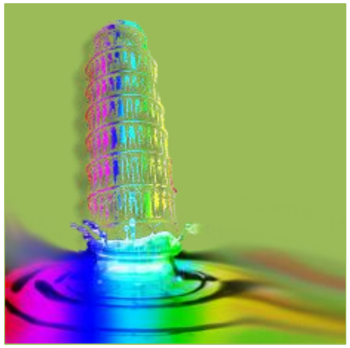
Centro E. Piaggio
bioengineering and robotics research center

IN SUPREMÆ DIGNITATIS 1343



Additive manufacturing

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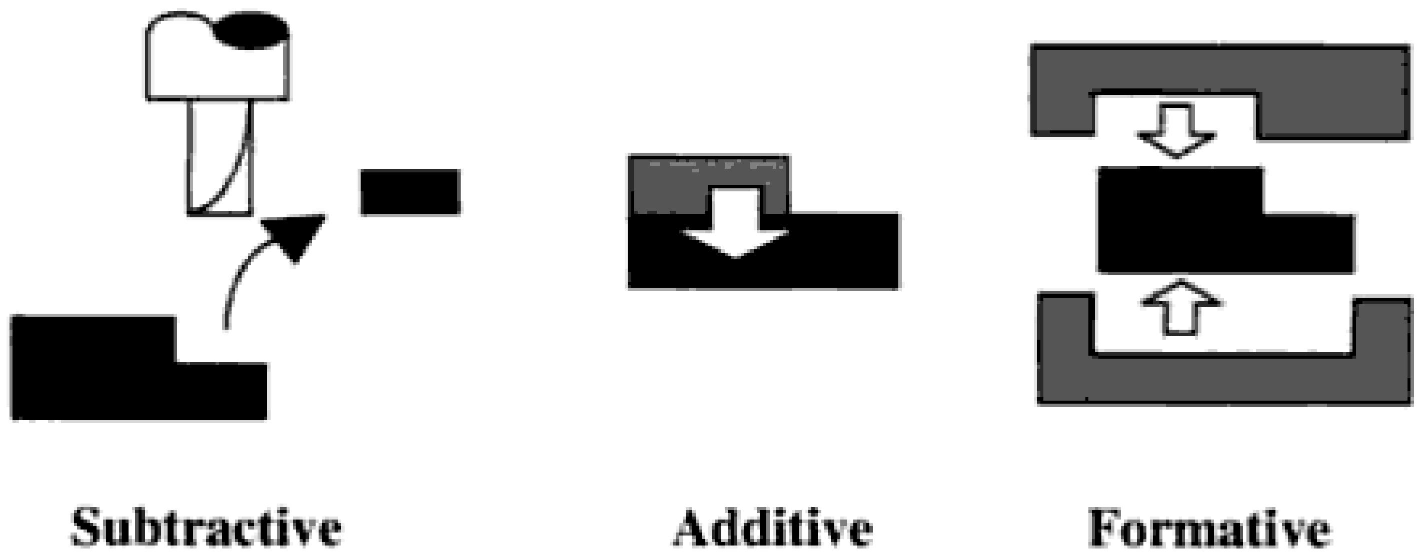
Building 3D object



