Laboratorio di Tecnologie Biomediche
Tecnologie di fabbricazione

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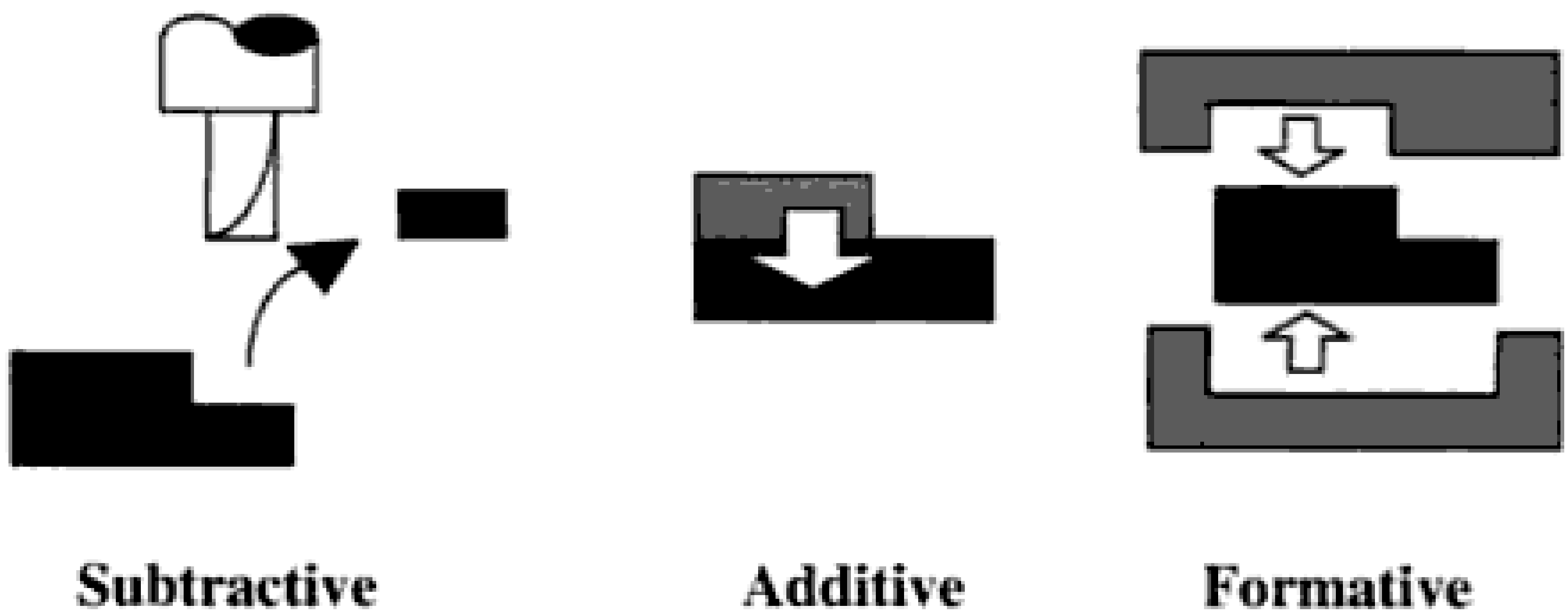
Building 3D objects



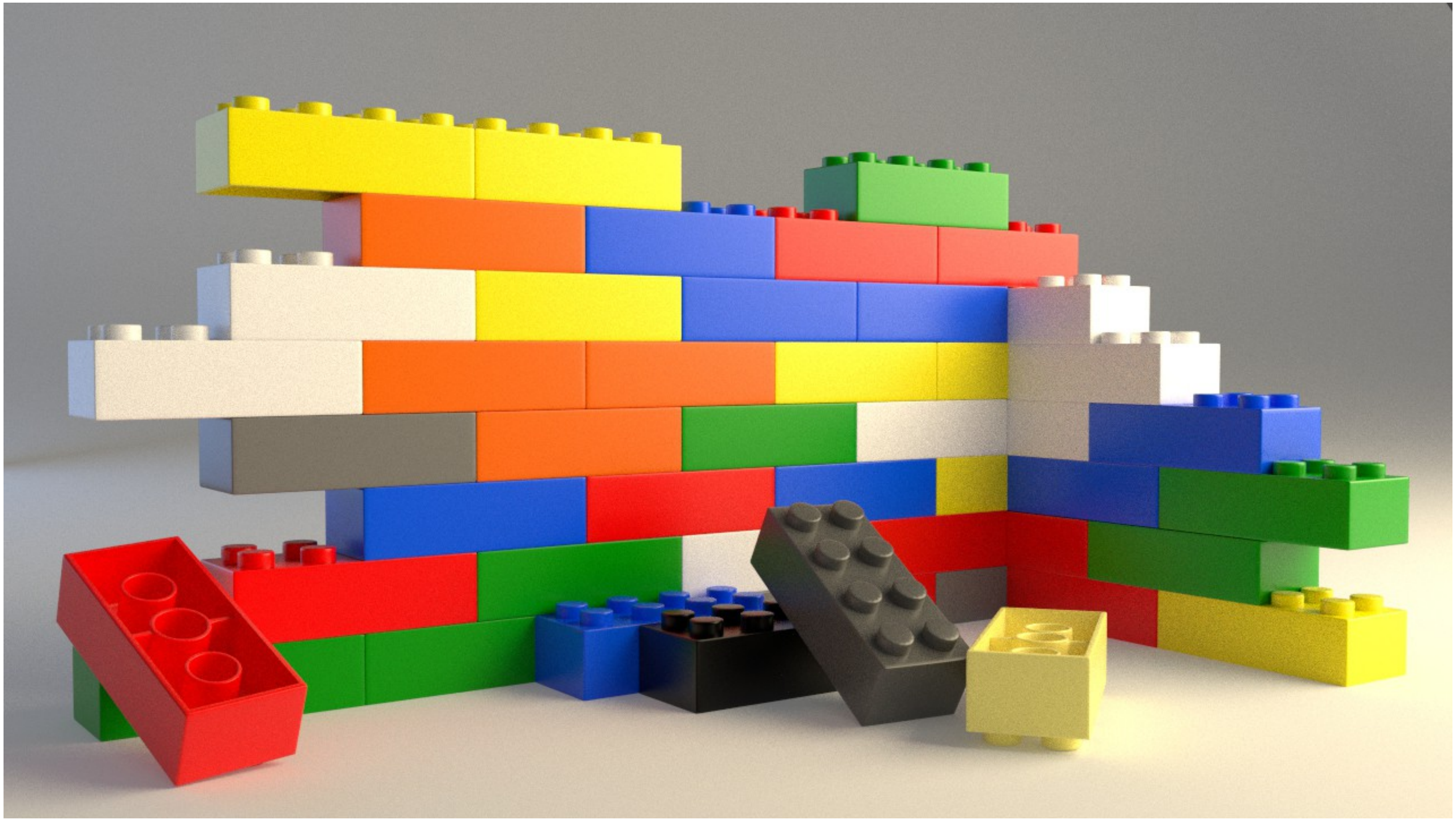
Building 3D objects: subtractive

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

Building 3D objects: formative

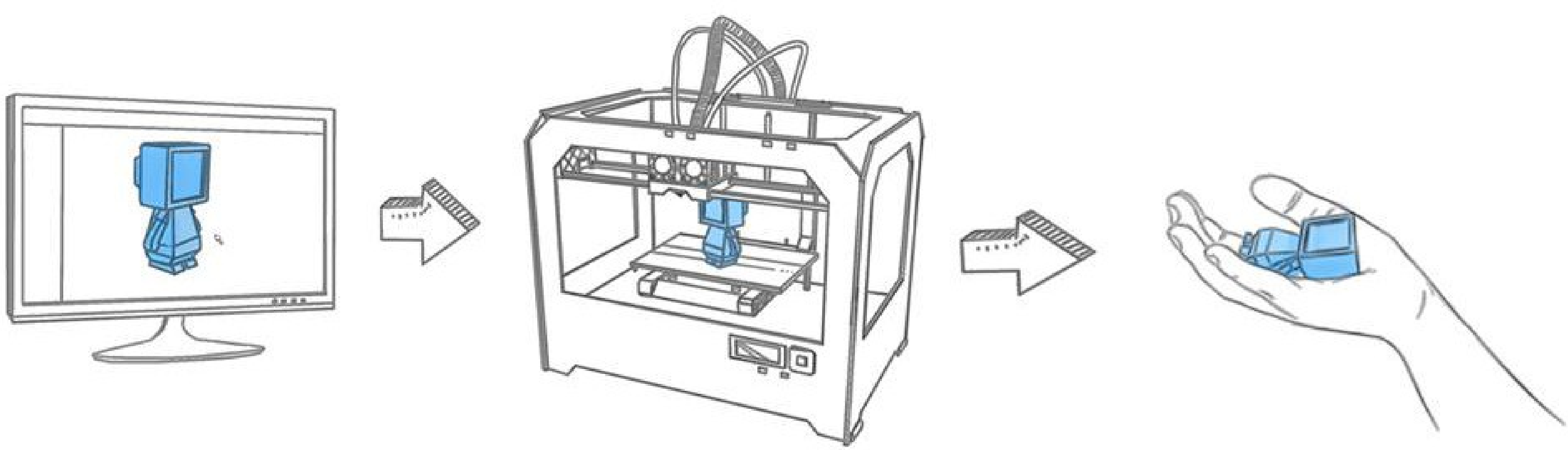
- Bending
- Forging
- Electromagnetic forming
- Plastic injection molding
- …

Building 3D objects: additive

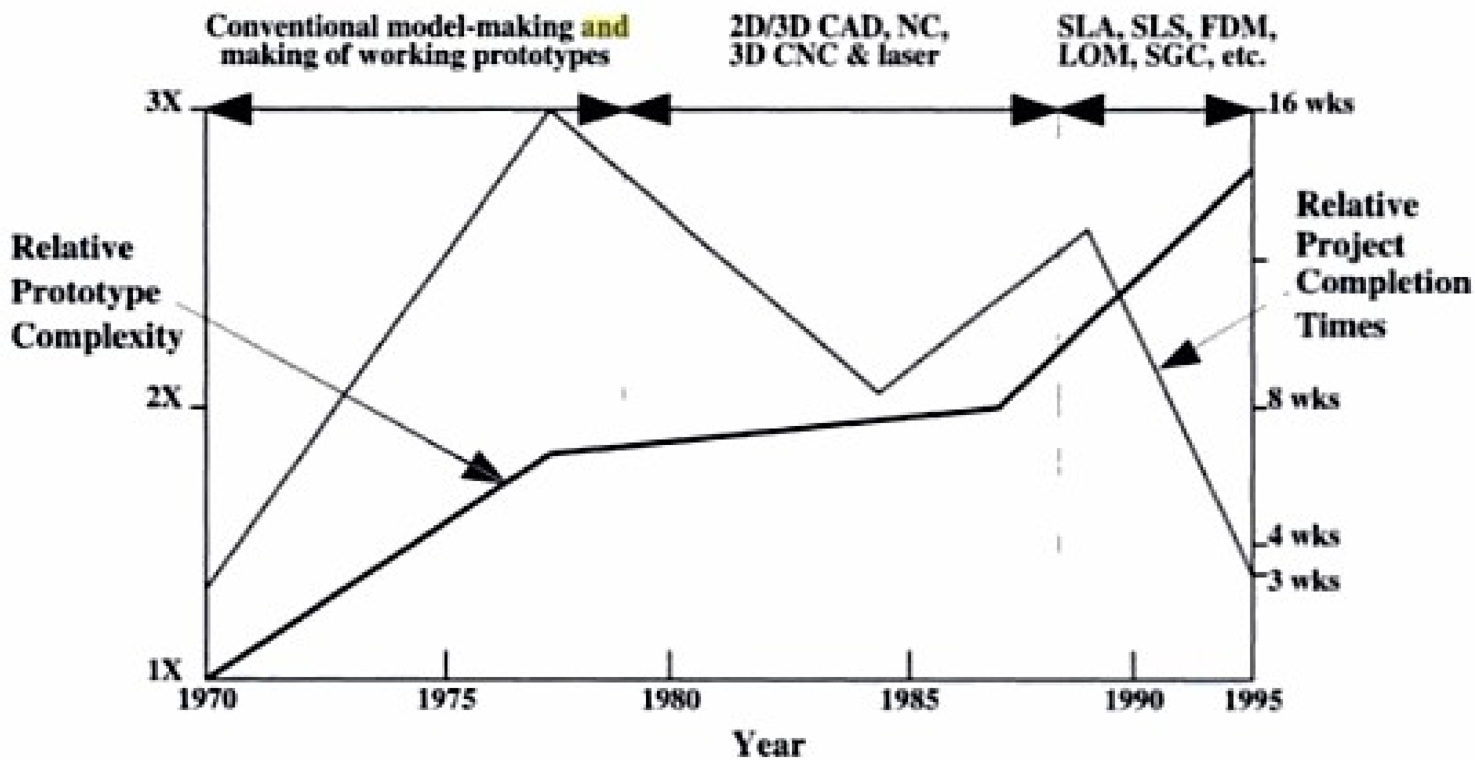


Additive manufacturing

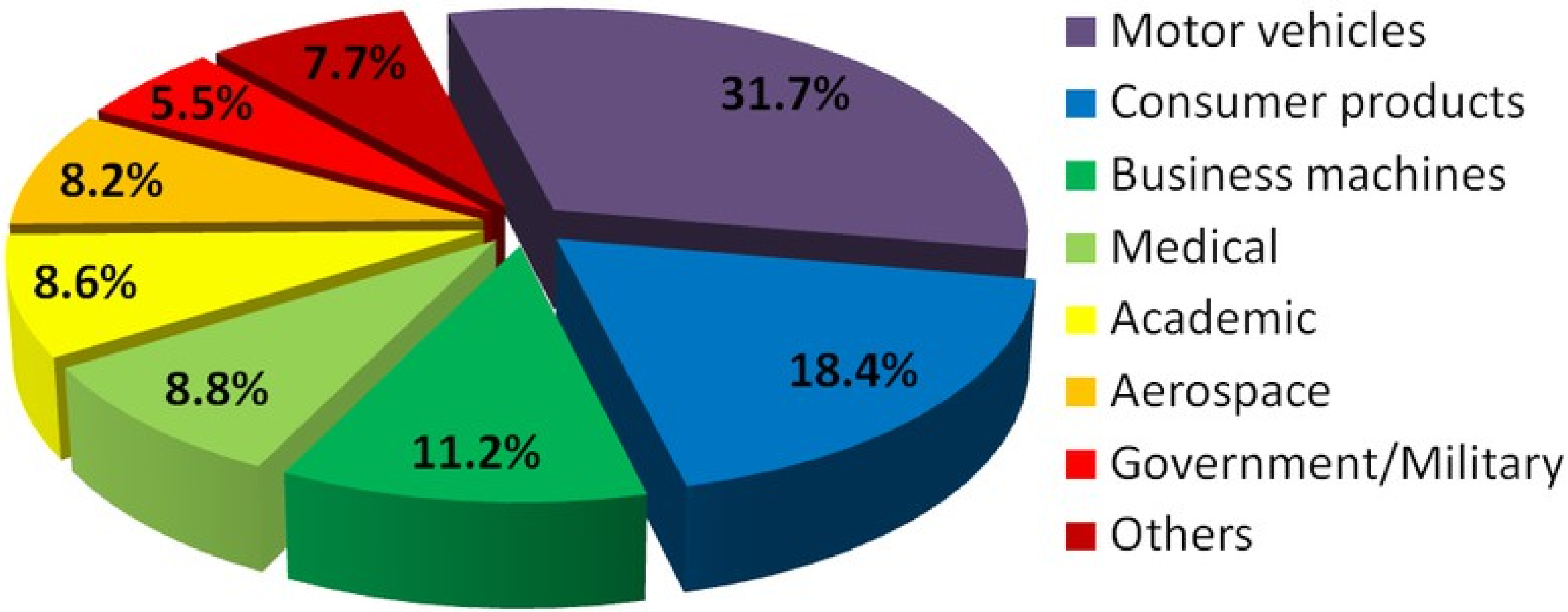
- Additive manufacturing is a process of making a 3D solid object of virtually any shape **from a digital model.**
- It is achieved using an additive process, where successive layers of material are laid down in different shapes.

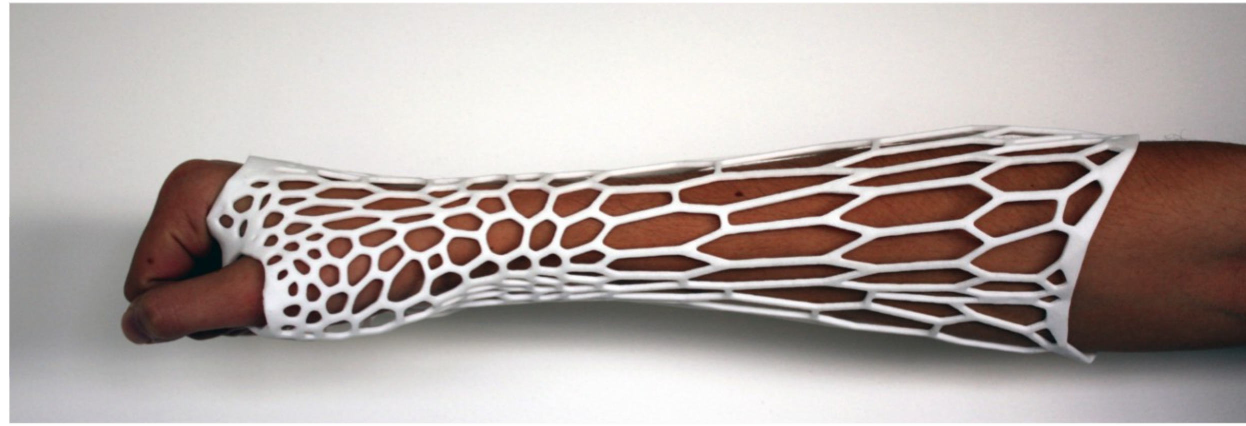


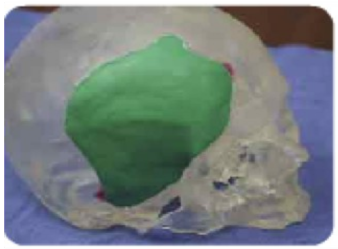
Additive manufacturing for Rapid prototyping

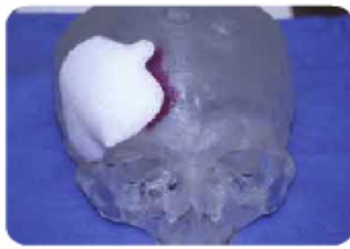


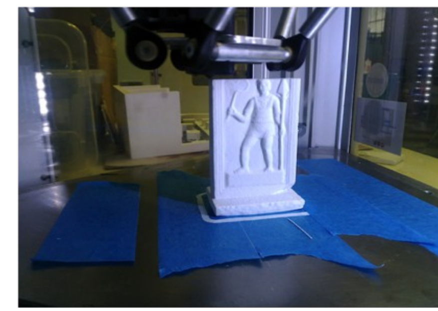
Additive manufacturing by Industry sectors

