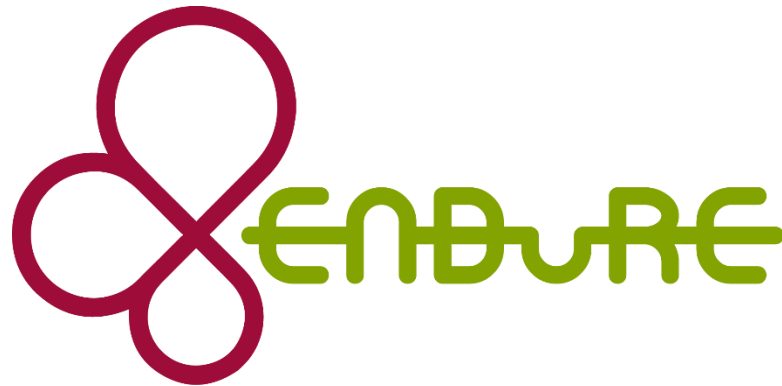




Rapid Prototyping

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ADDITIVE MANUFACTURING FOR RAPID PROTOTYPING

Introduction

3D world

- A picture says than 1000 words ...
... a model tells the whole story



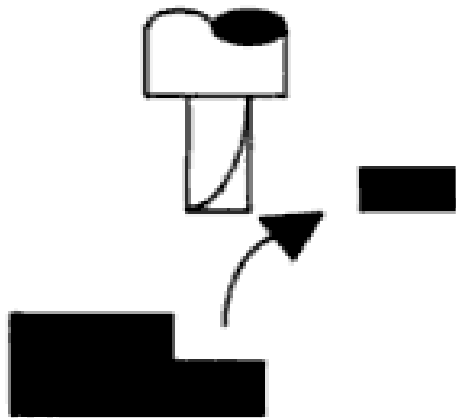
Some questions

- Which classes of materials can be processed with AM technologies?
 - a) Polymers
 - b) Metals
 - c) Ceramics
 - d) Biological materials
 - e) Others...

Some
questions

- When Stereolithography was invented?
 - a) Less than 10 years ago
 - b) Between 10 and 20 years ago
 - c) More than 20 years ago
 - d) Other...

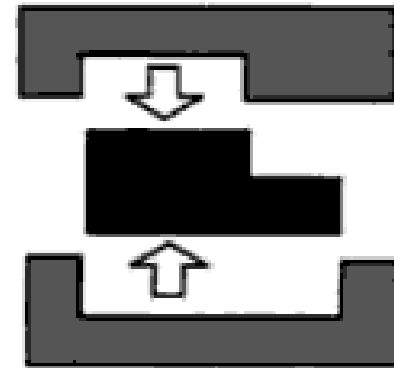
Building 3D object



Subtractive



Additive



Formative

Building 3D object: subtractive

- Milling
- Turning
- Drilling
- Planning
- Sawing
- Grinding
- EDM
- Laser cutting
- Water jet cutting
- ...

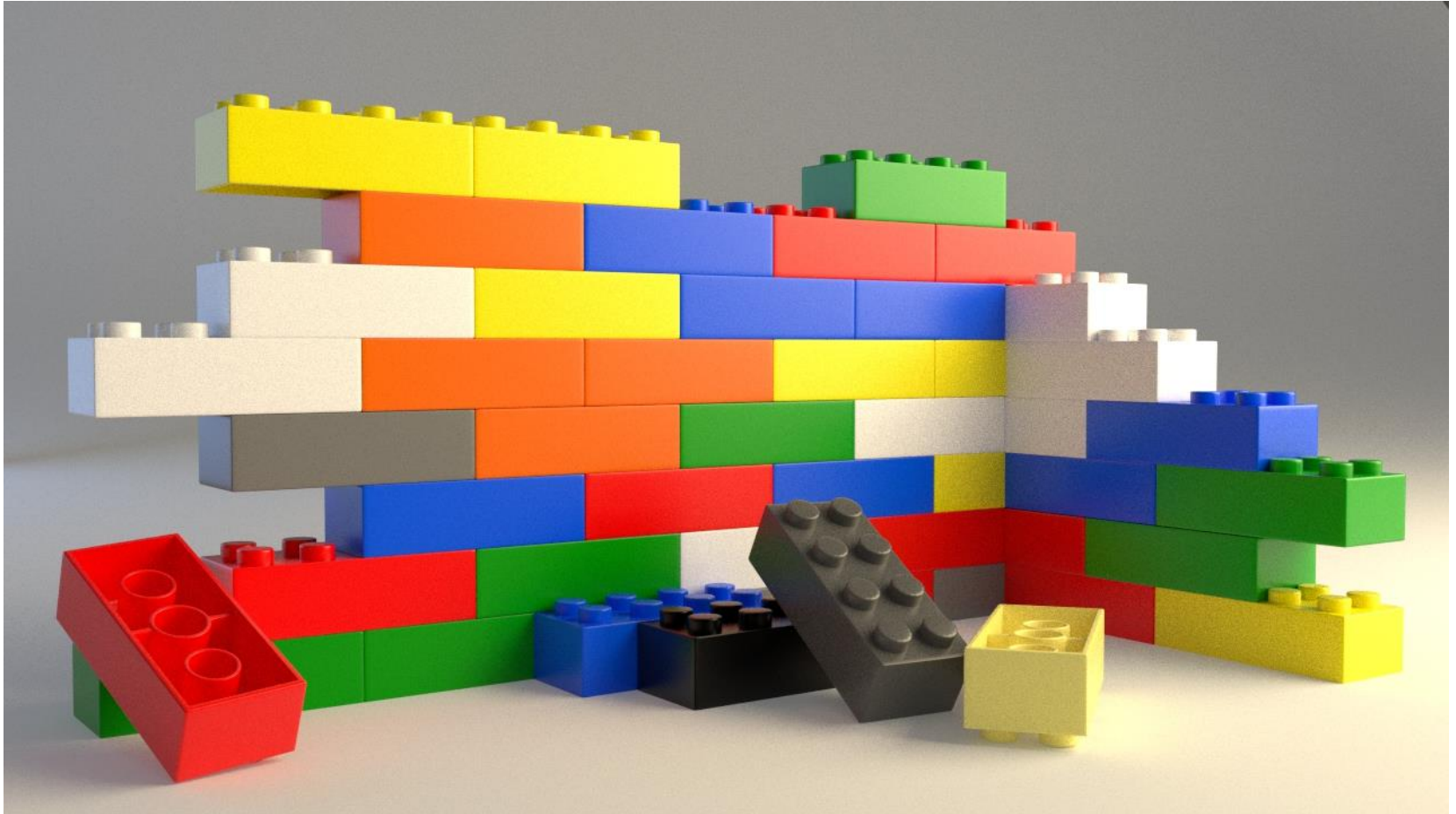


Building 3D object: formative

- Bending
- Forging
- Electromagnetic forming
- Plastic injection molding
- ...

