the product, process and materials

- Design
- Feedstocks characterization
- Process control
- Post processing (heat treatments and finishes)
- Properties of the finished product
- Qualification & certification
- NDT
- Maintenance and repair

Additive Manufacturing Steps



Stereolithography – 3D printing – Additive Manufacturing

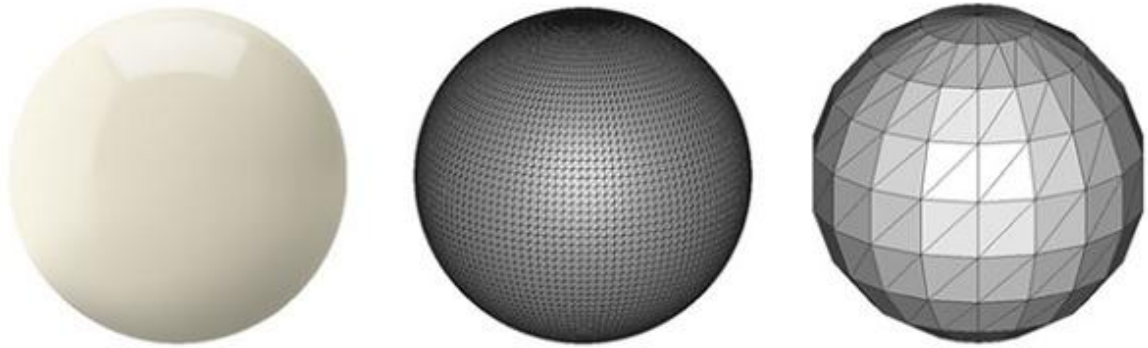
- Three-dimensional printing or rapid prototyping are processes by which components are manufactured directly from computer models by selectively curing, depositing or consolidating materials in successive layers

- These technologies have traditionally been limited to making models suitable for product visualization but, over the past decade, they have rapidly developed into a new paradigm called additive manufacturing

- We are now starting to see additive manufacturing used to manufacture a range of functional end-use components

STL file format

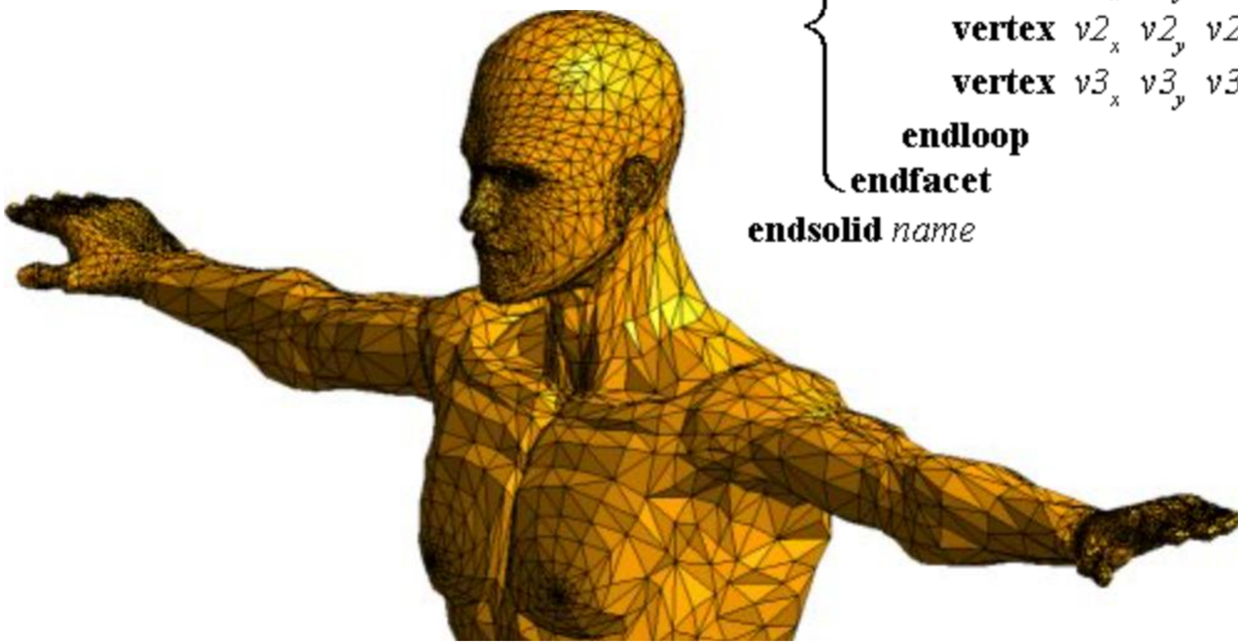
- STL format file
  Discretization by triangles
  of the surface of a solid

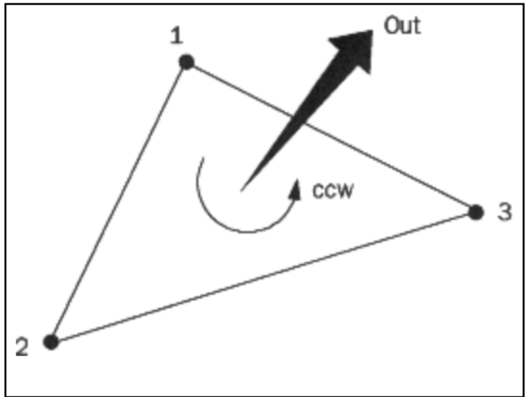


solid *name*

$$\left\{\begin{array}{l}\textbf{facet normal}\ n_i\ n_j\ n_k\\ \quad\textbf{outer loop}\\ \qquad\textbf{vertex}\ v1_x\ v1_y\ v1_z\\ \qquad\textbf{vertex}\ v2_x\ v2_y\ v2_z\\ \qquad\textbf{vertex}\ v3_x\ v3_y\ v3_z\\ \quad\textbf{endloop}\\ \textbf{endfacet}\end{array}\right\}^{+}$$

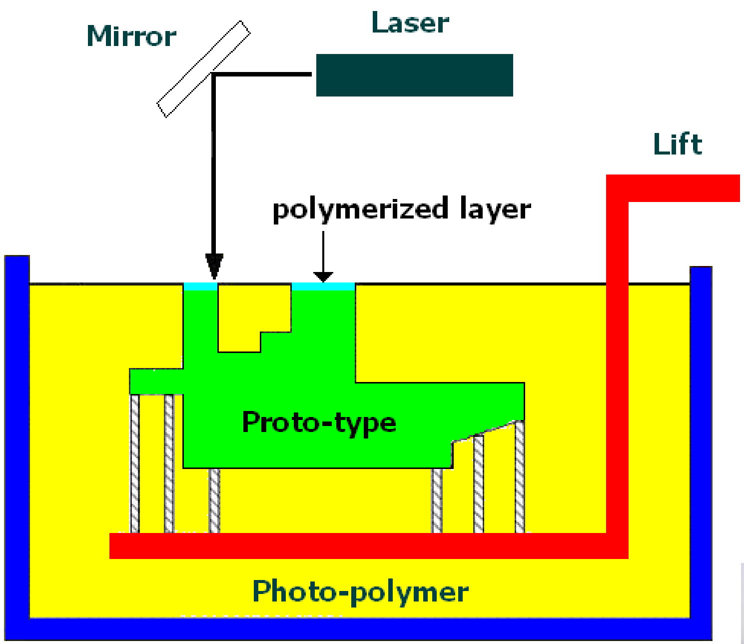
endsolid *name*

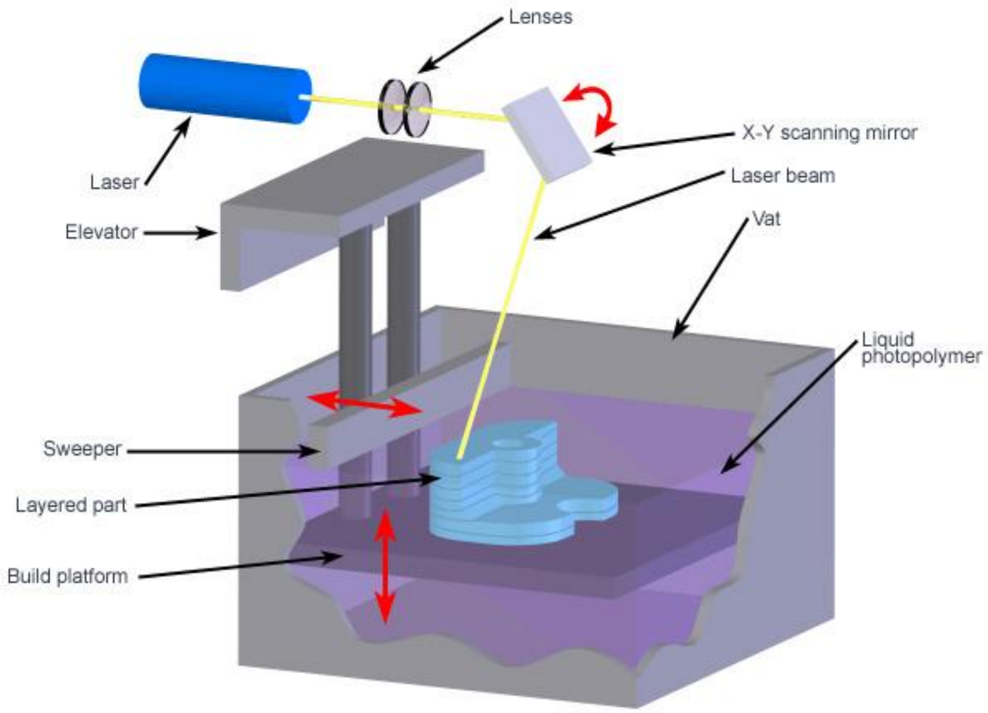




Orientation of a facet is determined by the direction of the unit normal and the order in which the vertices are listed.

Stereolithography





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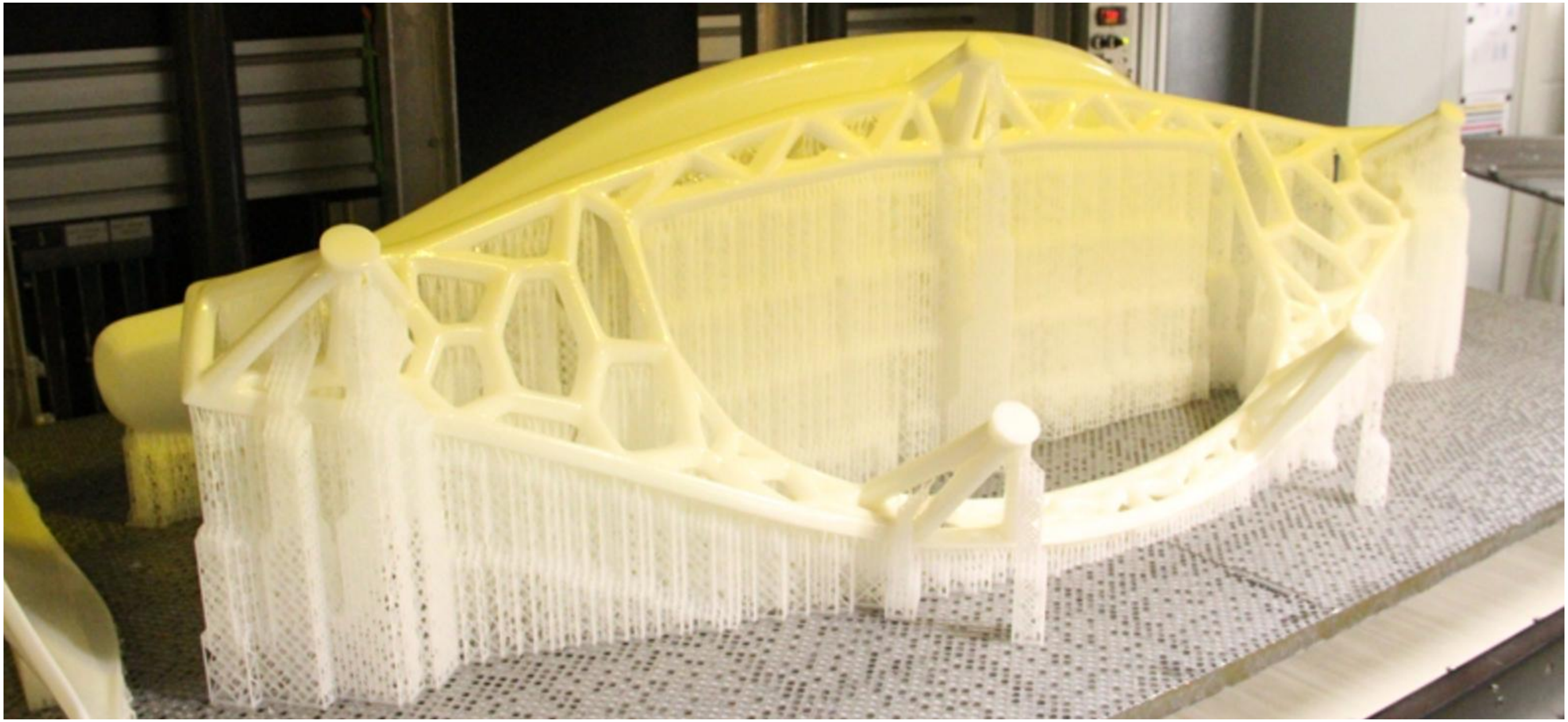
Stereolithography



Additive Manufacturing – (additivemanufacturing.com)

- Additive Manufacturing (AM) is an appropriate name to describe technologies that build 3D objects by adding layer upon layer of material, whether the material is plastic, metal, concrete or biological material

- Common to AM technologies is the use of a computer, 3D modeling software (Computer Aided Design or CAD), machine equipment and layering material. Once a CAD sketch is produced, the AM equipment reads the data from the CAD file and lays or adds successive layers of liquid, powder, sheet material or other, layer by layer to fabricate a 3D object

- The term AM encompasses many technologies, including subsets such as 3D printing, rapid prototyping (RP), direct digital manufacturing (DDM), layer manufacturing, and additive manufacturing

Additive Manufacturing – (additivemanufacturing.com)

- The AM application is unlimited
  While the first use of AM in the form of rapid prototyping focused on pre-production display models, AM is now being used to manufacture end-use products in aircraft, dental restorations, medical implants, automobiles, fashion products, …

- While adding the layer-by-layer approach is simple, there are many applications of AM technology with degrees of sophistication to meet different needs, including:
  - a visualization tool in design
  - a mean to create highly personalized products for both consumers and professionals
  - as industrial tooling
  - to produce small batches of production parts
  - to produce complex shaped parts (with cavities or undercuts)

Additive Manufacturing – (additivemanufacturing.com)

- Some see AM as a complement to basic subtractive manufacturing (material removal such as material drilling) and, to a lesser extent, forming (such as forging)
- Regardless, AM can offer consumers and professionals alike the accessibility to create, customize and / or repair the product and, in the process, redefine current manufacturing technology

Ex. of Additive Manufacturing – (additivemanufacturing.com)