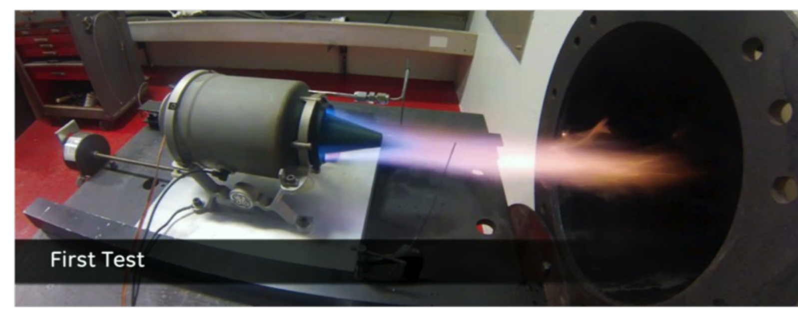


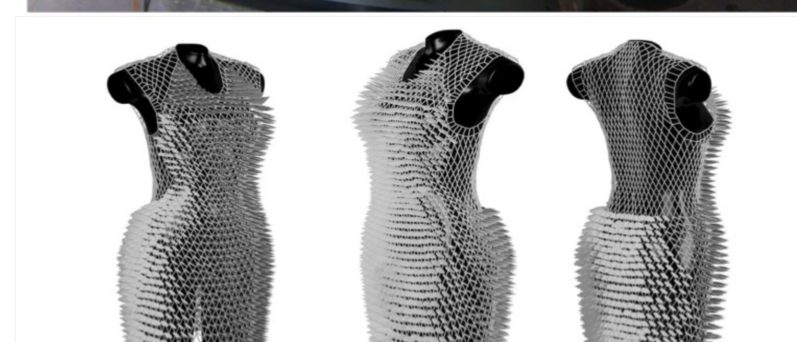








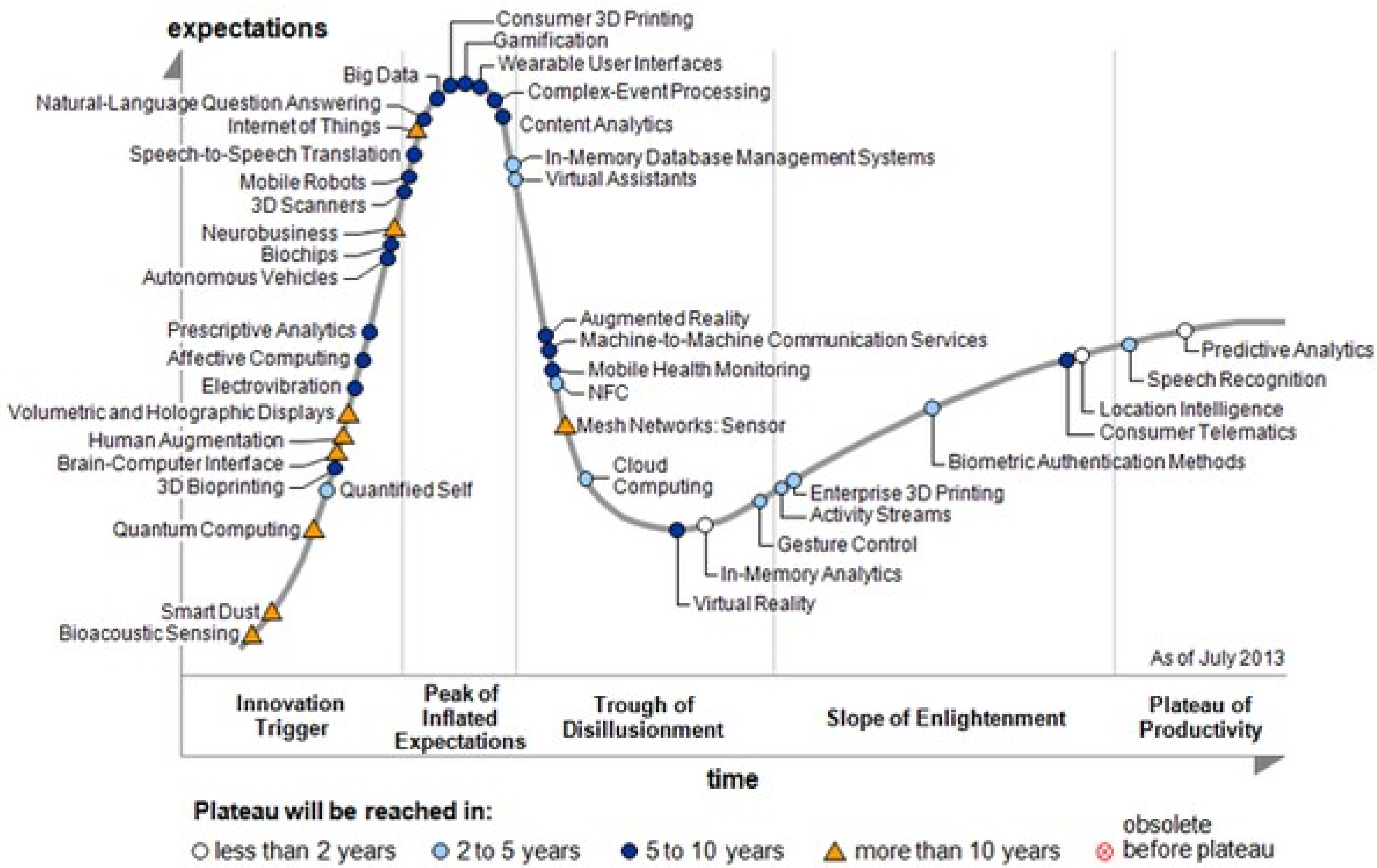

First Test



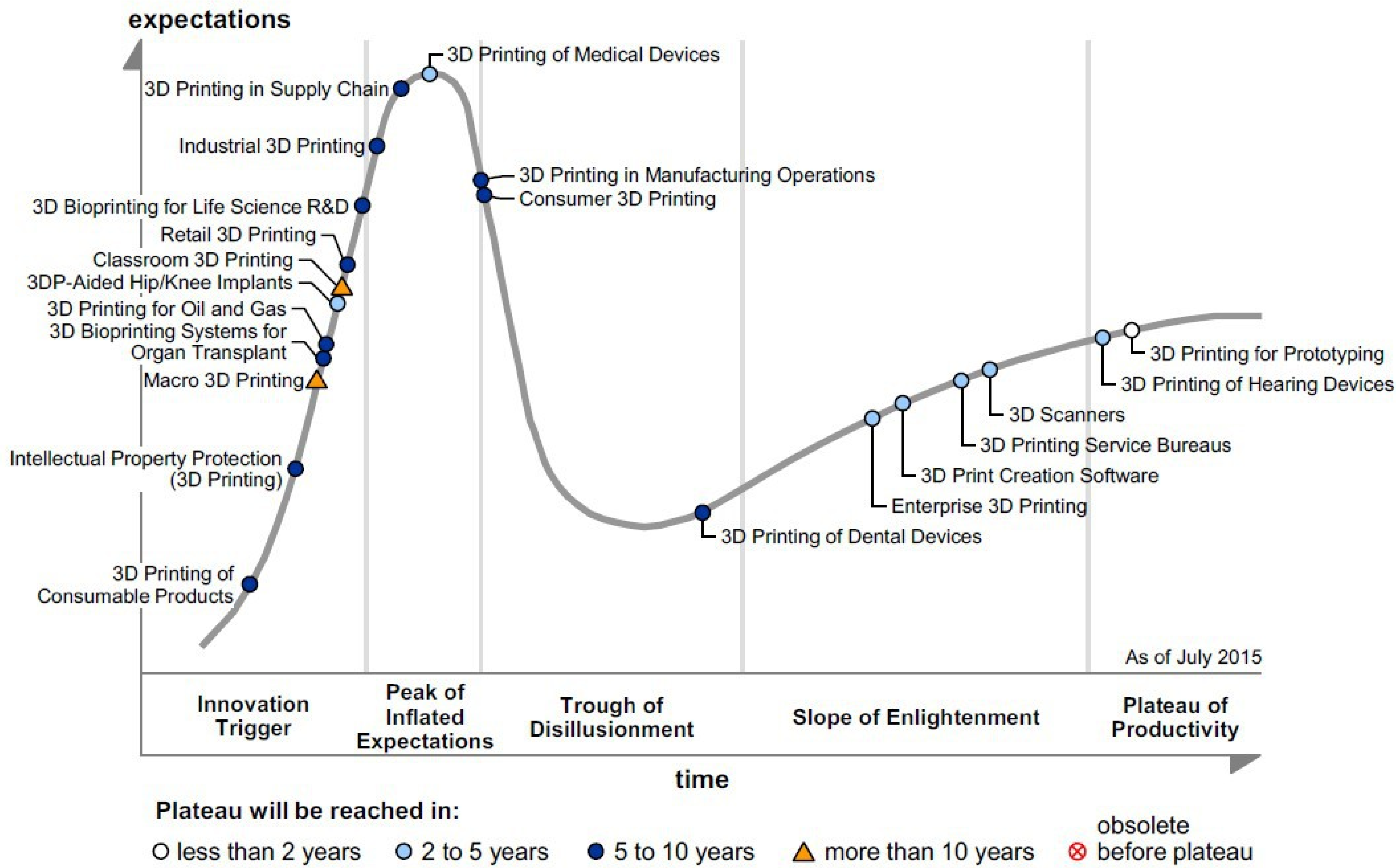
Computer Aided technologies (CAx)

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

Hype cycle 2013



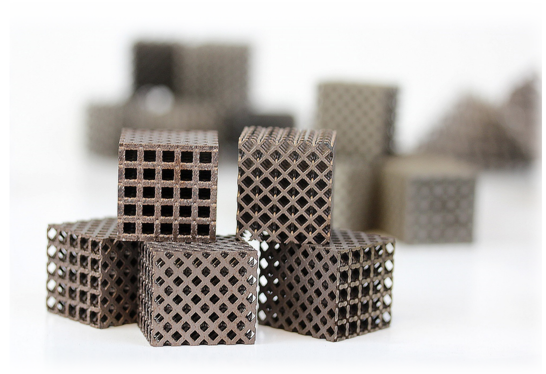
Hype cycle 2015

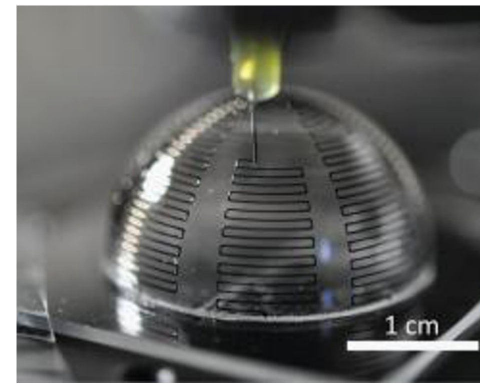


Source: Gartner (July 2015)

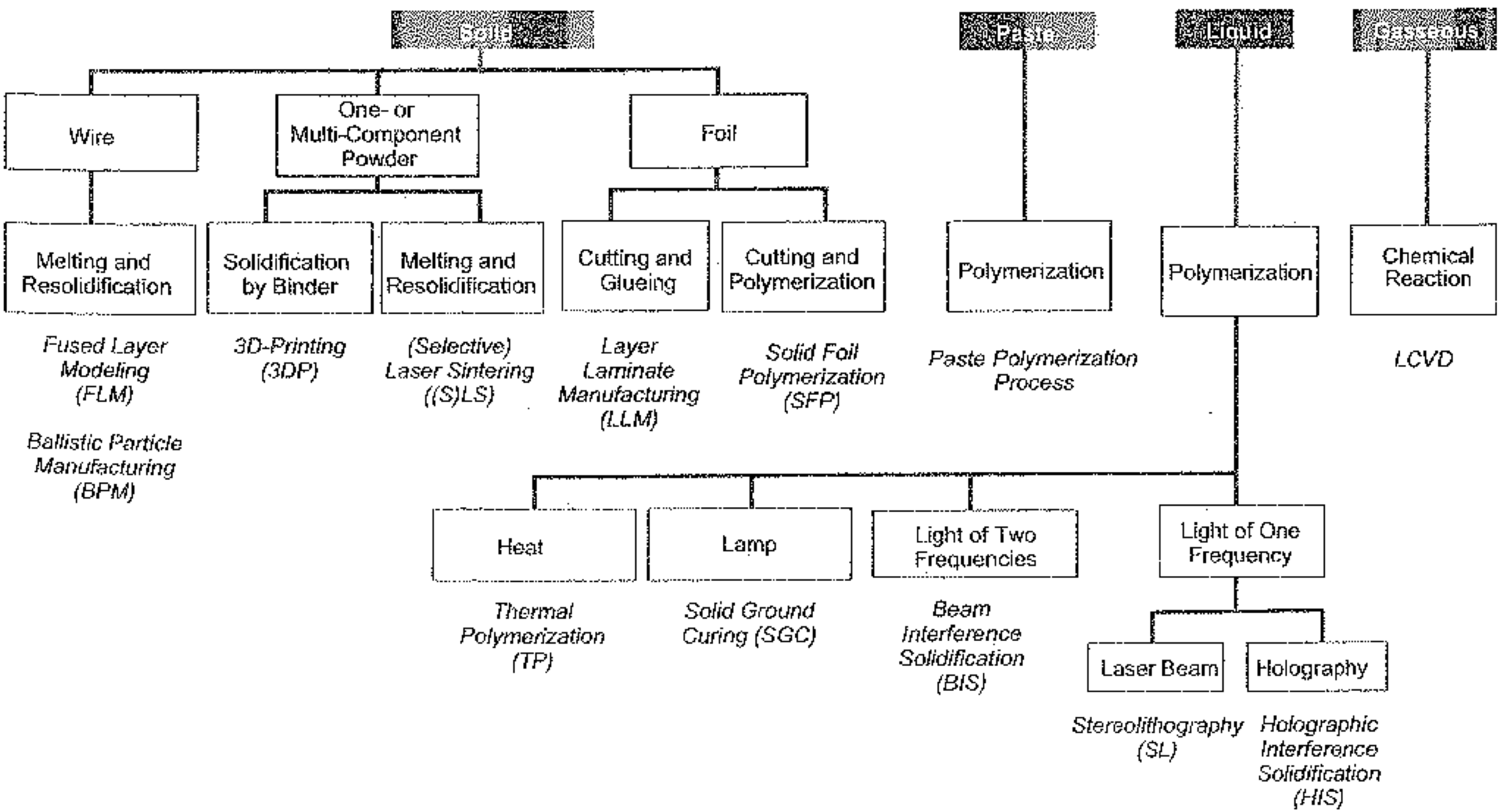
Materials

- Polymers
  - Thermoplastics
  - Resins
  - Wax
- Slurries and gels
- Metals
- Ceramics
- Biological materials





A possible classification



A(nother) possible classification

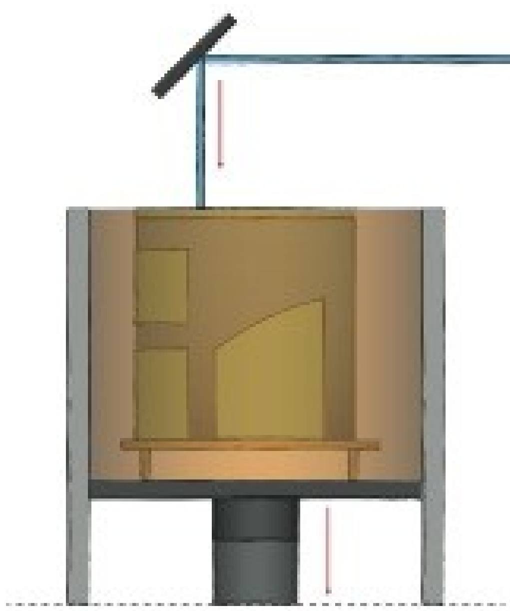
- ASTM/ISO 52900 classification
  - **Binder jetting**: AM process in which a liquid bonding agent is selectively deposited to join powder materials
  - **Directed energy deposition**: AM process in which focused thermal energy is used to fuse materials by melting as they are being deposited
    - Note: “Focused thermal energy” means that an energy source (e.g. laser, electron beam, or plasma arc) is focused to melt the materials being deposited.
  - **Material extrusion:** AM process in which material is selectively dispensed through a nozzle or orifice
  - **Material jetting:** AM process in which droplets of build material are selectively deposited
    - Note: Example materials include photopolymer and wax.
  - **Powder bed fusion:** AM process in which thermal energy selectively fuses regions of a powder bed
  - **Sheet lamination:** AM process in which sheets of material are bonded to form a part
  - **Vat photopolymerisation:** AM process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization.

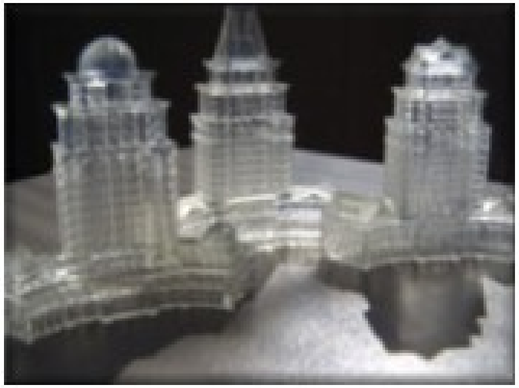
A(nother) possible classification

Materials	Example materials	Process categories						
		Vat photo-polymer-ization	Material jetting	Binder jetting	Powder bed fusion	Material extrusion	Directed energy deposition	Sheet lamination
Thermoset Polymers	Epoxies and acrylates	X	X					
Thermo-plastic polymers	Polyamide, ABS, PPSF		X	X	X	X		X
Wood	paper							X
Metals	Steel, Titanium alloys, Cobalt chromium			X	X		X	X
Industrial ceramic materials	Alumina, Zirconia, Silicone nitride	X		X	X			X
Structural ceramic materials	Cement, Foundry sand			X	X	X		
Note: Combinations of the above material classes, e.g. a composite, are possible								

Available technologies

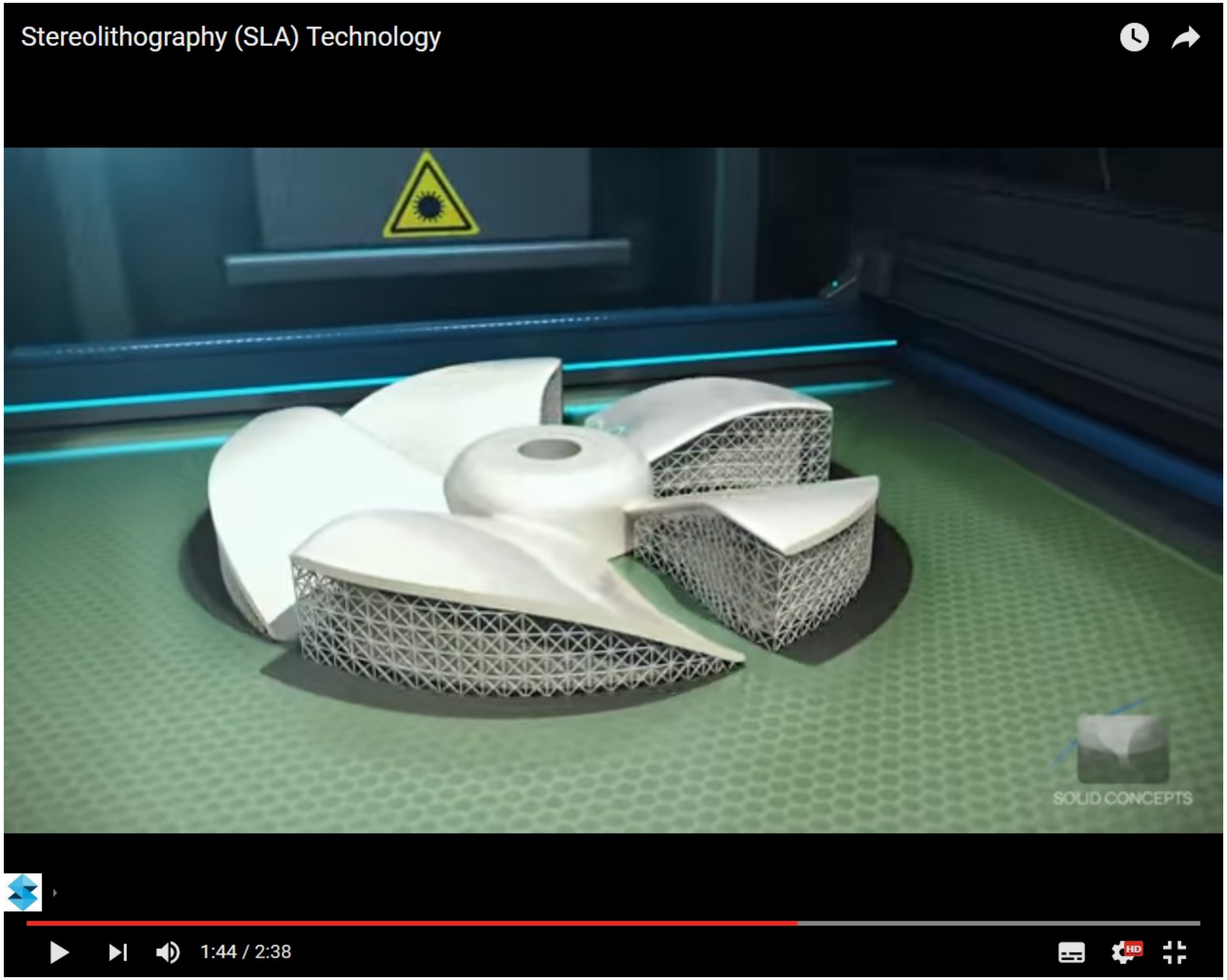
- Solidification of liquid materials
  - Vat photo-polymerization process



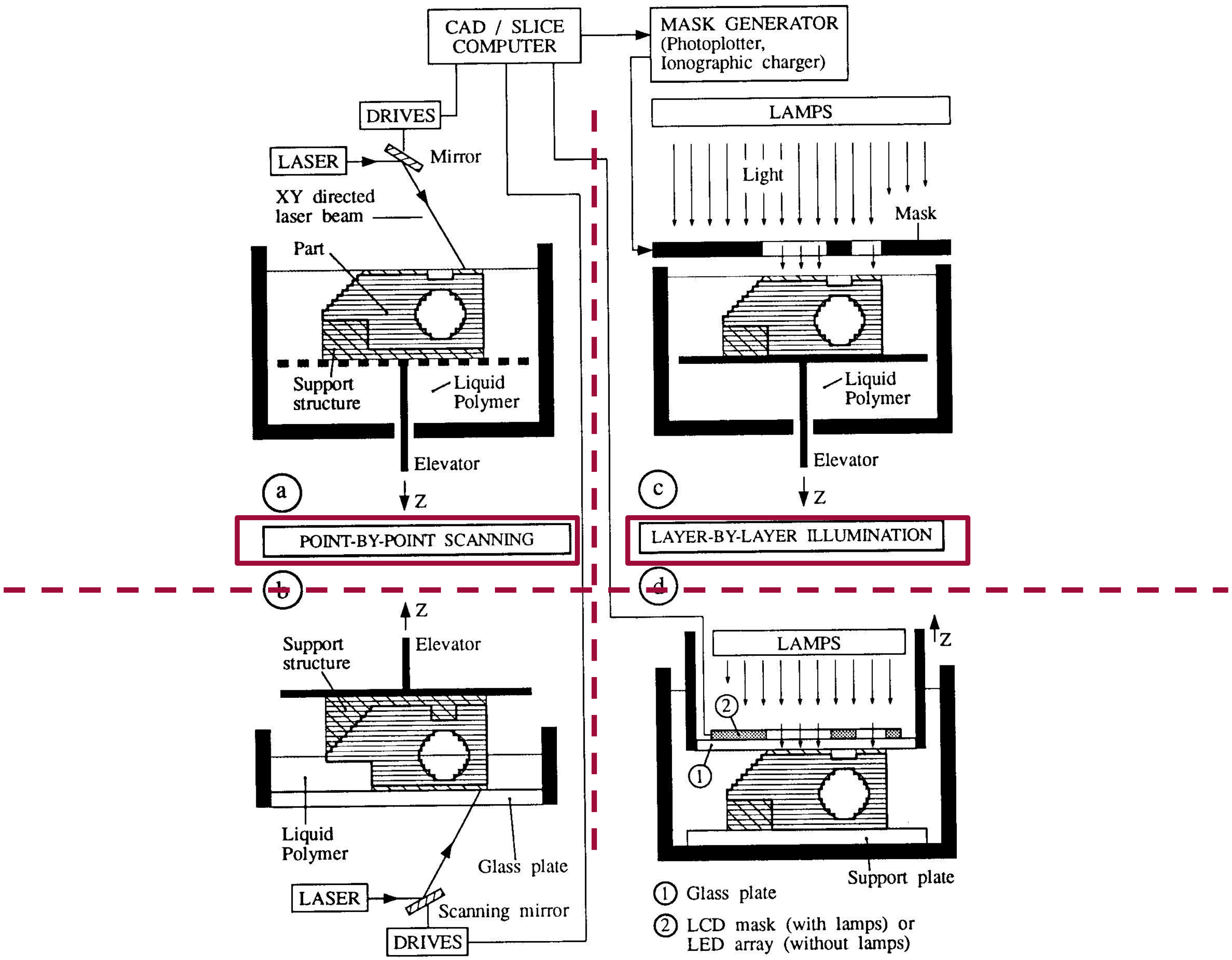


Stereolithography

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



Stereolithography: options



3D System SLA 7000

Laser	He-Cd
Wavelength	0.325 um
Power	800 mW
Minimum layer	0.025 mm
Building volume	500 x 500 x 600 mm^3
Scan speed	Max 9.52 m/s
Spot diameter	From 0.23 to 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%

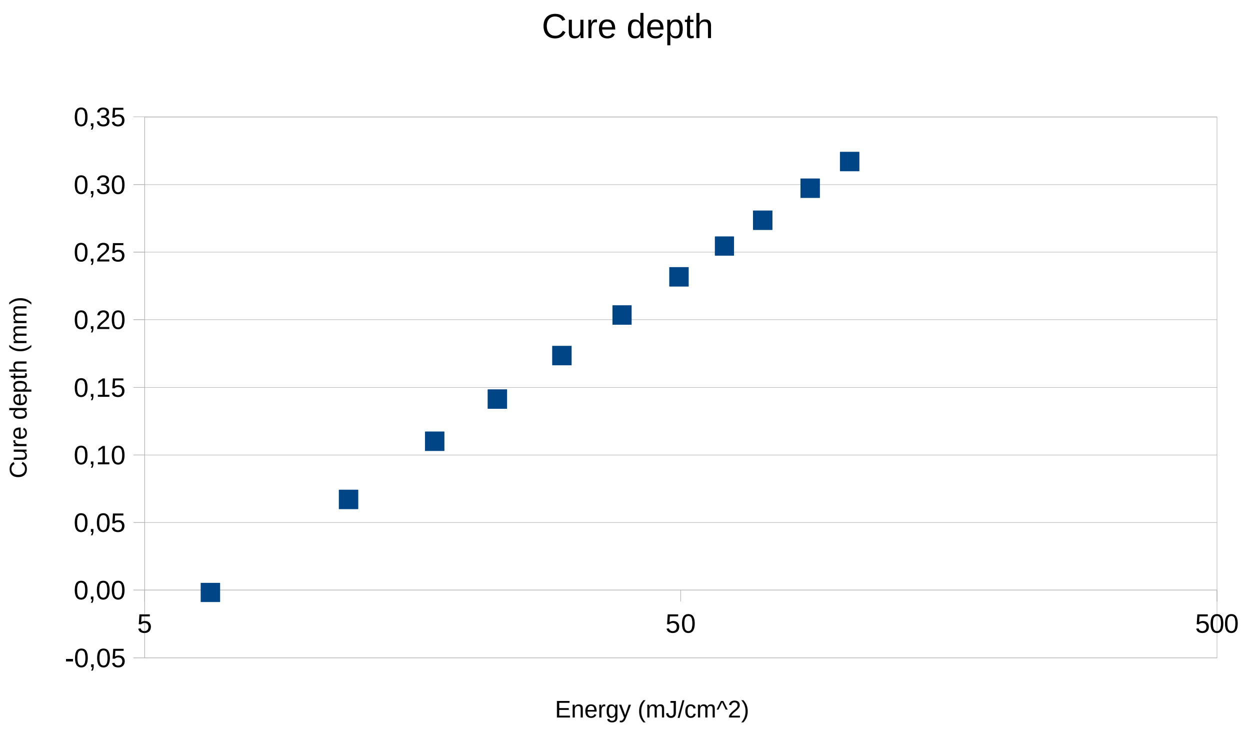
Materials: Somos 18120

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/cm²	[critical exposure]
D_P	4.57 mils	[slope of cure-depth vs. ln (E) curve]
E_{10}	57.0 mJ/cm²	[exposure that gives 0.254 mm (.010 inch) thickness]

Materials: Somos 18120

$$C_d = D_p \ln\left(\frac{E}{E_c}\right)$$



Cost

- Cost of materials:
  - 200€ per liter
  - A cube 20*20*20 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.