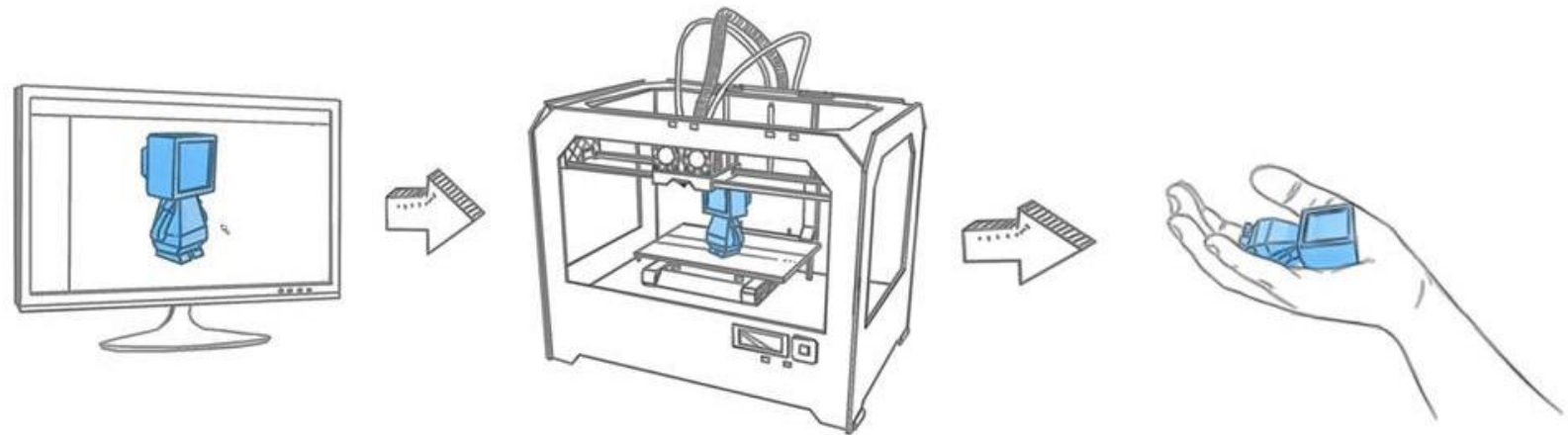


Building 3D object: additive

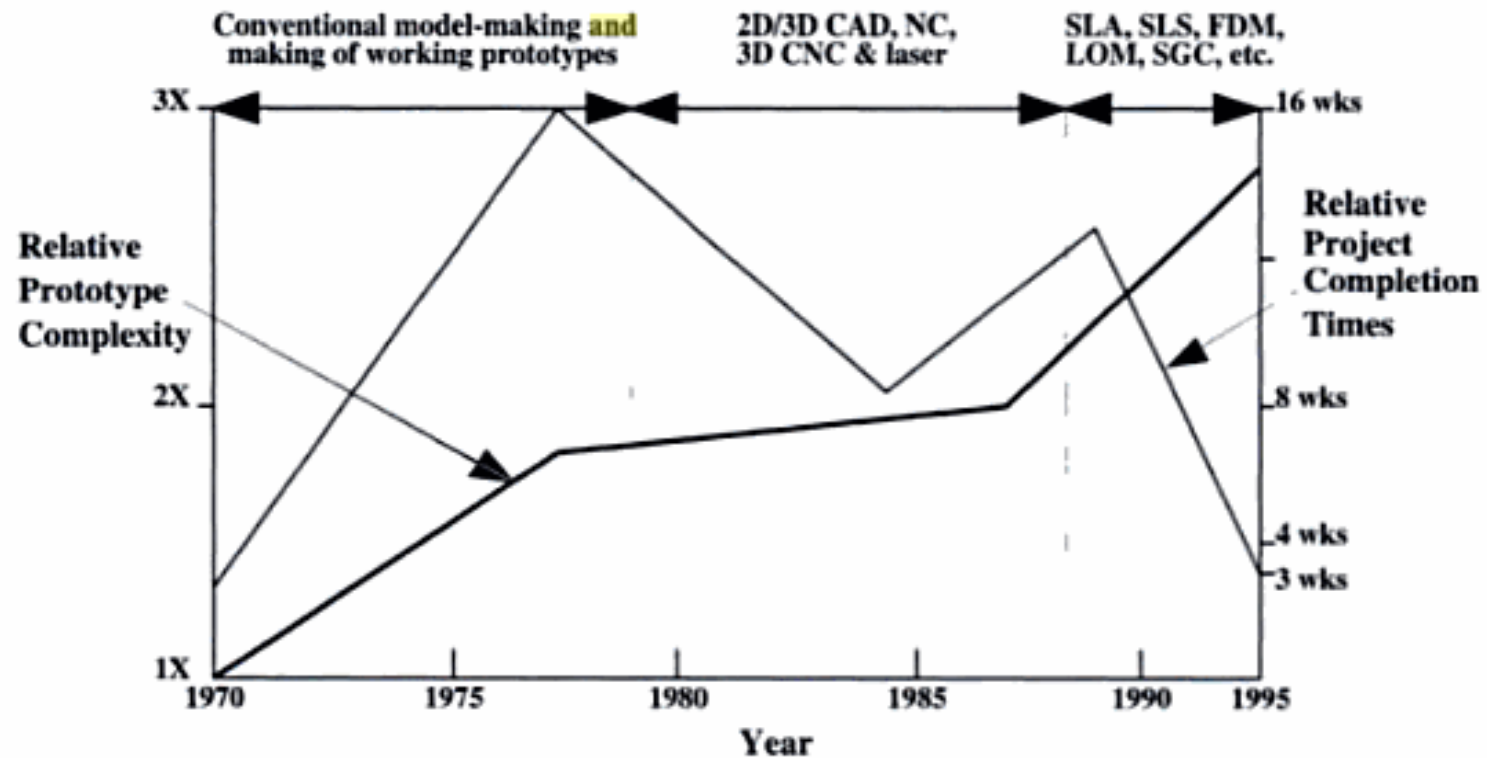


Additive manufacturing

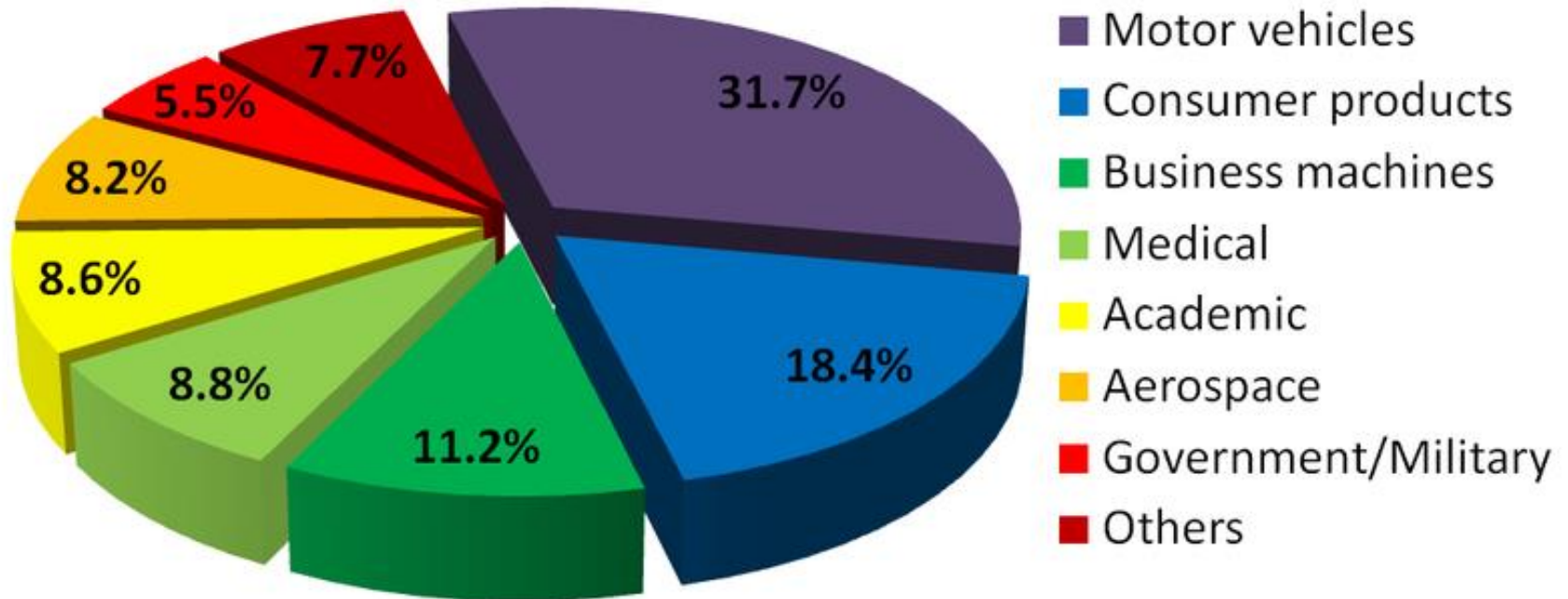
- Additive manufacturing is a process of making a 3D solid object of virtually any shape **from a digital model**.
- It is achieved using an additive process, where successive layers of material are laid down in different shapes.



Additive manufacturing for Rapid prototyping



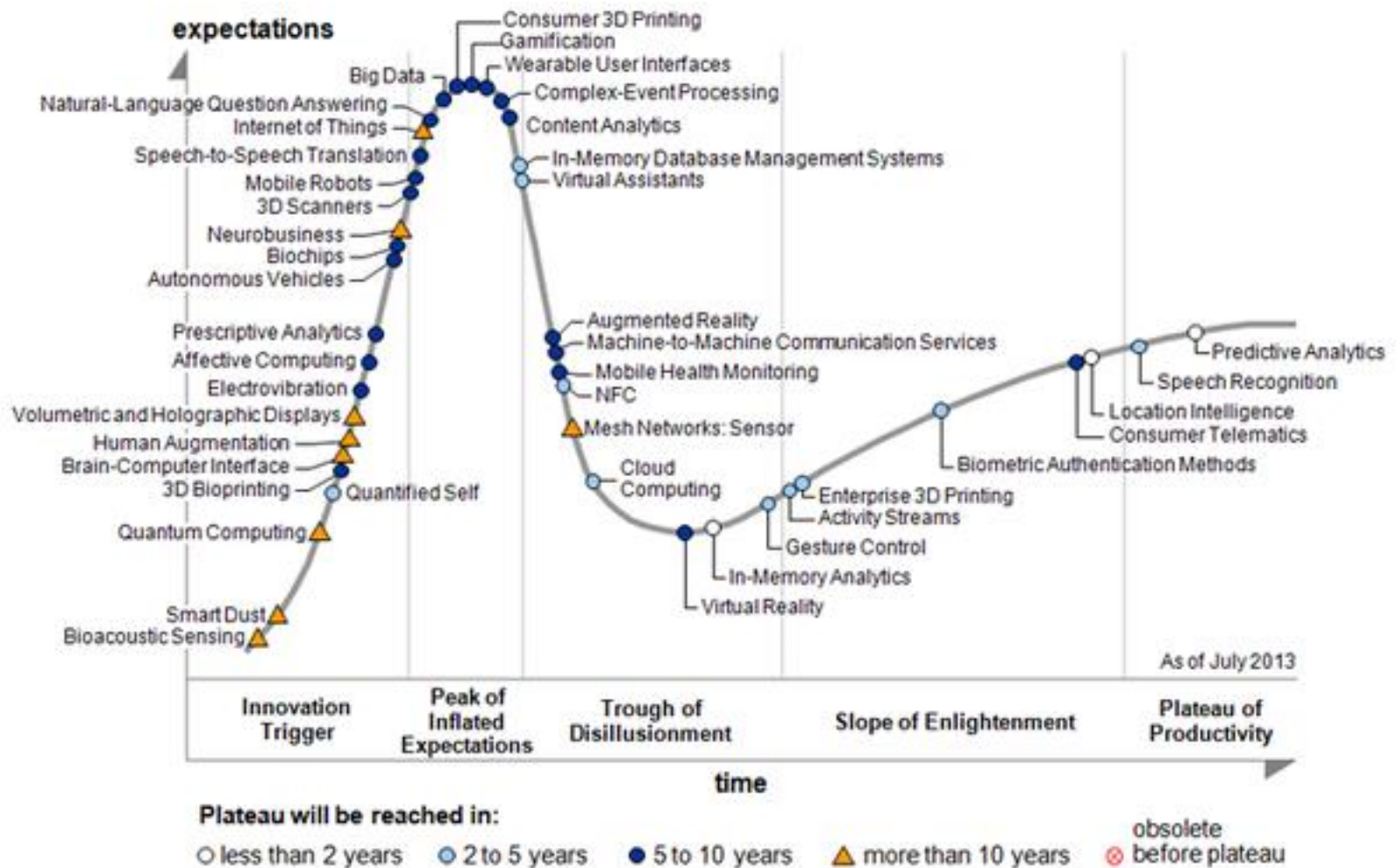
Additive manufacturing by Industry Sectors



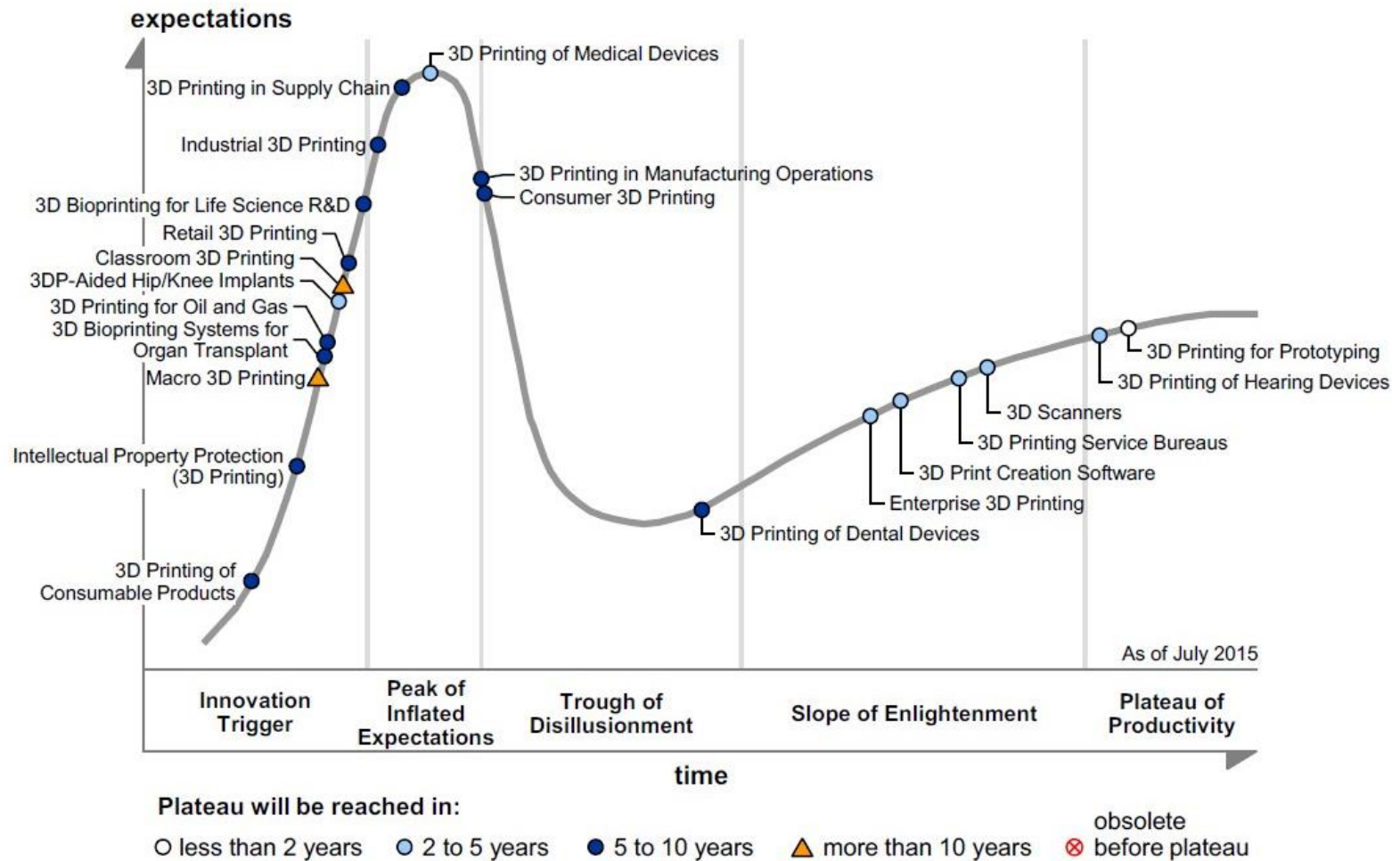
Computer Aided technologies (Cax)