- **SLA – Stereolithography**

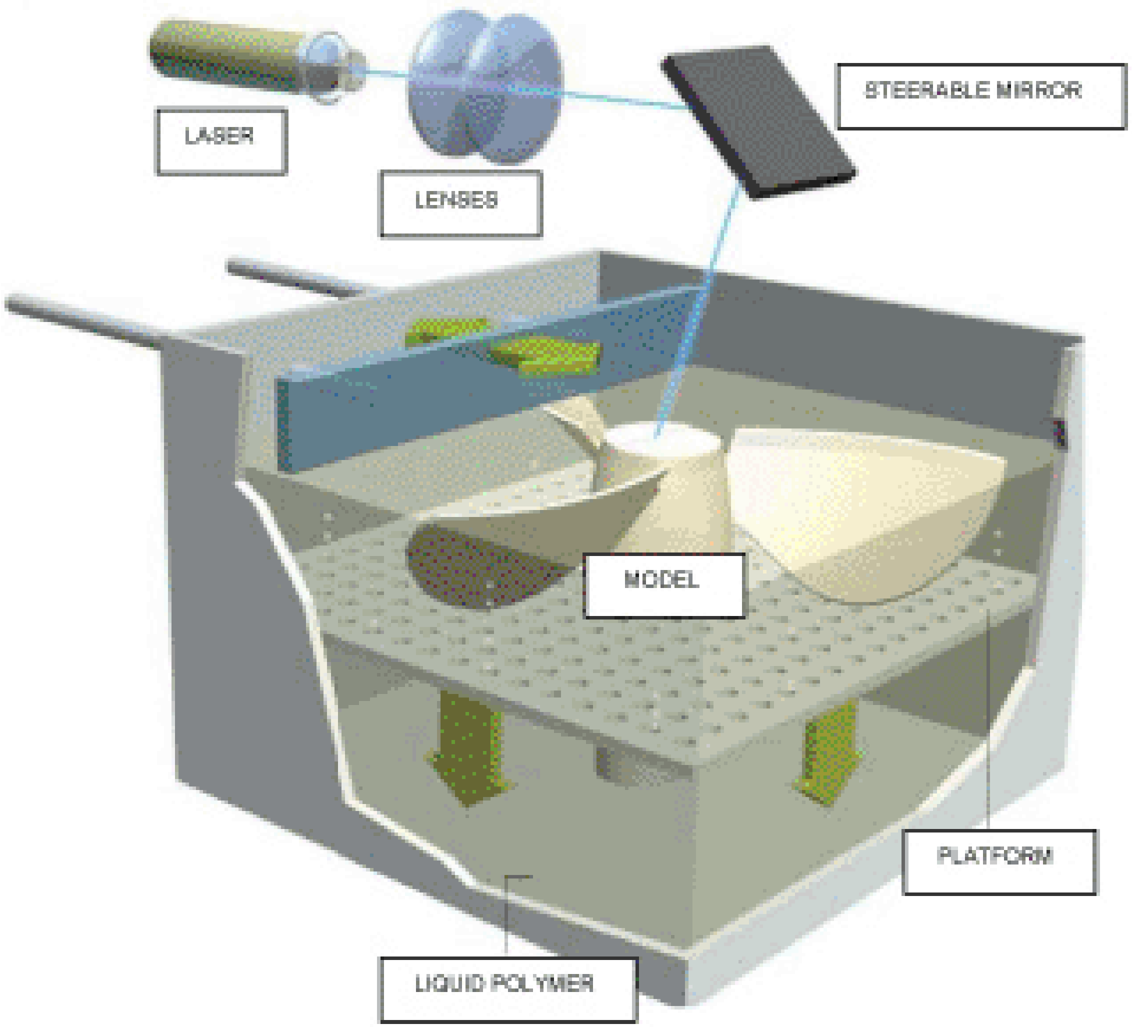
  High-end technology that uses laser technology to cure layer upon layer of photopolymer resin (polymer that changes properties when exposed to light) Construction takes place in a resin tank

  A laser beam, directed into the resin pool, traces the cross-sectional pattern of the model for that particular layer and cures it

  During the construction cycle, the platform on which the construction is repositioned, lowering by a single layer of thickness. The process repeats until the construction or model is complete and fascinating to look at. You may need specialized material to add support to some model features

  Templates can be machined and used as templates for injection molding, thermoforming or other casting processes

SLA



LASER
LENSES
STEERABLE MIRROR
MODEL
PLATFORM
LIQUID POLYMER

Ex. of Additive Manufacturing – (additivemanufacturing.com)

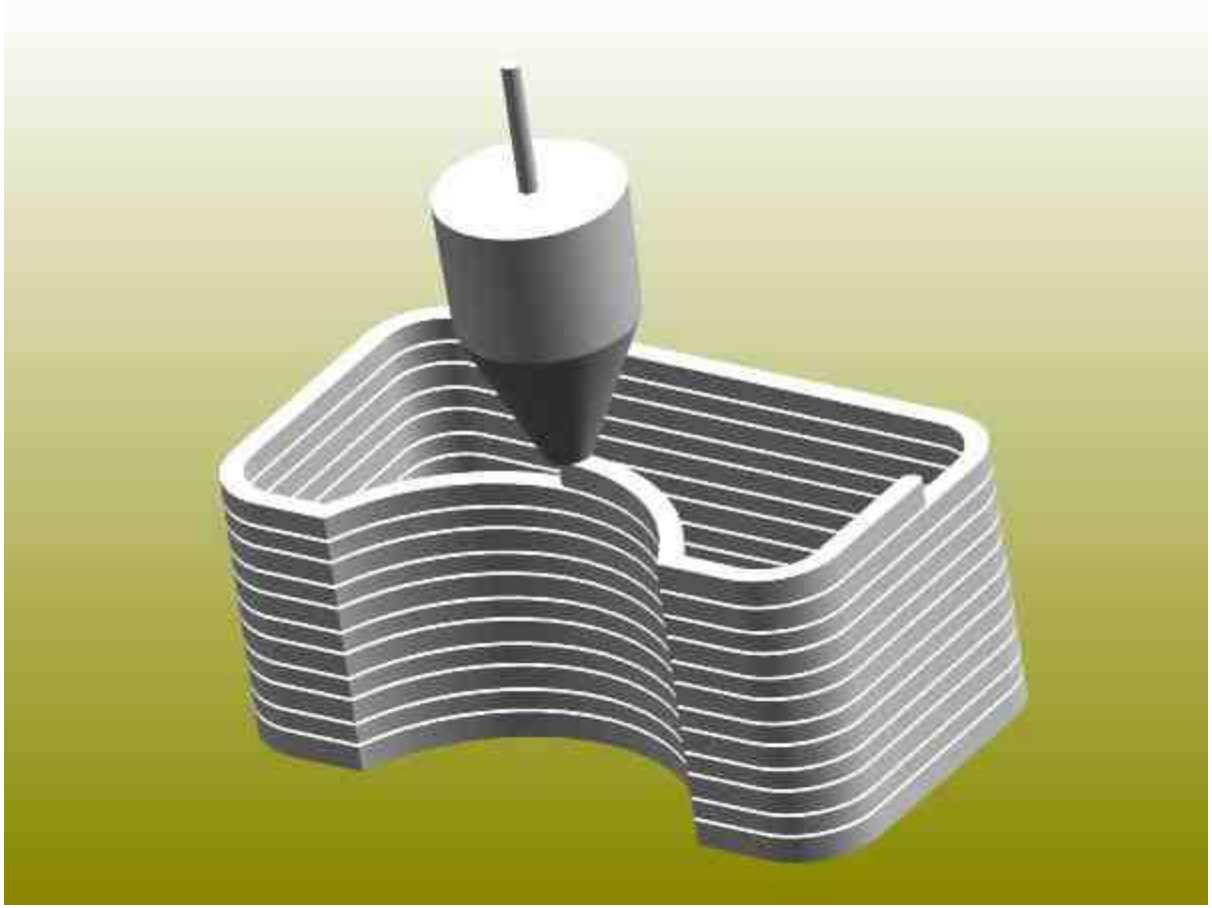
- **FDM – Fused deposition modeling**

  Process-oriented that involves the use of thermoplastic materials (polymer that turns into a liquid upon the application of heat and solidifies into a solid once cooled) injected through indexing nozzles on a platform. The nozzles trace the cross-sectional pattern for each particular layer as the thermoplastic material hardens before the next layer is applied. The process repeats until the construction or model is complete and fascinating to look at. You may need specialized material to add support to some model features. Similar to SLA, templates can be machined or used as templates. Very easy to use and cool

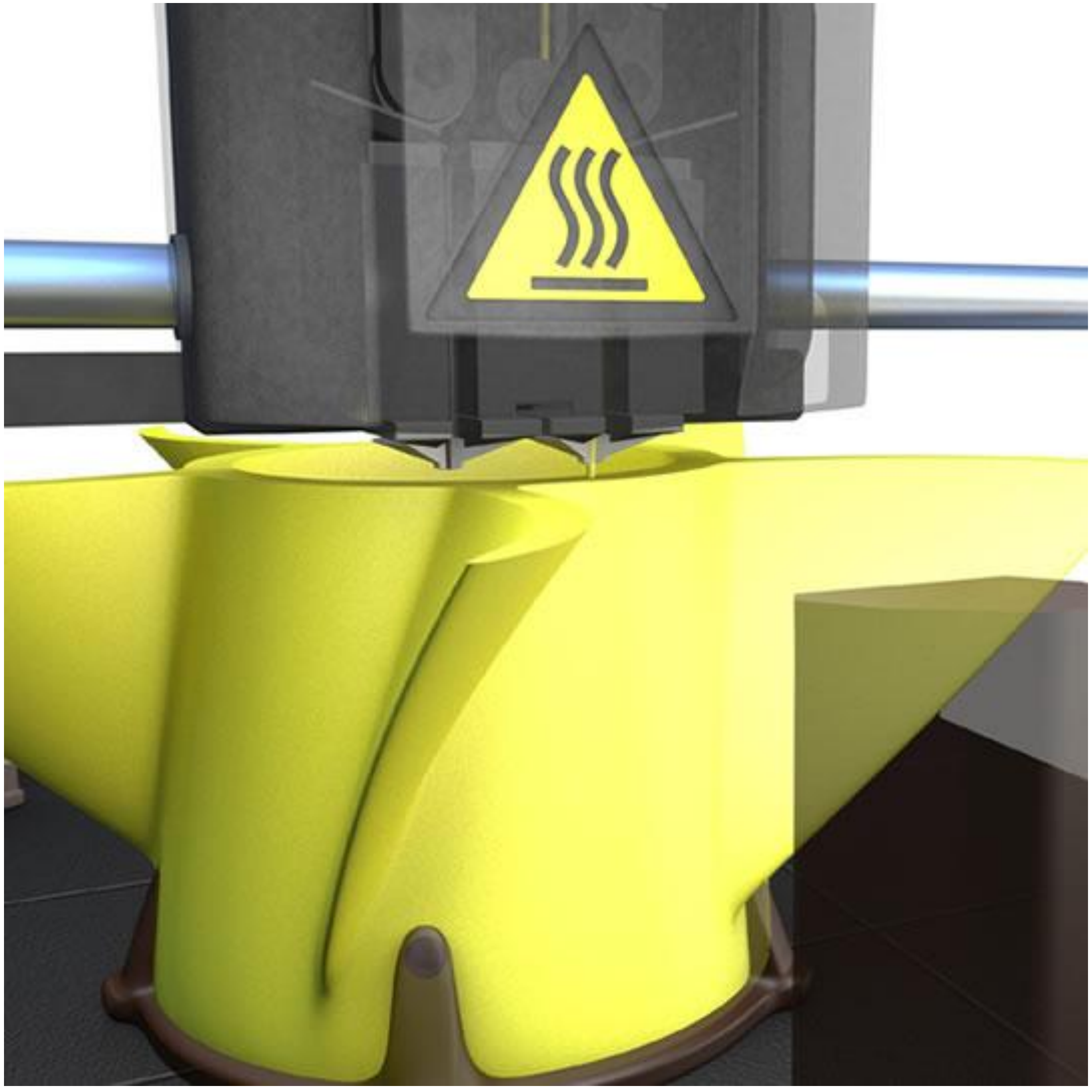
- **MJM - Multi-Jet Modeling**

  It is similar to an inkjet printer in that a head, capable of moving back and forth (3 dimensions - x, y, z) incorporates hundreds of small jets to apply a layer of thermopolymer material, layer by layer