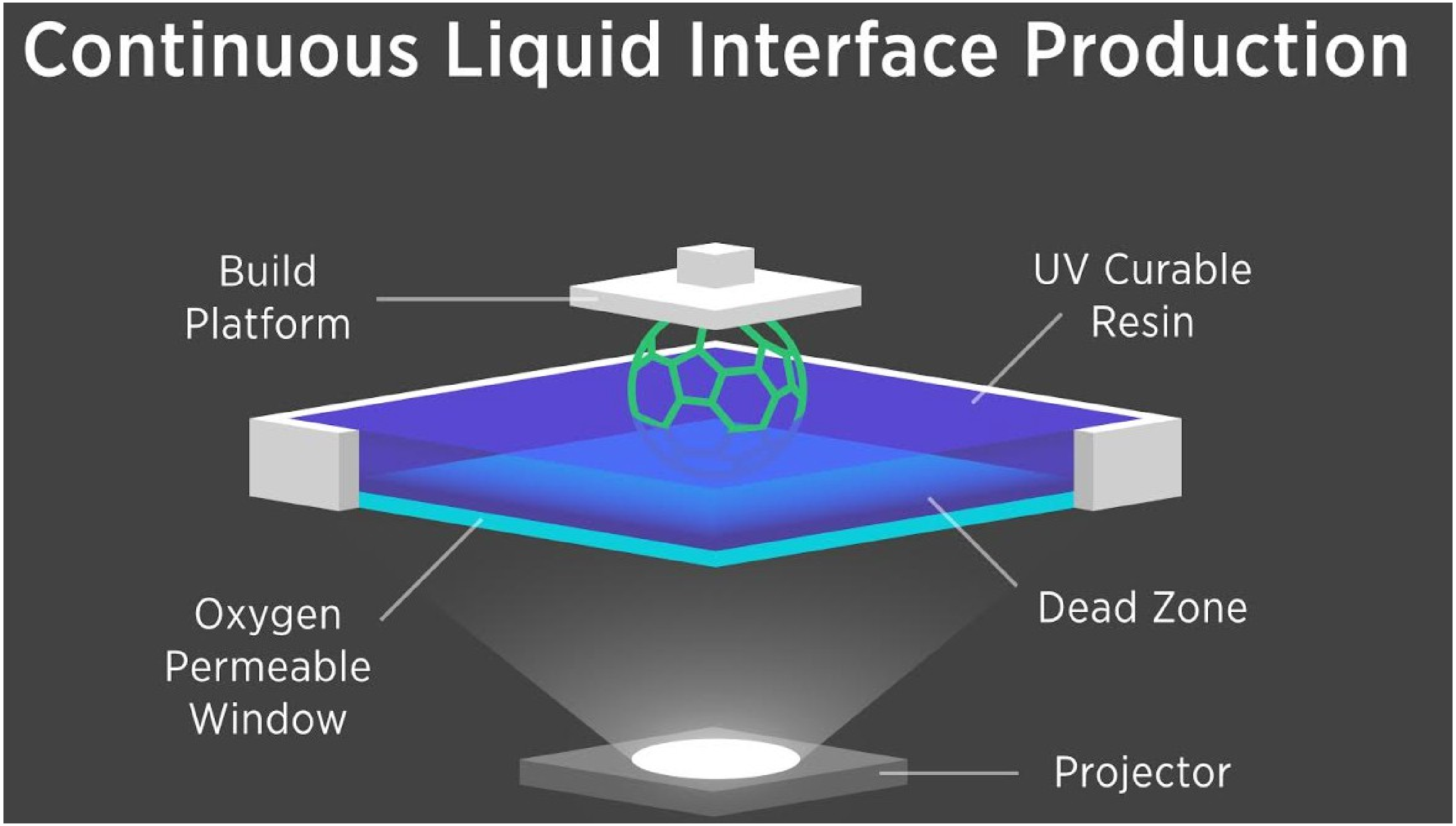
Pros

- 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 cm3 (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

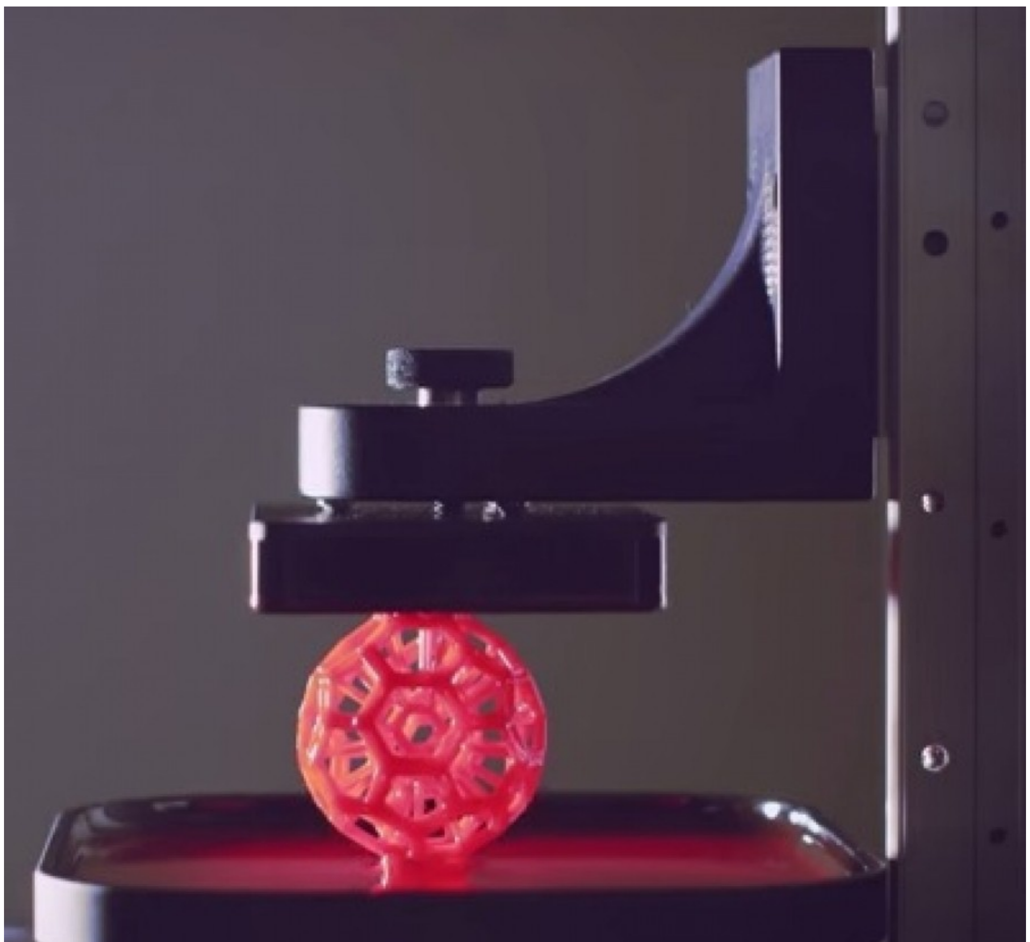
- Requires post-curing.
  - Long-term curing can lead to warping.
  - Parts are quite brittle and have a tacky surface.
  - Support structures are typically required.
  - Supports must be removed by hand
  - Uncured material is toxic.
- Little material choice
- Costs
  - Material
  - trained operator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

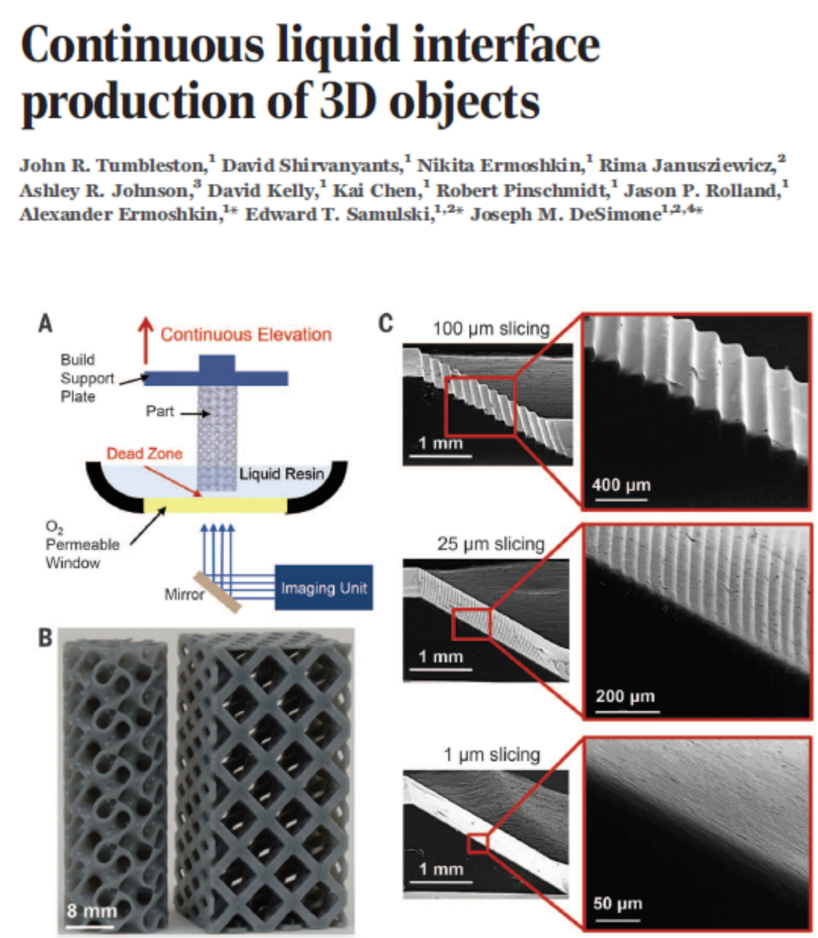
Carbon 3D


Continuous Liquid Interface Production
Build Platform
UV Curable Resin
Oxygen Permeable Window
Dead Zone
Projector

Carbon 3D

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



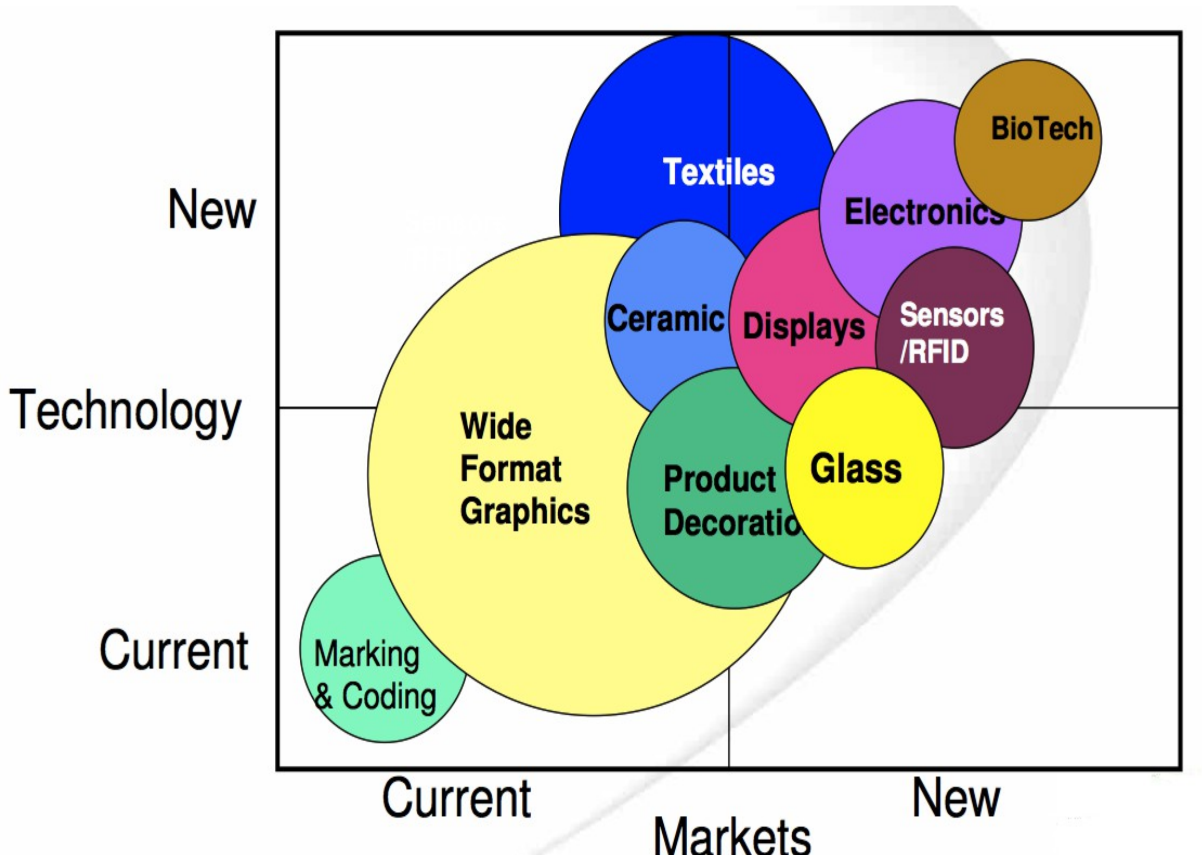


Continuous liquid interface production of 3D objects

John R. Tumbleston,[1] David Shirvanyants,[1] Nikita Ermoshkin,[1] Rima Januszіewicz,[2] Ashley R. Johnson,[3] David Kelly,[1] Kai Chen,[1] Robert Pinschmidt,[1] Jason P. Rolland,[1] Alexander Ermoshkin,[1]* Edward T. Samulski,[1,2]* Joseph M. DeSimone[1,2,4]*

Inkjet technologies

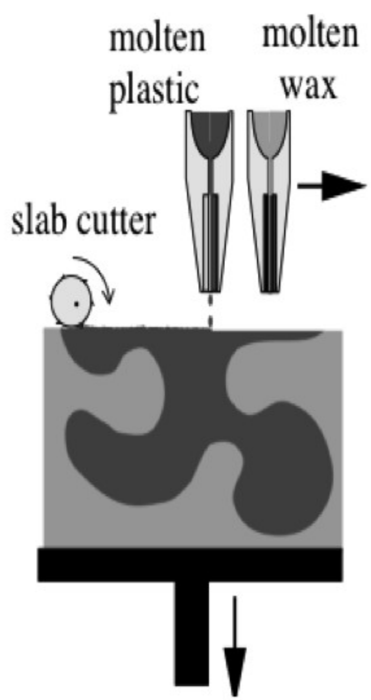
- The ink-jet technology is a contact free dot matrix printing procedure. Ink is issued from a small aperture directly onto a specific position on a medium
- Binder Jetting
- Material Jetting



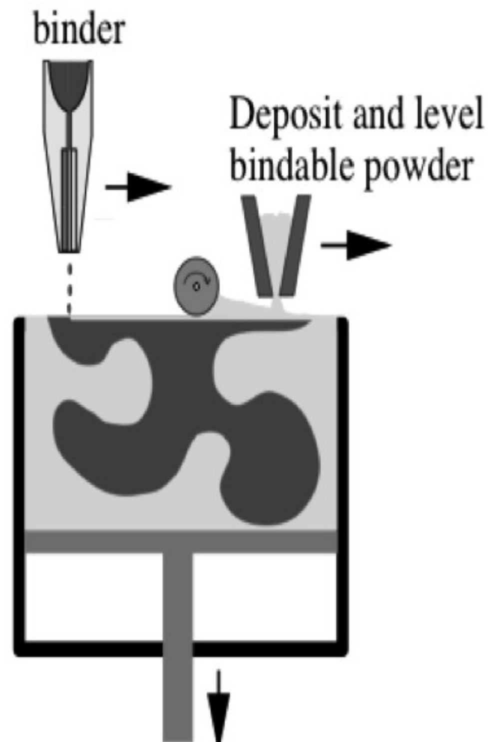
Polyjet

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

Generation from the solid phase

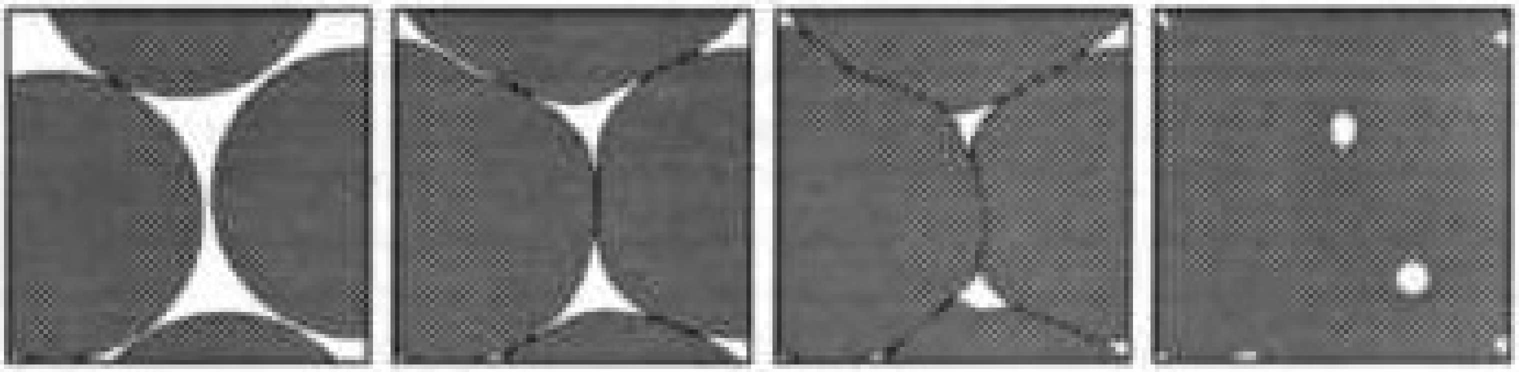


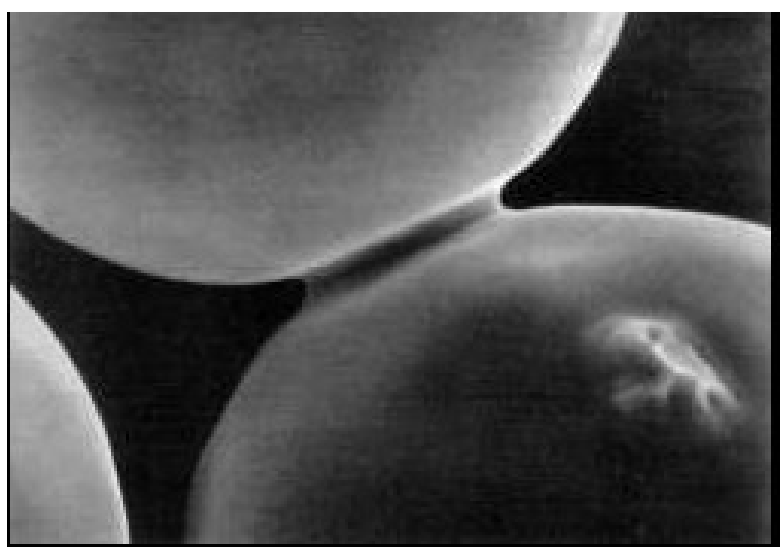
Multijet modeling
(Ballistic)



3DP

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 Matallurgy).
- 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

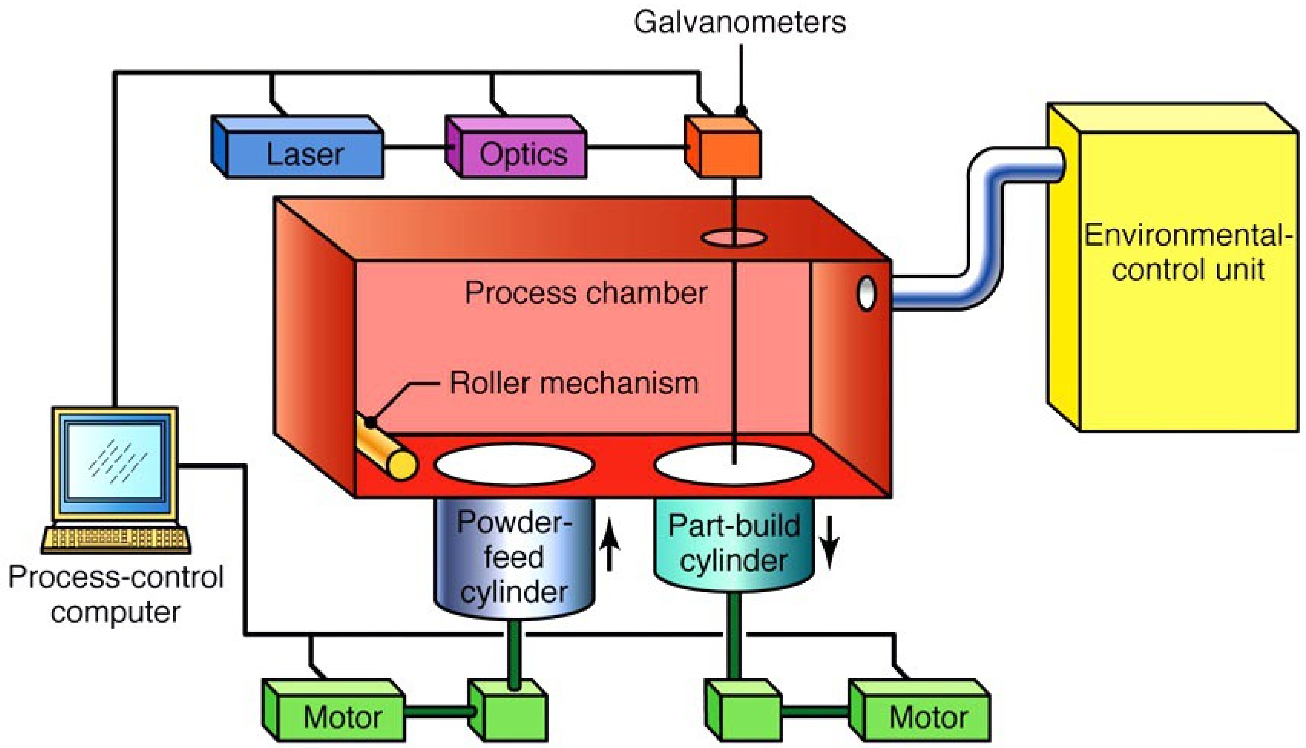
- Sintering process used in Rapid Prototyping differs from the Powder Metallurgy, such as:
  - Plastic based powders, in addition to metal powders.
  - Local sintering, not overall sintering.
  - Very short sintering period.
- Laser (heat source) is exposed to sections to be sintered for a very short 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 (Powder bed fusion)

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

Laser sintering

Laser sintering



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

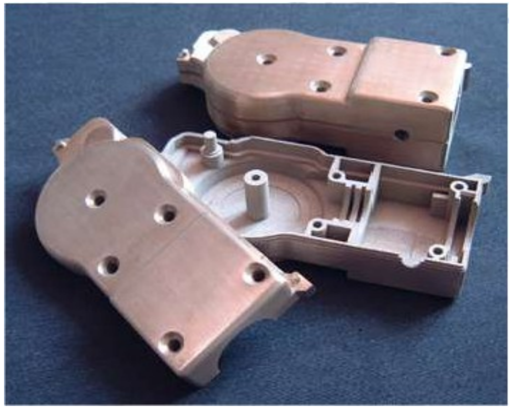
Laser sintering: materials

- 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).

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.





Laser sintering

- Advantages:
  - Cheap and no harmed healthy material,
  - Large selection of used materials,
  - no support construction,
  - Decreasing of destruction possibility of inside stresses.
- 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

Electron beam melting

- Electron Beam Melting (EBM) is a type of rapid prototyping for metal parts. The technology manufactures parts by melting metal powder layer per layer with an electron beam in a high vacuum. Unlike some metal sintering techniques, the parts are fully solid, void-free, and extremely strong.
- EBM is also referred to as Electron Beam Machining.
- High speed electrons .5-.8 times the speed of light are bombarded on the surface of the work material generating enough heat to melt the surface of the part and cause the material to locally vaporize.
- EBM does require a vacuum, meaning that the workpiece is limited in size to the vacuum used. The surface finish on the part is much better than that of other manufacturing processes.
- EBM can be used on metals, non-metals, ceramics, and composites.