- CAD – Design
- CAE – Engineering
- CAM – Manufacturing
- CAPP – Process Planning
- CIM – Computer Integrated Manufacturing

Hype cycle 2013

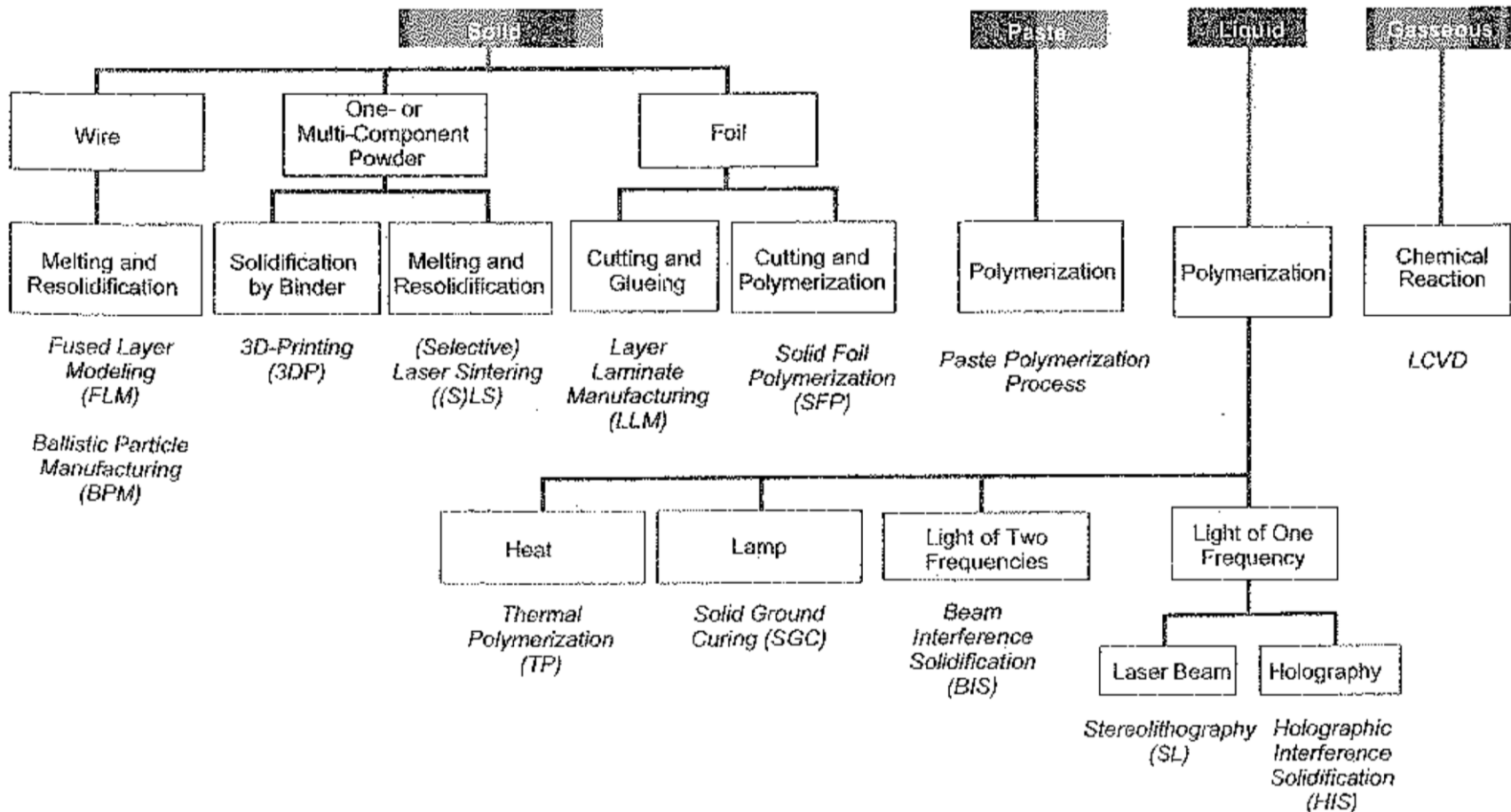


Hype cycle 2015



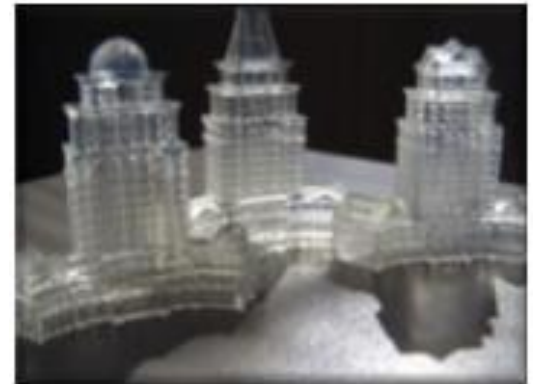
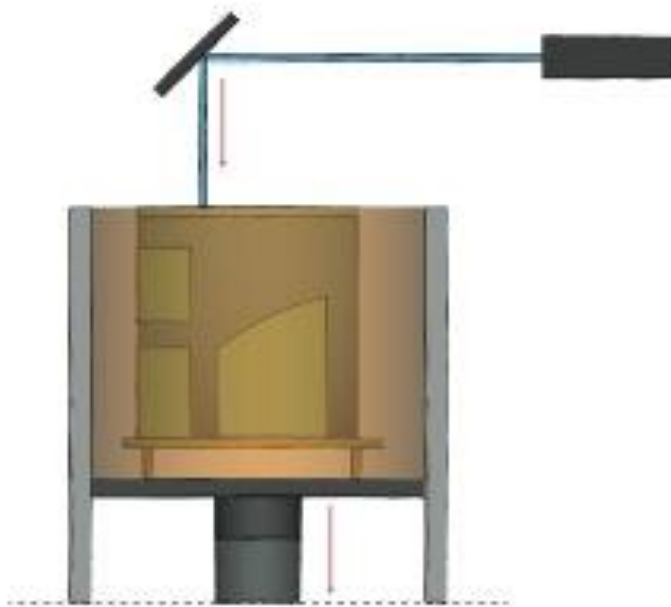
Source: Gartner (July 2015)