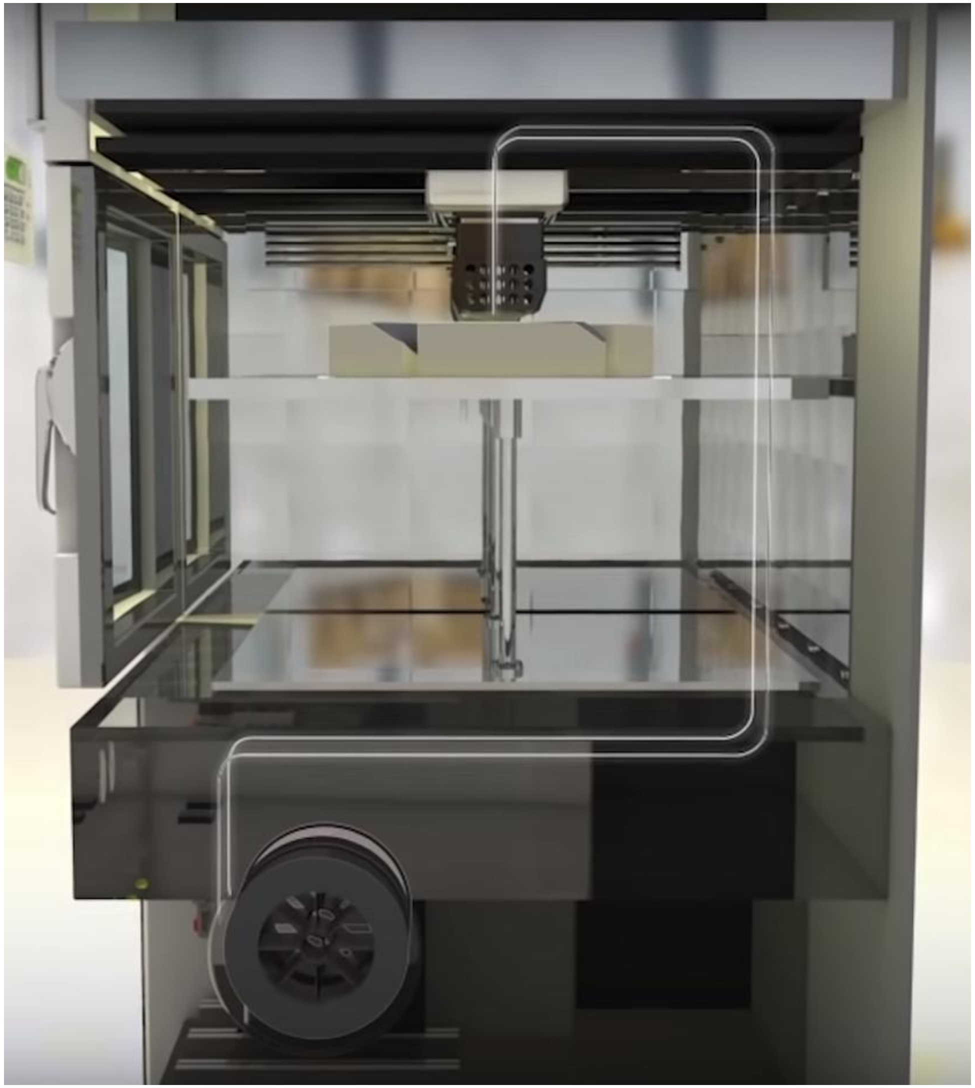
FDM



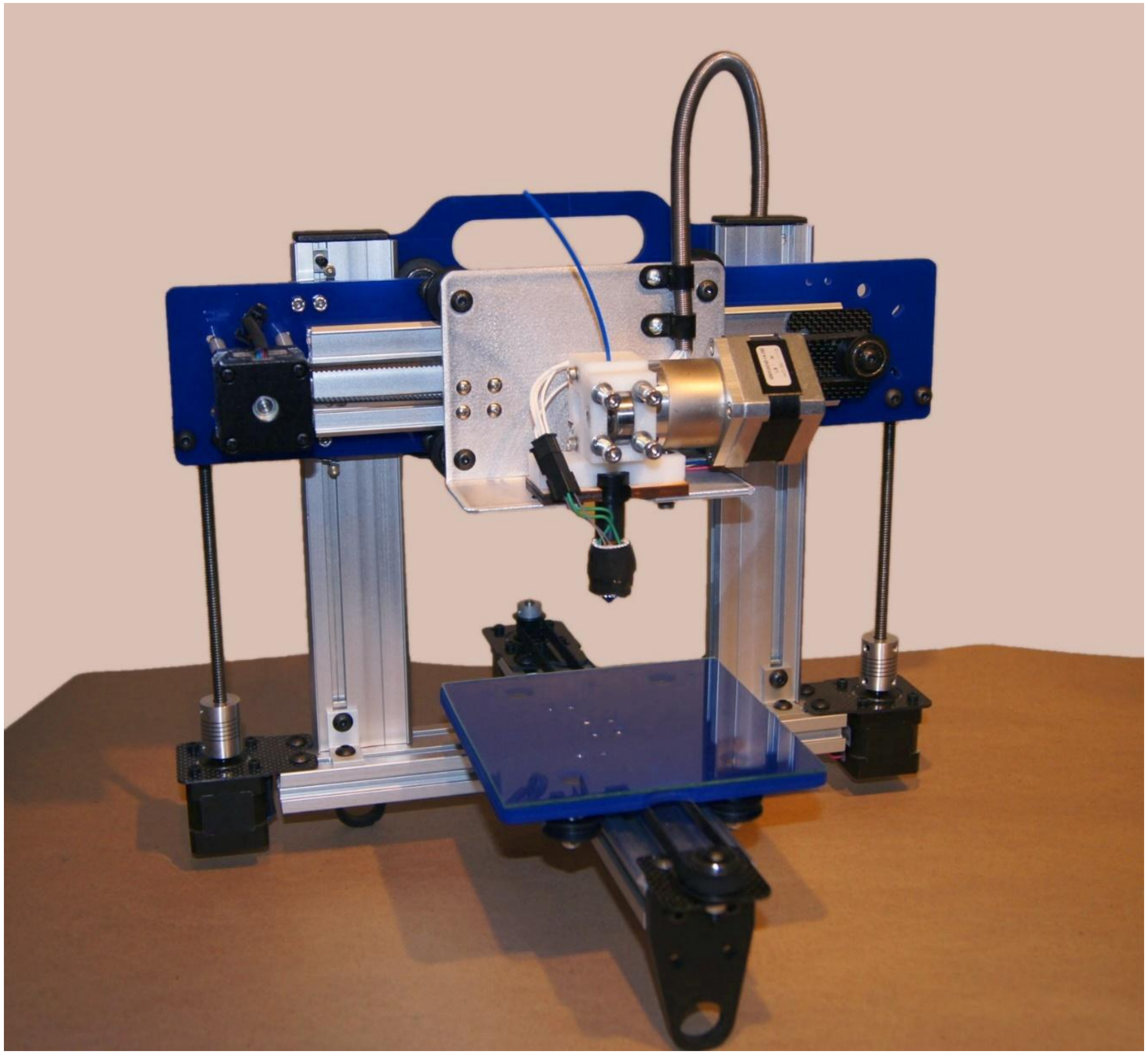
FDM



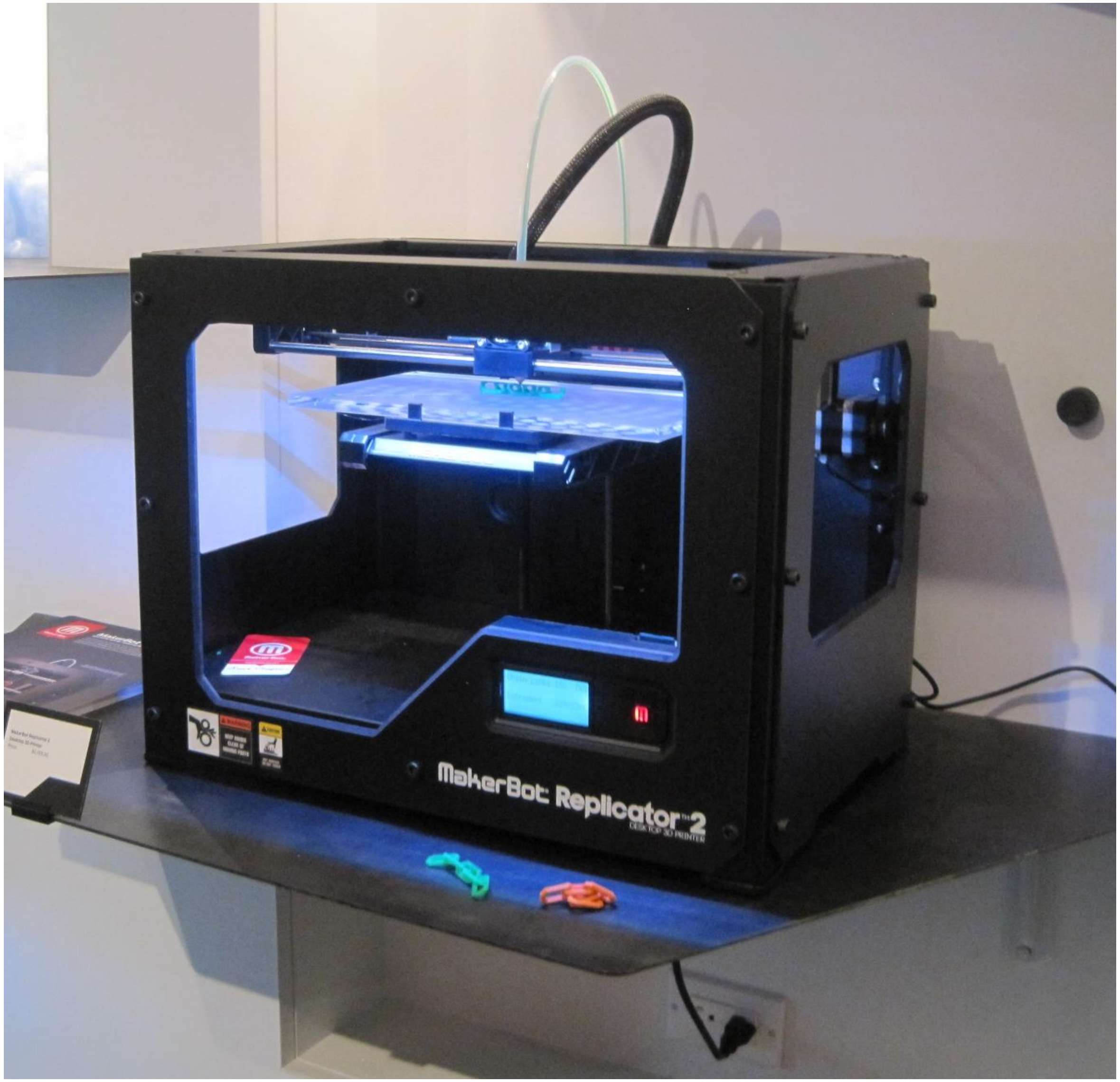
FDM



FDM - machine structure



FDM - machine

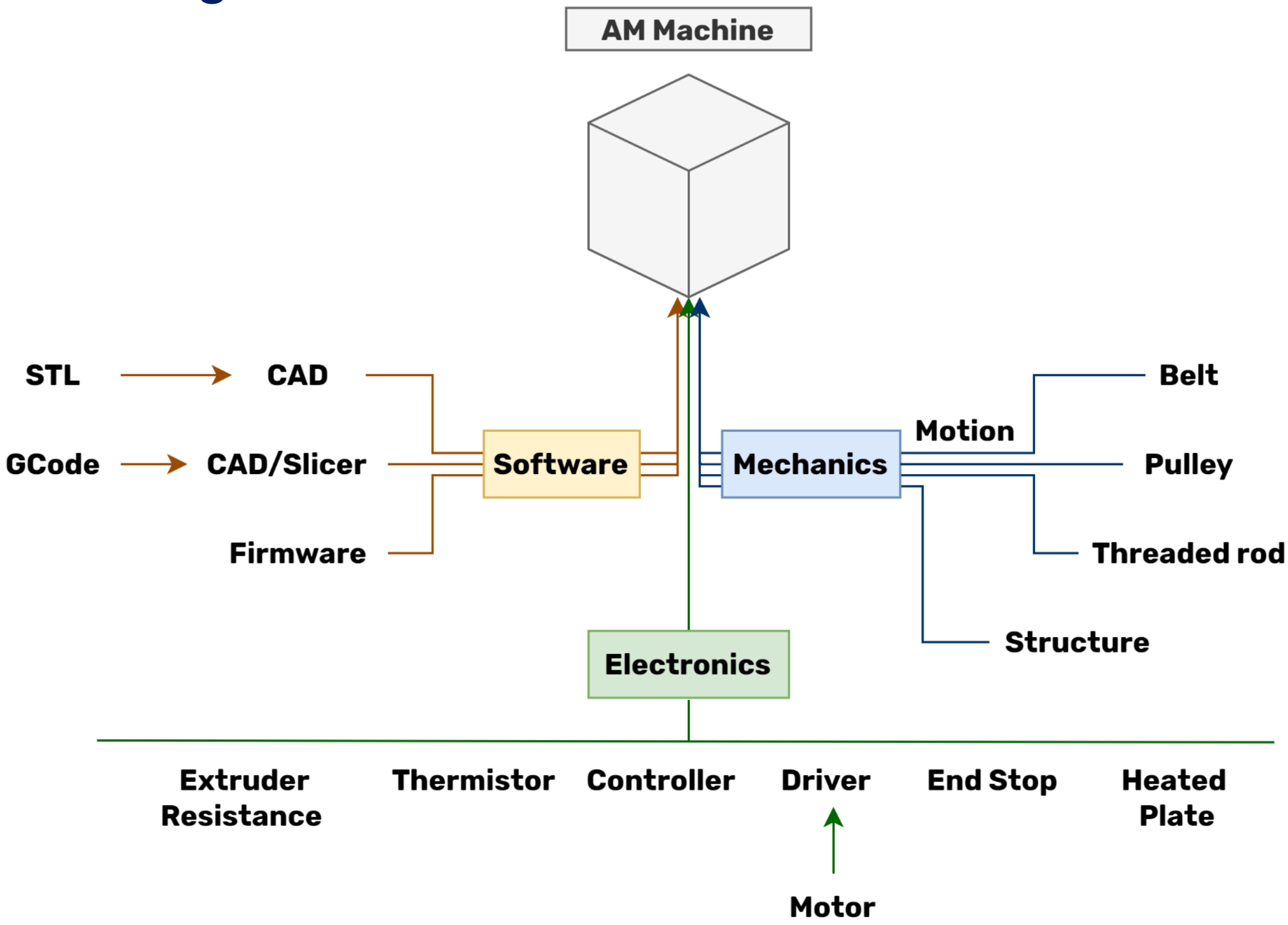


FDM - machine

FDM - machines

FDM – machines dimensions

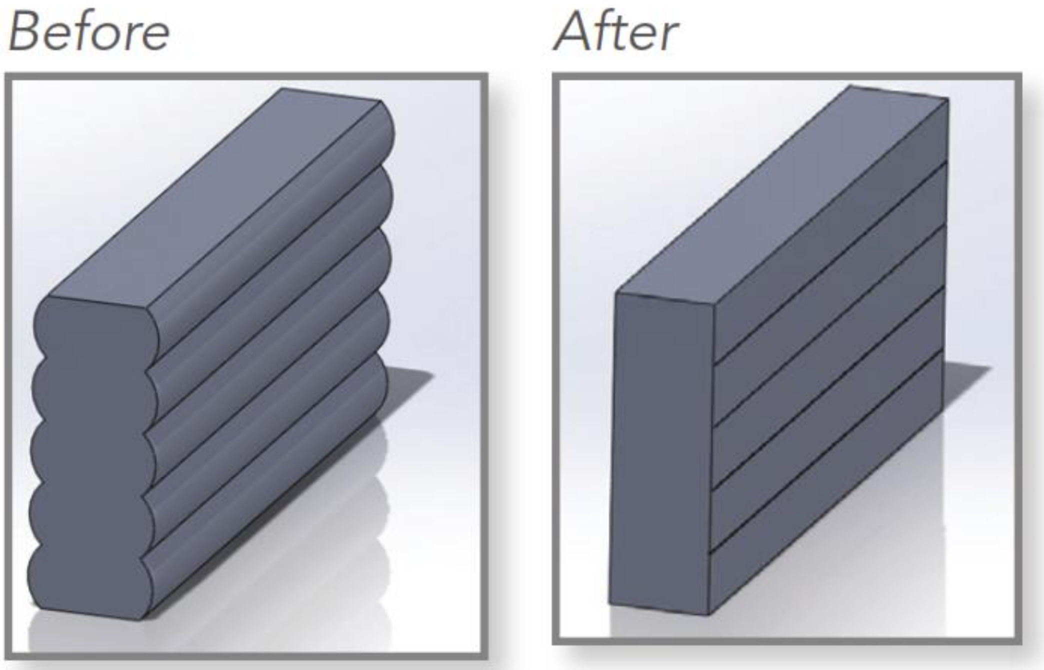
Machine diagram



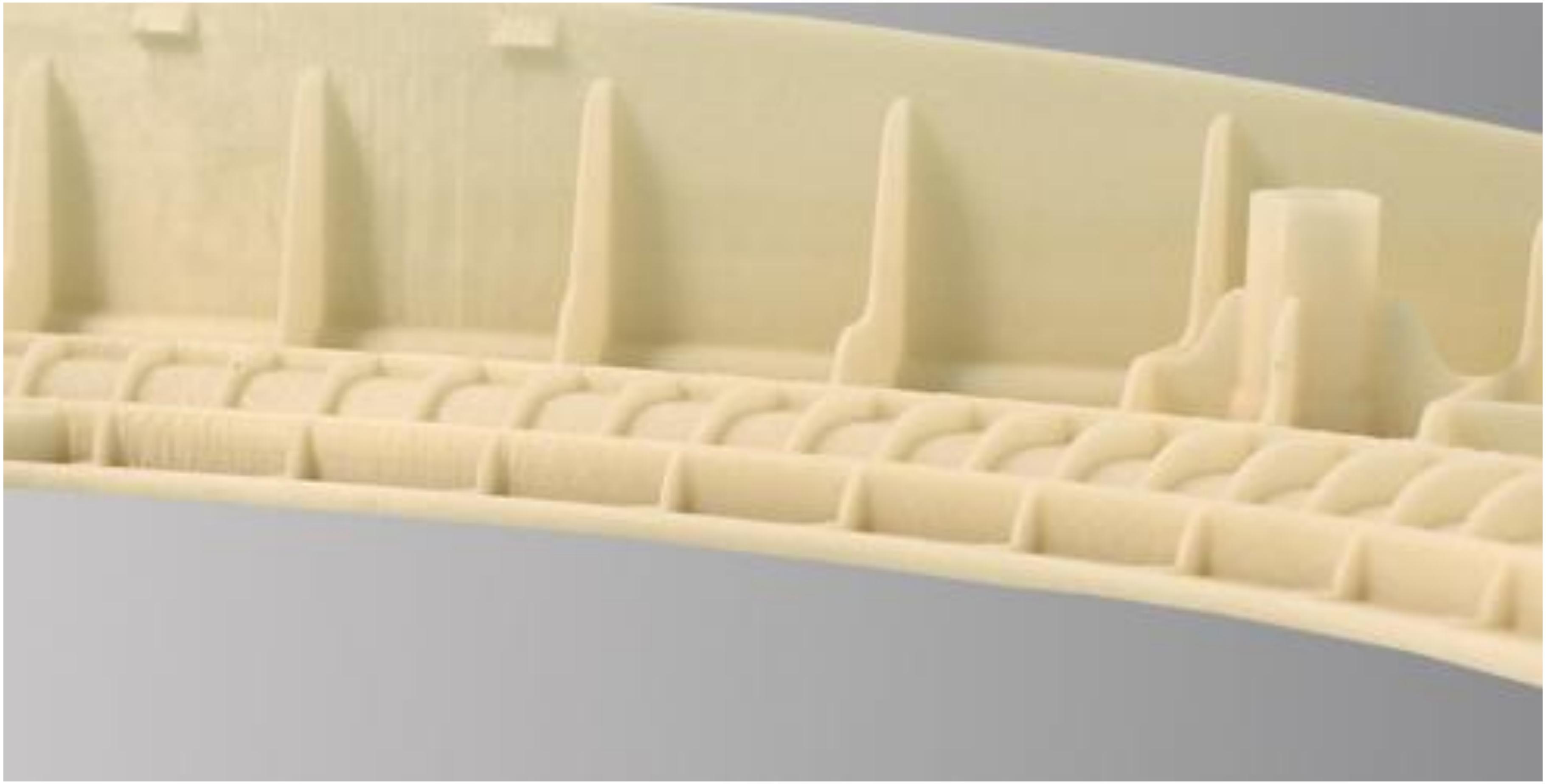
FDM - Surface finish

- Even a color print deserves the artistic finishing touches. A printed piece can be spray painted, hand painted for additional effects, and polished for enhanced realism