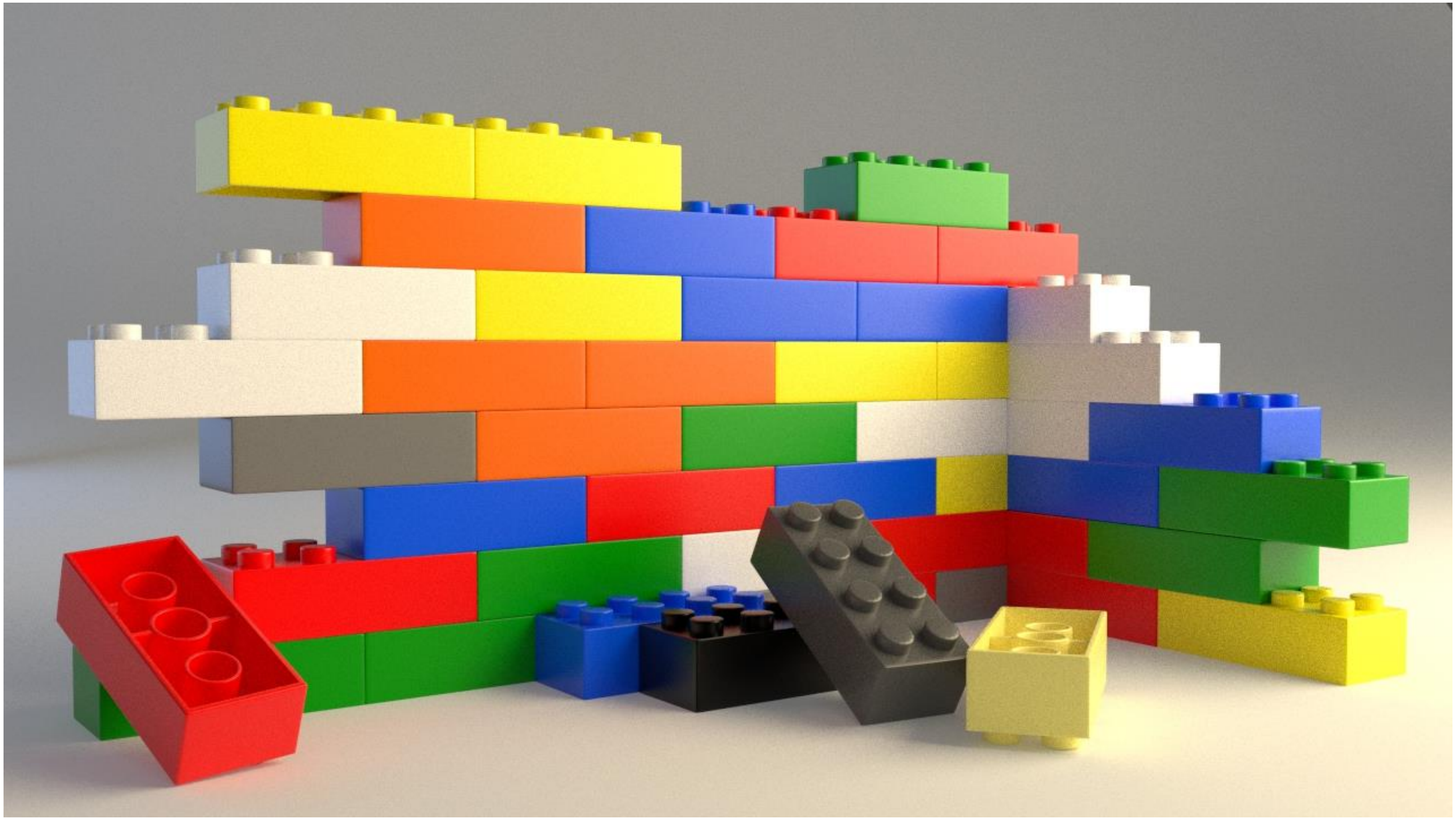
Building 3D object: subtractive

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

Building 3D object: formative

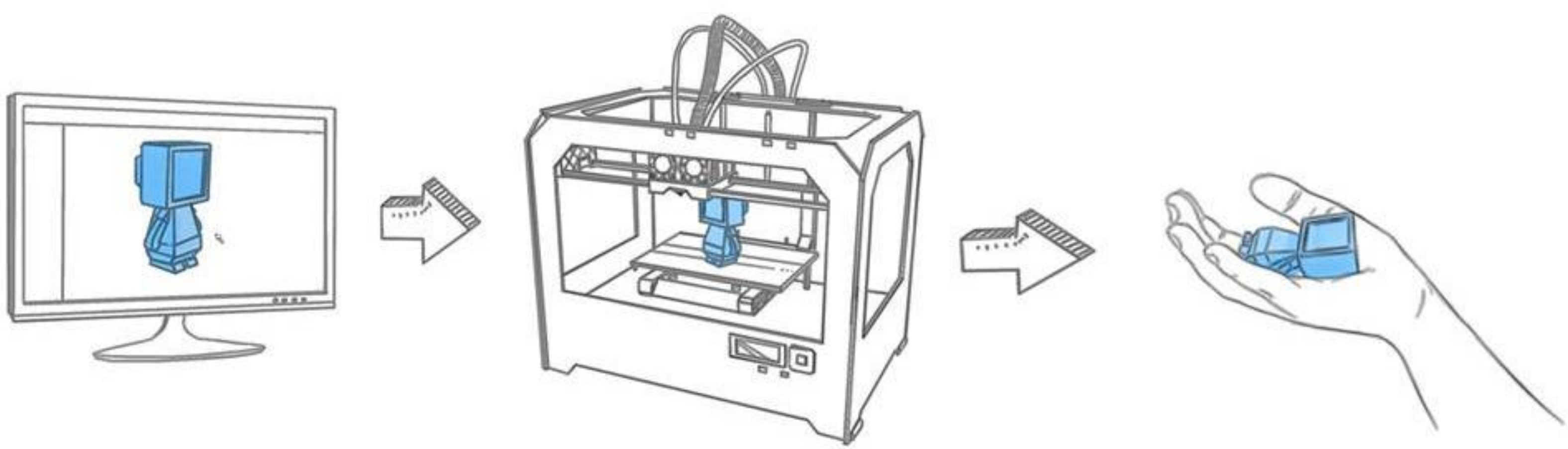
- Bending
- Forging
- Electromagnetic forming
- Plastic injection molding
- …