A possible classification



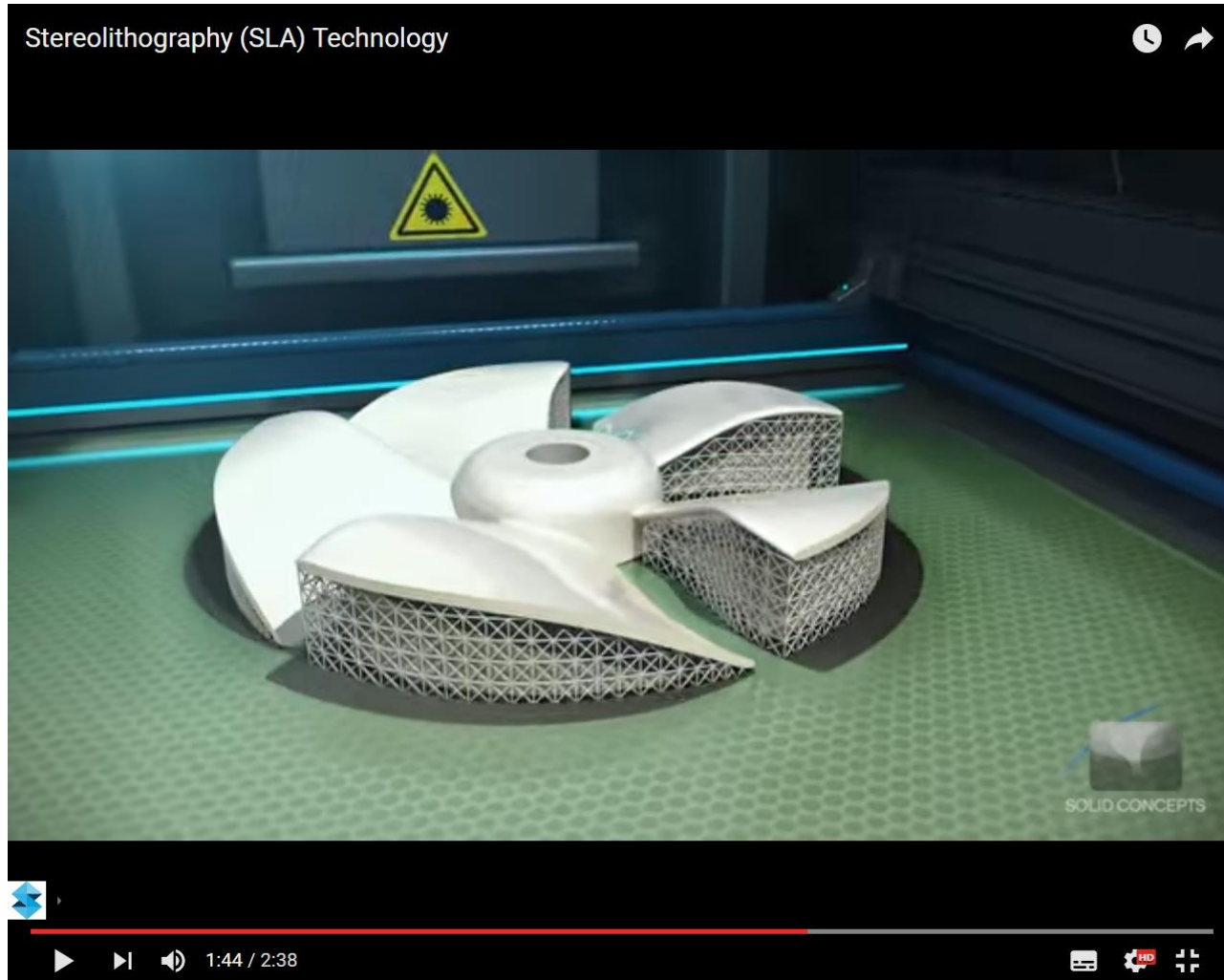
Available technologies

- Solidification of liquid materials
 - Photo-polymerization process

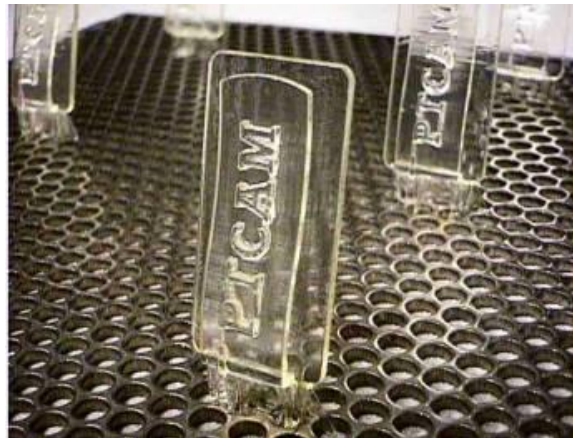


Stereolithography

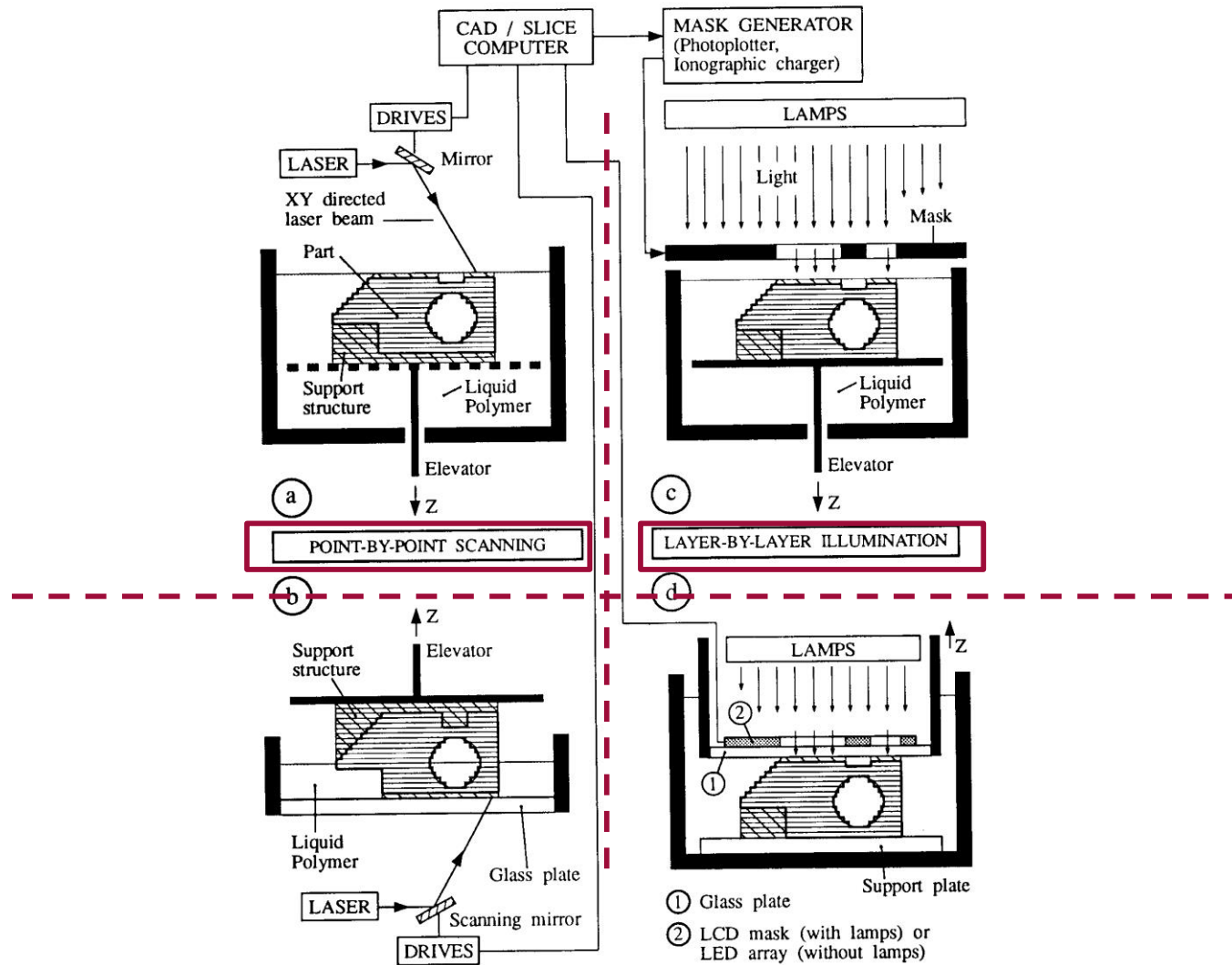
- <https://www.youtube.com/watch?v=NM55ct5KwiI>



Stereolithography

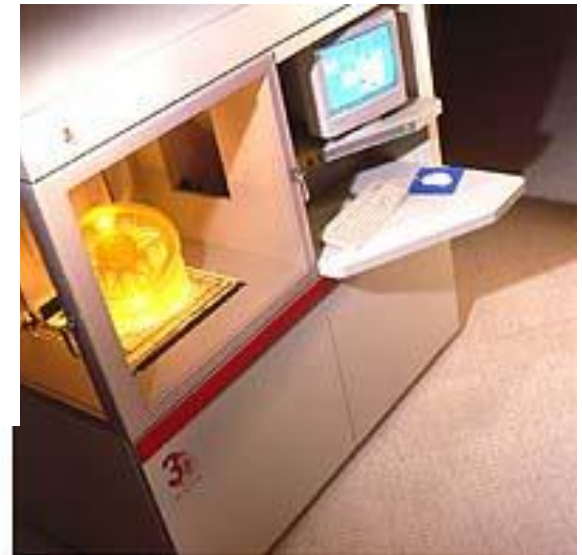


Stereolithography: options



3D System SLA 7000

Laser	He-Cd
Lunghezza d'onda	0.325 μm
Potenza	800 mW
Spessore minimo	0.025 mm
Volume vasca	253
Volume di lavoro	500 x 500 x 600 mm ³
Velocità di scansione	Max 9.52 m/s
Diametro Spot	Da 0.23 a 0.84 mm



Materials: Somos 18120

TECHNICAL DATA							
Mechanical Properties		Somos® ProtoGen 18120 UV Postcure at HOC -2		Somos® ProtoGen 18120 UV Postcure at HOC +3		Somos® ProtoGen 18120 UV & Thermal Postcure	
ASTM Method	Property Description	Metric	Imperial	Metric	Imperial	Metric	Imperial
D638M	Tensile Strength	51.7 - 54.9 MPa	7.5 - 8.0 ksi	56.9 - 57.1 MPa	8.2 - 8.3 ksi	68.8 - 69.2 MPa	9.9 - 10.0 ksi
D638M	Tensile Modulus	2,620 - 2,740 MPa	381 - 397 ksi	2,540 - 2,620 MPa	370 - 380 ksi	2,910 - 2,990 MPa	422 - 433 ksi
D638M	Elongation at Break	6 - 12%	6 - 12%	8 - 12%	8 - 12%	7 - 8%	7 - 8%
D638M	Poisson's Ratio	0.43 - 0.45	0.43 - 0.45	N/A	N/A	0.43	0.43
D790M	Flexural Strength	81.8 - 83.8 MPa	11.9 - 12.2 ksi	83.8 - 86.7 MPa	12.2 - 12.6 ksi	88.5 - 91.5 MPa	13.2 ksi
D790M	Flexural Modulus	2,360 - 2,480 MPa	343 - 359 ksi	2,400 - 2,450 MPa	350 - 355 ksi	2,330 - 2,490 MPa	361 ksi
D2240	Hardness (Shore D)	84 - 85	85 - 87	N/A	N/A	87 - 88	87 - 88
D256A	Izod Impact (Notched)	0.14 - 0.26 J/m	0.26 - 0.49 ft-lb/in	N/A	N/A	0.13 - 0.25 J/m	0.24 - 0.47 ft-lb/in
D570-98	Water Absorption	0.77%	0.77%	N/A	N/A	0.75%	0.75%

Materials: Somos 18120

TECHNICAL DATA - LIQUID PROPERTIES

Appearance	Translucent
Viscosity	~300 cps @ 30°C
Density	~1.16 g/cm ³ @ 25°C

TECHNICAL DATA - OPTICAL PROPERTIES

E _c	6.73 mJ/cm ²	[critical exposure]
D _p	4.57 mils	[slope of cure-depth vs. ln (E) curve]
E ₁₀	57.0 mJ/cm ²	[exposure that gives 0.254 mm (.010 inch) thickness]

Cost

- Cost of materials:
 - 200€ per liter
 - A cube $20*20*20\text{ cm}^3$ approx 8 liters
- Post processing Requirements:
 - Careful practices are required to work with the resins.
 - Frameworks must be removed from the finished part.
 - Alcohol baths then Ultraviolet ovens are used to clean and cure the parts.