Electron beam melting

ARCAM A2 machine for
direct metal deposition

Components made of Ti
and Co-Cr alloys

Biomedical components
made of Ti alloys

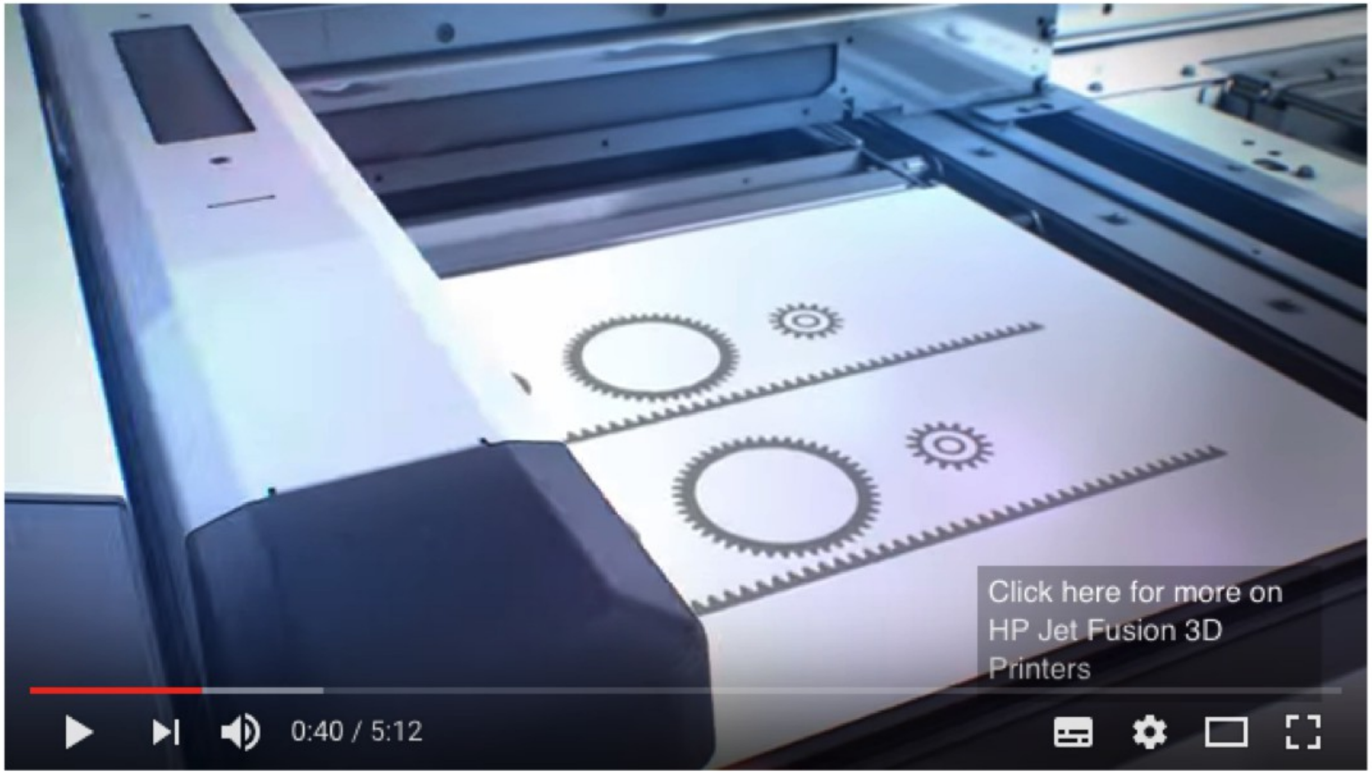
Electron beam melting

- High productivity
- Suitable for very massive parts
- No residual internal stress (constant 680-720°C build temperature)
- Less supports are needed for manufacturing of parts
- Possibility to stack parts on top of each other (mass production)
- Sintered powder = good for thermal conductivity = less supports
- Process under vacuum (no gaz contaminations)
- Very fine microstructures (Ti6Al4V), very good mechanical and fatigue results (Ti6Al4V)

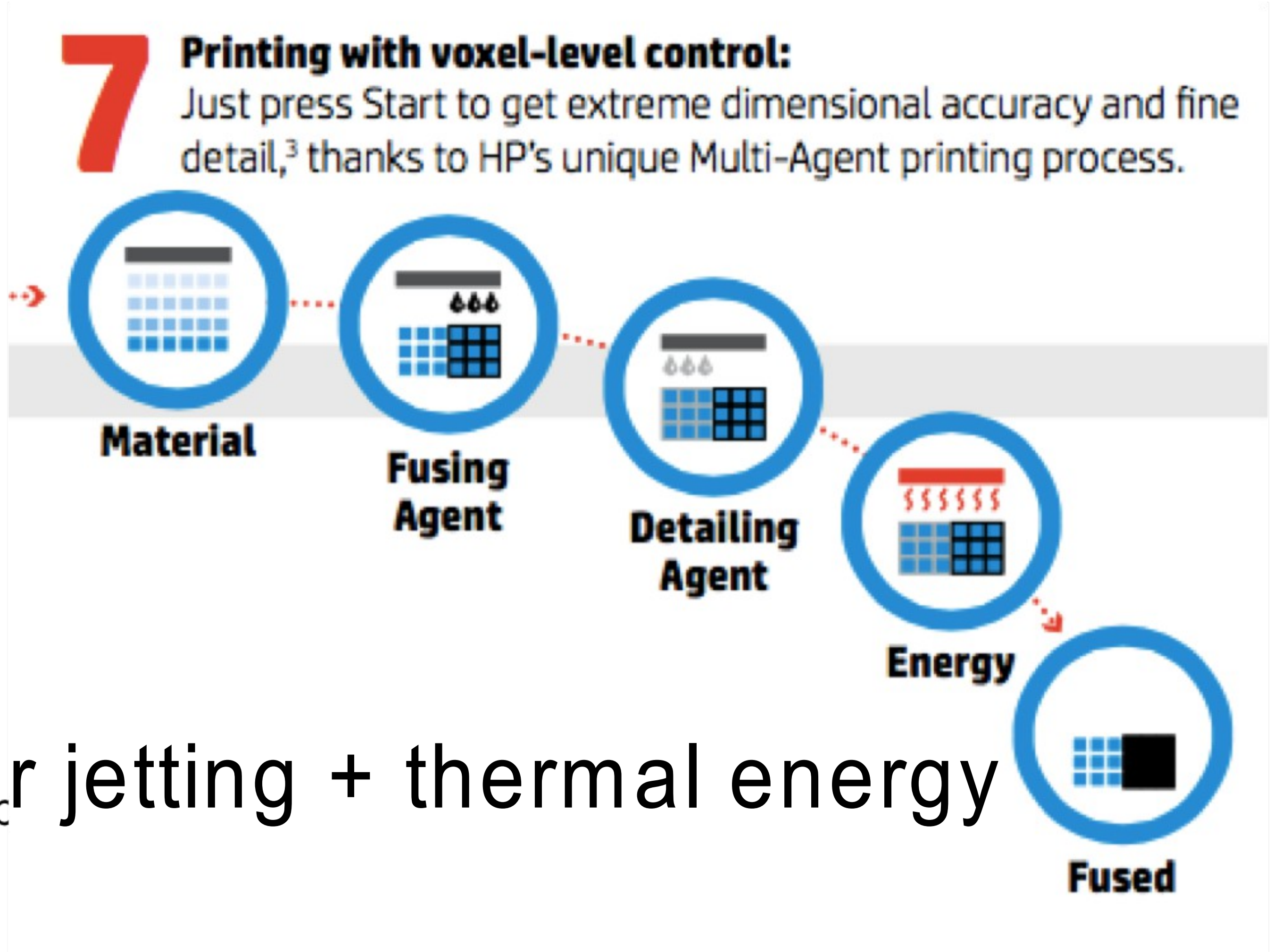
Electron beam melting

- Powder is sintered -> tricky to remove (e.g. interior channels)
- Long dead time between 2 productions (8 hour for cooling – A2, A2X, A2XX systems)
- Tricky to work with fine powder
- Expensive maintenance contract

Multijet fusion

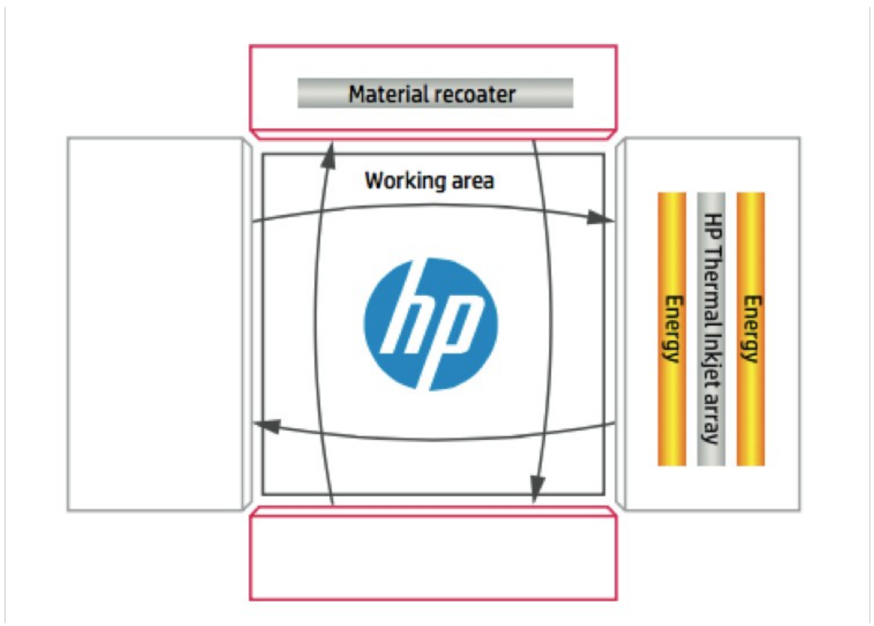
- https://www.youtube.com/watch?time_continue=1&v=VXntl3ff5tc
- https://www.youtube.com/watch?v=qEPqlVs11KM
- 

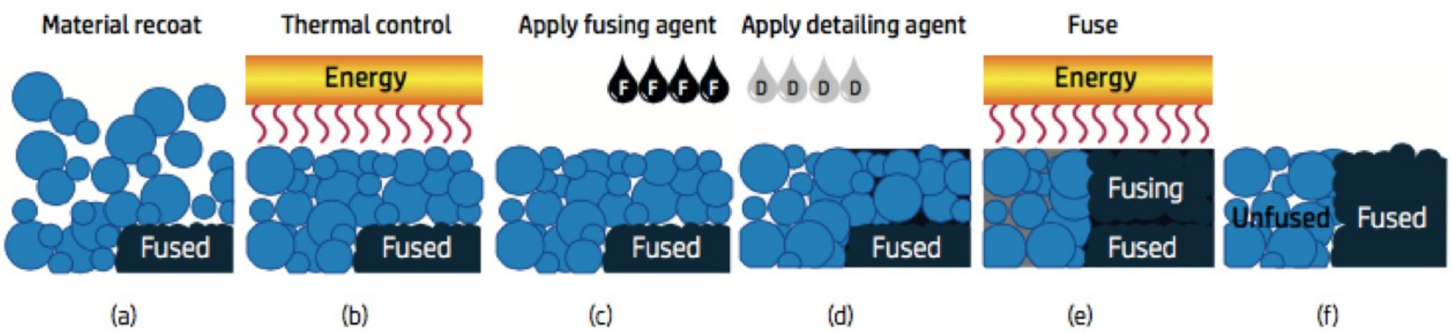
Multijet fusion



- Binder jetting + thermal energy

Multijet fusion





Laser engineering net shaping (LENS, Directed energy deposition)

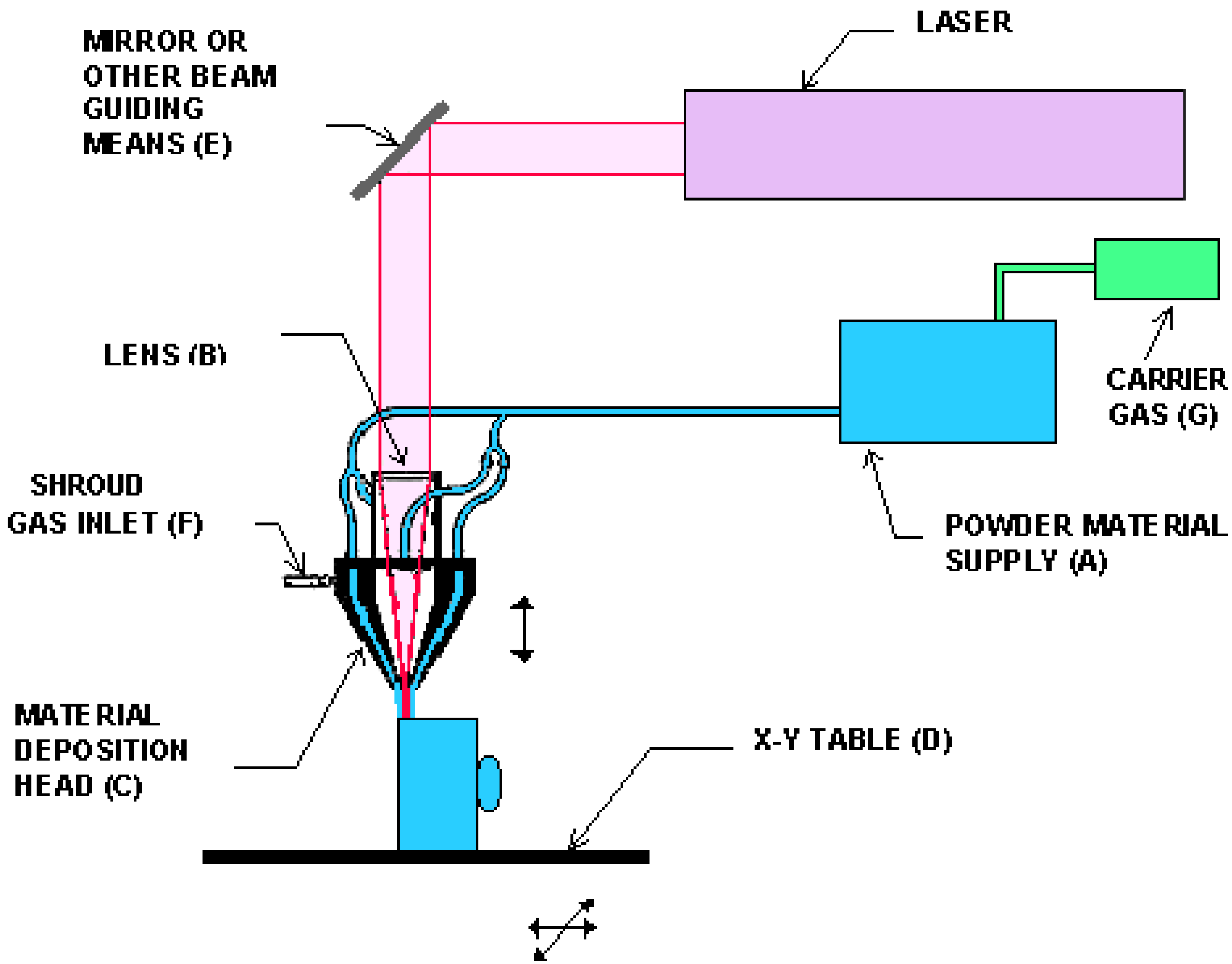
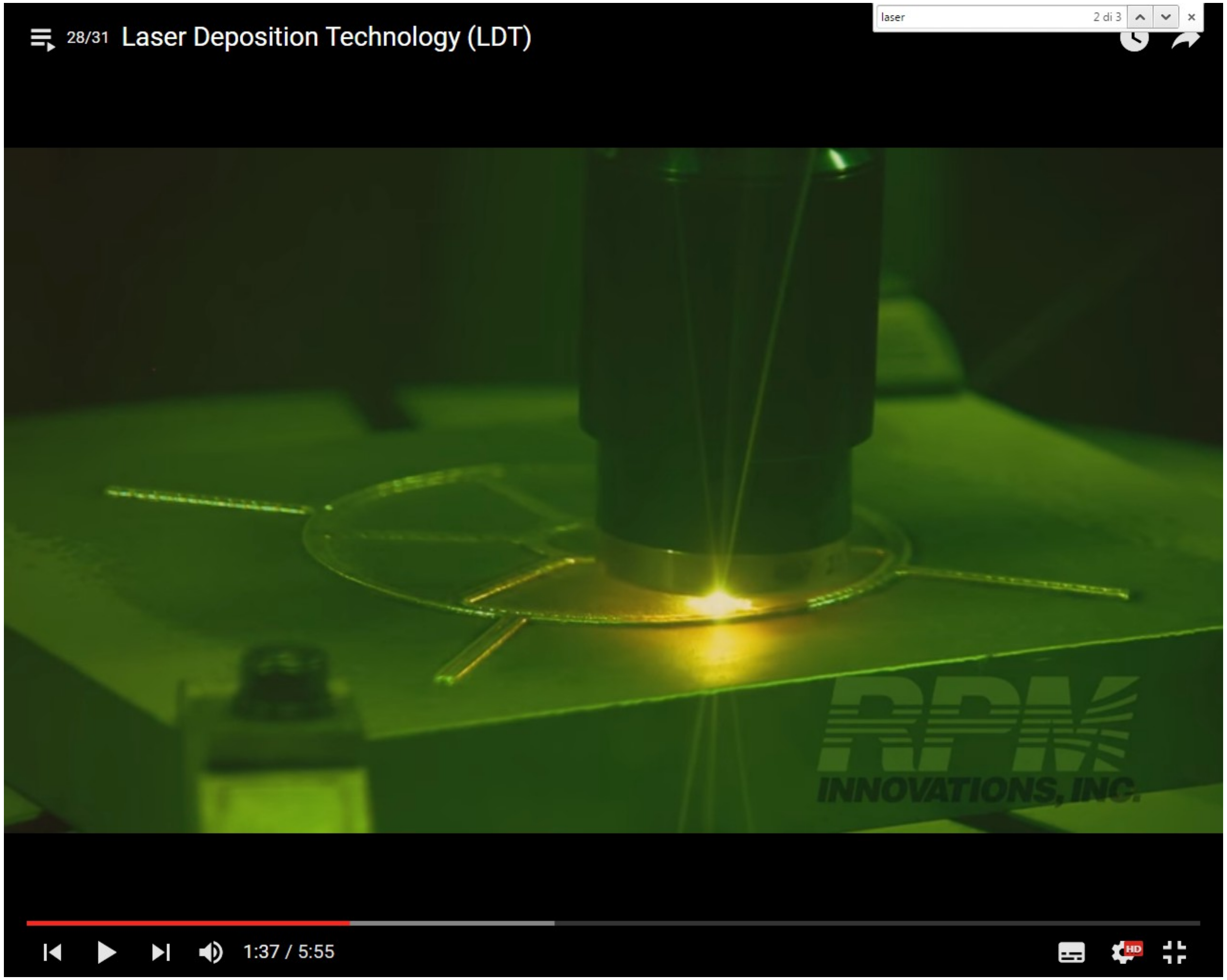


Fig. 8. Laser engineered net shaping.

Laser engineering net shaping (LENS, Directed energy deposition)

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



Laser engineering net shaping (LENS, Directed energy deposition)

- Fully Dense Metal parts with good metallurgica properties
- Laser melts metal powder
- Powder delivered coaxially with laser
- Inert gas protects weld pool
- Near net shape with some finish machining

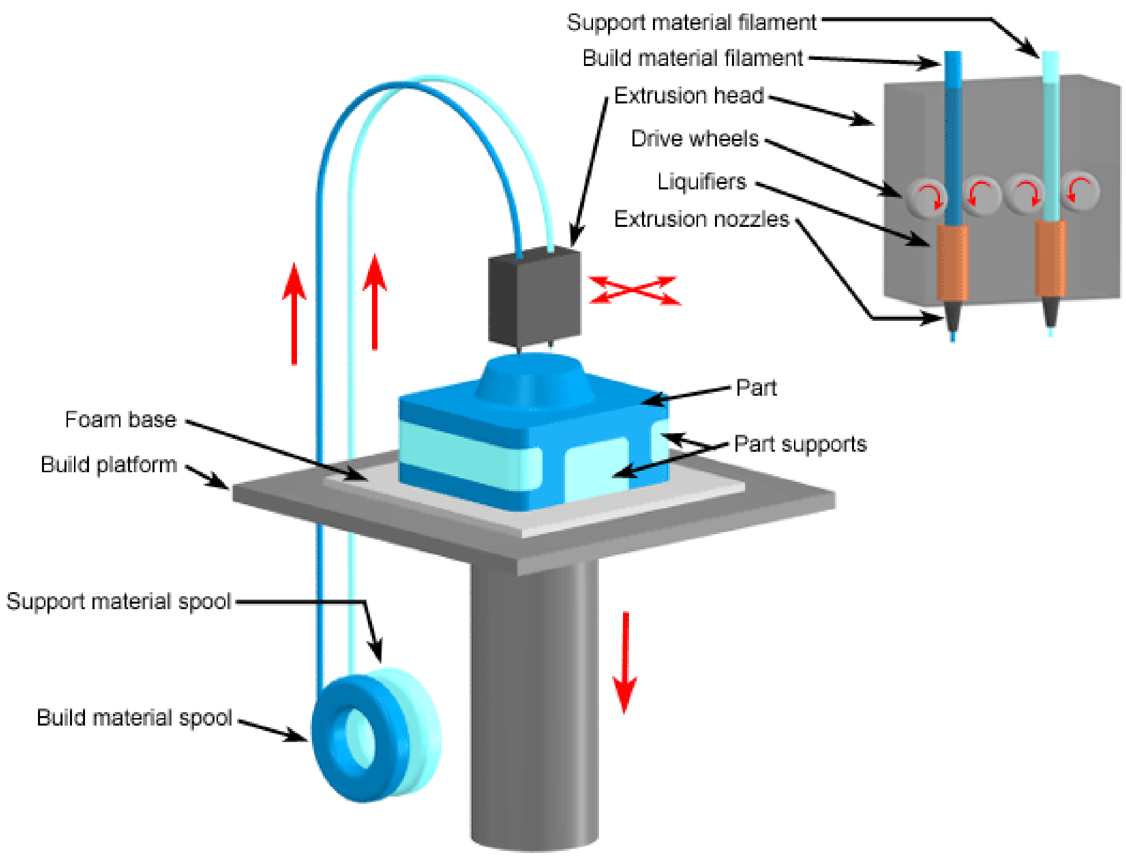
Laser engineering net shaping (LENS, Directed energy deposition)

- 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.

Fused Deposition Modelling (FDM, Material extrusion)

- 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



Fused Deposition Modelling

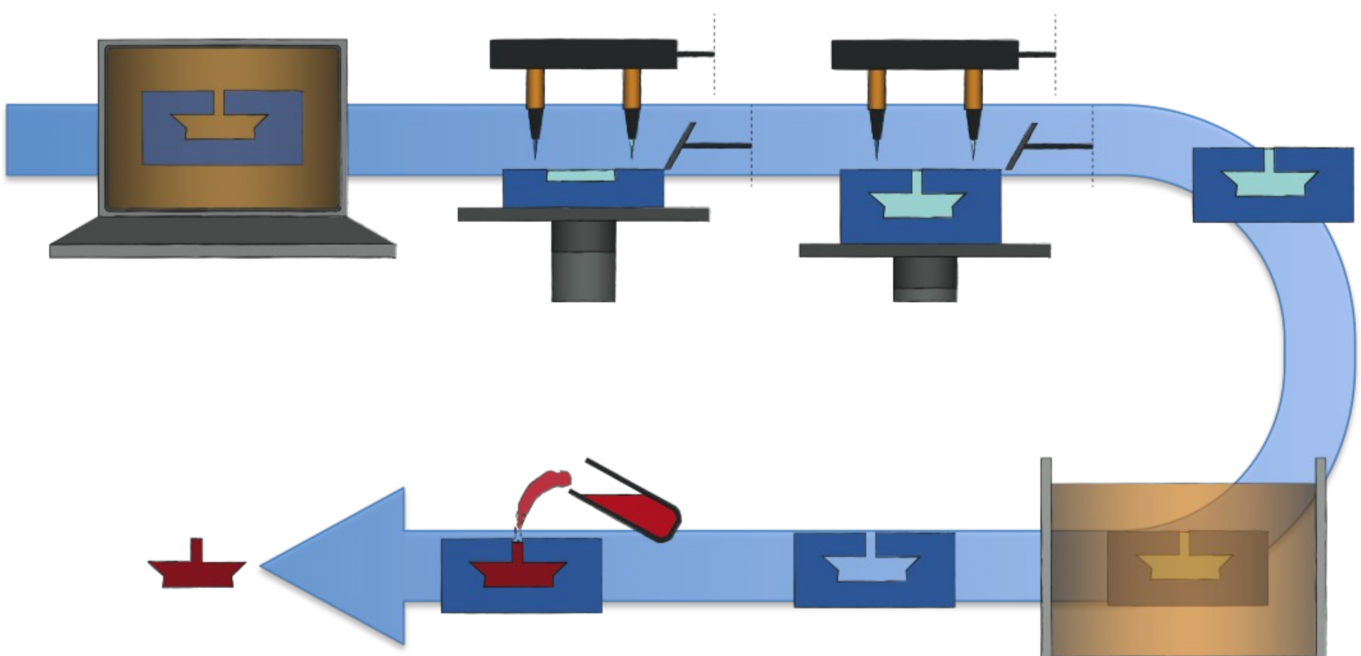
- https://www.youtube.com/watch?v=WHO6G67GJbM

Fused Deposition Modelling

- "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 graphene loaded materials)
  - Metallic loaded plastics

Rapid tooling

- Indirect rapid prototyping
  - Molds fabricated with RP devices (CAD/CAM)
  - Casting of the desired (bio-)material
  - Extraction of the final object

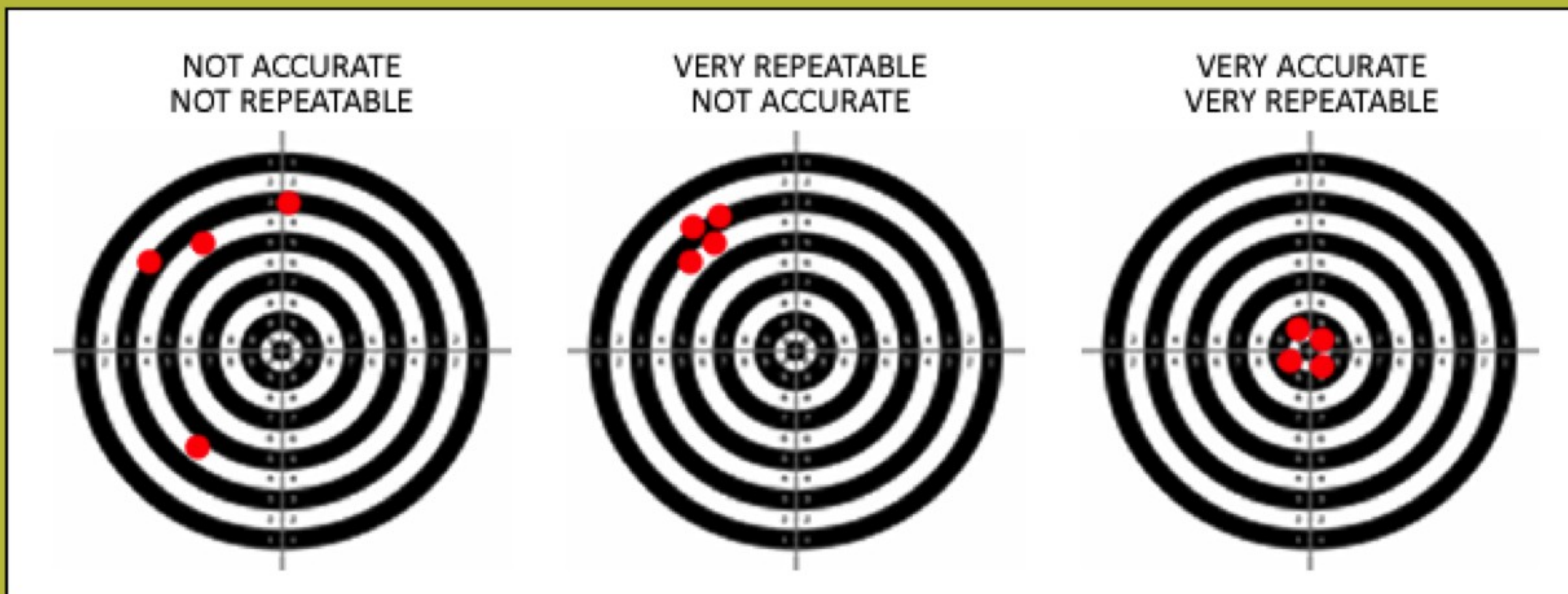


- General consideration on additive manufacturing technologies

Additive manufacturing

- Features of AM Systems:
  - Process type - Stereo lithography, Laminating, Fused deposition modelling, Sintering of powder, Solid ground curing, etc.
  - Work space(mm) - depends on the models
  - Material - photopolymer resin, coated paper, ABS, wax, metal alloy, etc.