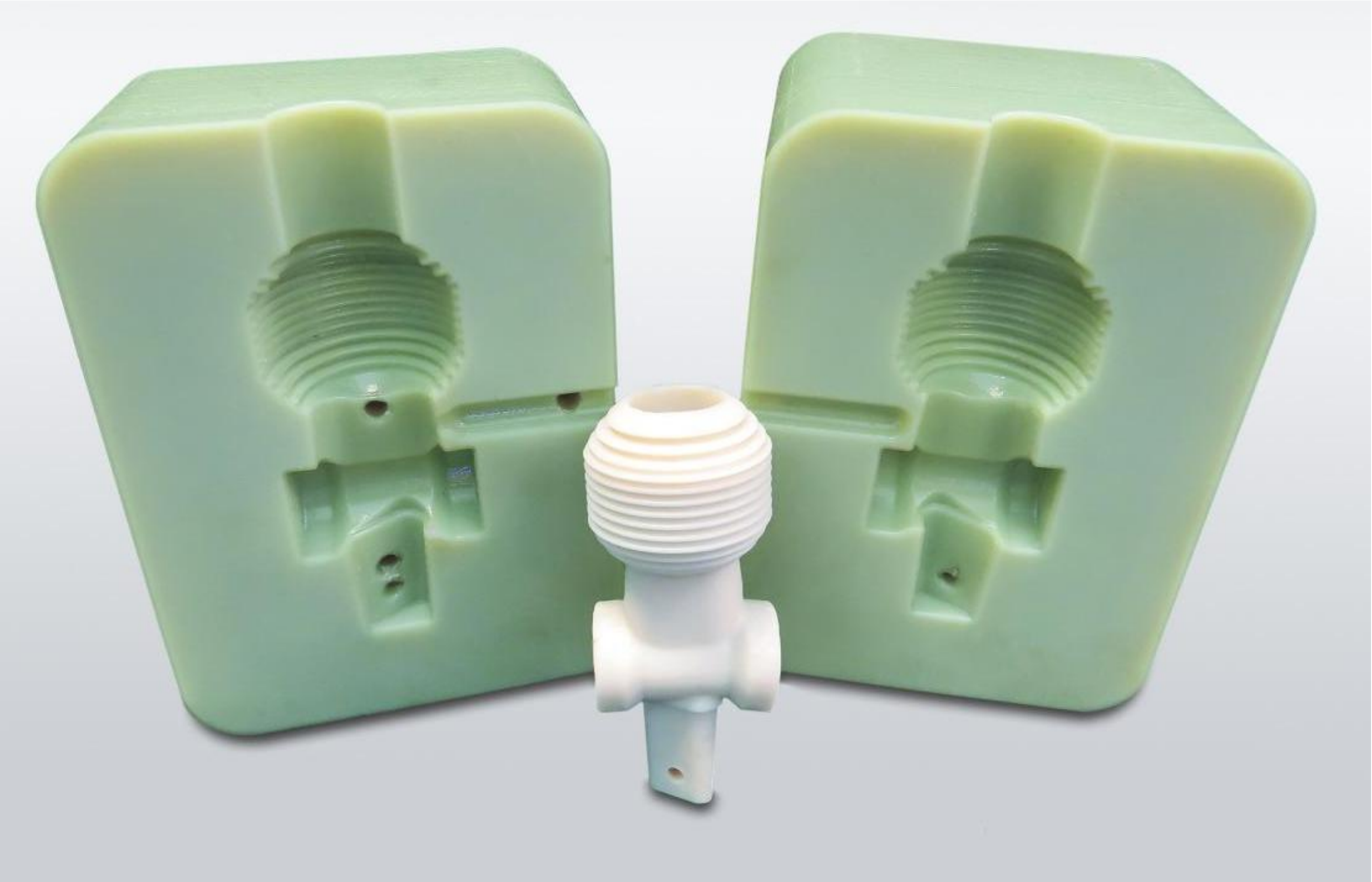
Illustration of the finishing effect on FDM surfaces



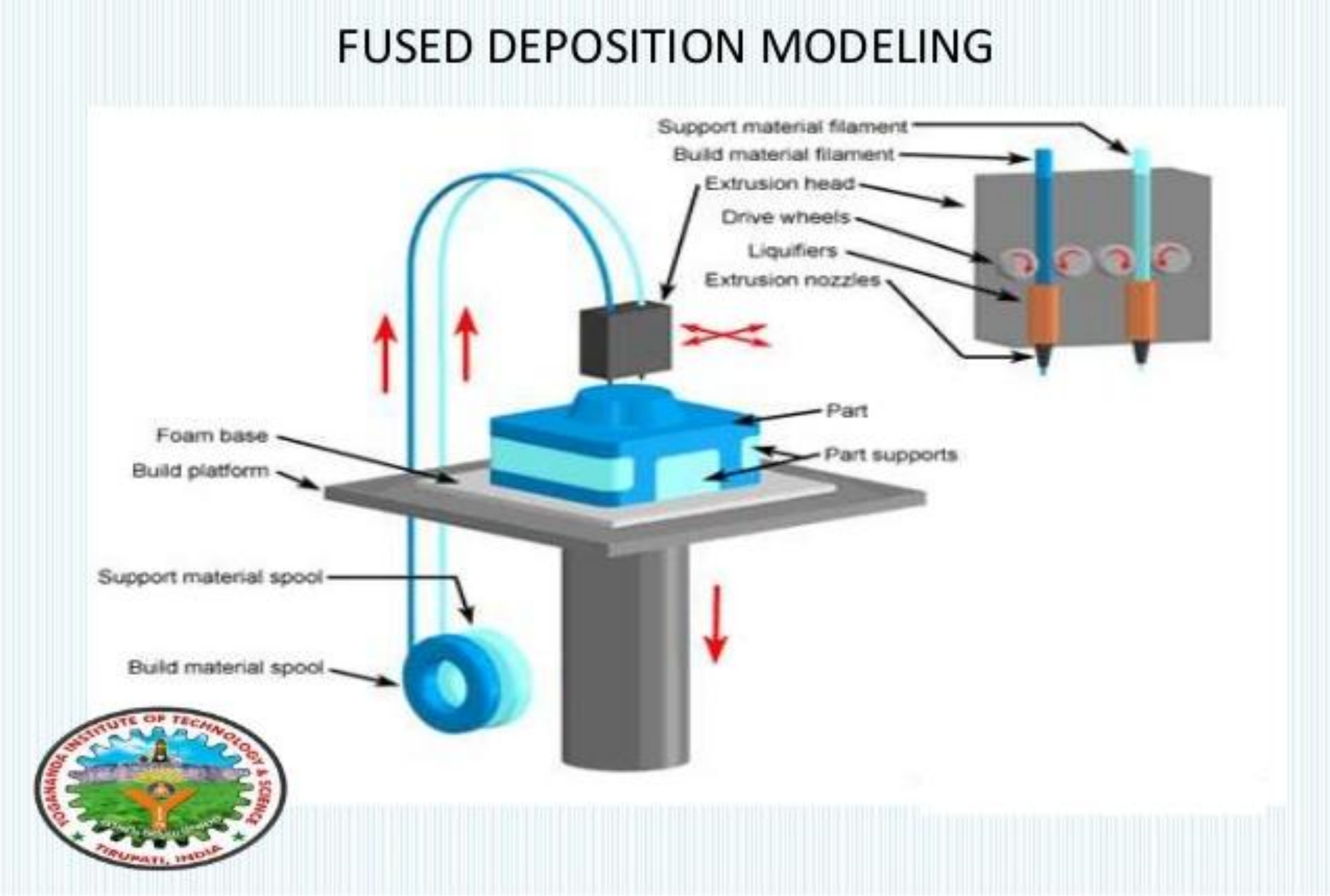
FDM - Appearance of the piece



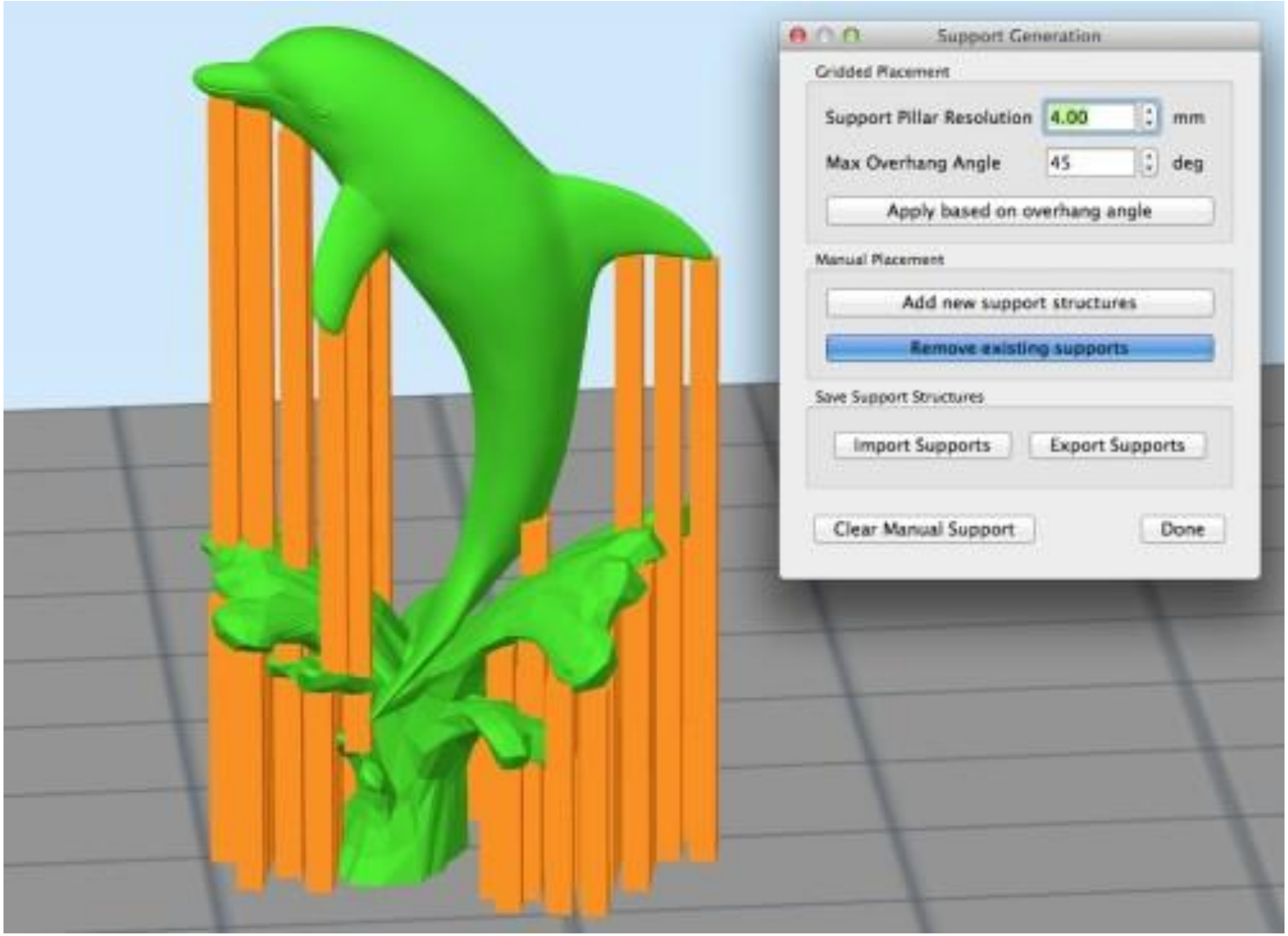
FDM - To make work equipment



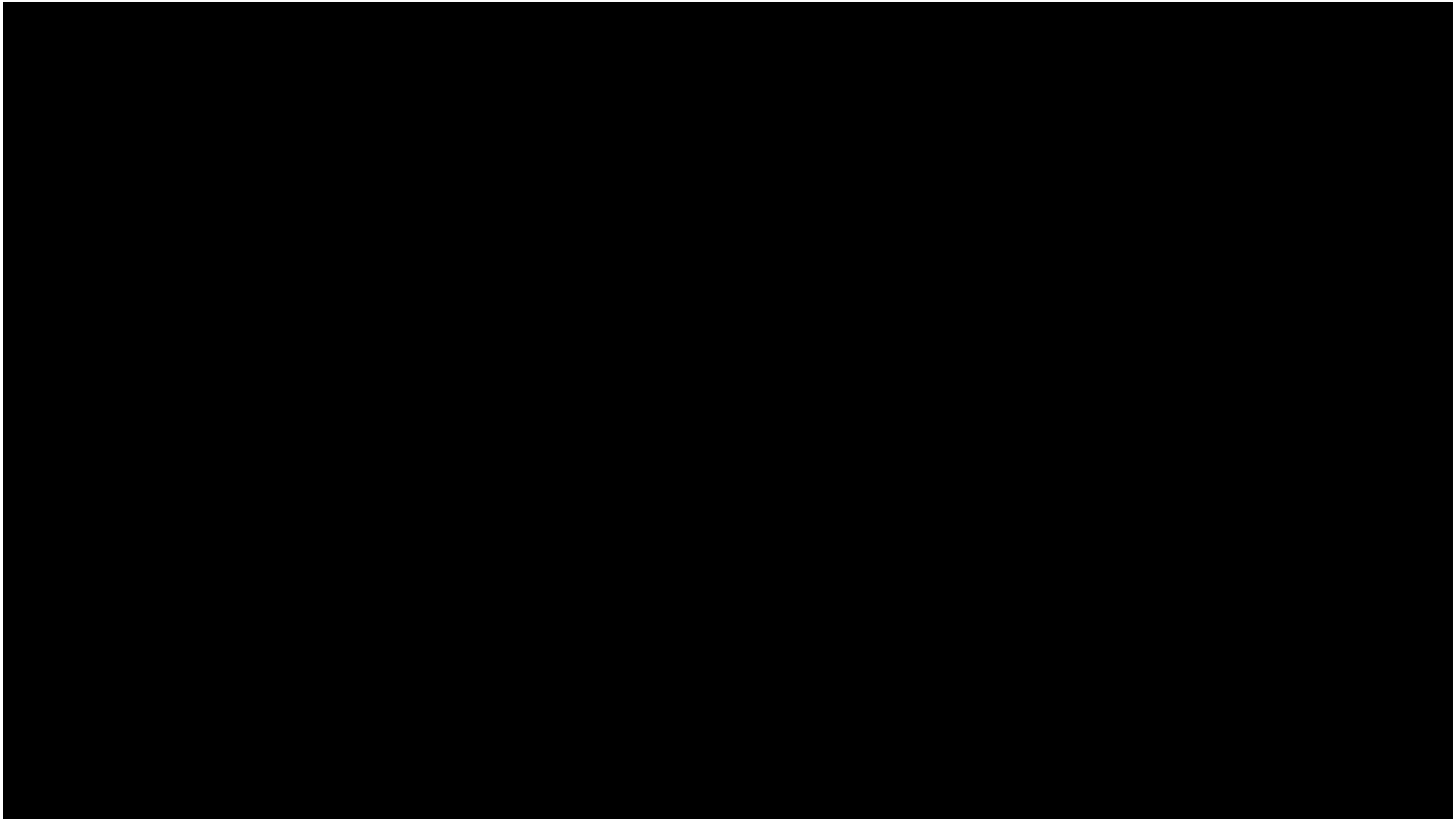
FDM - With support material



FDM - Meaning of the support material



FDM



MJM

- **MJM - Multi-jet Modeling**

  Multijet modeling (MJM) is the additive manufacturing process of a large industrial printhead that sprays material onto a printing plate one layer at a time. The print head has many very small holes that spray droplets of build material and backing material at the same time to build your part one layer at a time.