Pros

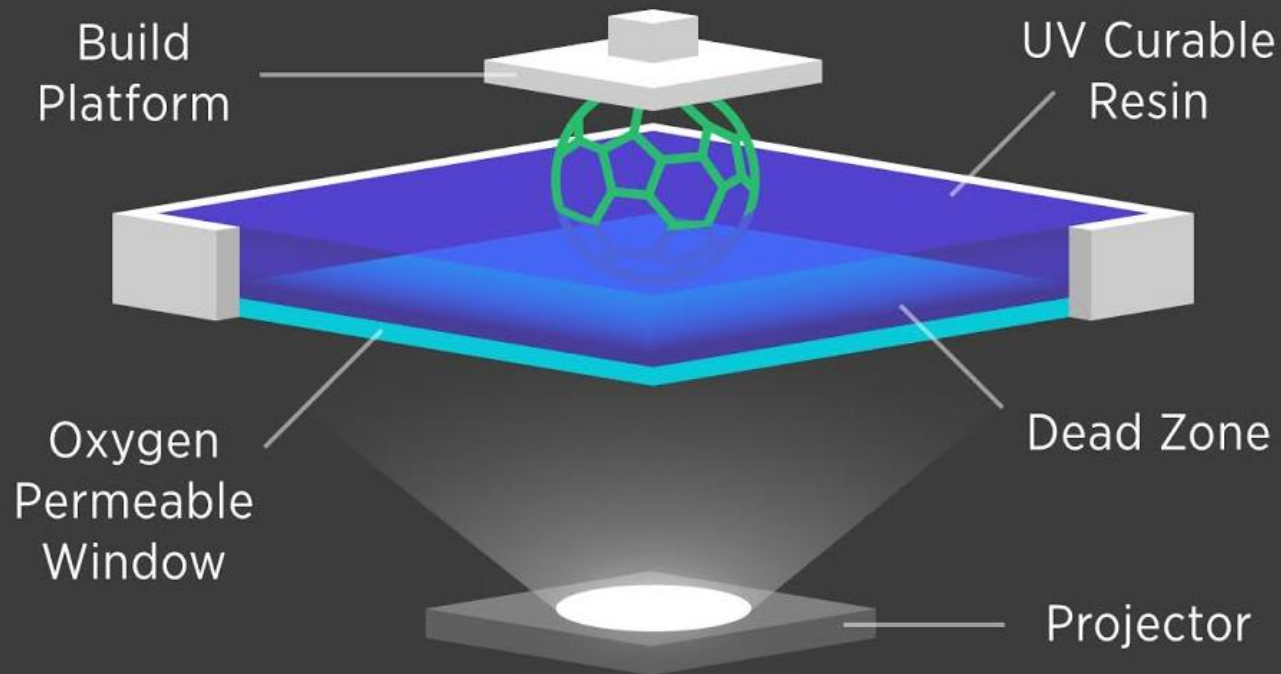
- Probably the most accurate functional prototyping on the market.
 - Layer thickness (from 20 to 150 μm)
 - Minimum feature size 80 to 300 μm
 - Smooth surface finish, high dimensional tolerance, and finely detailed features (thin-walls, sharp corners, etc...)
- Large build volume
 - Up to 50 x 50 x 60 cm^3 (approx)
- Used in: Investment Casting, Wind Tunnels, and Injection Molding as tooling
- Resins can be custom engineered to meet different needs: higher-temps, speed, finish...

Cons

- Requires post-curing.
- Long-term curing can lead to warping.
- Parts are quite brittle and have a tacky surface.
- Support structures are typically required.
 - Supports must be removed by hand
- Uncured material is toxic.
- Little material choice
- Costs
 - Material
 - trained operator
 - Lab environment necessary (gasses!)
 - Laser lasts 2000hrs, costs \$20000!
- Slow process

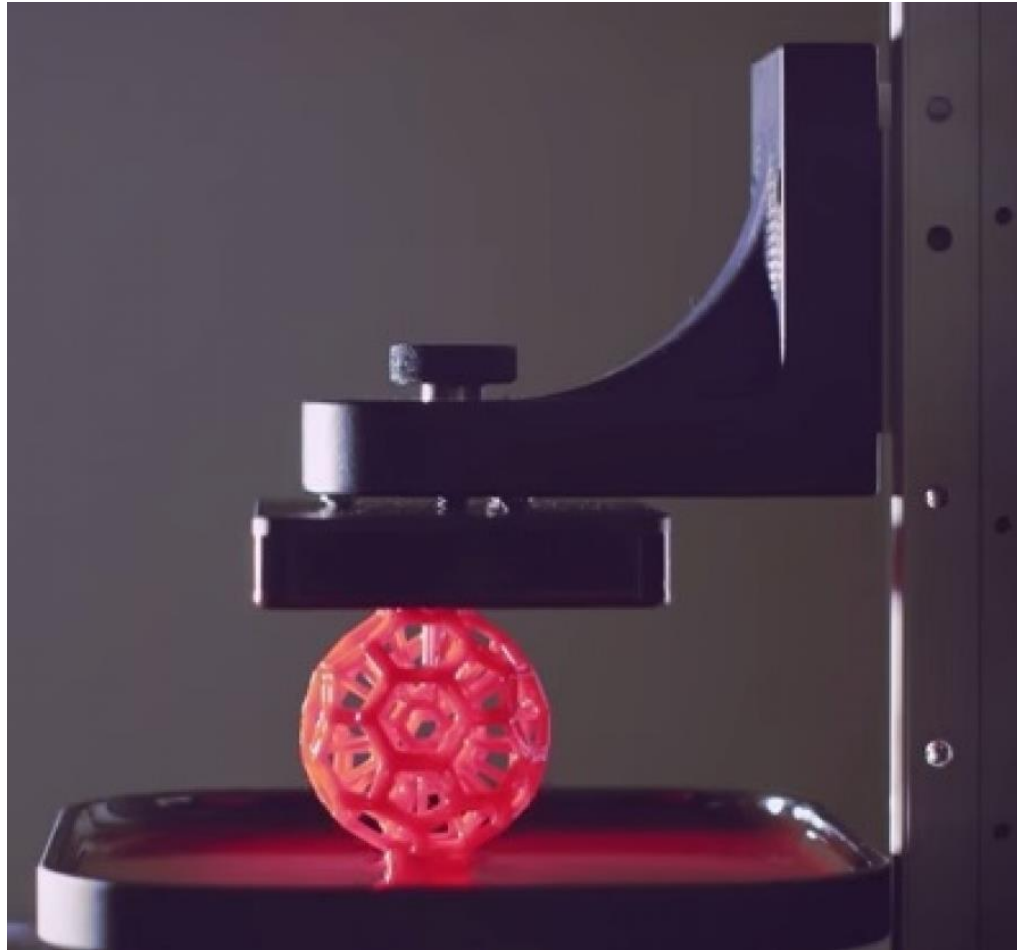
Carbon 3D

Continuous Liquid Interface Production



Carbon 3D

<https://www.youtube.com/watch?v=UpH1zhUQY0c>



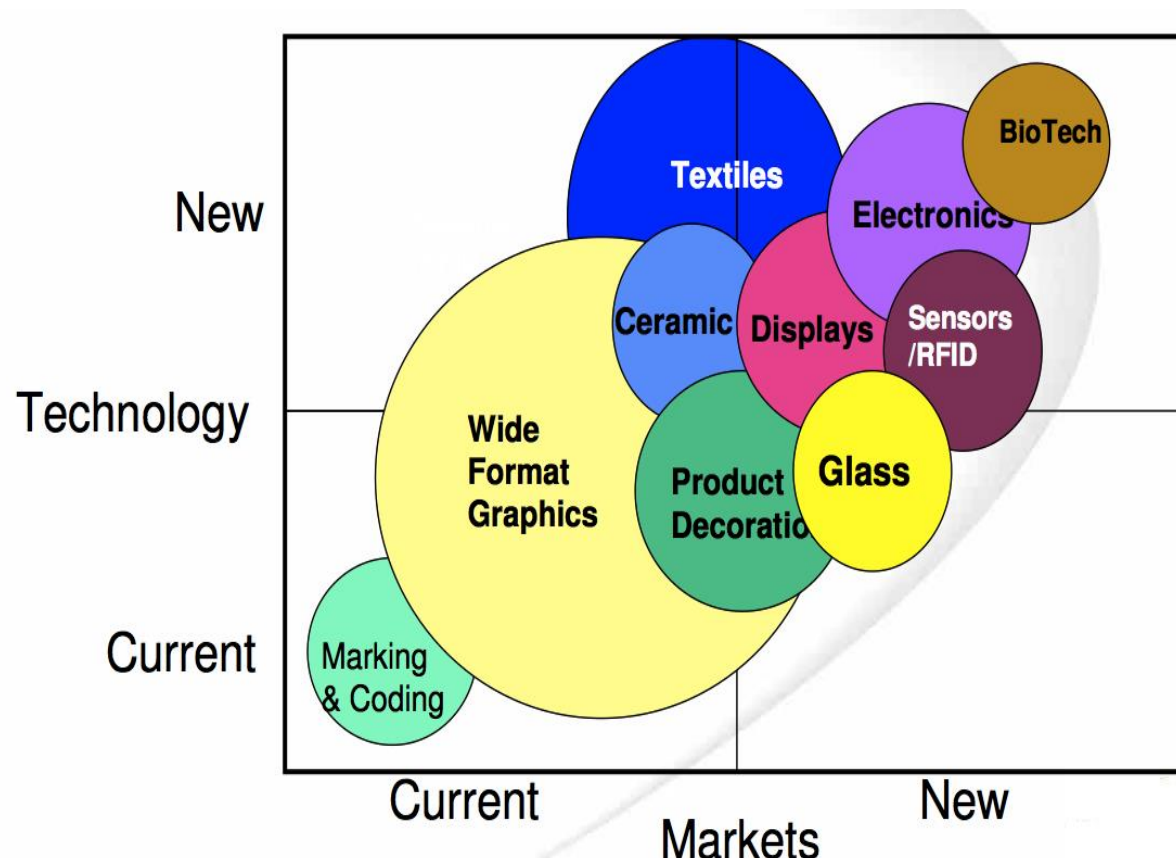
Available technologies

- Generation from the solid phase:
 - Conglutination of granules or powders by additional binders
 - 3D inkjet printer
 - incipiently or completely melted solid materials, powder, or powder mixtures:
 - Extrusion (FDM),
 - Ballistic and PolyJet
 - Sintering processes

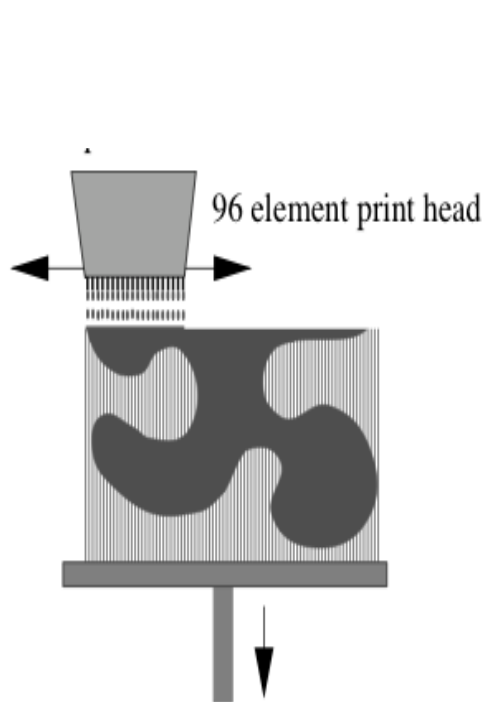


Inkjet technology

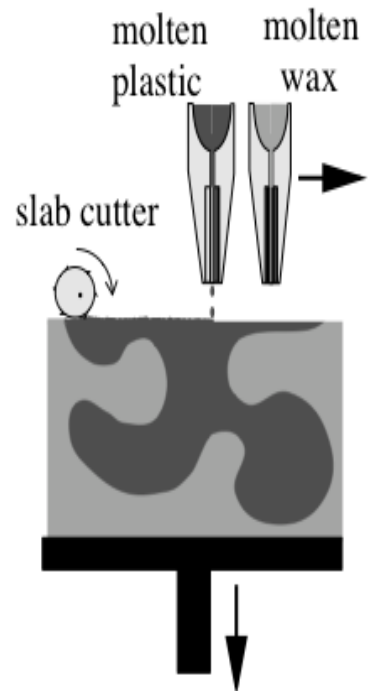
- The ink-jet technology is a contact free dot matrix printing procedure. Ink is issued from a small aperture directly onto a specific position on a medium