Accuracy – repeatability – resolution



ACCURACY
Degree of comformity of a measurement to a standard or known value

REPEATABILITY
The closeness of aggreement amoung a number of consecutive measurements

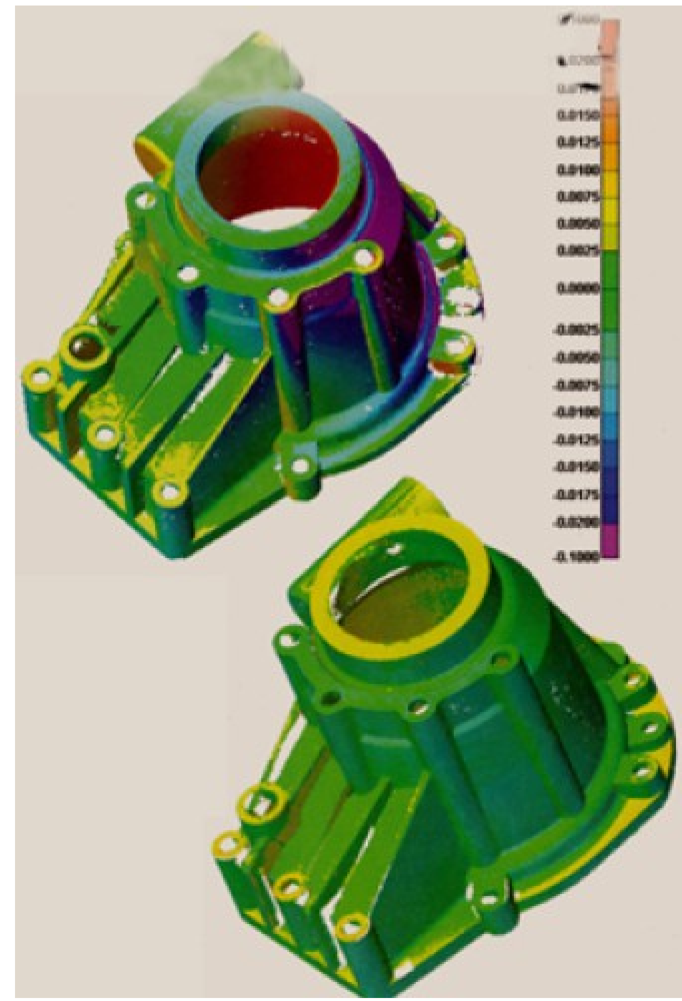
RESOLUTION
The smallest degree of movement that a scale can detect

Features of AM systems

	Layer thickness(mm)	Accuracy (mm)
SLA	0.05 - 0.3	0.01 - 0.2
LOM	0.1 - 1	0.1 - 0.2
FDM	≈0.05	0.130 - 0.260
SLS	≈0.08	0.03 - 0.4
SGC	0.01 - 0.15	0.05 - 0.5

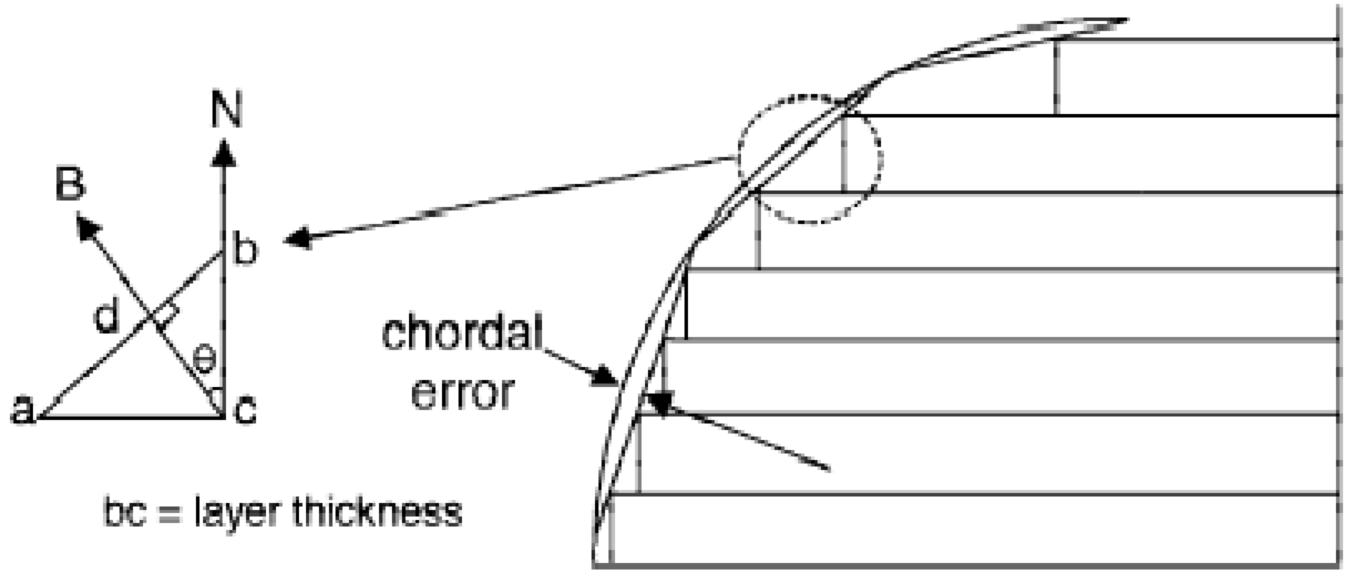
Drawbacks of AM

- Accuracy and resolution
  - tolerances are still not quite at the level of CNC, because of intervening energy exchanges and/or complex chemistry one cannot say with any certainty that one method of RP is always more accurate than another, or that a particular method always produces a certain tolerance.



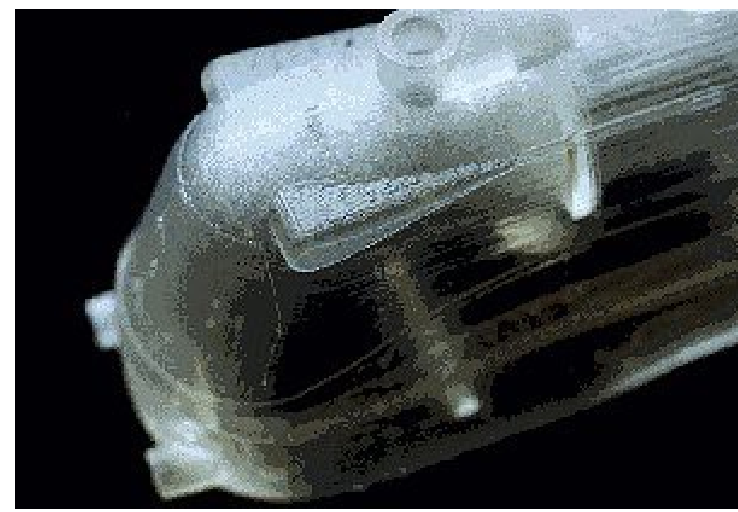
Drawbacks of AM

- Stair Stepping:
  - Since rapid prototyping builds object in layers, ther is inevitably a "stair stepping" effect produced because the layers have a finite thickness.



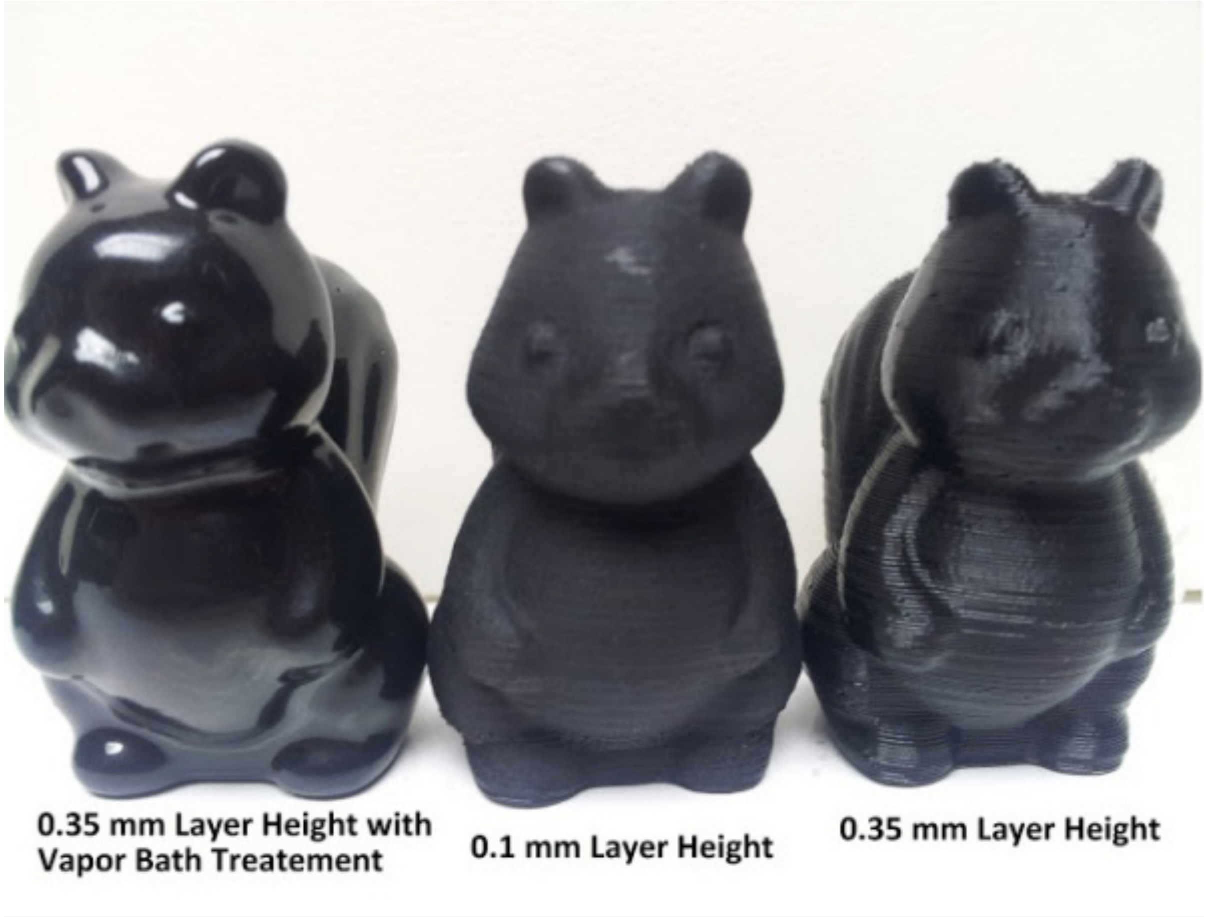
Drawbacks of AM

- Surface finish
  - The finish and appearance of a part are related to accuracy, but also depend on the method of RP employed.
  - Technologies based on powders have a sandy or diffuse appearance, sheet-based methods might be considered poorer in finish because the stairstepping is more pronounced.



Drawbacks of AM

- Surface finish



Technology	SLA	SLS	FDM	Wax Inkjet	3D printer	LOM
Max Part Size (cm)	30x30x50	34x34x60	30x30x50	30x15x21	30x30x40	65x55x40
Speed	Average	Average to fair	Poor	Poor	Excellent	Good
Accuracy	Very good	Good	Fair	Excellent	Fair	Fair
Surface finish	Very good	Fair	Fair	Excellent	Fair	Fair to poor
Strenghts	Market leader, large part size, accuragy, wide product	Market leader, accuracy, materials, large part size	Lab on desktop, price, materials	Accuracy, finish, lab on desktop	Speed, lab on desktop, price, color	Large part size, good for large castings, material cost
Weaknesses	Post processing messy liquids	Size and weight, system price, surface finish	Speed	Speed limited, materials, part size	Limited materials, fragile parts, finsh	Part stability, smoke, finish and accuracy

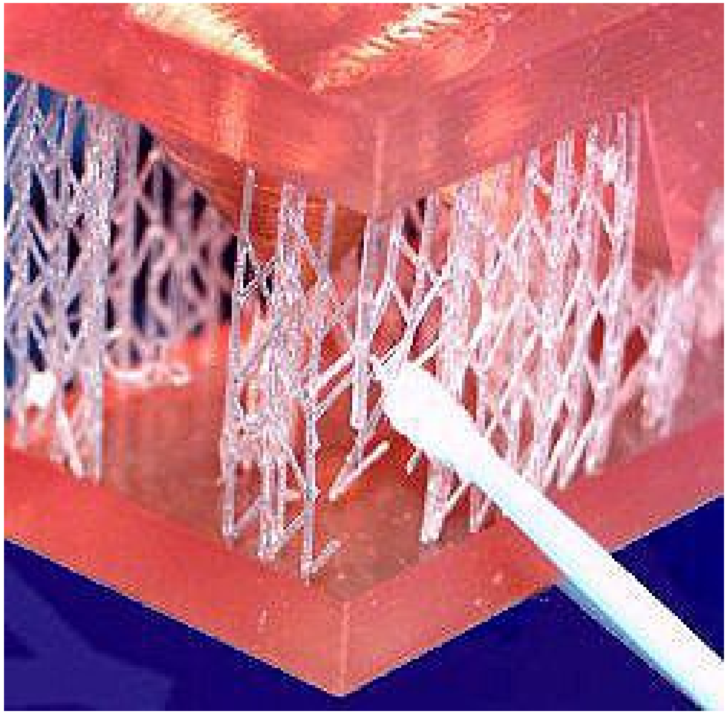
Drawbacks of AM

- Costs and time due to secondary operations
  - Post Curing (Stereolithography)
  - Infiltration, for fragile parts (3DP, MJM, SLS)
  - Final machining of metal parts
  - Removing of the support structures

Drawbacks of AM

Support structure (red material), water-soluble, fused deposition modeling

Support structure, stereolithography.



Cost

- System costs
  - from $30,000 to $800,000
  - training, housing and maintenance (a laser for a stereolithography system costs more than $20,00
- Material
  - High cost
  - Available choices are limited.

Cost

Machine	Cost	Material	Application
Fused Deposition Modeler 1600 (FDM)	$10/hr	ABS or Casting Wax	Strong Parts Casting Patterns
Laminated Object Manufacturing (LOM)	$18/hr	Paper (wood-like)	Larger Parts Concept Models
Sanders Model Maker 2 (Jet)	$3.30/hr	Wax	Casting Pattern
Selective Laser Sintering 2000 (SLS)	$44/hr	Polycarbonate TrueForm SandForm	light: 100%; margin: 0">Casting Patterns Concept Models
Stereolithography 250 (SLA)	$33/hr	Epoxy Resin (Translucent)	Thin walls Durable Models
Z402 3-D Modeller (Jet)	$27.50/hr	Starch/Wax	Concept Models

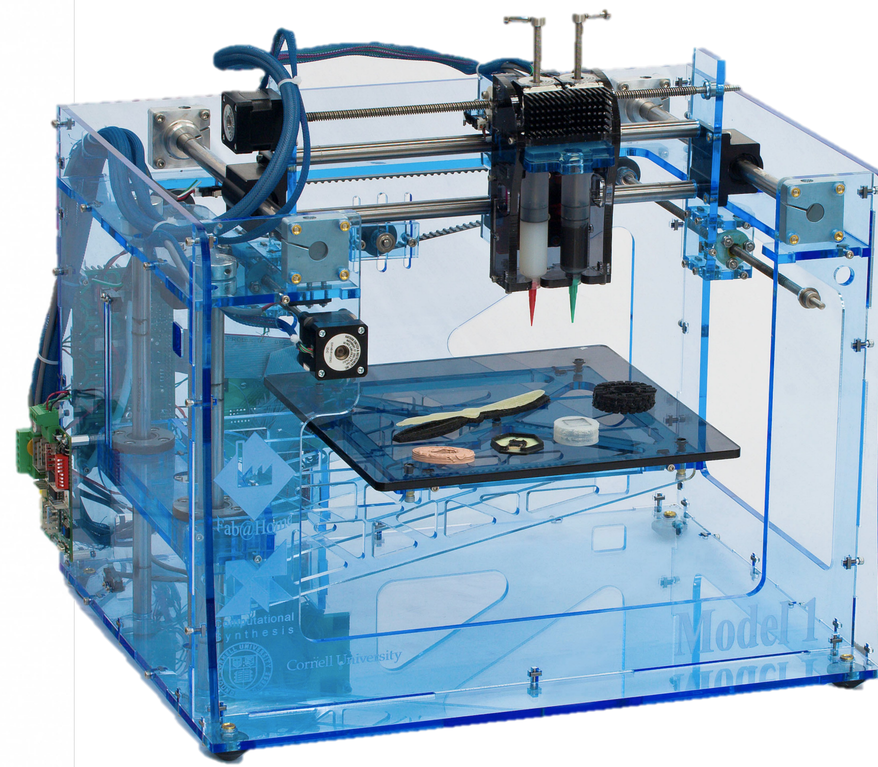
Cost - vendors

Photopolymer		
3D System (formerly DTM)	US	http://www.3dsystems.com
EOS	Germany	http://www.eos.info/en
CMET	Japan	http://www.cmet.co.jp/eng/
Envisiontec Perfactory	Germany	http://www.envisiontec.de

Deposition			
Stratasys	FDM	US	http://www.stratasys.com
Solidscape (now it is a Stratasys company)	Inkjet	US and the Netherlands	http://www.solid-scape.com
3D Systems (formerly DTM)	Thermojet™	US	http://www.3dsystems.com
Soligen	casting cores/patterns	US	http://www.soligen.com

Selective laser sintering		
3D Systems	US	http://www.3dsystems.com
EOS	Germany	http://www.eos.info/en

Open Source 3D printers



Asking for a quote

https://www.stratasysdirect.com/

stratasys
DIRECT MANUFACTURING

https://www.3dhubs.com/

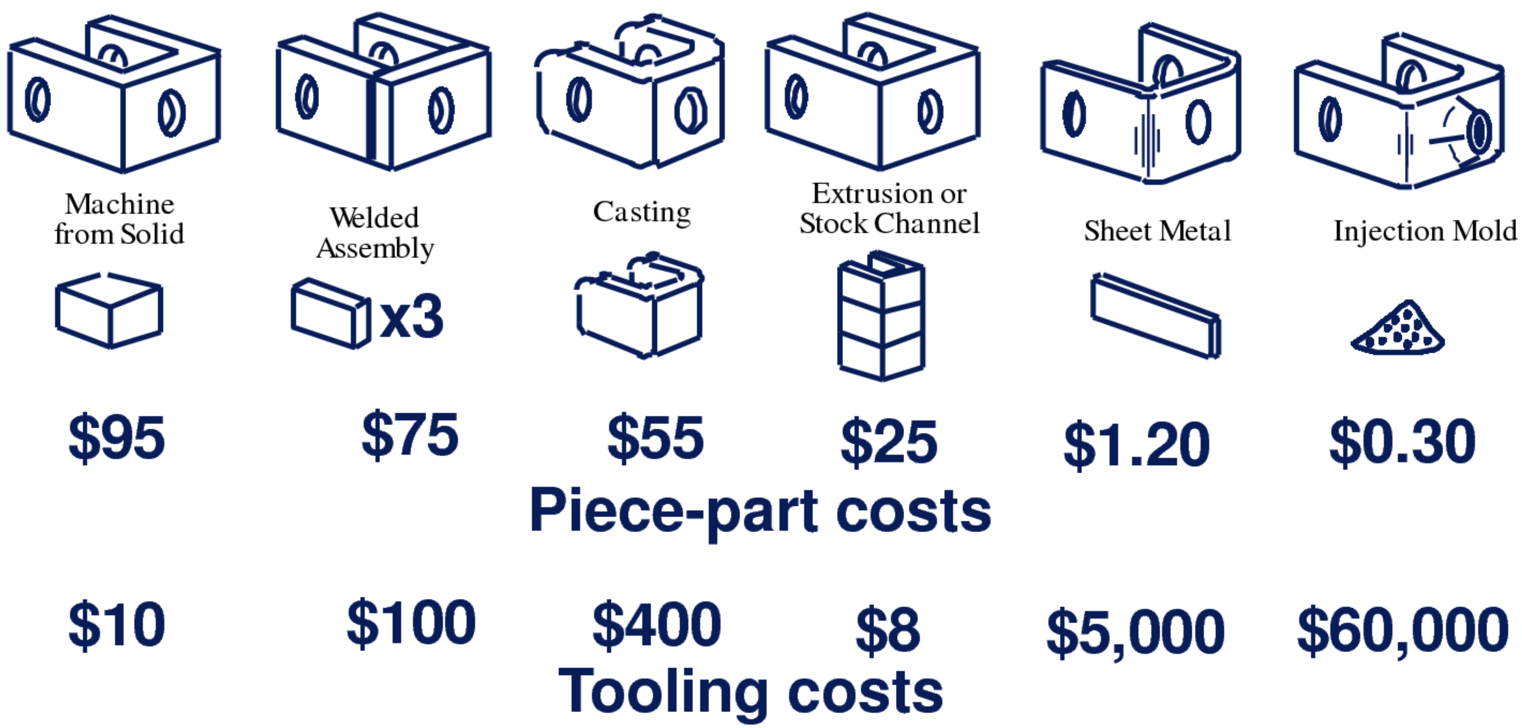
3D HUBS

Question

- Is it a good choice to 3D print every object?