+ Building 3D object: additive

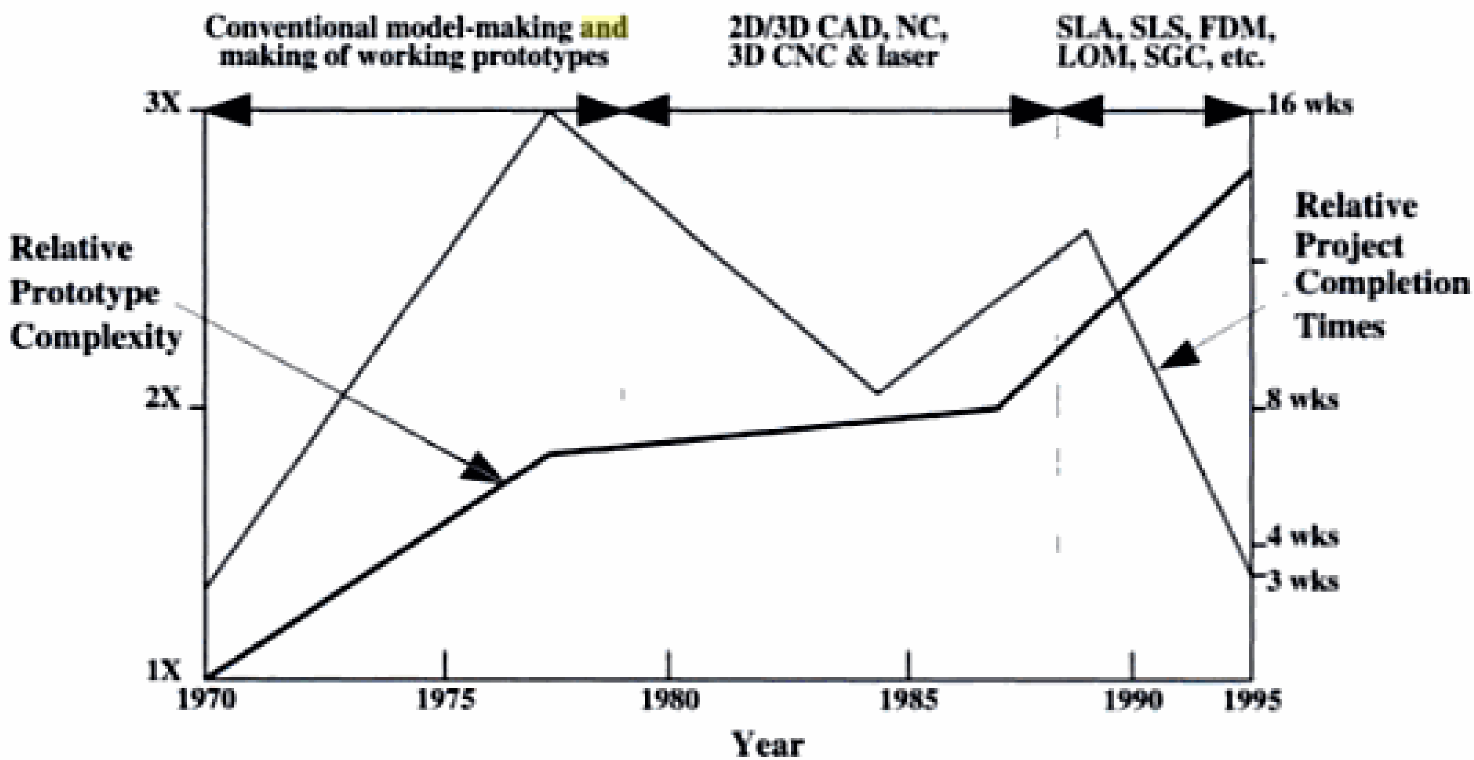


Additive manufacturing

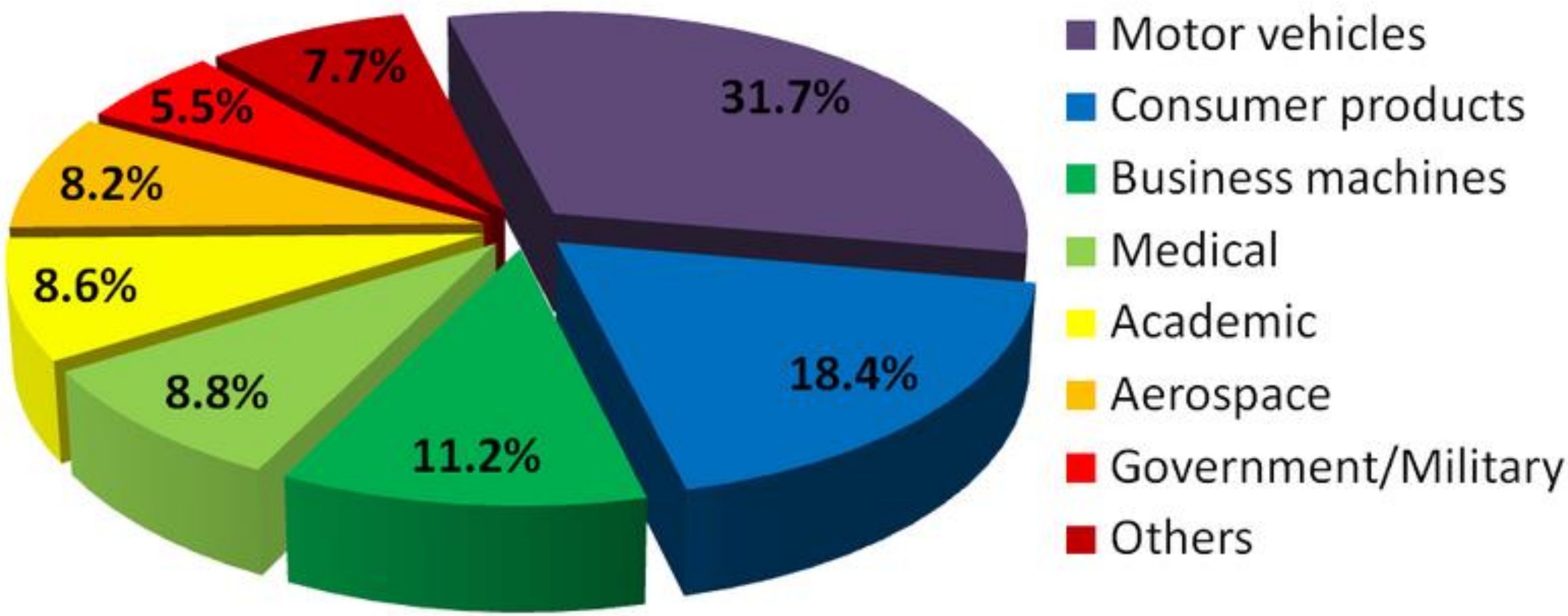
- Additive manufacturing is a process of making a 3D solid object of virtually any shape **from a digital model**.
- It is achieved using an additive process, where successive layers of material are laid down in different shapes.