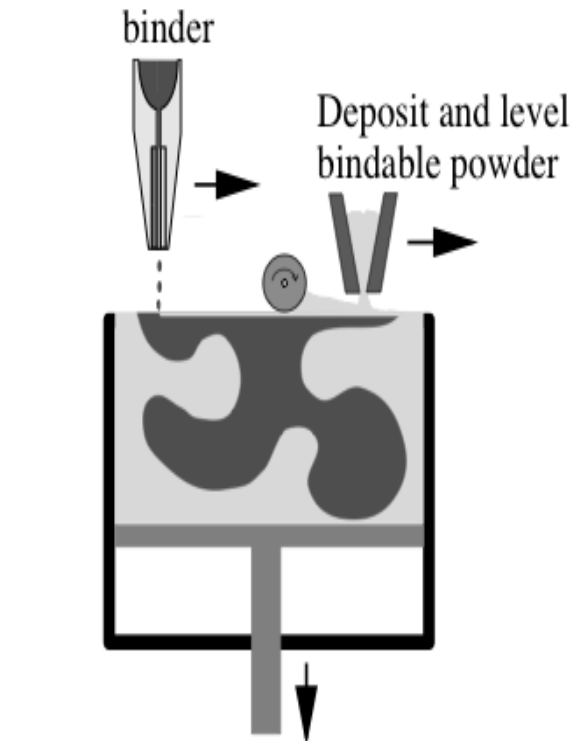
AM using inkjet



d. Multi-Jet Modeling
3D Systems, Inc. (U.S.)



c. Model Maker
Sanders, Inc. (U.S.)



a. Three Dimensional Printing
MIT, and Soligen, Inc. (U.S.)

<https://www.youtube.com/watch?v=Som3CddHfZE>



Sintering



Sintering

- bonding of the metal, ceramic or plastic powders together when heated to temperatures in excess of approximately half the absolute melting temperature.
- In the industry, sintering is mainly used for metal and ceramic parts (Powder Metallurgy).
- After pressing (compaction) of the powder inside mold for deforming into high densities, while providing the shape and dimensional control, the compacted parts are then sintered for achieving bonding of the powders metallurgically.

Sintering in Rapid Prototyping

- Sintering process used in Rapid Prototyping differs from the Powder Metallurgy, such as:
 - Plastic based powders, in addition to metal powders.
 - Local sintering, not overall sintering.
 - Very short sintering period.
- Laser (heat source) is exposed to sections to be sintered for a very short time. Hard to achieve an ideal sintering.
- In some applications, for achieving the ideal sintering, the finished parts are heated in a separate sintering oven.

Laser Sintering

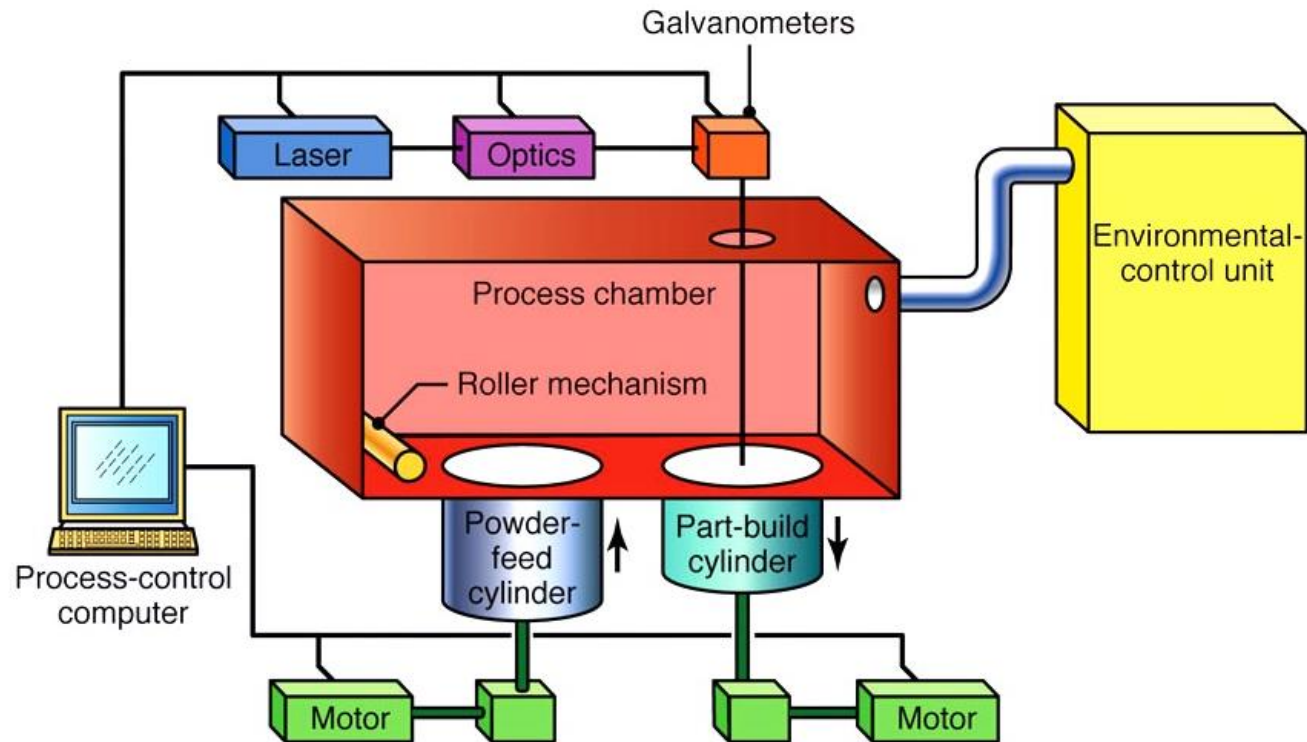
<https://www.youtube.com/watch?v=bgQvqVq-SQU>



SLS samples



Selective Laser Sintering



Selective Laser Sintering

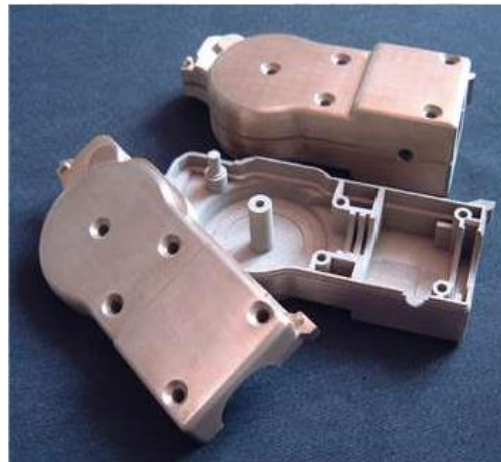
- The fabrication chamber is maintained at a temperature just below the melting point of the powder
- Heat from the laser need only elevate the temperature slightly to cause sintering. This greatly speeds up the process;
- No supports are required with this method since overhangs and undercuts are supported by the solid powder bed;
- Surface finishes and accuracy are not quite as good as with stereolithography, but material properties can be quite close to those of the intrinsic materials

Materials

- Polymers
 - nylon, ABS, PVC, and polystyrene,
 - nylon/polycarbonate powders are health hazards (dangerous to breathe).
 - glass-filled or with other fillers
 - metals encapsulated in plastic.
- Metals
 - low melting metal alloys of nickel bronze, steel, titanium, alloy mixtures, and composites
- Green sand (for sand casting).

Metal Laser Sintering

- For direct production of tooling, including for plastic injection molding, metal die casting, sheet metal forming as well as metal parts, directly from steel based and other metal powders.



- A gear for Volvo Corp.
- Die Cast Parts (500 Al parts produced)
- Motor Housing

Selective Laser Sintering

Advantages:

- Cheap and no harmed healthy material,
- Large selection of used materials,
- Is not needed supported construction,
- Decreasing of destruction possibility of inside stresses.

Selective Laser Sintering

Disadvantages:

- Roughness surface after final modification it means „stairs“ effect,
- Porosity of components,
- Different intensity in various parts of generated components,
- Material transformations are needing cleaning of the production device

Laser Engineered Net Shaping

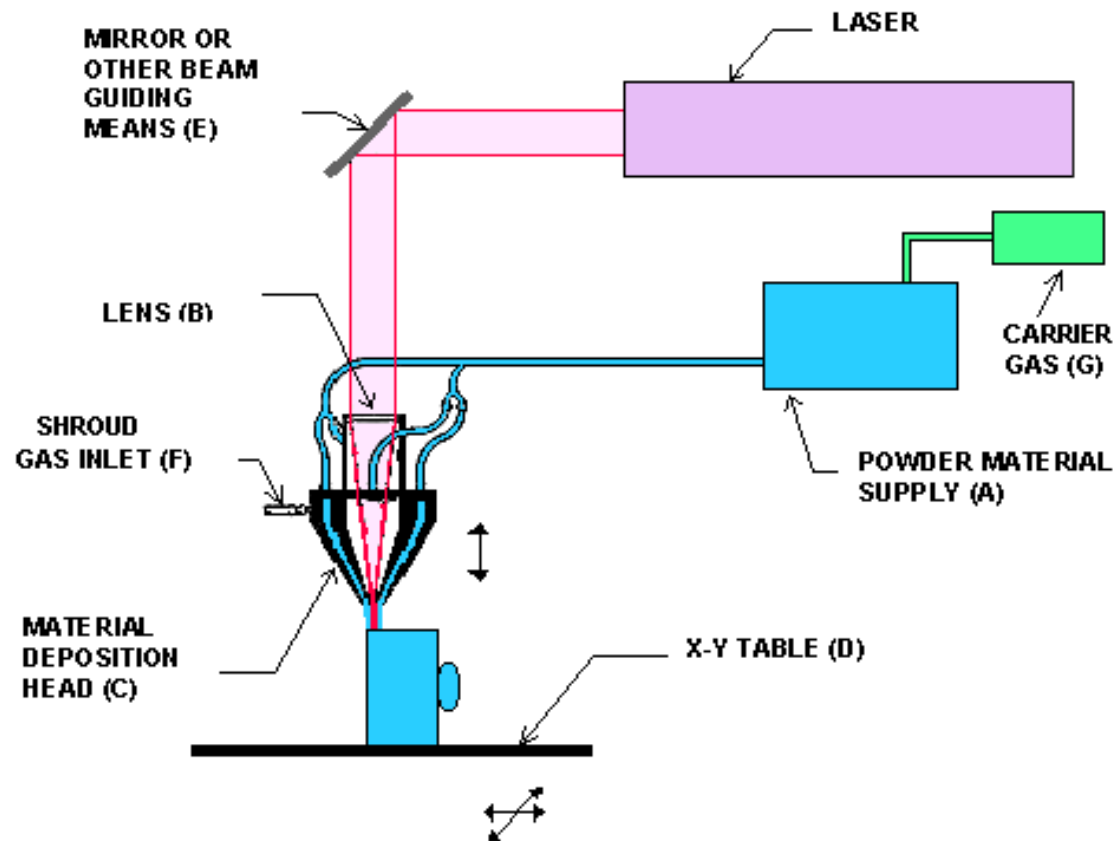


Fig. 8. Laser engineered net shaping.