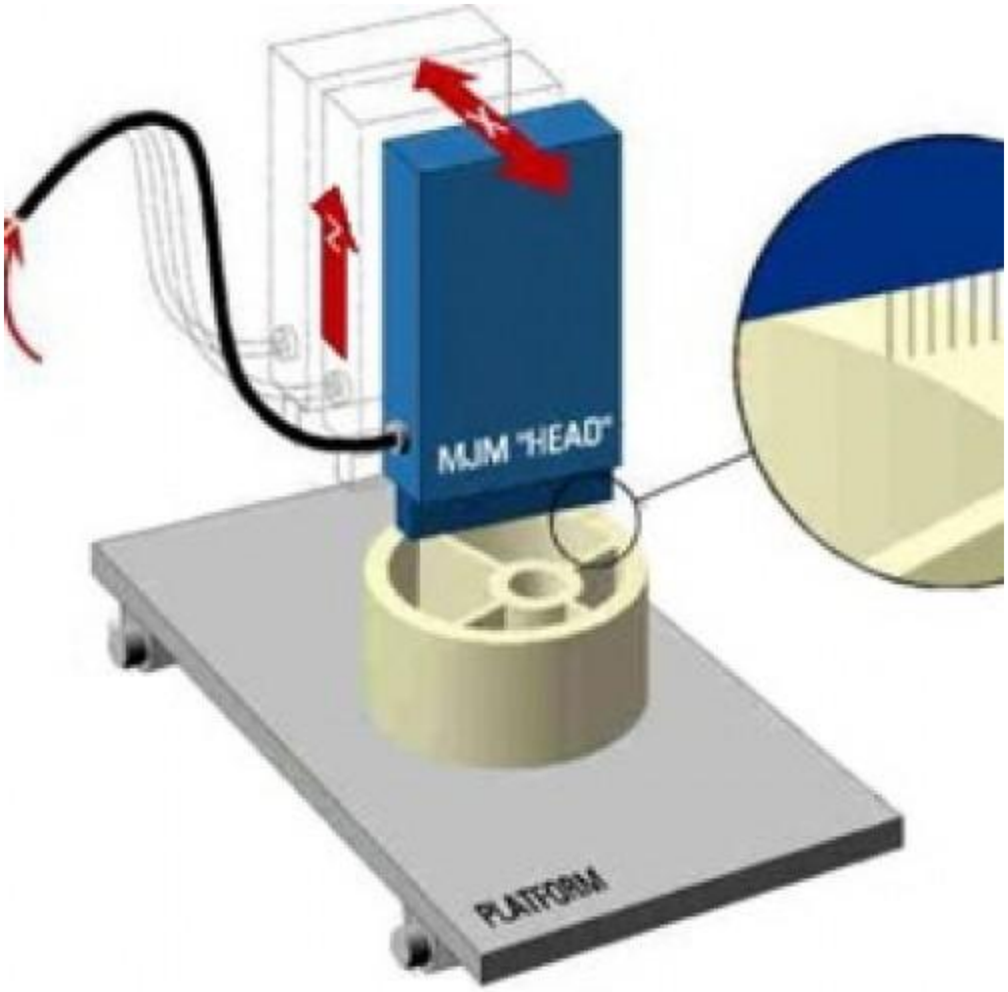
  The material used is a type of photopolymer similar to the SLA process which requires UV light to harden

  This type of 3D printing is found in a wide variety of business applications, including dental, medical, jewelry, and manufacturing

MJM - Advantages

- One of the major advantages of MJM is that the support structure is made of wax. This leads to a manual finishing process that requires an oven to melt the wax, leaving the printed part finished. Also because the print head emits such small droplets, MJM allows you to get details in extremely small and precise parts. Printing a screen, similar to the one on a screen door, is quite easy for this technology. No other technology can achieve the level of detail that MJM offers in terms of smooth surface and fine detail without any hassle for support
  - True to the exceptional internal geometry design
  - Fast and durable hard plastic parts
  - Castable models
  - 100% Real Wax high-definition precision patterns for direct investment casting applications
  - Multiple finishing options
    - Note: If you are using (wax) holder, please note that you need to have drainage holes in the model

MJM



MJM – High definition features

Ex. of Additive Manufacturing – (additivemanufacturing.com)

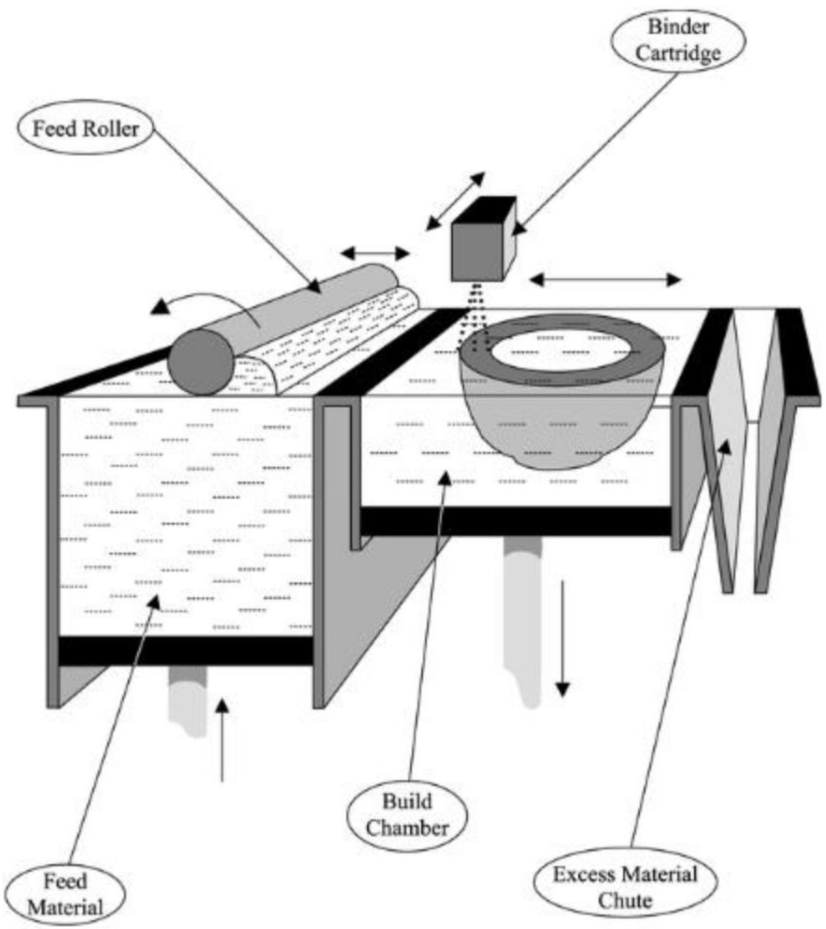
- **3DP**

  It involves building a model in a container filled with starch powder or gypsum-based material. An inkjet printer head applies a small amount of binder to form a layer. After applying the binder, a new layer of powder is swept over the previous layer with the application of more binder. The process repeats until the model is completed. Since the model is powder-supported, no support is needed. Also, this is the only process that makes color models

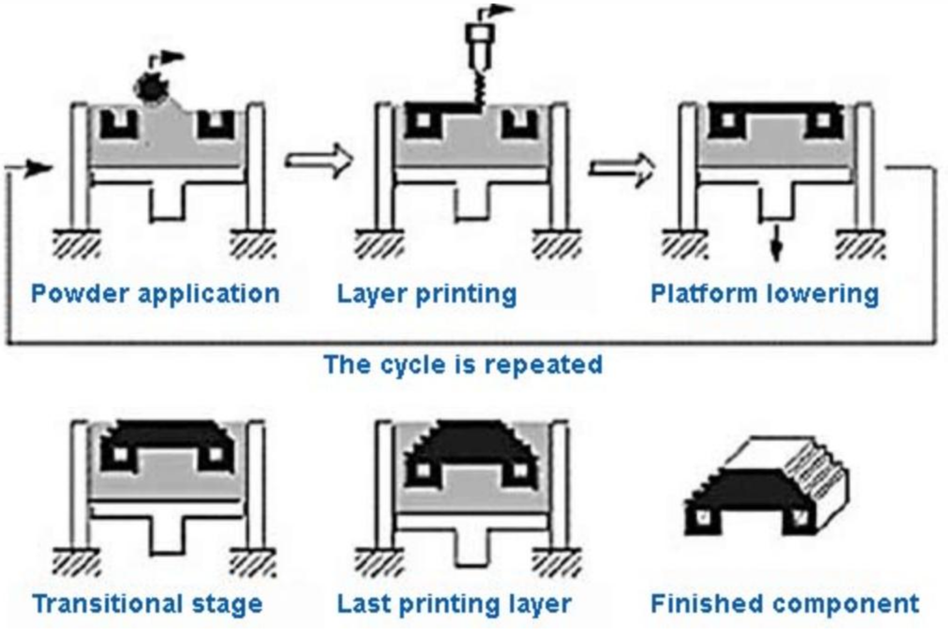
- **SLS – Selective Laser Sintering**

  It uses a high-powered laser to melt small particles of plastic, metal, ceramic or glass. During the construction cycle, the platform on which the construction is repositioned, lowering by a single layer of thickness. The process repeats until the model is completed. Unlike SLA technology, the support material is not needed as the construction is supported by unsintered material

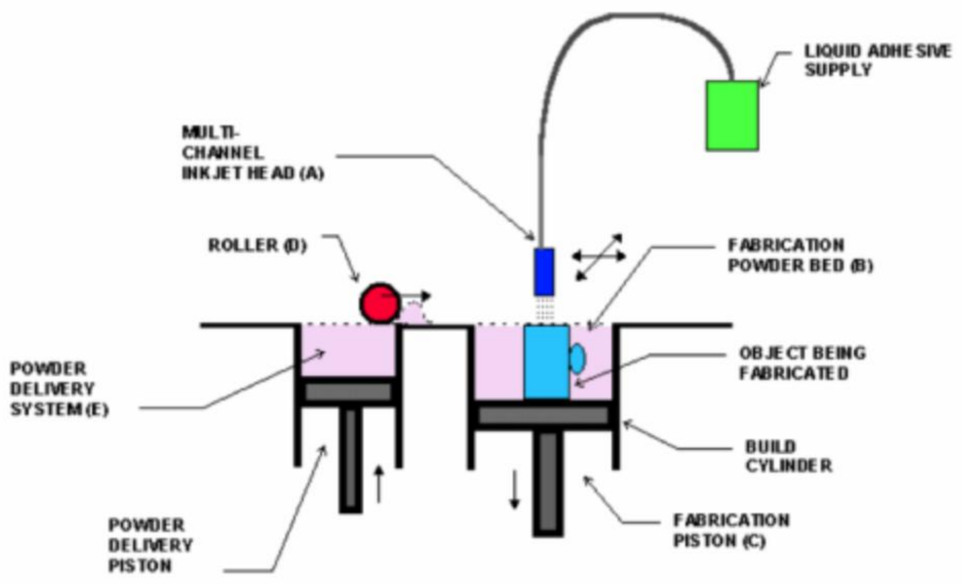
3DP



Binder Cartridge
Feed Roller
Build Chamber
Feed Material
Excess Material Chute

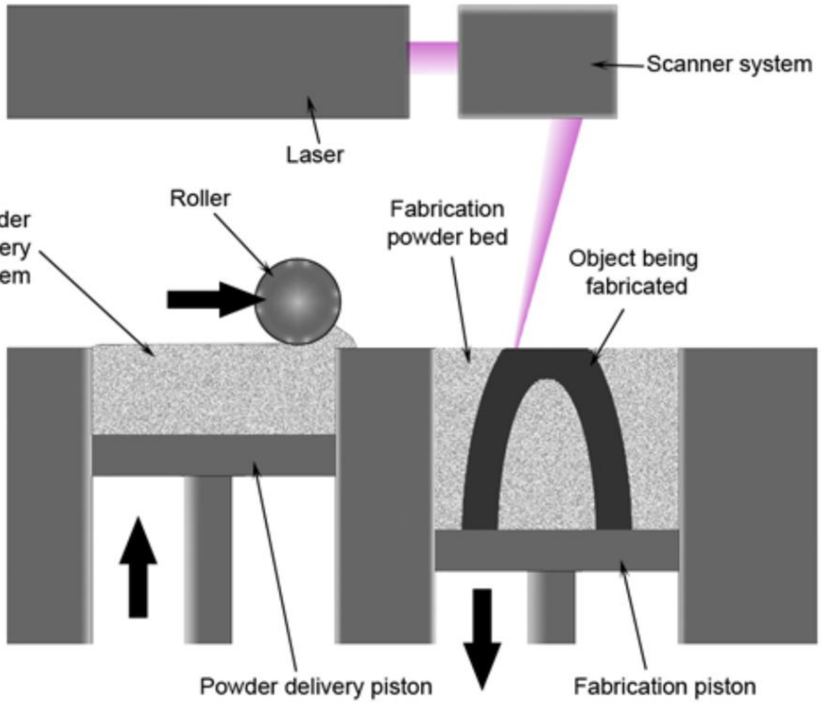


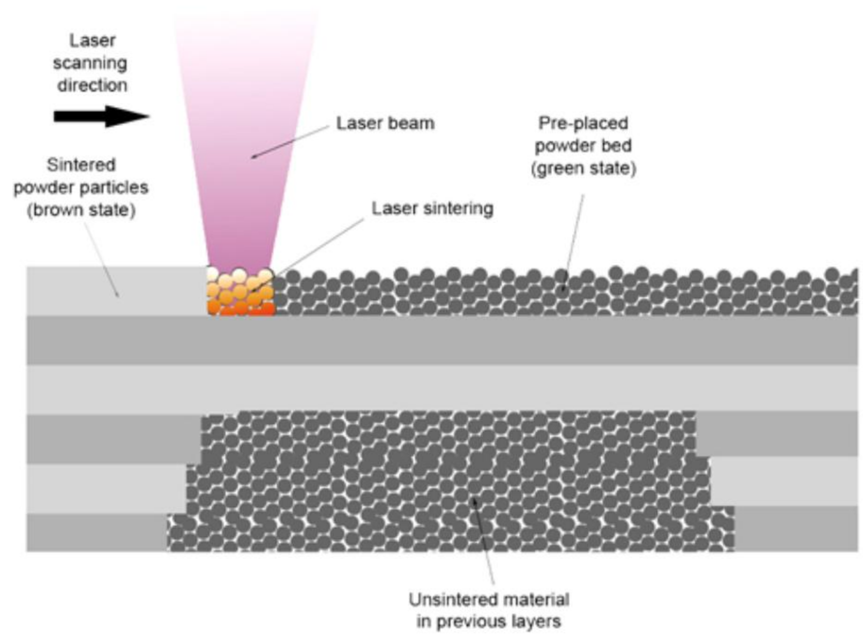
Powder application
Layer printing
Platform lowering
The cycle is repeated
Transitional stage
Last printing layer
Finished component



LIQUID ADHESIVE SUPPLY
MULTI-CHANNEL INKJET HEAD (A)
ROLLER (D)
FABRICATION POWDER BED (B)
OBJECT BEING FABRICATED
POWDER DELIVERY SYSTEM (E)
BUILD CYLINDER
FABRICATION PISTON (C)
POWDER DELIVERY PISTON

SLS - Selective Laser Sintering





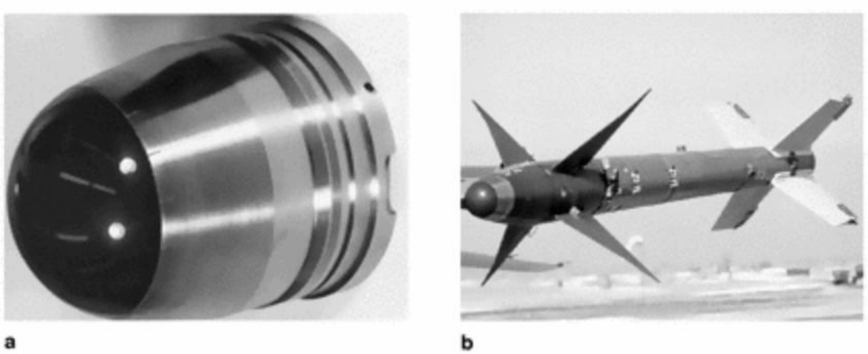
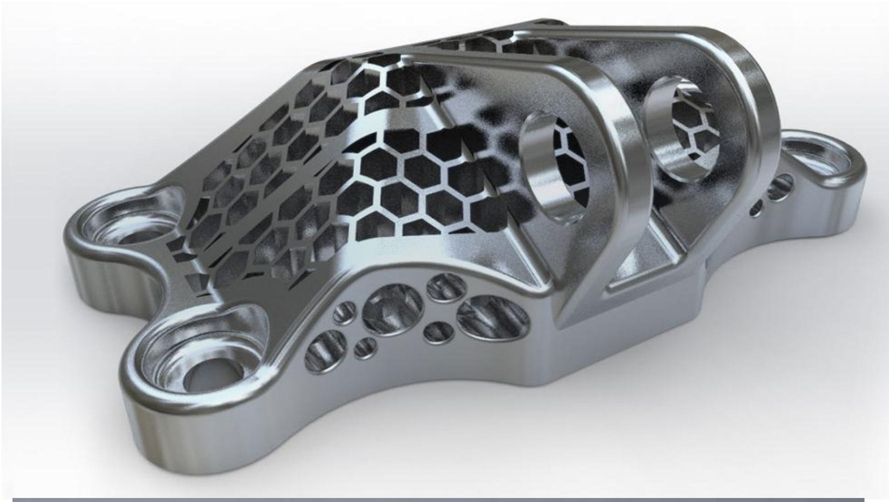
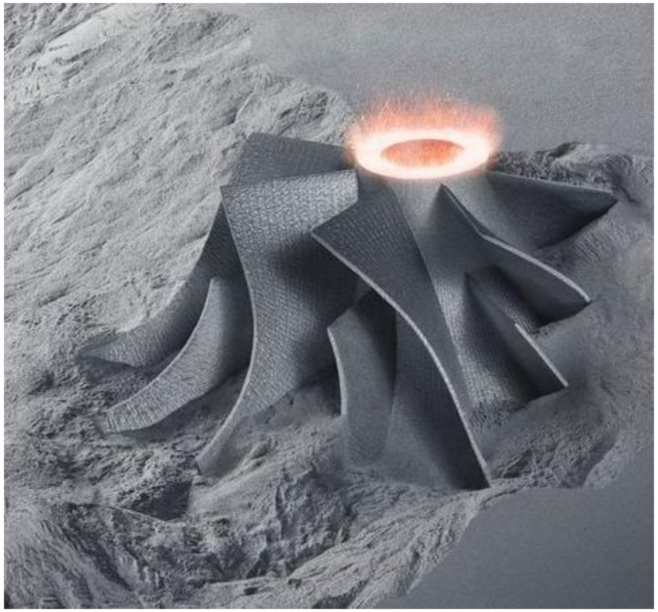
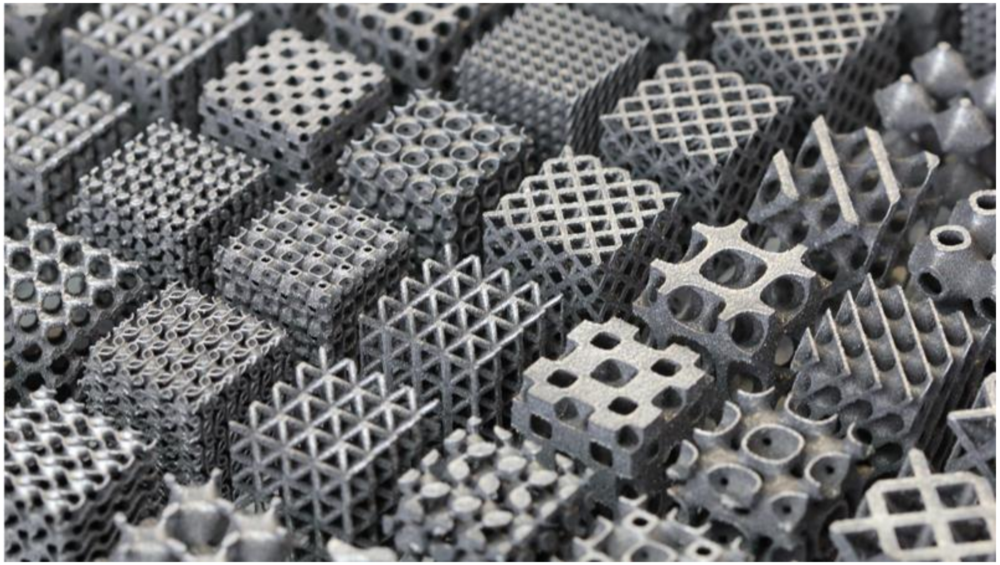


Figure 2. (a) A titanium guidance section housing for a (b) Sidewinder missile.