Design for manufacturing

A simple fork end for Pneumatic Piston



Production Volume: Recurring Costs versus Non-Recurring Costs

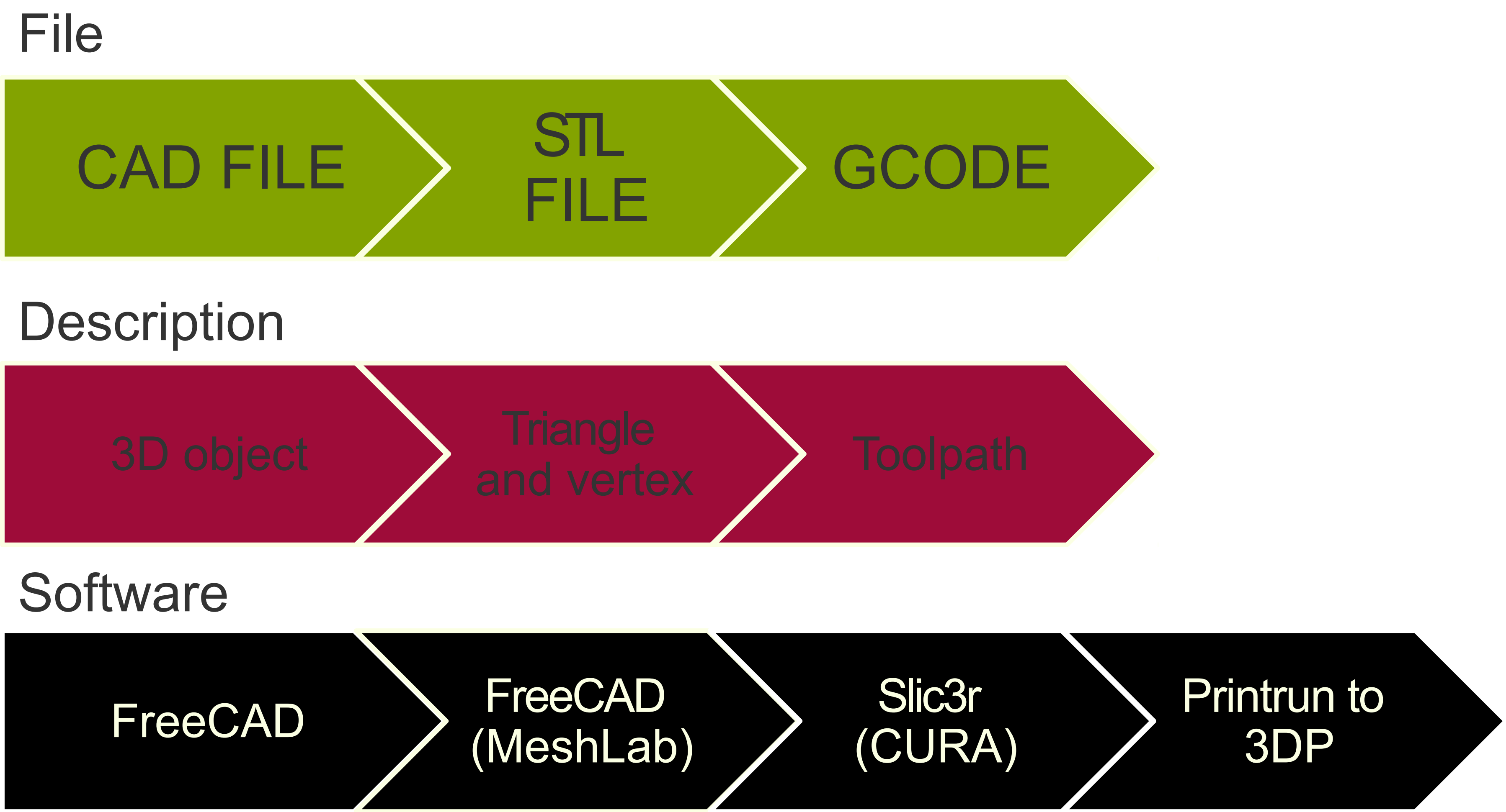
Software for Additive Manufacturing

carmelo.demaria@centropiaggio.unipi.it

AM work-flow

- Solid Modelling
- Tesselation/Generation of STL file
- Support Generation
- “Slicing” of the Model
- Model Physical Buildup
- Cleanup and Post Curing
- Surface Finishing

AM work-flow


File
CAD FILE
STL FILE
GCODE
Description
3D object
Triangle and vertex
Toolpath
Software
FreeCAD
FreeCAD (MeshLab)
Slic3r (CURA)
Printrun to 3DP

Data Source

Data source

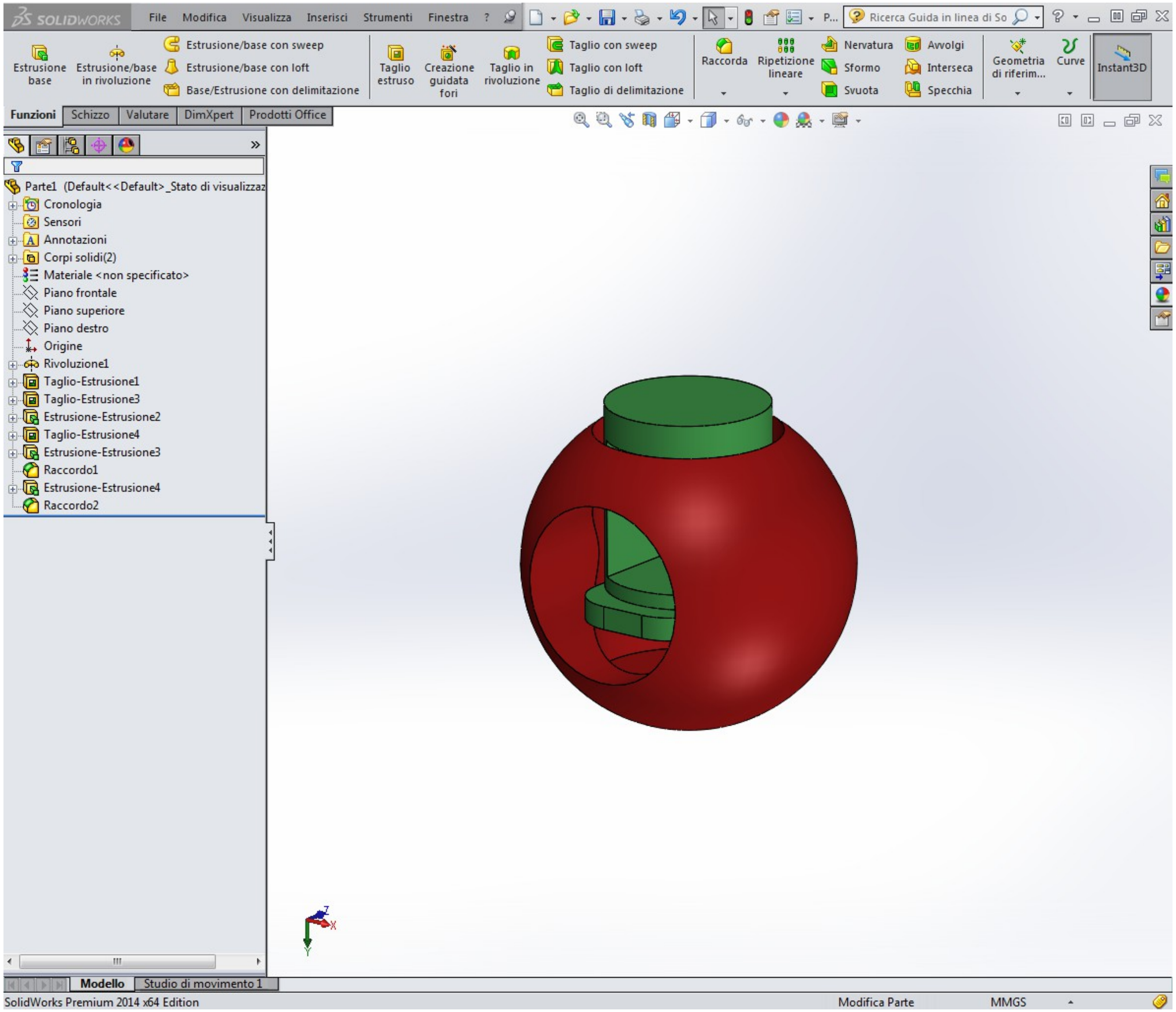
- Representation of a volume
  - CAD model
    - Your specific design
    - Web repository
- Instruments output
  - Segmentation of medical Images (Tomographic Data: CT scan, RM scan)
  - Surface scanning
    - Laser
    - Optical (also phone camera)

CAD model

Dimensions of CAD Elements	Elements	Type of CAD Model
0D	Point	Corner Model
1D	Line	Edge Model
2D	Surface	Surface Model
3D	Solid/Volume	Solid or Volume Model

- Most of the CAD software are proprietary with a relatively high cost
- Free or Open Source examples
  - FreeCAD
  - 123D Design
  - Sketch Up

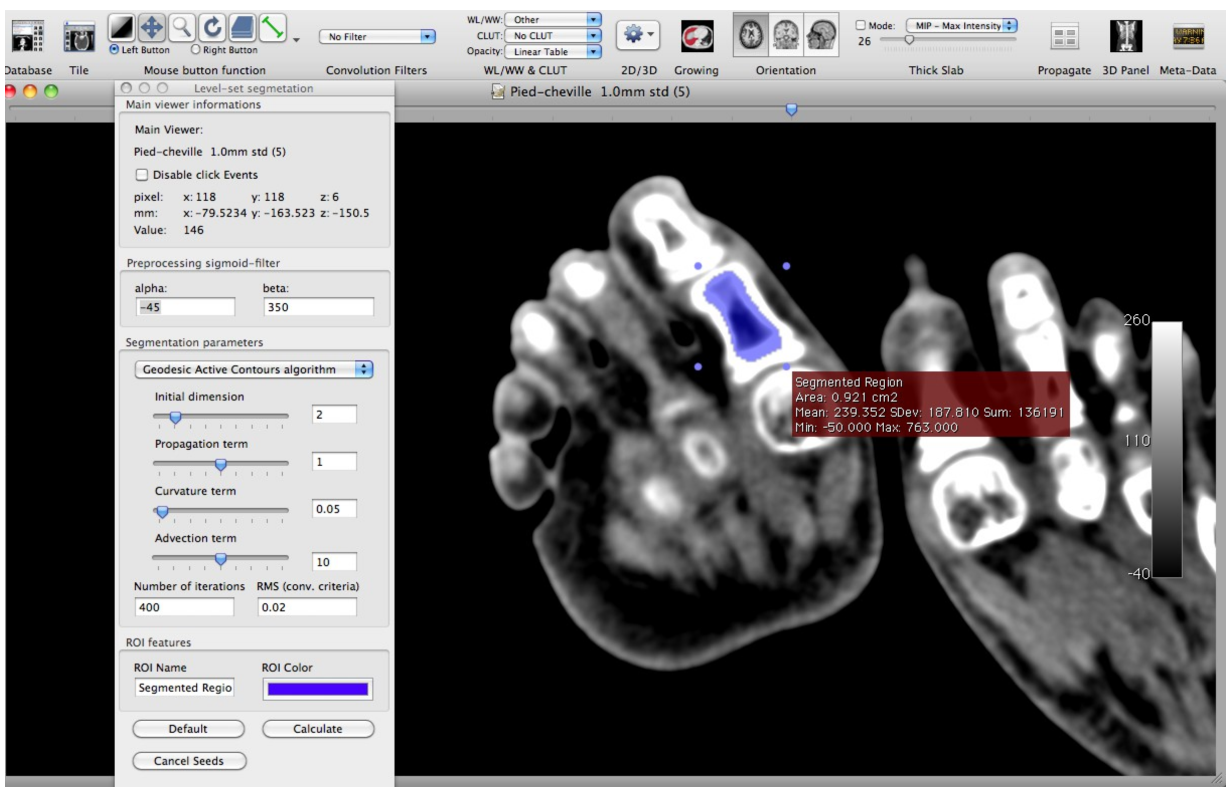
CAD model



SOLIDWORKS
File
Modifica
Visualizza
Inserisci
Strumenti
Finestra
?
Ricerca Guida in linea di So
Estrusione base
Estrusione/base in rivoluzione
Estrusione/base con sweep
Estrusione/base con loft
Base/Estrusione con delimitazione
Taglio estruso
Creazione guidata fori
Taglio in rivoluzione
Taglio con sweep
Taglio con loft
Taglio di delimitazione
Raccorda
Ripetizione lineare
Nervatura
Sformo
Svuota
Avvolgi
Interseca
Specchia
Geometria di riferim...
Curve
Instant3D
Funzioni
Schizzo
Valutare
DimXpert
Prodotti Office
Parte1 (Default<<Default>_Stato di visualizzaz
Cronologia
Sensori
Annotazioni
Corpi solidi(2)
Materiale <non specificato>
Piano frontale
Piano superiore
Piano destro
Origine
Rivoluzione1
Taglio-Estrusione1
Taglio-Estrusione3
Estrusione-Estrusione2
Taglio-Estrusione4
Estrusione-Estrusione3
Raccordo1
Estrusione-Estrusione4
Raccordo2
Modello
Studio di movimento 1
SolidWorks Premium 2014 x64 Edition
Modifica Parte
MMGS

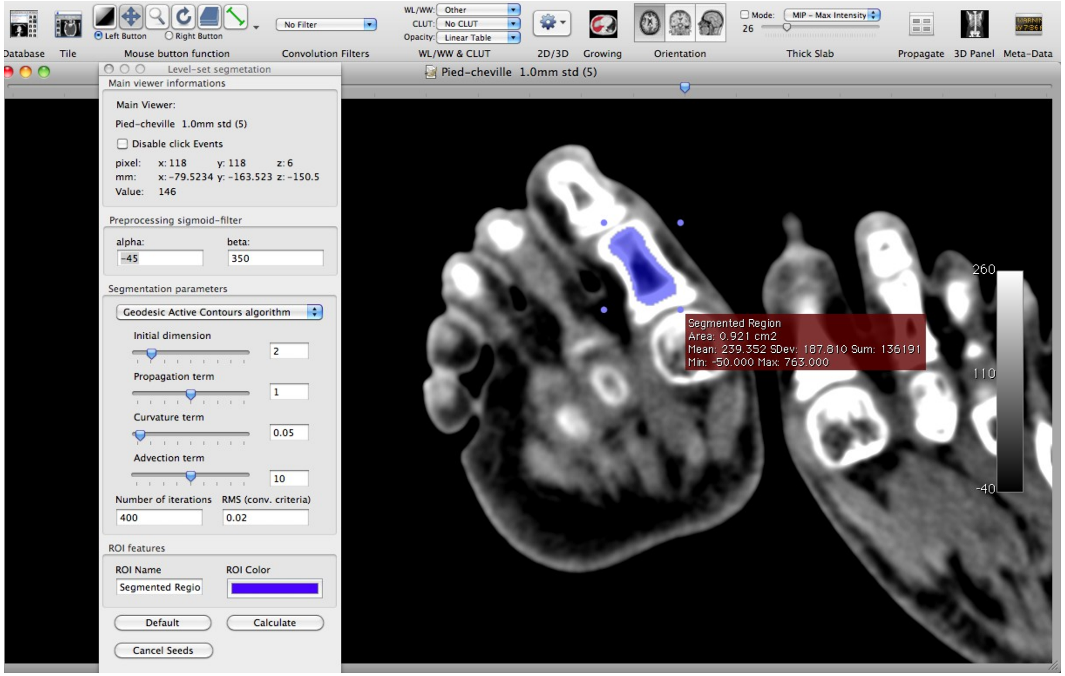
Segmentation

- Segmentation subdivides an image into its constituent regions or objects.
- The level to which the subdivision is carried ou depends on the problem being solved



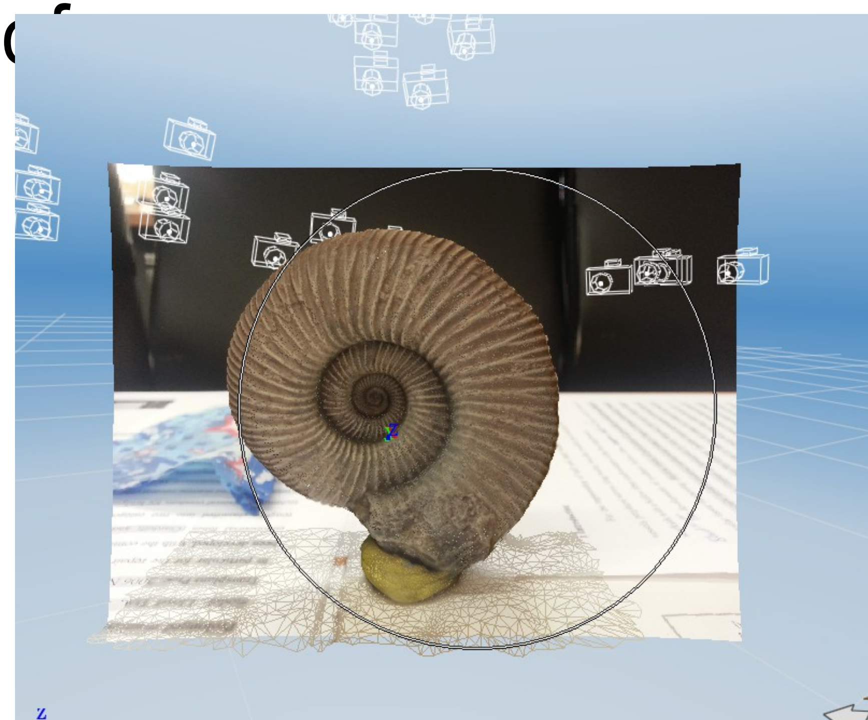
Bioimaging software

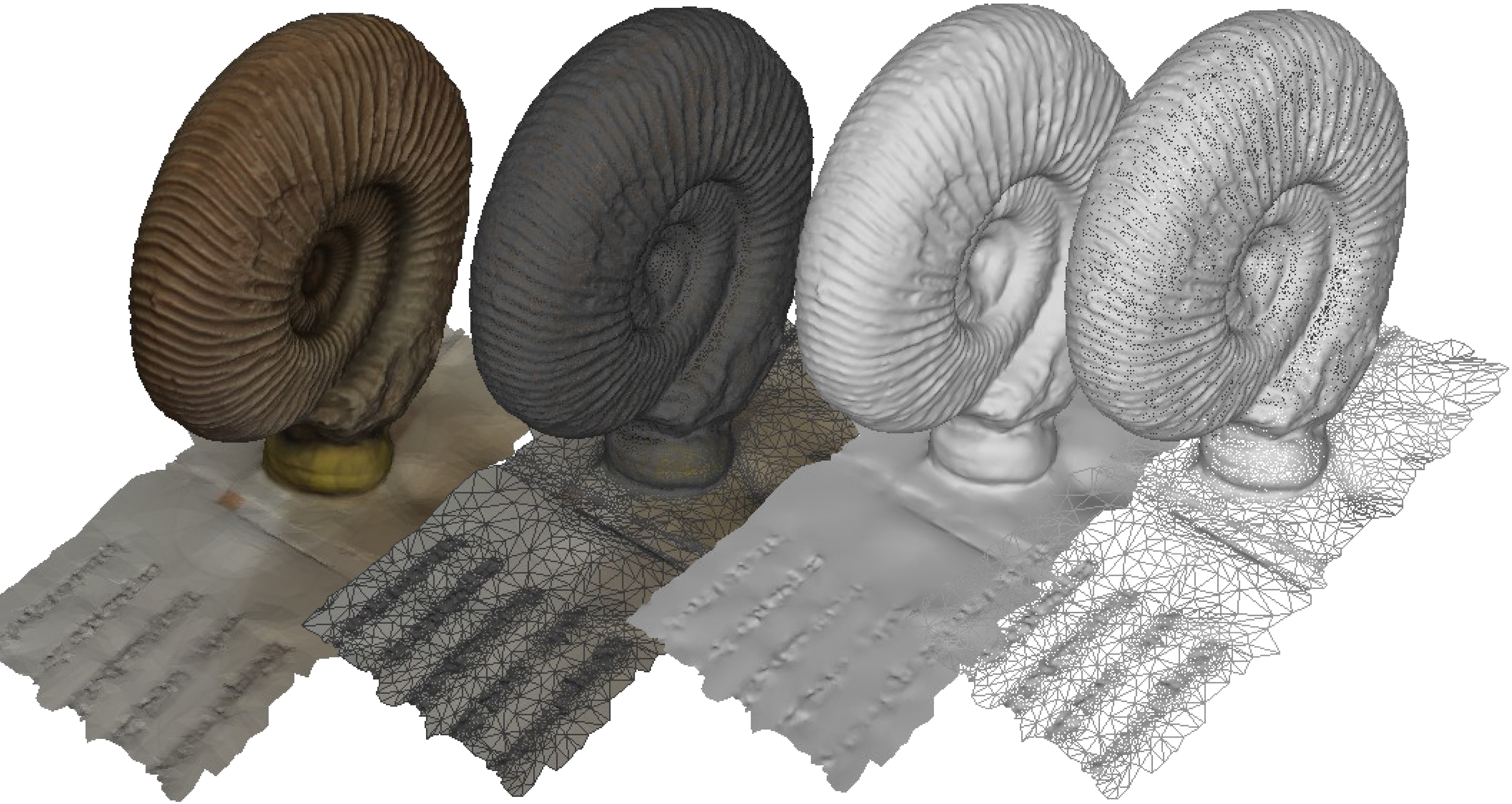
- OsiriX (www.osirix-viewer.com)
- 3DSlicer (www.slicer.org)
- ImageJ (rsb.info.nih.gov/ij)
- MIPAV (mipav.cit.nih.gov)
- itk-SNAP (www.itksnap.org)



From 3D scan to 3D model

- Use of 123DCatch
- http://www.123dapp.com/catch
- 3D model of a fossil
  - Ammonite from Museum of Natural History in Pisa



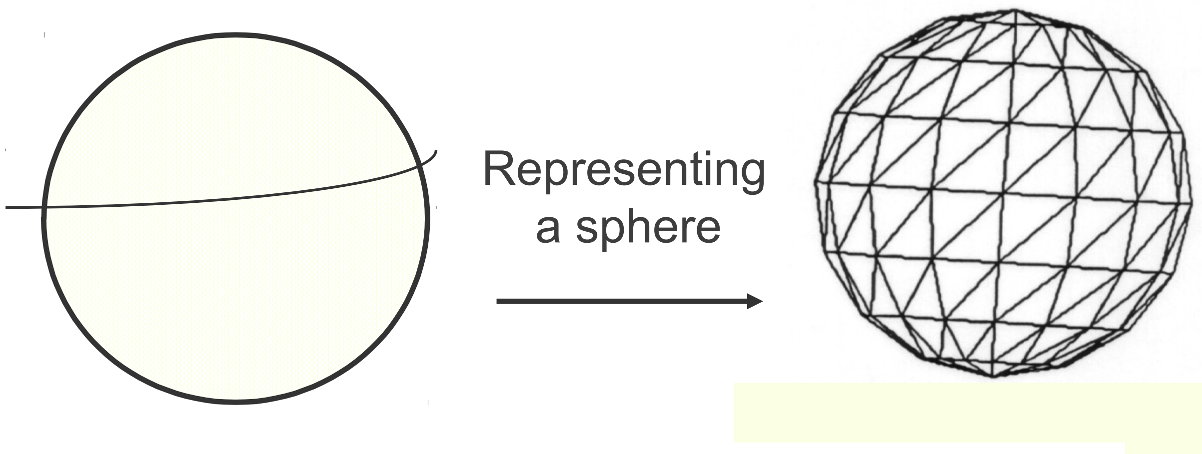


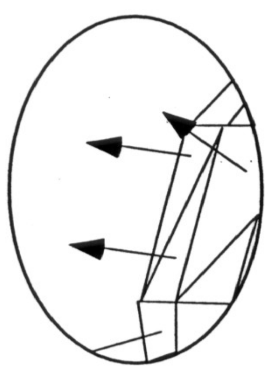
Exchange formats

STL file (*.stl)

- STL files describe only the surface geometry of a three dimensional object without any representation of color, texture or other common CAD model attributes.
- An STL file describes a raw unstructured triangulated surface by the unit normal and vertices (ordered by the right-hand rule) of the triangles using a three-dimensional Cartesian coordinate system.