Laser Engineered Net Shaping

- In development (Sandia Labs, Optomec)
- Fully Dense Metal parts with good metallurgical properties
- Laser melts metal powder
- Powder delivered coaxially with laser
- Inert gas protects weld pool
- Near net shape with some finish machining

Laser Engineered Net Shaping

- In addition to titanium, a variety of materials can be used such as stainless steel, copper, aluminum etc.
- Materials composition can be changed dynamically and continuously, leading to objects with properties that might be mutually exclusive using classical fabrication methods.
- Has the ability to fabricate fully-dense metal parts with good metallurgical properties at reasonable speeds;
- Objects fabricated are near net shape, but generally will require finish machining.

Laser Engineered Net Shaping

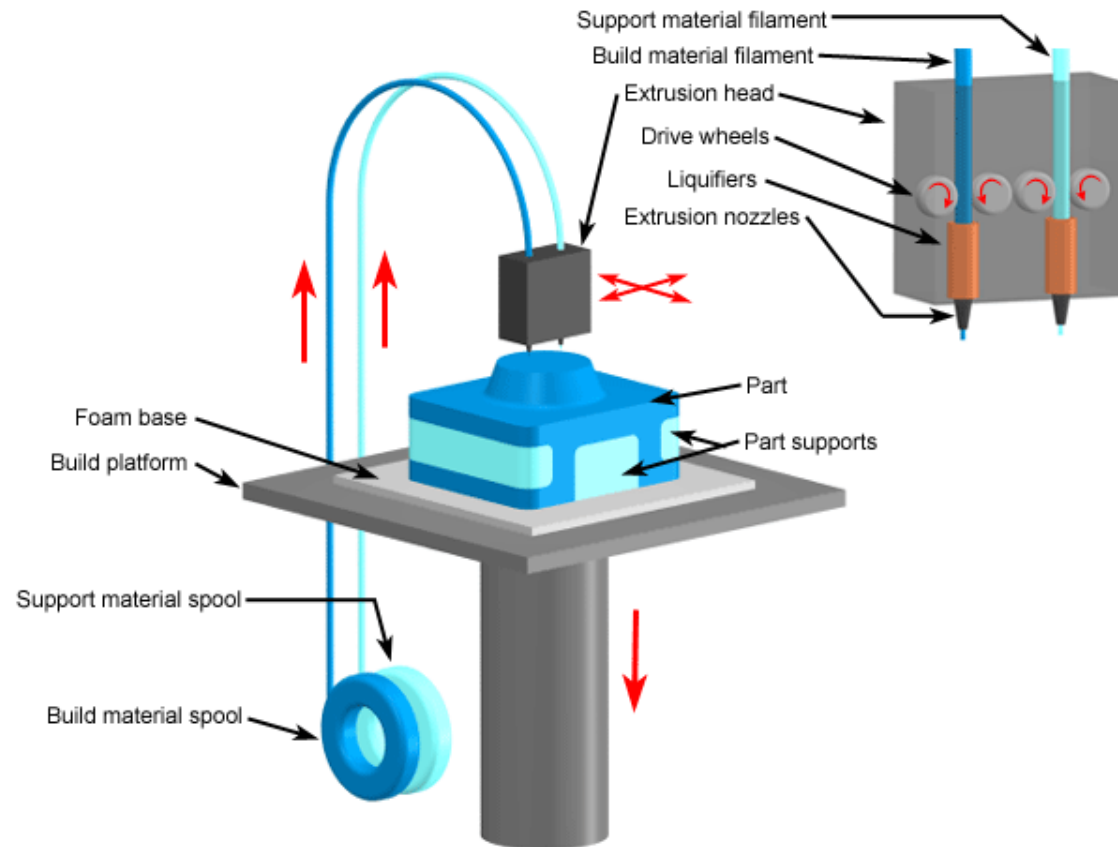
<https://www.youtube.com/watch?v=d2foaRi4nxM>



Fused deposition modelling (FDM)

- FDM is the second most widely used rapid prototyping technology, after stereolithography.
- A plastic filament is unwound from a coil and supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off.
- The nozzle is mounted to a mechanical stage which can be moved in both horizontal and vertical directions.
- As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer.
- The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. The entire system is contained within a chamber which is held at a temperature just below the melting point of the plastic.

Fused deposition modelling



Copyright © 2008 CustomPartNet

Fused deposition modelling

<https://www.youtube.com/watch?v=WHO6G67GJbM>



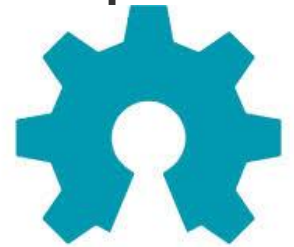


OPEN 3D PRINTING

The Rep Rap Project

Open 3D printing: the RepRap project

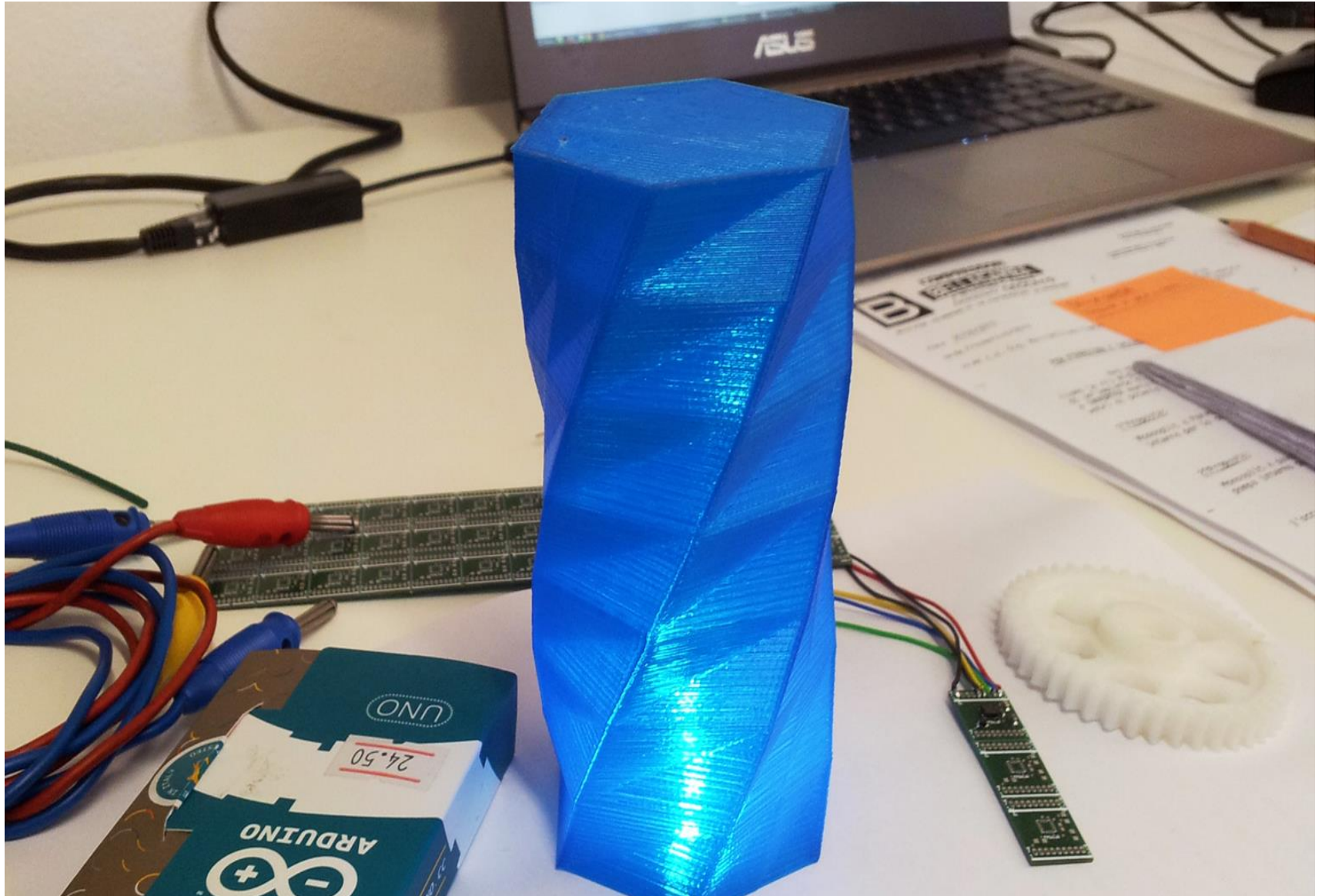
- RepRap is first general-purpose self-replicating manufacturing machine.
- RepRap takes the form of a free desktop 3D printer capable of printing plastic objects.
- Since many parts of RepRap are made from plastic and RepRap prints those parts, RepRap self-replicates by making a kit of itself - a kit that anyone can assemble given time and materials.