SLS


TruPrint 1000
Compact and robust 3D printing
TRUMPF
TruPrint 1000

Other additive manufacturing methods

- **DLP – digital light processing**: a vat of liquid polymer is exposed to the light of a projector in inactinic light conditions. The liquid polymer is exposed. The build plate then moves down in small increments and the liquid polymer is again exposed to light. The process repeats until the model is built, layer by layer. The liquid polymer is then drained from the vat, leaving the finished solid model

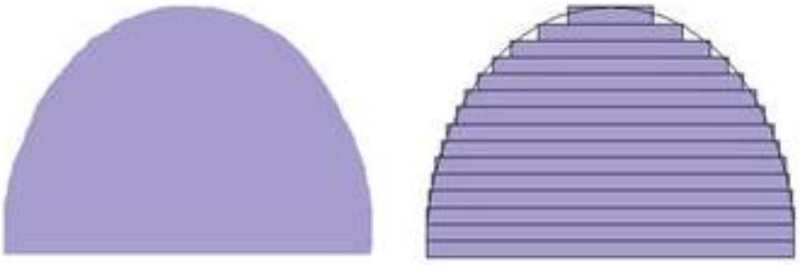
- **DMLS – direct metal laser sintering**: SLS-like technology that uses metals as a material

- **LOM – laminated object manufacturing**: layers of paper, plastic or laminated metal are glued and cut using a blade or laser until the desired shape is achieved

- **EBM – electron beam melting**: a source of high energy, composed of a suitably concentrated and accelerated beam of electrons, strikes a metal material in a "micro-granulometric" form causing it to melt

Defects - Process parameters

- Temperature
- Translation speed
- Flow of material
- Layer height
- Internal fill ratio
  and many others …

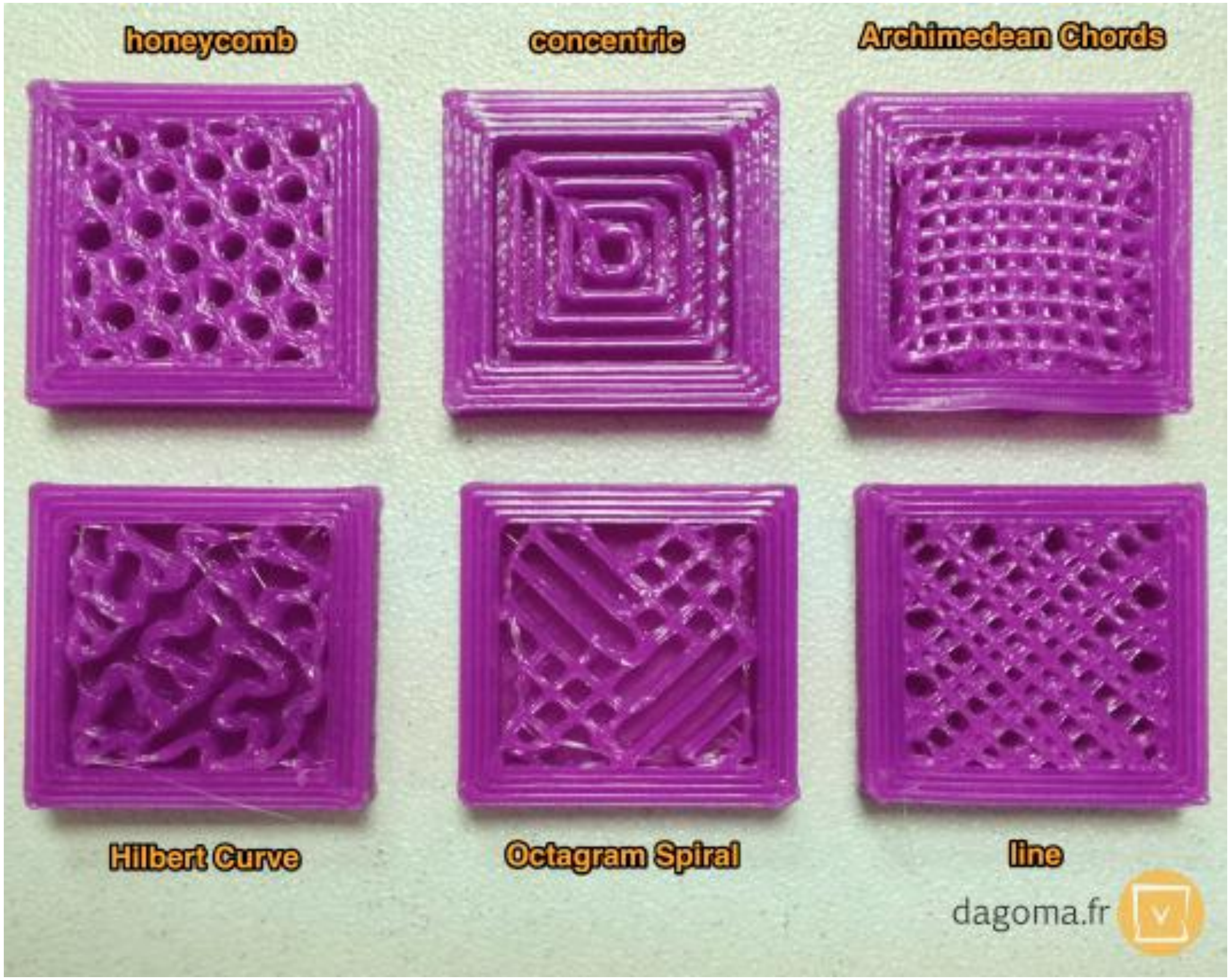


The internal filling

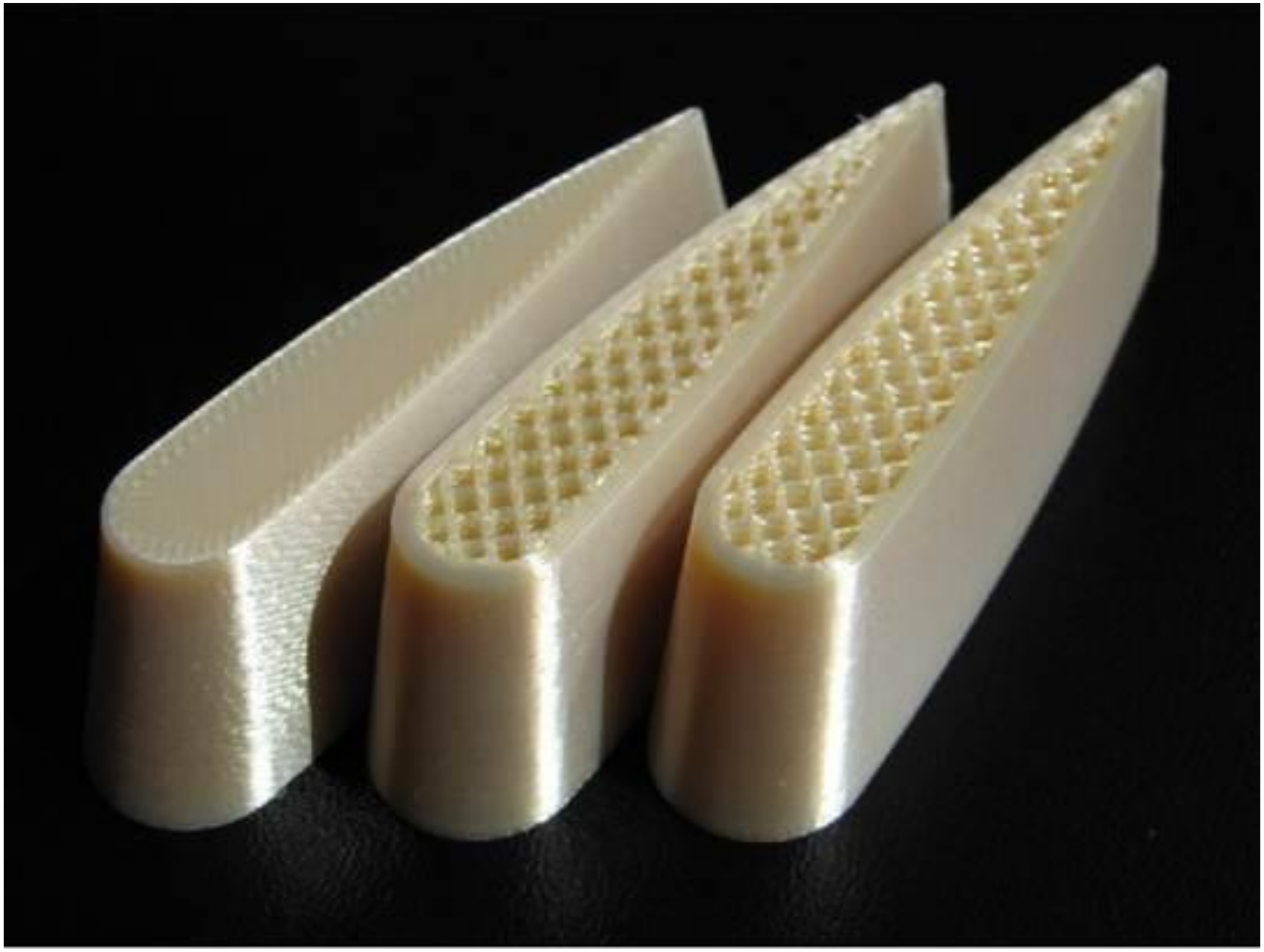
- Saving of material
- Reduction of production times
- Mass reduction
- Same resistance characteristics

The internal filling

The internal filling



The internal filling



Time and costs

3D Print Specs	Slice Settings	3D File

Motorcycle Gas Tank

Material: PLA
Size: X: 358 Y: 657 Z: 322 mm (X: 14 Y: 26 Z: 12.5 in)
Filament Used (mm): 1,169,684
Material Cost: $468
Print Time 0.4 mm Nozzle: 251 hours
Print Time 0.6 mm Nozzle: 179 hours
Print Time 1.2 mm Nozzle: 81 hours

3D Print Specs	Slice Settings	3D File

Rim

Material: PLA
Size: X: 480 Y: 480 Z: 230 mm (X: 19 Y: 19 Z: 9 in)
Filament Used (mm): 248,638
Material Cost: $99
Print Time 0.4 mm Nozzle: 186 hours
Print Time 0.6 mm Nozzle: 133 hours
Print Time 1.2 mm Nozzle: 60 hours

Time and costs

3D Print Specs | Slice Settings | 3D File

Chair

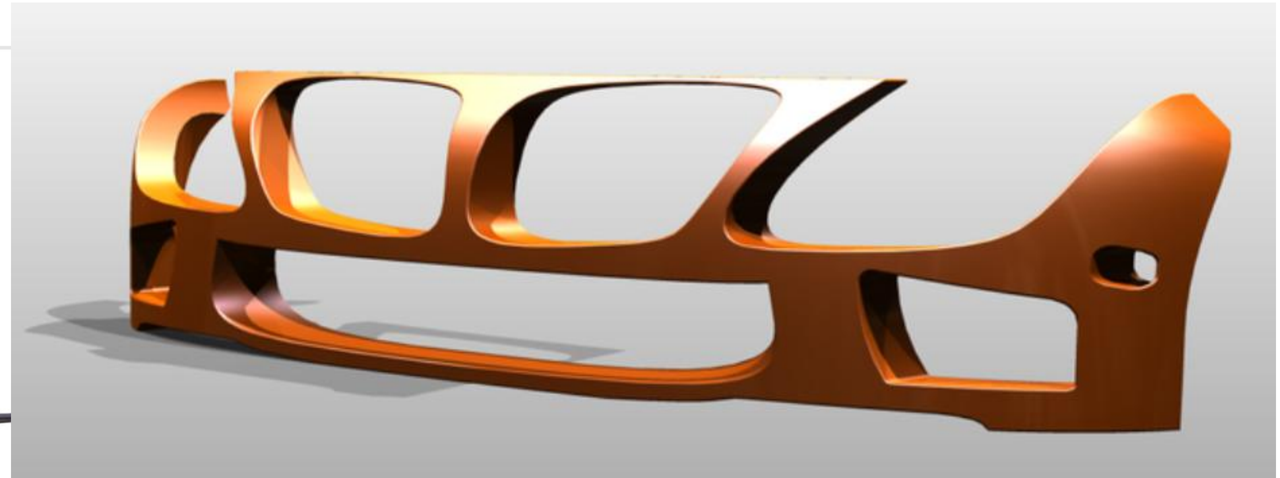
Material: PLA
Size: X: 554 Y: 835 Z: 488 mm (X: 22 Y: 39 Z: 19 in)
Filament Used (mm): 1,404,889
Material Cost: $562
Print Time 0.4 mm Nozzle: 225 hours
Print Time 0.6 mm Nozzle: 161 hours
Print Time 1.2 mm Nozzle: 72 hours

3D Print Specs | Slice Settings | 3D File

Engine Block

Material: PLA
Size: X: 673 Y: 546 Z: 406 mm (X: 26.5 Y: 21.5 Z: 16 in)
Filament Used (mm): 2,404,715
Material Cost: $962
Print Time 0.4 mm Nozzle: 568 hours
Print Time 0.6 mm Nozzle: 406 hours
Print Time 1.2 mm Nozzle: 183 hours

Time and costs



3D Print Specs | Slice Settings | 3D File

Bumper

Material: PLA

Size: X: 375 Y: 850 Z: 355 mm (x2) (X: 15 Y: 33.5 Z: 14 in (x2)