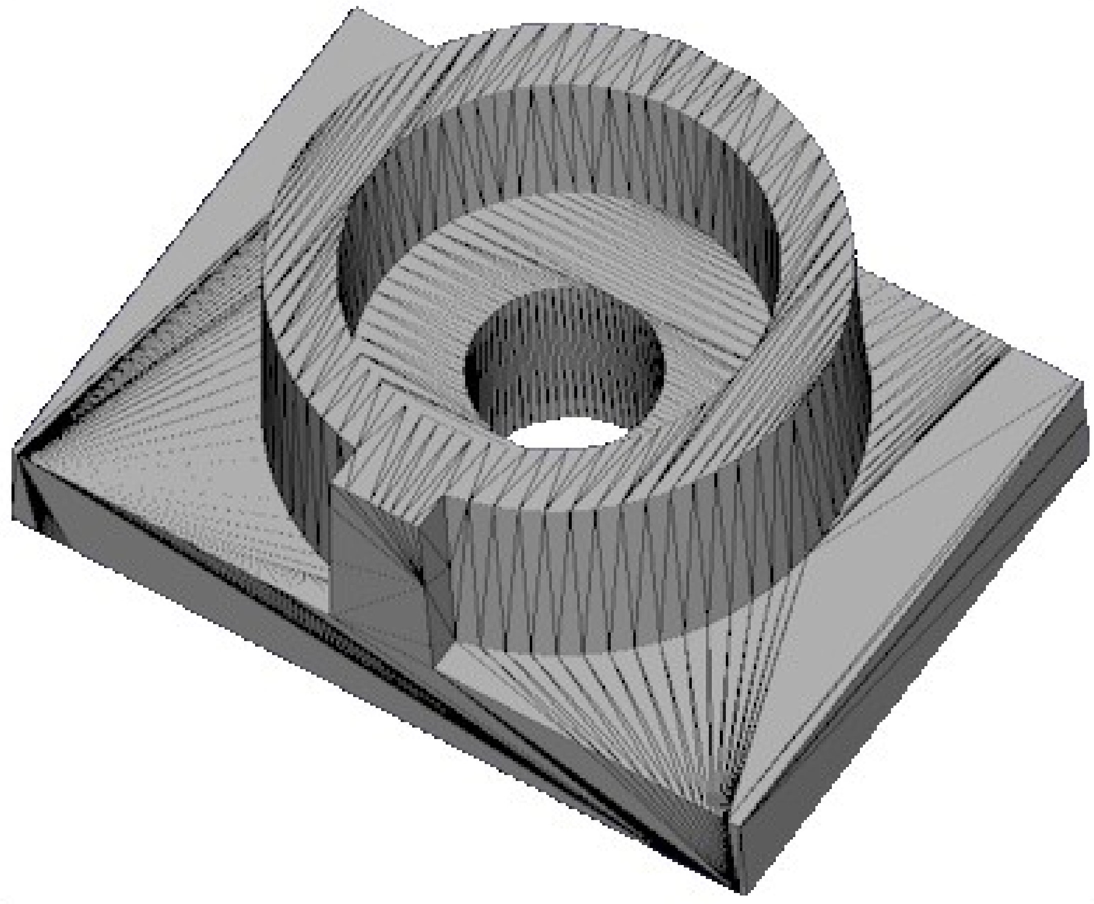
Example of *.stl representation





```
solid obj1
  facet normal 1.457591e-01 -9.885599e-01 -3.877669e-02
    outer loop
      vertex 9.614203e+00 4.757629e+00 0.000000e+00
      vertex 7.875000e+00 4.501190e+00 0.000000e+00
      vertex 9.483117e+00 4.764183e+00 -6.598330e-01
    endloop
  endfacet
  facet normal 1.161178e-01 -9.870778e-01 -1.104267e-01
    outer loop
      vertex 9.483117e+00 4.764183e+00 -6.598330e-01
      vertex 7.875000e+00 4.501190e+00 0.000000e+00
      vertex 9.109818e+00 4.782848e+00 -1.219212e+00
    endloop
  endfacet
  facet normal 6.134766e-02 -9.843393e-01 -1.652652e-01
```

Example of *.stl representation



STL file

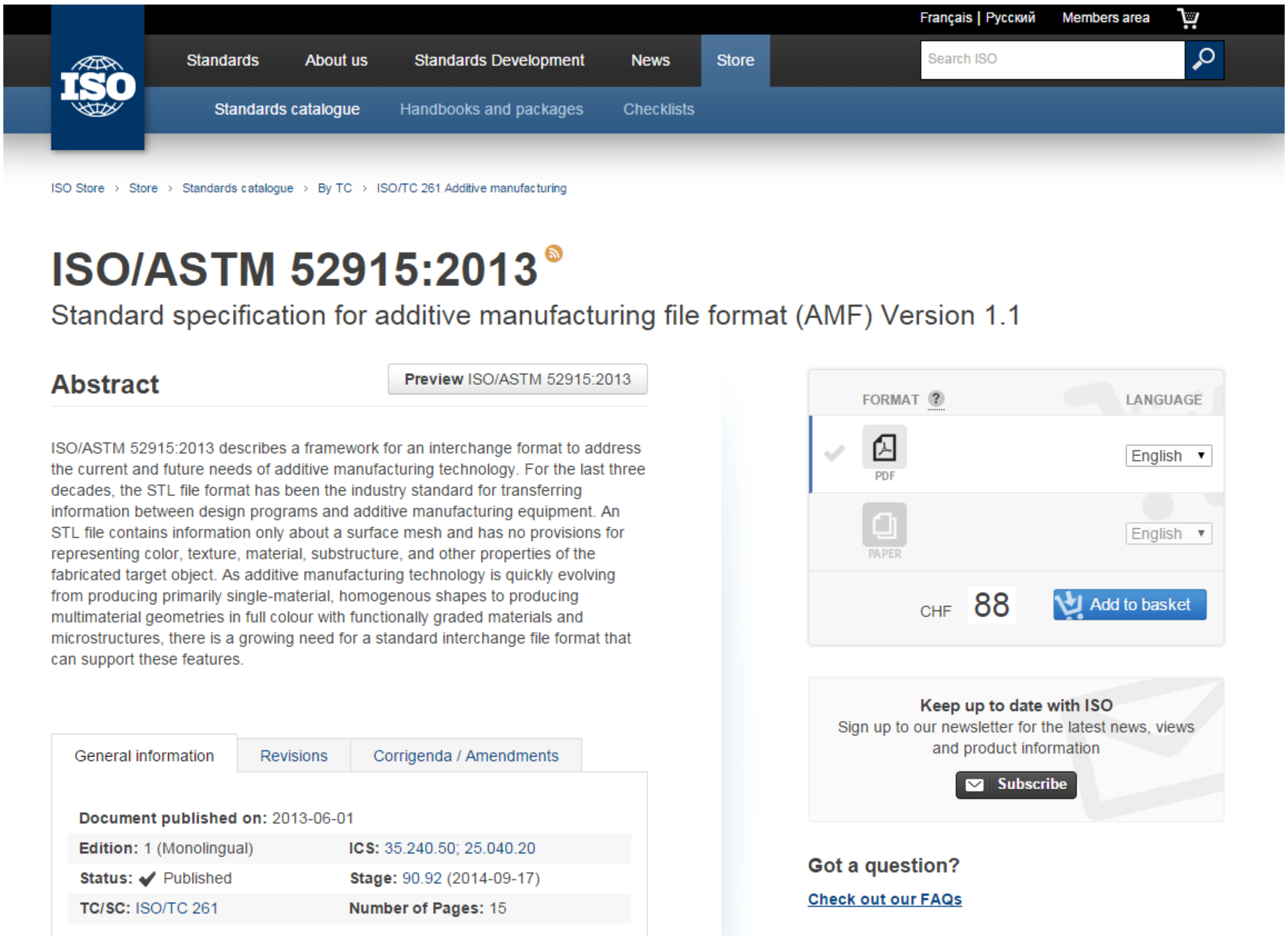
Advantages	Disadvantages
Simple	Geometry leaks
Sequential memory access*	No specified units
Portable	Unnecessary redundancy
	Incompatible with color, multiple materials, etc
	Poor scalability
*Does not require large amounts of RAM, critical in '80s	Lacks auxiliary information

- There are several other formats
  - 3D PDF, ISO 14649 (STEP-NC), STEP / IGES, SAT, Parasolid, X3D VRML, PLY, 3DS, SLC

Additive manufacturing format (AMF)

- XML format
  - metadata
- Compressibility
  - Curved mesh
- Encryption and watermark
- Multiple material
  - Graded Material
  - Internal microstructures
- Appearance
  - Color
  - Tolerance
  - Texture

AMF – ISO standard



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ISO/ASTM 52915:2013

Standard specification for additive manufacturing file format (AMF) Version 1.1

Abstract

Preview ISO/ASTM 52915:2013

ISO/ASTM 52915:2013 describes a framework for an interchange format to address the current and future needs of additive manufacturing technology. For the last three decades, the STL file format has been the industry standard for transferring information between design programs and additive manufacturing equipment. An STL file contains information only about a surface mesh and has no provisions for representing color, texture, material, substructure, and other properties of the fabricated target object. As additive manufacturing technology is quickly evolving from producing primarily single-material, homogenous shapes to producing multimaterial geometries in full colour with functionally graded materials and microstructures, there is a growing need for a standard interchange file format that can support these features.

FORMAT ?   LANGUAGE

PDF   English

PAPER   English

CHF 88   Add to basket

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General information   Revisions   Corrigenda / Amendments

Document published on: 2013-06-01

Edition: 1 (Monolingual)	**ICS:** 35.240.50; 25.040.20
Status: ✔ Published	**Stage:** 90.92 (2014-09-17)
TC/SC: ISO/TC 261	**Number of Pages:** 15

Got a question?

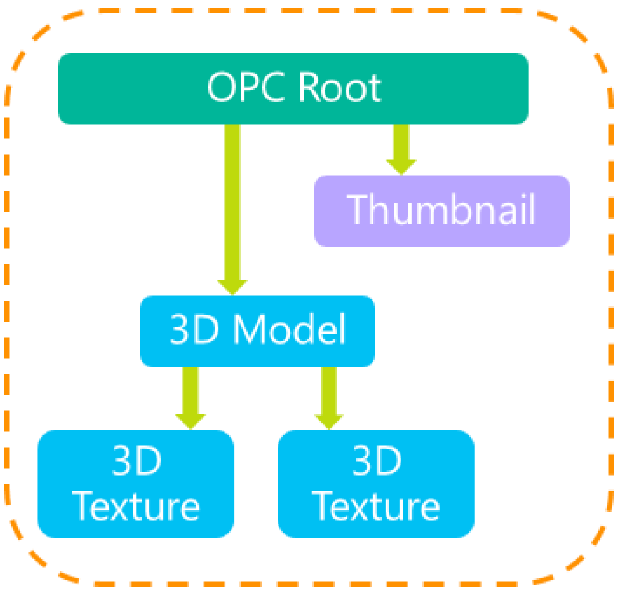
Check out our FAQs

Email customer services

3MF format

- http://3mf.io/

3MF design considerations



Complete

- Open Packaging Conventions (OPC)

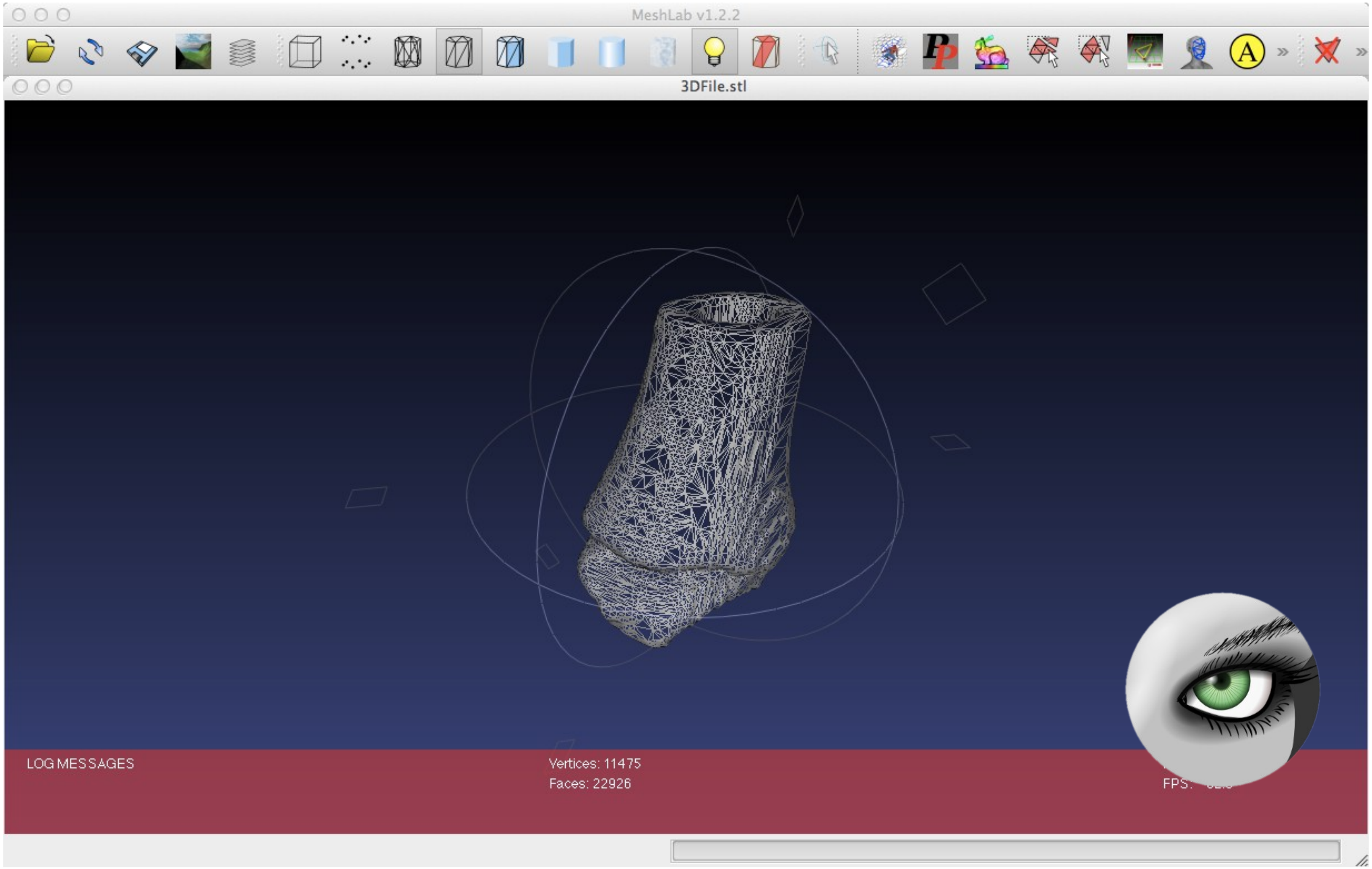
Compact

- ZIP package
- References avoid duplication

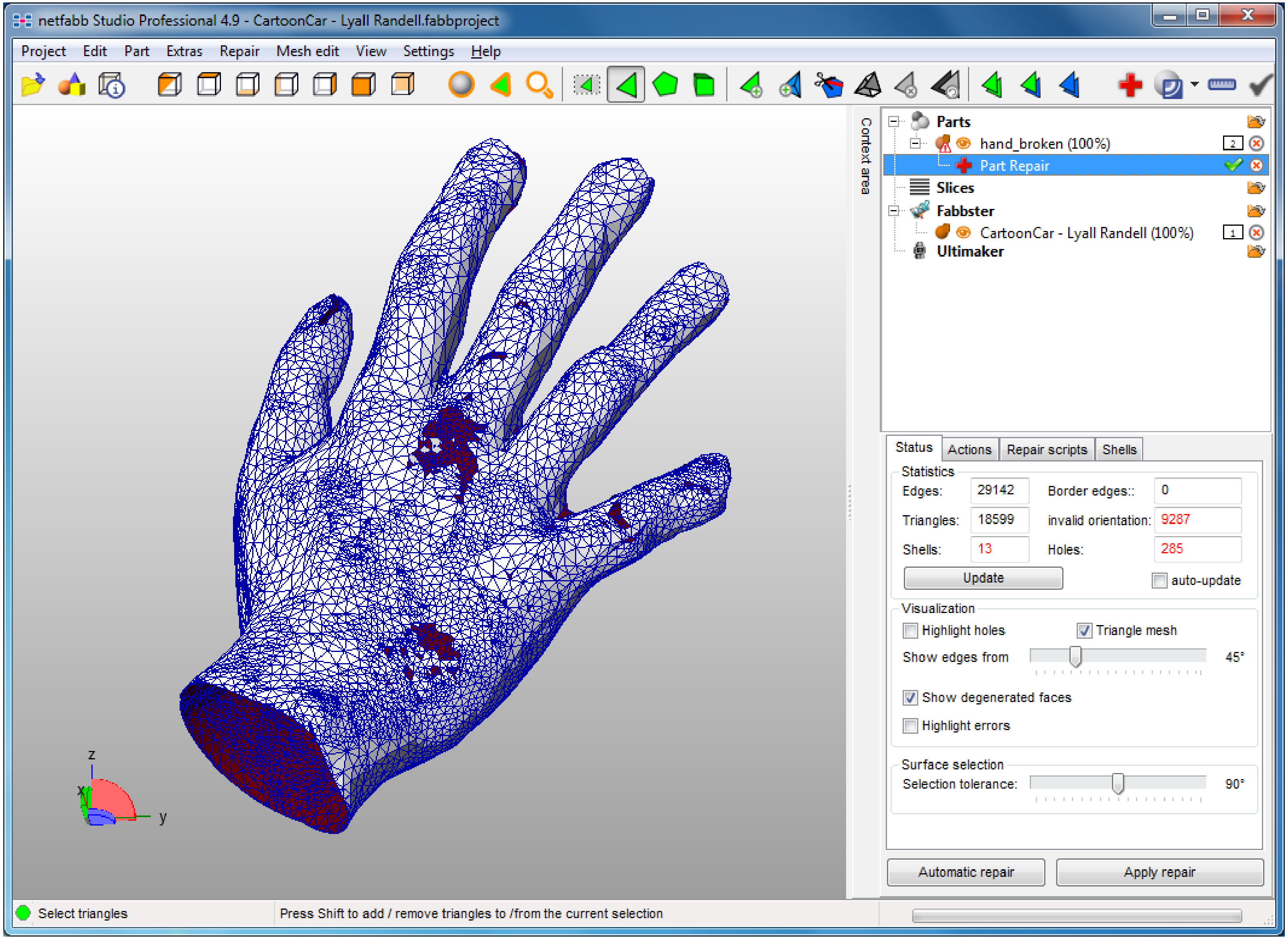
Human-readable

- XML
- Well-known binary formats (e.g. PNG, JPEG)

MeshLab

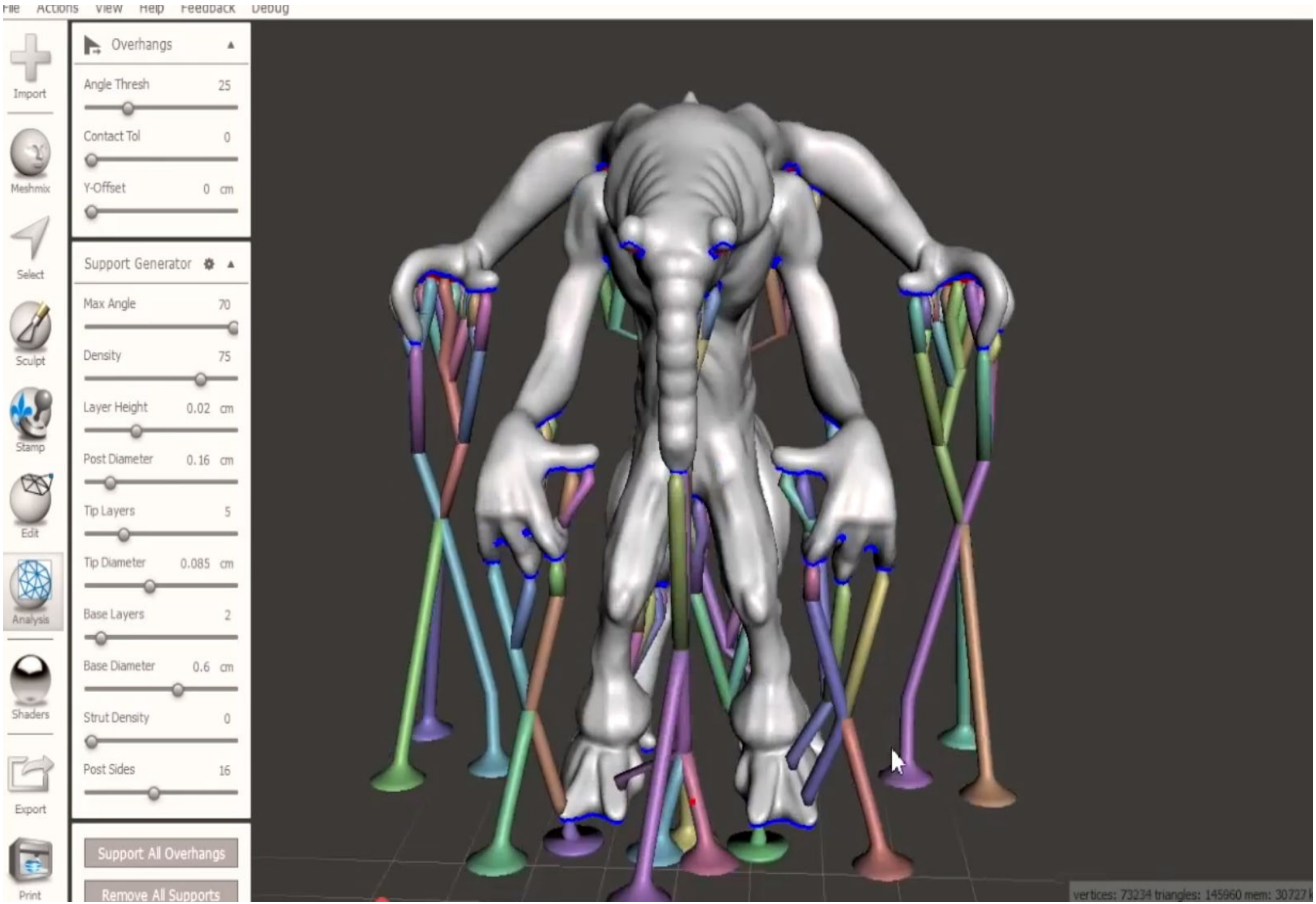

MeshLab v1.2.2
3DFile.stl
LOG MESSAGES
Vertices: 11475
Faces: 22926
FPS:

Netfabb



netfabb Studio Professional 4.9 - CartoonCar - Lyall Randell.fabbproject
Project Edit Part Extras Repair Mesh edit View Settings Help
Context area
Parts
hand_broken (100%)
Part Repair
Slices
Fabbster
CartoonCar - Lyall Randell (100%)
Ultimaker
Status Actions Repair scripts Shells
Statistics
Edges: 29142
Border edges:: 0
Triangles: 18599
invalid orientation: 9287
Shells: 13
Holes: 285
Update
auto-update
Visualization
Highlight holes
Triangle mesh
Show edges from 45°
Show degenerated faces
Highlight errors
Surface selection
Selection tolerance: 90°
Automatic repair
Apply repair
Select triangles
Press Shift to add / remove triangles to /from the current selection

MeshMixer


File Actions View Help Feedback Debug
Import
Meshmix
Select
Sculpt
Stamp
Edit
Analysis
Shaders
Export
Print
Overhangs
Angle Thresh 25
Contact Tol 0
Y-Offset 0 cm
Support Generator
Max Angle 70
Density 75
Layer Height 0.02 cm
Post Diameter 0.16 cm
Tip Layers 5
Tip Diameter 0.085 cm
Base Layers 2
Base Diameter 0.6 cm
Strut Density 0
Post Sides 16
Support All Overhangs
Remove All Supports