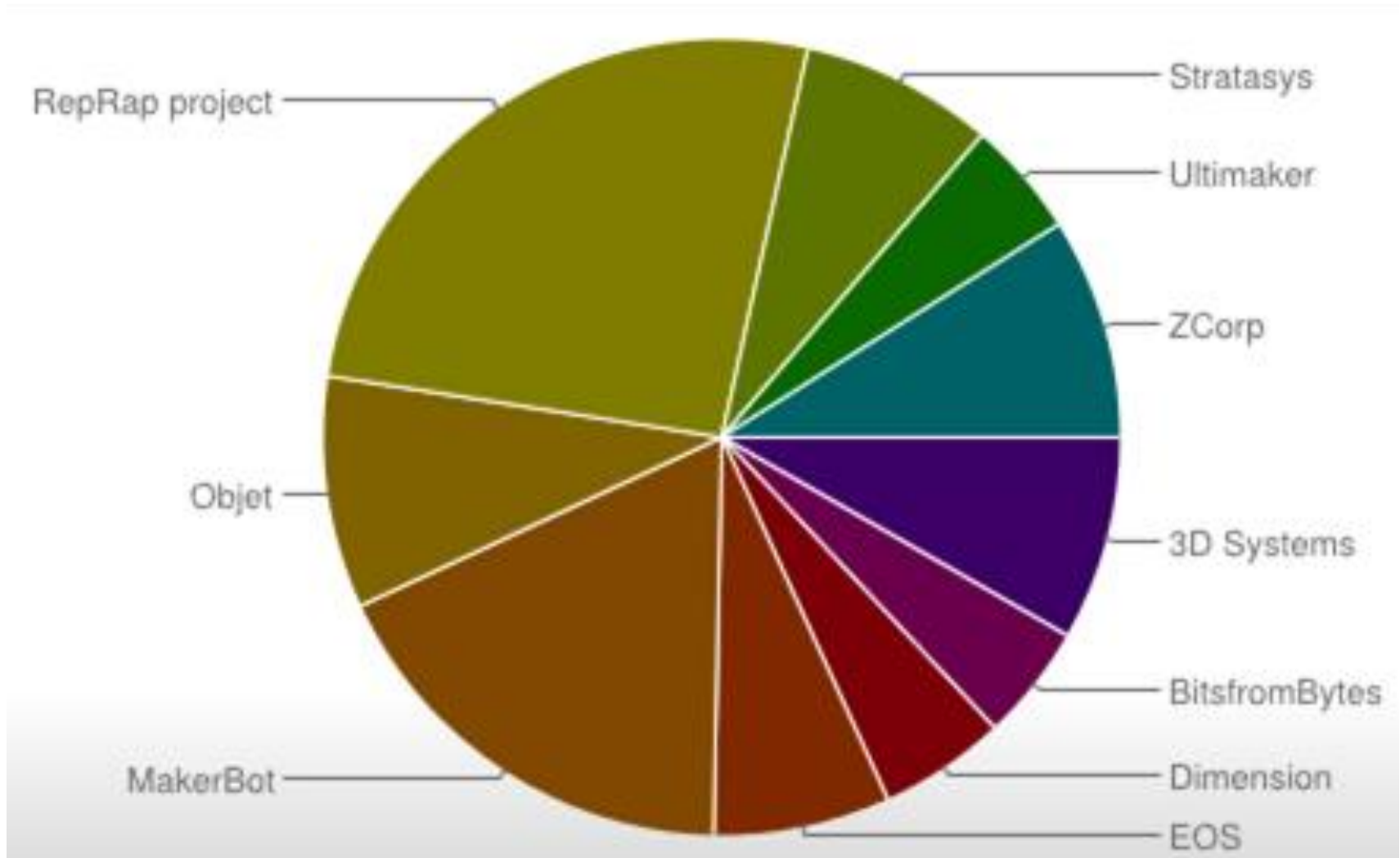
open source
hardware



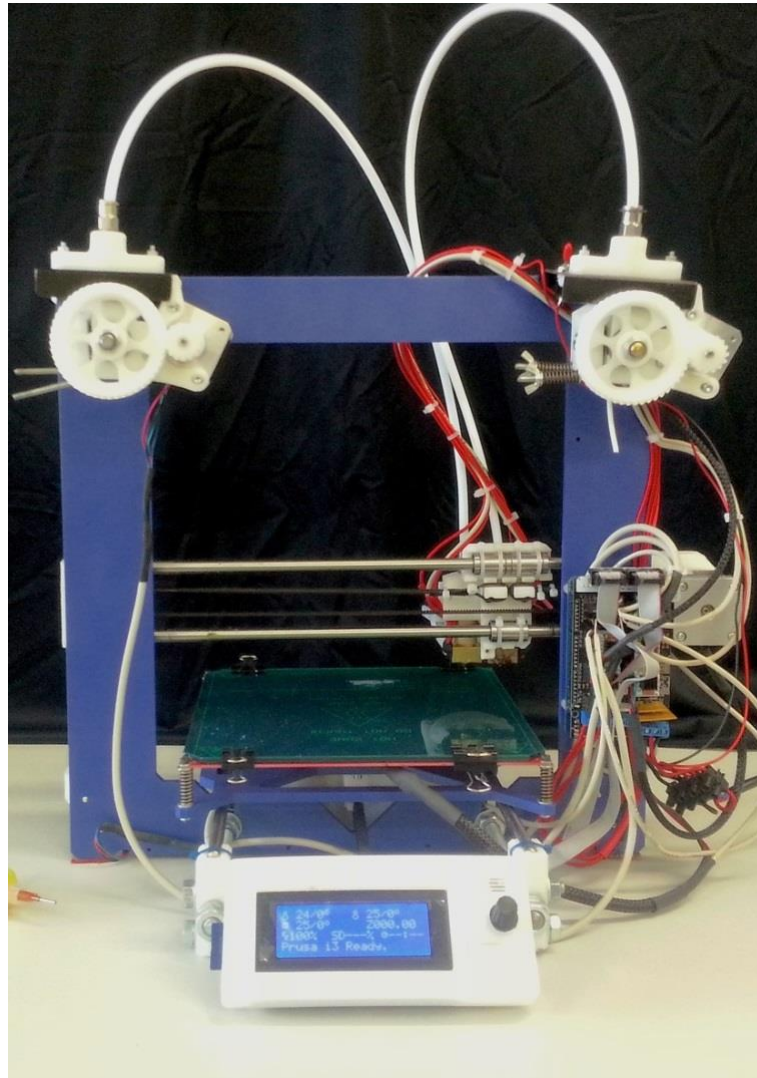
The RepRap Project



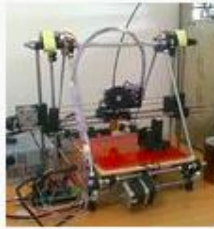
The RepRap Project



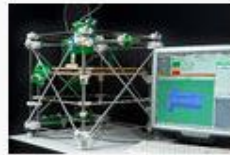
The RepRap Project



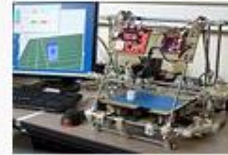
How many RepRaps?



Prusa (license: [GPL](#))



Darwin (license: [GPL](#))



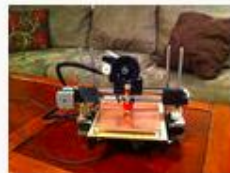
Mendel (license: [GPL](#))



Huxley (license: [GPL](#))



RepRap Morgan (license: [GPL](#))



Printbot (license: [CC-BY-SA](#))



Cartesio (license: [CC-BY-SA](#))



RepRapPro Mendel (license: [GPL](#))



RepRapPro Huxley (license: [GPL](#))



Eventorbot (license: [CC-BY-SA](#))



3drag (license: [CC-BY-SA](#))



Prusa i3 Rework Introduction (license: [GPL](#))

Materials

- FFF = Fused Filament Fabrication
- Filament: fine diameter plastic that exits from an extruder (some may refer to the plastic feed stock as filament as well)
- Typically, the diameter of the filament varies between 1 mm and 3mm
- The standard extruder produces filament using high pressure and heat to force molten plastic thru a very tiny hole.

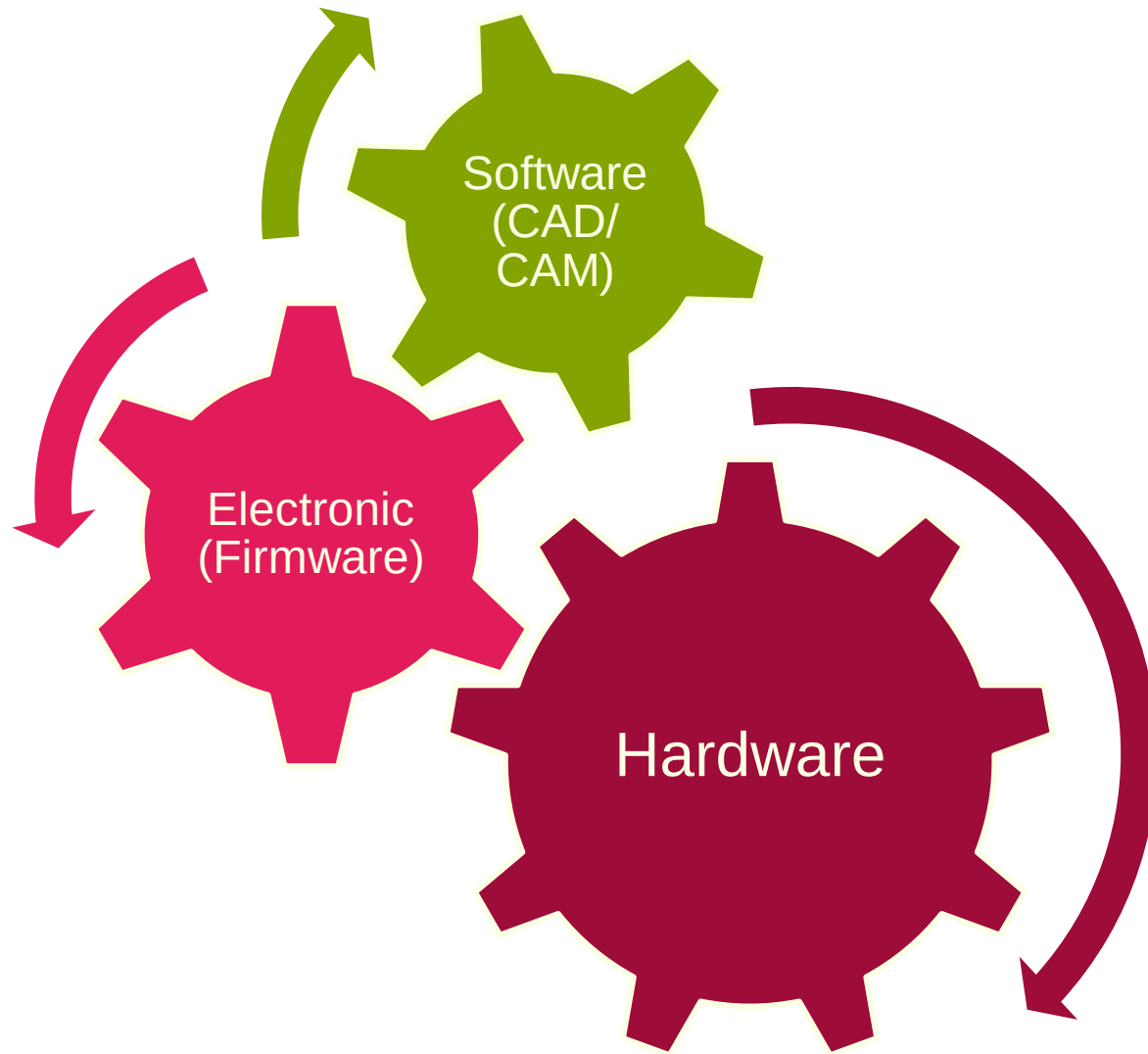
Materials

- “Standard” materials:
 - Poly-Lactic-Acid (PLA) (soft and hard)
 - Acrylonitril-Butadiene-Stiren (ABS)
- “Experimental” materials:
 - Nylon
 - Polycarbonate (PC)
 - Poly vinyl alcohol (PVA)
 - Conductive (carbon and graphen loaded materials)
 - Metallic loaded plastics

Open questions

- WHICH ARE THE INTELLECTUAL PROPERTY IMPLICATIONS OF LOW-COST 3D PRINTING?
- IS THE OPEN SOURCE 3-D PRINTING AN ENABLING TECHNOLOGY FOR SELF-DIRECTED SUSTAINABLE DEVELOPMENT?

Main components of a 3D printer system



Prusa I3 rework



Mechanical structure

	Single Sheet Frame
Plastic Parts (exc Extruder)	26
Non Printed Parts	337 (approx)
Cost	\$300 – 1000
Controller Electronics	Almost all RepRap controller
Printing Size	200 x 200 x 200
Motors	5 x NEMA 17 Stepper
Frame Material	6 mm Aluminium (or Wood)
Frame Manufacture	Laser Cutter, CNC, Water Jet
Pro	Easy assembling
Con	Specialised tools

Mechanical structure

- 3D positioner
- Plastic parts + “vitamins”



Extruder