Filament Used (mm): 2,079,496

Material Cost: $832

Print Time 0.4 mm Nozzle: 462 hours

Print Time 0.6 mm Nozzle: 330 hours

Print Time 1.2 mm Nozzle: 149 hours

Infill Percentage: 15%

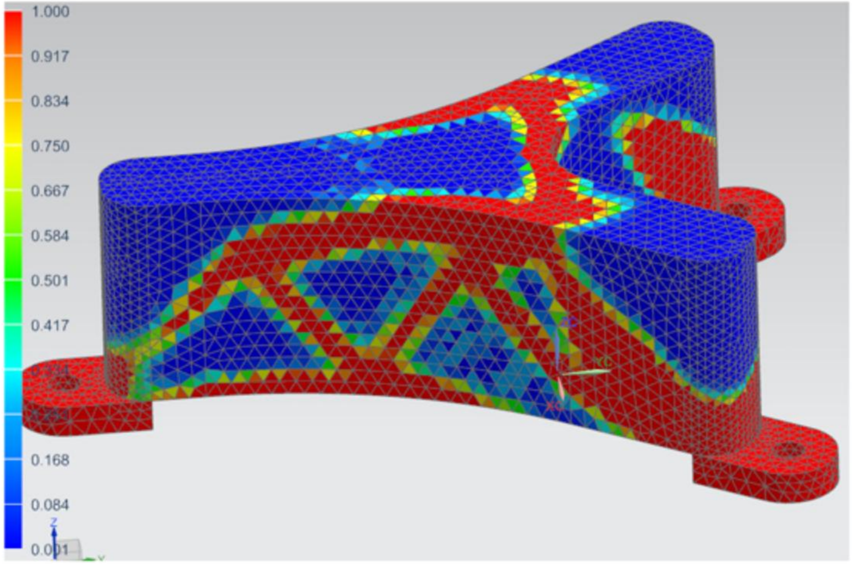
Top Solid Layers: 6

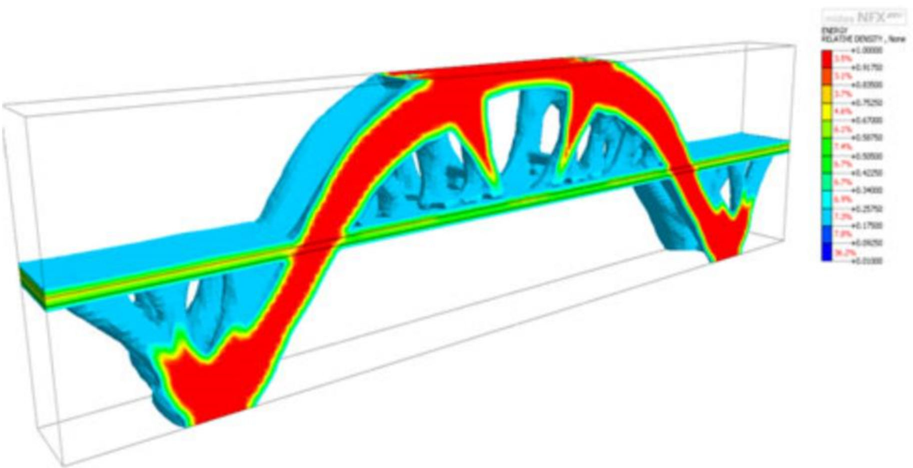
Bottom Solid Layers: 6

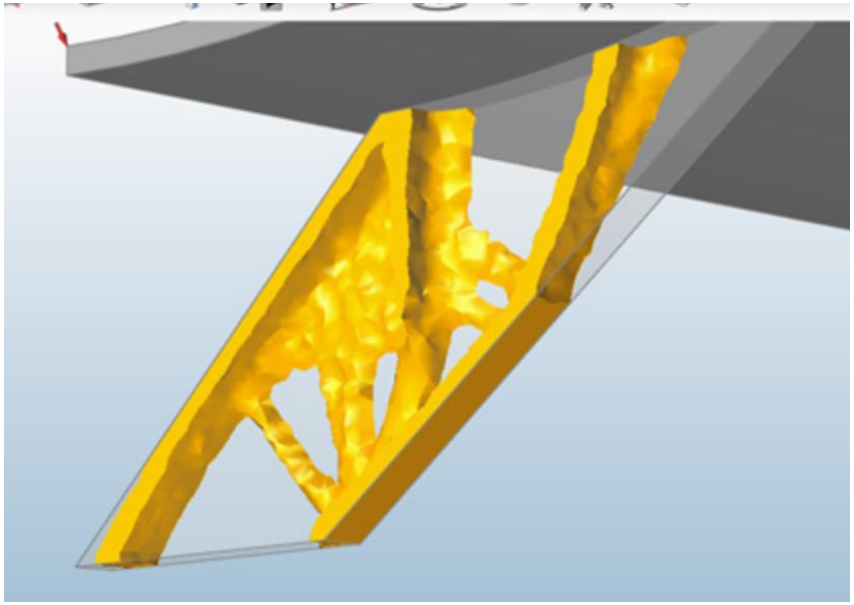
Outside Perimeters: 3

Supports Used: Yes

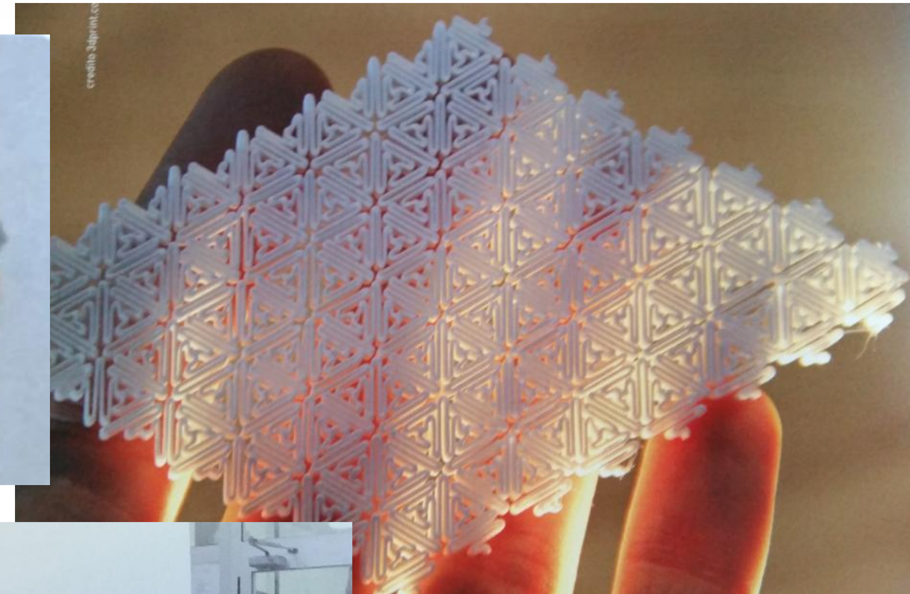
New Design Modes
The topological modeler





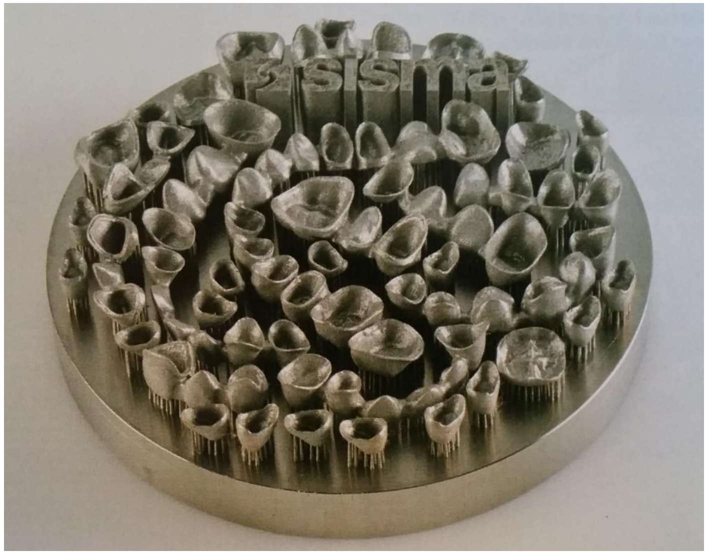


Examples

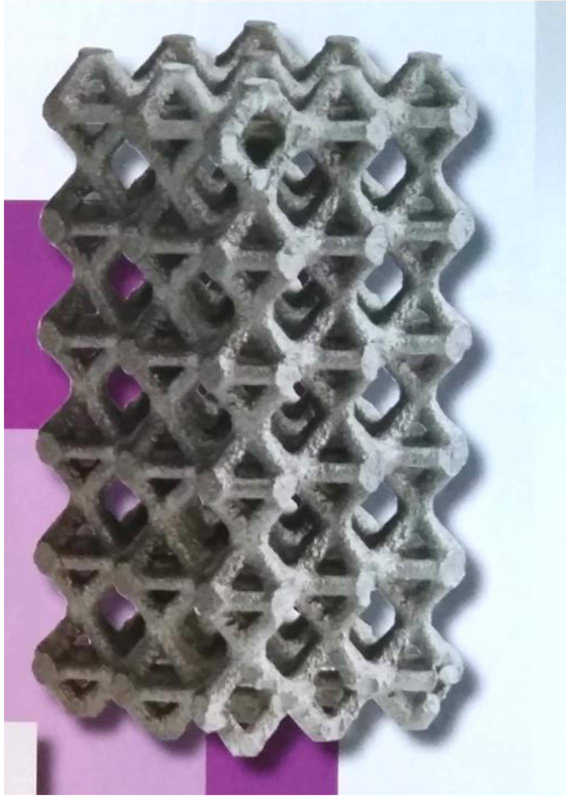


Il service CRP Technology è in grado di stampare prodotti definitivi. In queste due immagini vediamo la fase di stampa di uno scarpone da sci mediante una stampante 3D SLS (Sinterizzazione laser selettiva) che fonde il materiale Windform SP che ha sviluppato internamente. Si tratta di un materiale altamente duttile che presenta un'ottima resistenza meccanica, è impermeabile e possiede eccellenti caratteristiche di tenuta ai liquidi e ai gas.