From CAD to CAM

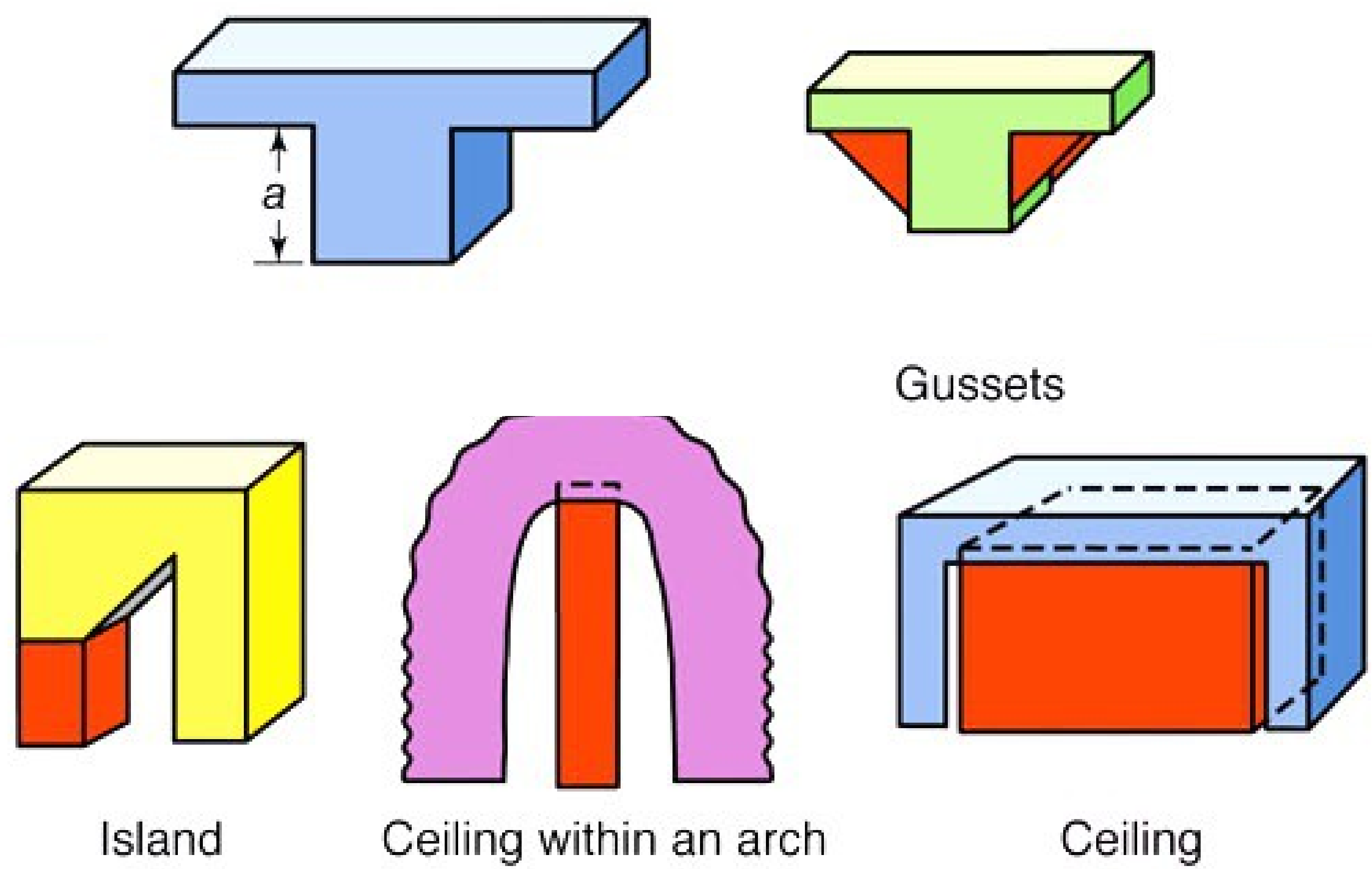
Processing of *.stl files

- After the CAD system has generated *.stl file, it can be passed to the AM machine
- Machine then processes the *.stl file, slicing it into many thin layers stacked on one another. The resulting files are called slice files.
- The shapes of the slices represent cross sections
- In AM processes thick solid sections of material are often removed and replaced with cross hatching
- Thus AM parts are usually hollow, with cross hatching on the inside to add strength/stability

Support material

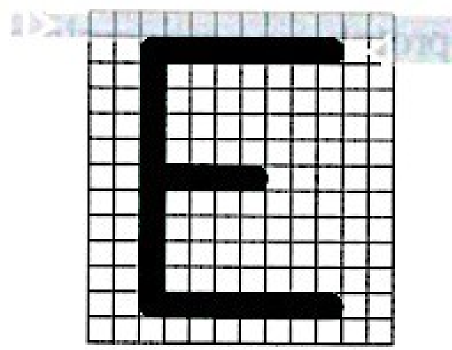
- Some AM techniques use two materials in the course of constructing parts.
- The first material is the part material and the second is the support material (to support overhanging features during construction).
- The support material is later removed by heat or dissolved away with a solvent or water.

Support material

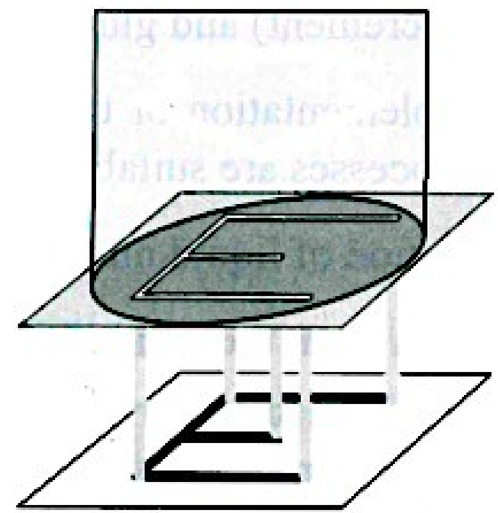


Patterning

Vector



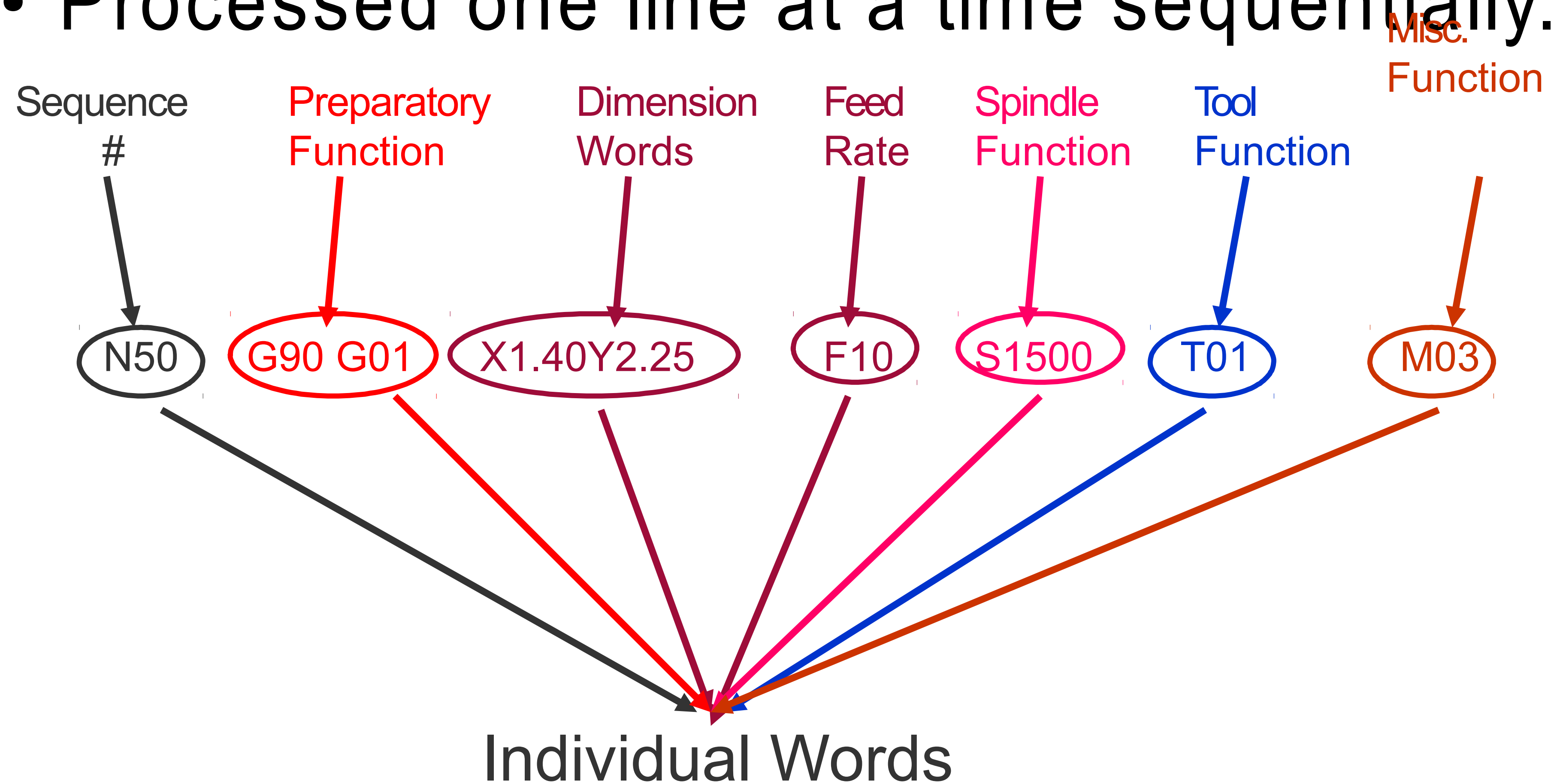
Raster



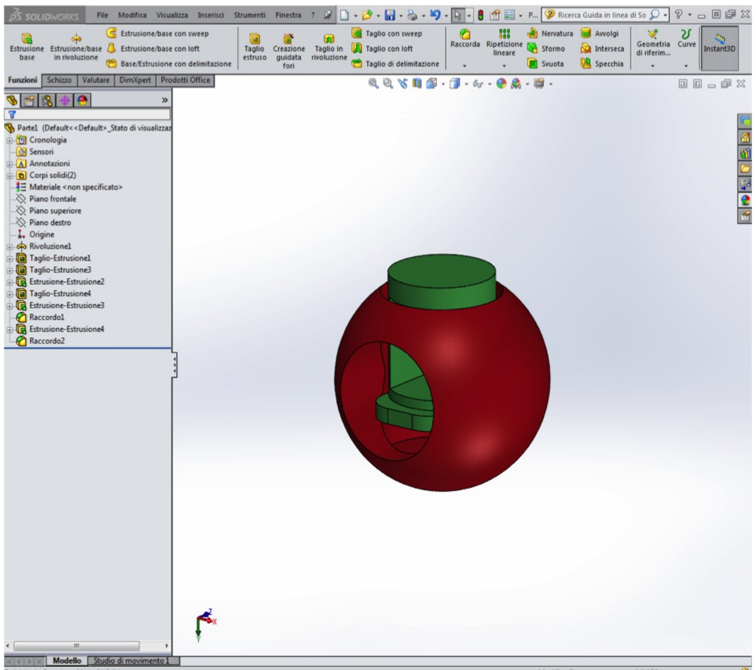
Projection

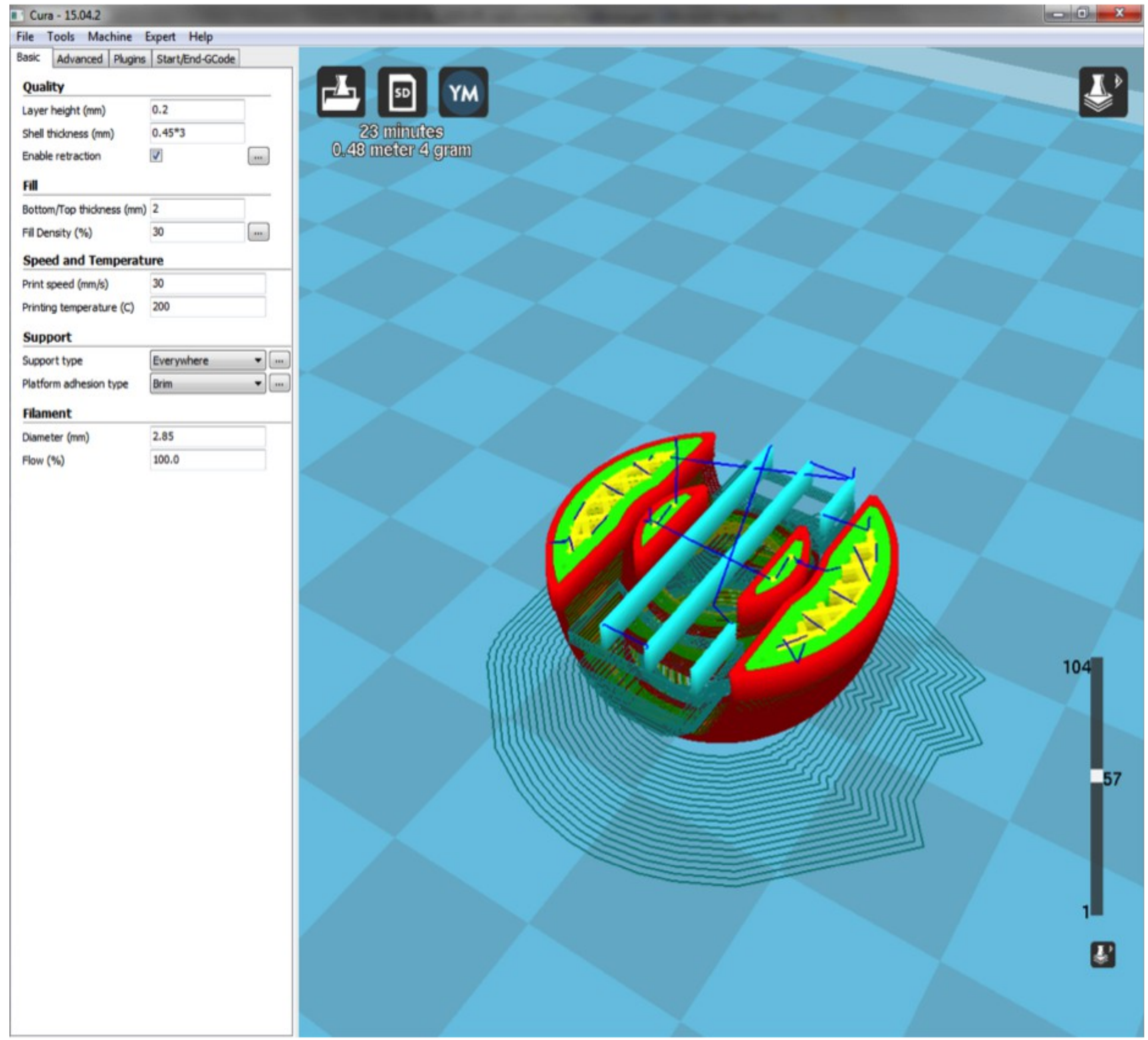
G-code

- Originally called "Word Address" programming format.
- Processed one line at a time sequentially.



Example of slicing with FDM

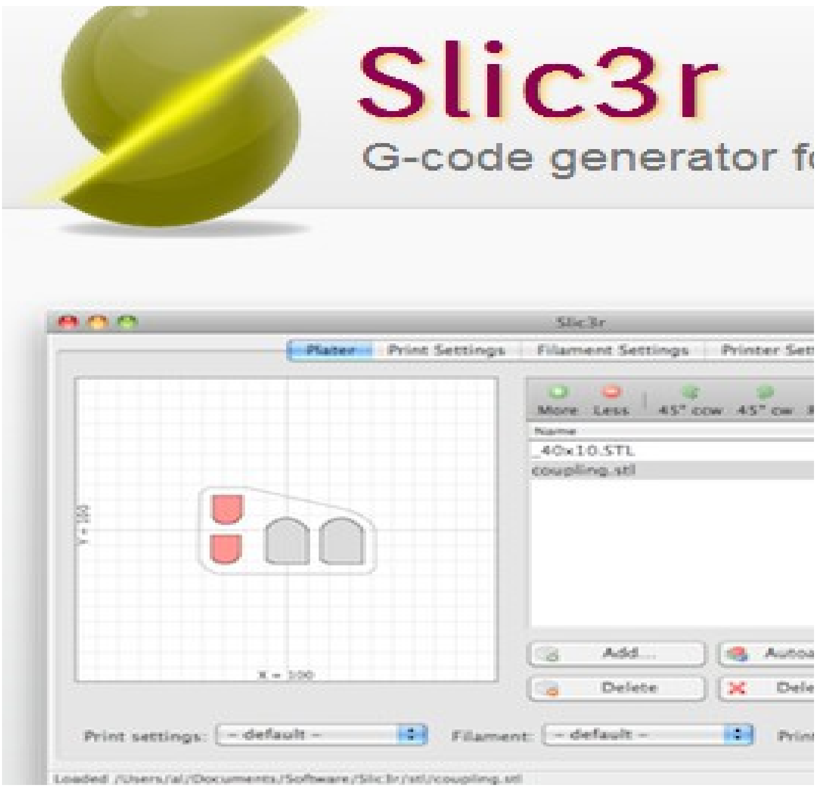


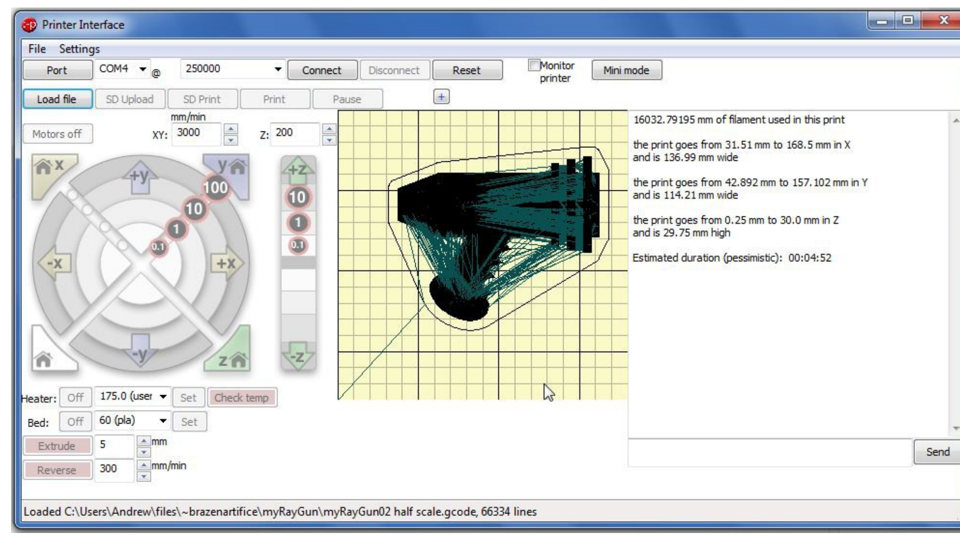


G-code example

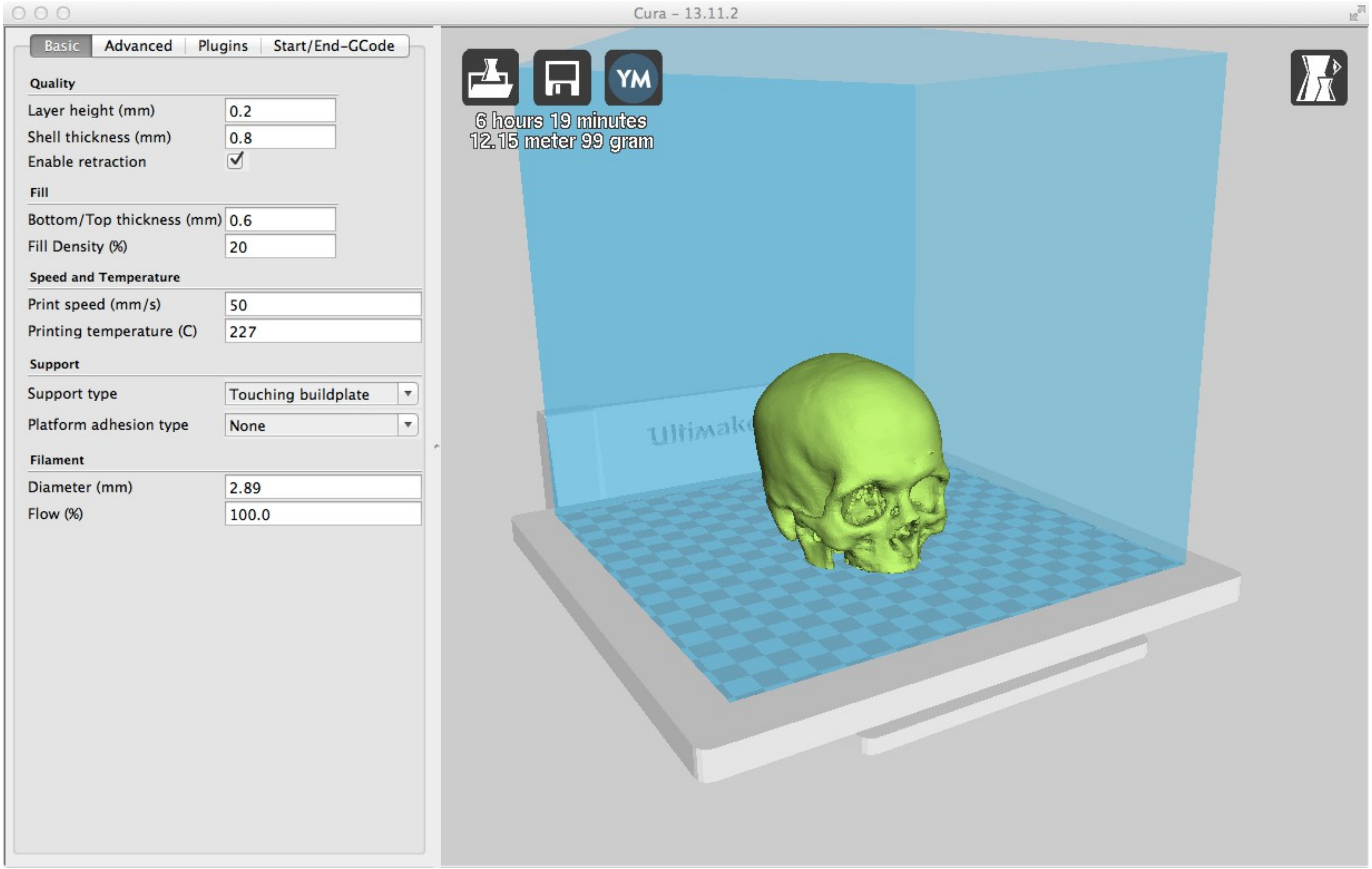
- ;Generated with Cura_SteamEngine 13.11.2
- M109 T0 S227.000000
- T0
- ;Sliced ?filename? at: Tue 26-11-2013 17:33:05
- ;Basic settings: Layer height: 0.2 Walls: 0.8 Fill: 20
- ;Print time: #P_TIME#
- ;Filament used: #F_AMNT#m #F_WGHT#g
- ;Filament cost: #F_COST#
- G21 ;metric values
- G90 ;absolute positioning
- M107 ;start with the fan off
- G28 X0 Y0 ;move X/Y to min endstops
- G28 Z0 ;move Z to min endstops
- G1 Z15.0 F?max_z_speed? ;move the platform down 15mm
- G92 E0 ;zero the extruded length
- G1 F200 E3 ;extrude 3mm of feed stock
- G92 E0 ;zero the extruded length again
- G1 F9000
- M117 Printing...
- ;Layer count: 179
- ;LAYER:0
- M107
- G0 F3600 X87.90 Y78.23 Z0.30
- ;TYPE:SKIRT
- G1 F2400 E0.00000
- G1 F1200 X88.75 Y77.39 E0.02183
- G1 X89.28 Y77.04 E0.03342
- G1 X90.12 Y76.69 E0.05004
- G1 X90.43 Y76.63 E0.05591
- G1 X91.06 Y76.37 E0.06834

Slic3r


Slic3r
Plater
Print Settings
Filament Settings
Add...
Delete
Print settings:
- default -
Filament:
- default -


Printer Interface
File Settings
Port
COM4
250000
Connect
Disconnect
Reset
Monitor printer
Mini mode
Load file
SD Upload
SD Print
Print
Pause
Motors off
mm/min
XY: 3000
Z: 200
Heater: Off 175.0 (user Set Check temp
Bed: Off 60 (pla) Set
Extrude 5 mm
Reverse 300 mm/min
16032.79195 mm of filament used in this print
the print goes from 31.51 mm to 168.5 mm in X and is 136.99 mm wide
the print goes from 42.892 mm to 157.102 mm in Y and is 114.21 mm wide
the print goes from 0.25 mm to 30.0 mm in Z and is 29.75 mm high
Estimated duration (pessimistic): 00:04:52
Send
Loaded C:\Users\Andrew\files\~brazenartifice\myRayGun\myRayGun02 half scale.gcode, 66334 lines

Cura



Cura - 13.11.2
Basic
Advanced
Plugins
Start/End-GCode
Quality
Layer height (mm) 0.2
Shell thickness (mm) 0.8
Enable retraction
Fill
Bottom/Top thickness (mm) 0.6
Fill Density (%) 20
Speed and Temperature
Print speed (mm/s) 50
Printing temperature (C) 227
Support
Support type Touching buildplate
Platform adhesion type None
Filament
Diameter (mm) 2.89
Flow (%) 100.0
YM
6 hours 19 minutes
12.15 meter 99 gram