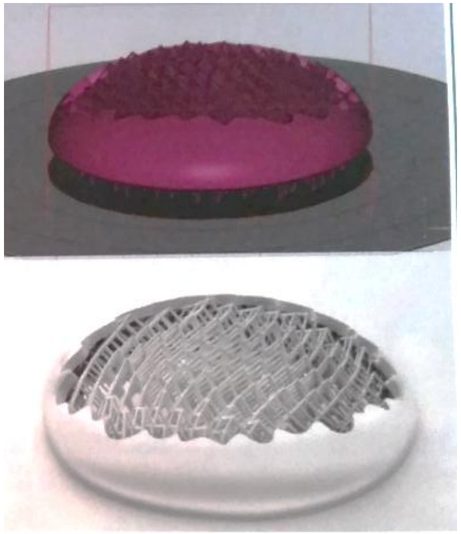
Examples



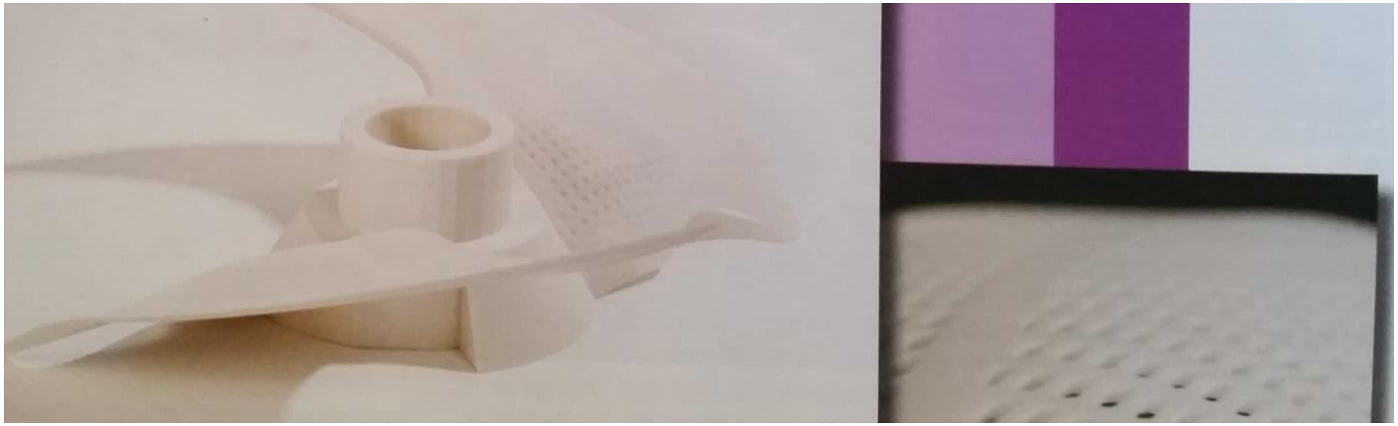
Dental elements in Cr-Co



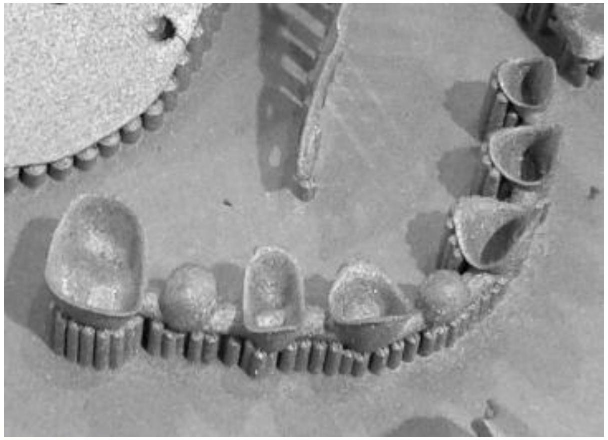
Part in Ag

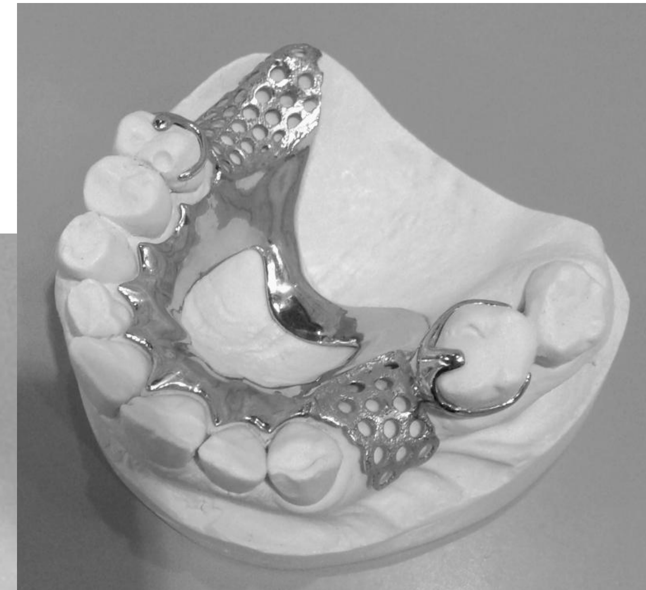


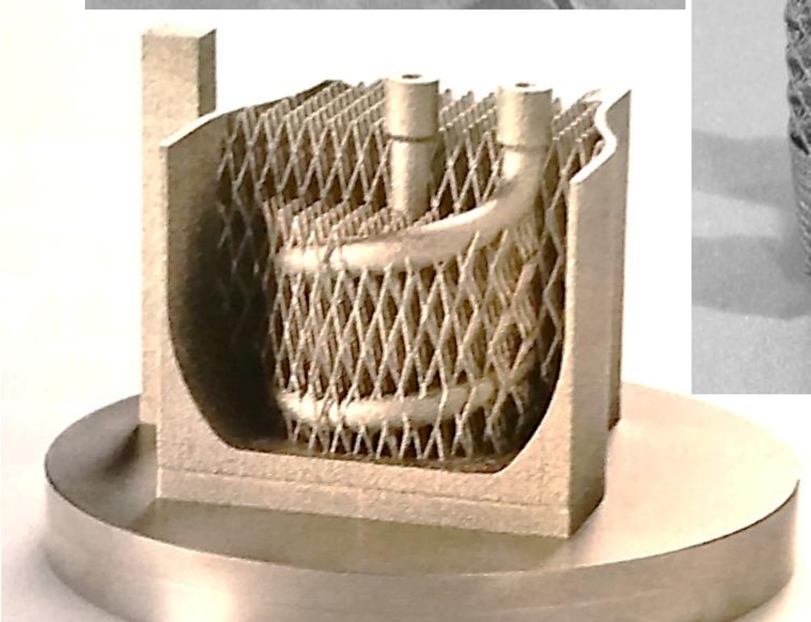
Bronze bracelet



Examples

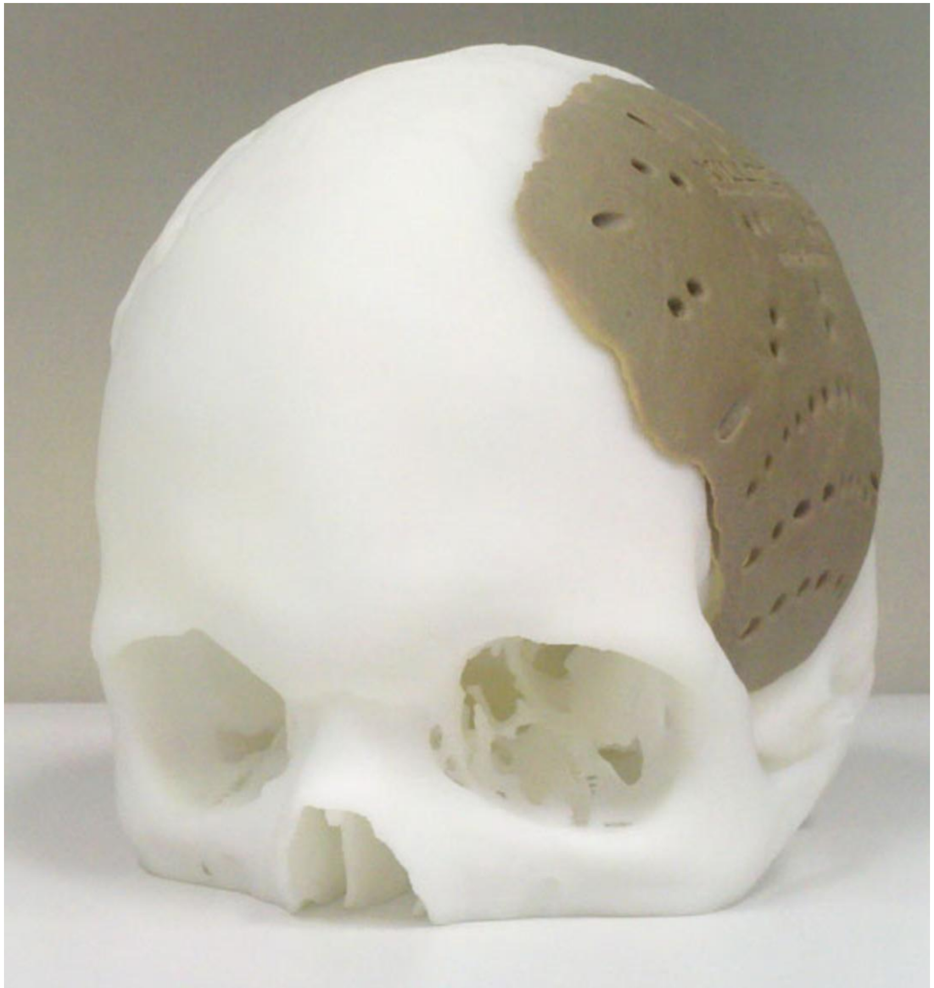






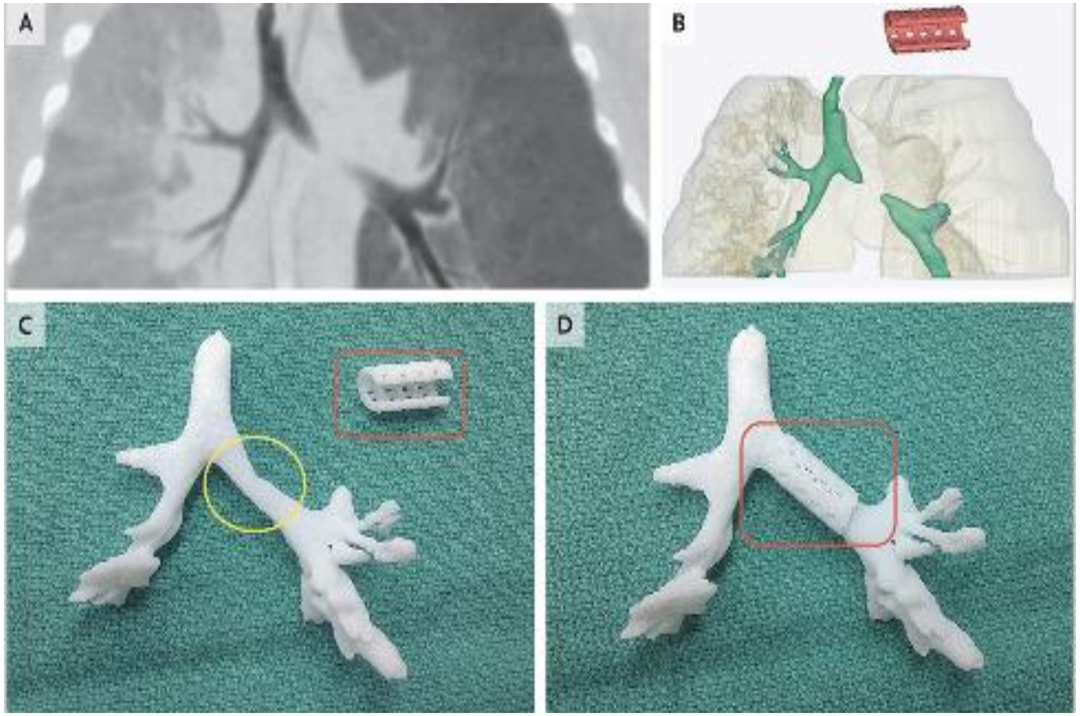
Liquid-air heat exchanger in AISI 316

Examples of prosthesis realization

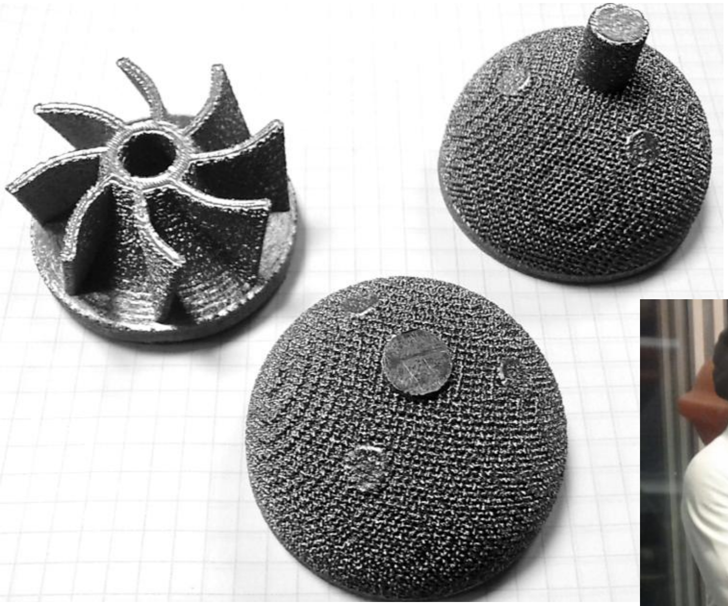


Example of biomedical application

- The University of Michigan used 3D printing to save a 20-month-old baby suffering from a life-threatening collapsed bronchus by creating a tracheal implant splint using a biopolymer
  To create the device, doctors took a CT scan of the child's trachea / bronchus and used it to model a device that was then 3D printed using stereolithography
  The material used, a bioabsorbable polymer known as polycaprolactone is designed to be absorbed by the body over a period of about three years, about the time it takes for patients to develop a healthy trachea

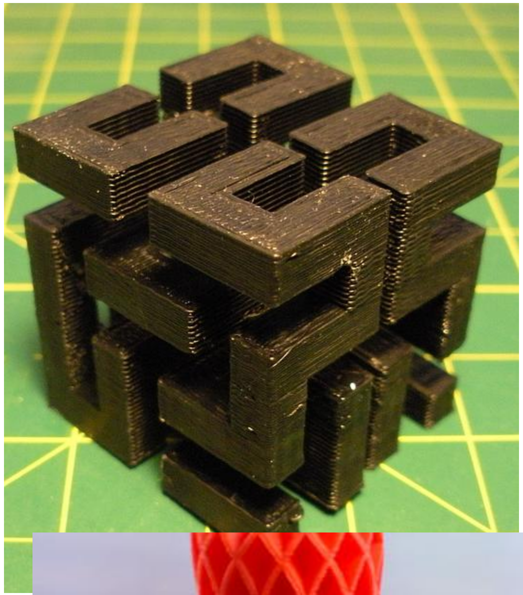


Examples



Examples of topological modeling

Examples of design products



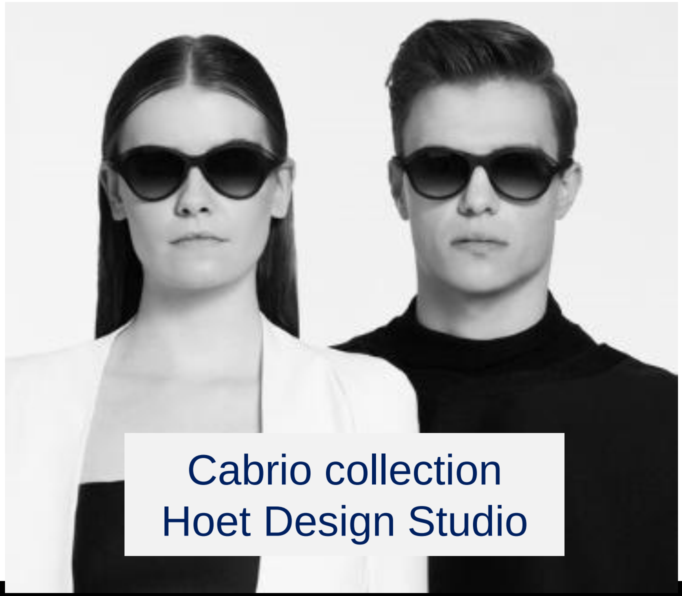
Examples of design products

Examples of fashion products

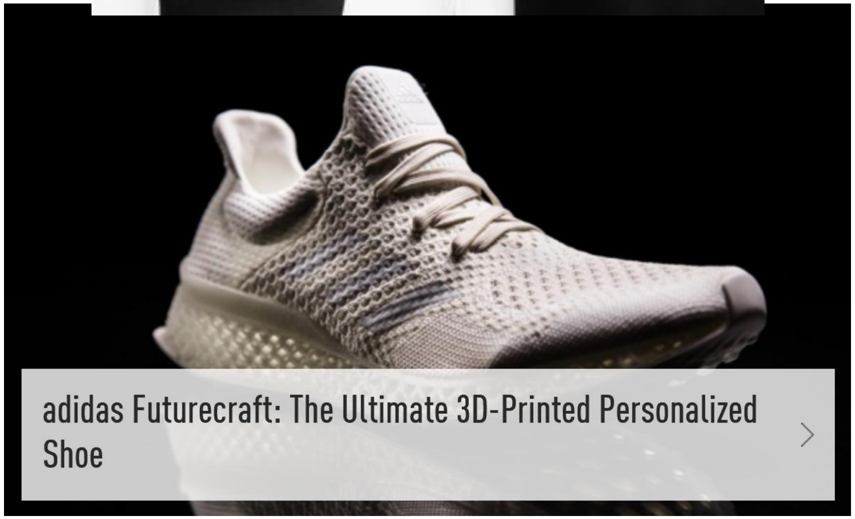
Examples of fashion products

- The technical solution… it takes a new way of designing

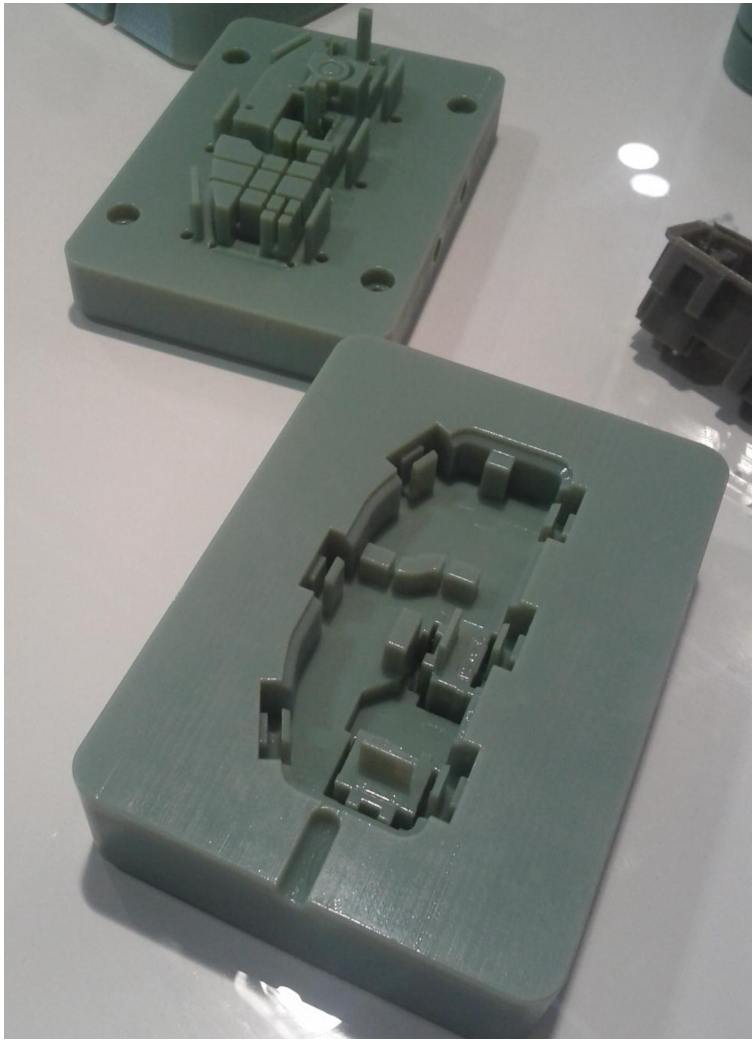
Examples of customization – Mass-customization
(materialise.com)



Cabrio collection
Hoet Design Studio



Examples - Implementation of equipment to produce



Porcelain

Post processing

- Since the 3D-printed part can present support structures or a bad surface finishing or can require other working steps, it is necessary to carry out further operations for obtaining the final part
  - Unpacking of workpieces
  - Removal of support structures
  - Removal of loose and sintered powder from the component surface
  - Smoothing and cleaning of internal passages
  - Surface cleaning
  - Surface homogenization, surface grinding & smoothing and polishing
  - Surface preparation for subsequent manufacturing steps, e.g. coating and painting
  - Application of a color dye
  - Thermal treatment
  - Debinding and sintering

Final considerations

Considerations

- 3D printers bring considerable advantages both in the **professional** and in the **consumer** world: the main potential of additive manufacturing is the **almost total freedom of form that can be produced**
  - by depositing layer by layer, the problems of undercut and cavity are solved, the overhangs are managed with the creation of ad hoc supports to be removed once the print is finished using, in some cases, materials other than those of the sometimes water-soluble products (example: it is possible get a hollow sphere in one piece)

Considerations

- Significant advantages:
  - reduction of production cost 🡐 but is it always true?
    - the classic production lines are no longer necessary
    - production waste is eliminated 🡐 but is it always true?
    - it is possible to print components and mechanisms already assembled (reduction of labor costs)
  - future prospect that, thanks to the potential widespread diffusion of this technology, will allow the customer to create the product in their office thanks to the electronic sending of the digital model (CAD) of the product itself
    - disappearance of transport costs 🡐 even if the material for the realization of the product will always have to be supplied

Considerations

- Significant advantages:
  - drastic reduction in time-to-market
  - possibility of producing small batches to be immediately placed on the market to test their effectiveness and palatability
  - ability to customize or modify the product based on feedback or user needs
    - thanks to the great flexibility of this technology, customized products can be obtained at no additional cost
    - in the same production batch it is possible to create pieces that are **different from each other**, made to measure, without having to equip the machine differently

Considerations

- In the context of the consumer market, the possibility of printing the objects you want on your own is becoming more and more consistent
  - you can buy not the assembly box but the STL file with the geometry of the desired object (car spare part) ← but the different quality of the product, for example injected, and the low quality of the entry-level machines remain
  - to solve the problem you can contact online printing services where you can upload your project, or choose one from the catalog, have it printed in the desired material and have it delivered directly to your home ← but this is in contrast to what has been said about cancellation costs

- If you download a CAD model to print or modify it, how can you guarantee the **copyright** of the object? The STL file copies us as many times as you want and you pass it on to as many people as you want like an mp3 ...

Considerations

- In the world of design, on the other hand, there are problems that have arisen from the transition from traditional to additive techniques
  - current CAD modeling systems are not always adequate for the possibilities that 3D printing offers and require updates
  - production planning should be completely rethought
  - to fully exploit the potential of additive techniques and of the geometries of the products that can be obtained, it is necessary to introduce **topological optimizers**
    - the number of elements to be managed in CAD in the modeling of parts with reticular microstructures or patterns of elements that intertwine (as in the case of clothes) grows exponentially with a consequent problem of storing and managing these elements

Considerations

- The STL format shows several limitations as it does not contain additional information, such as color or material to use in the various parts of the product to be made
  - a new format called AMF Additive Manufacturing Format is being defined

Process and product certification problems

- Important for prototypes but especially for production
- What guarantees are there of repeatability of the process?
  - How much are the particular products the same?
  - How much do they behave in the same way?
  - How can they be tested?

- Need to certify the raw material, the machine, the process and the process parameters ...