Additive manufacturing for Rapid prototyping

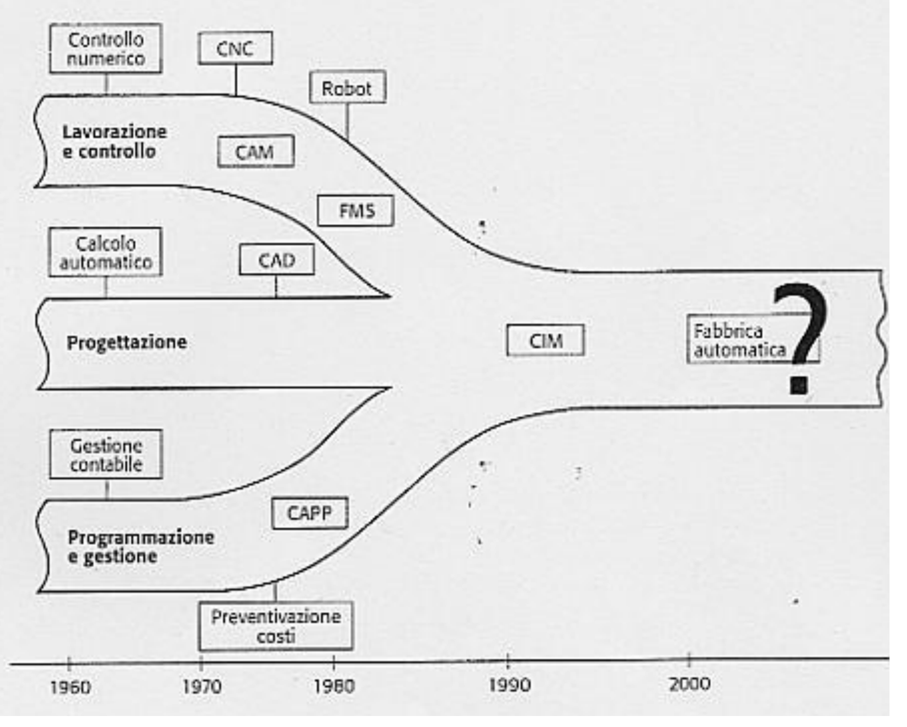


Additive manufacturing by Industry Sectors

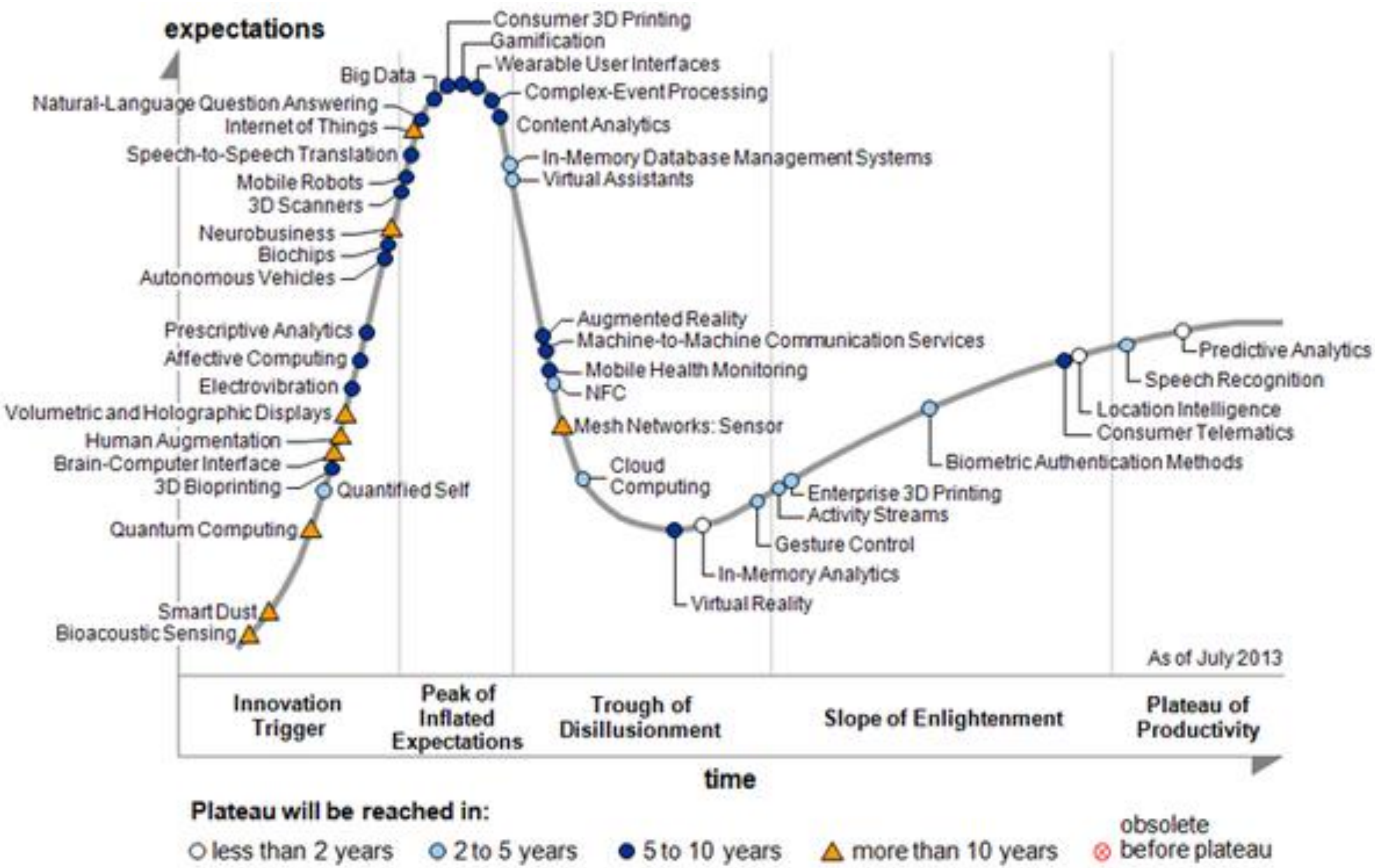


Computer Aided technologies (Cax)

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

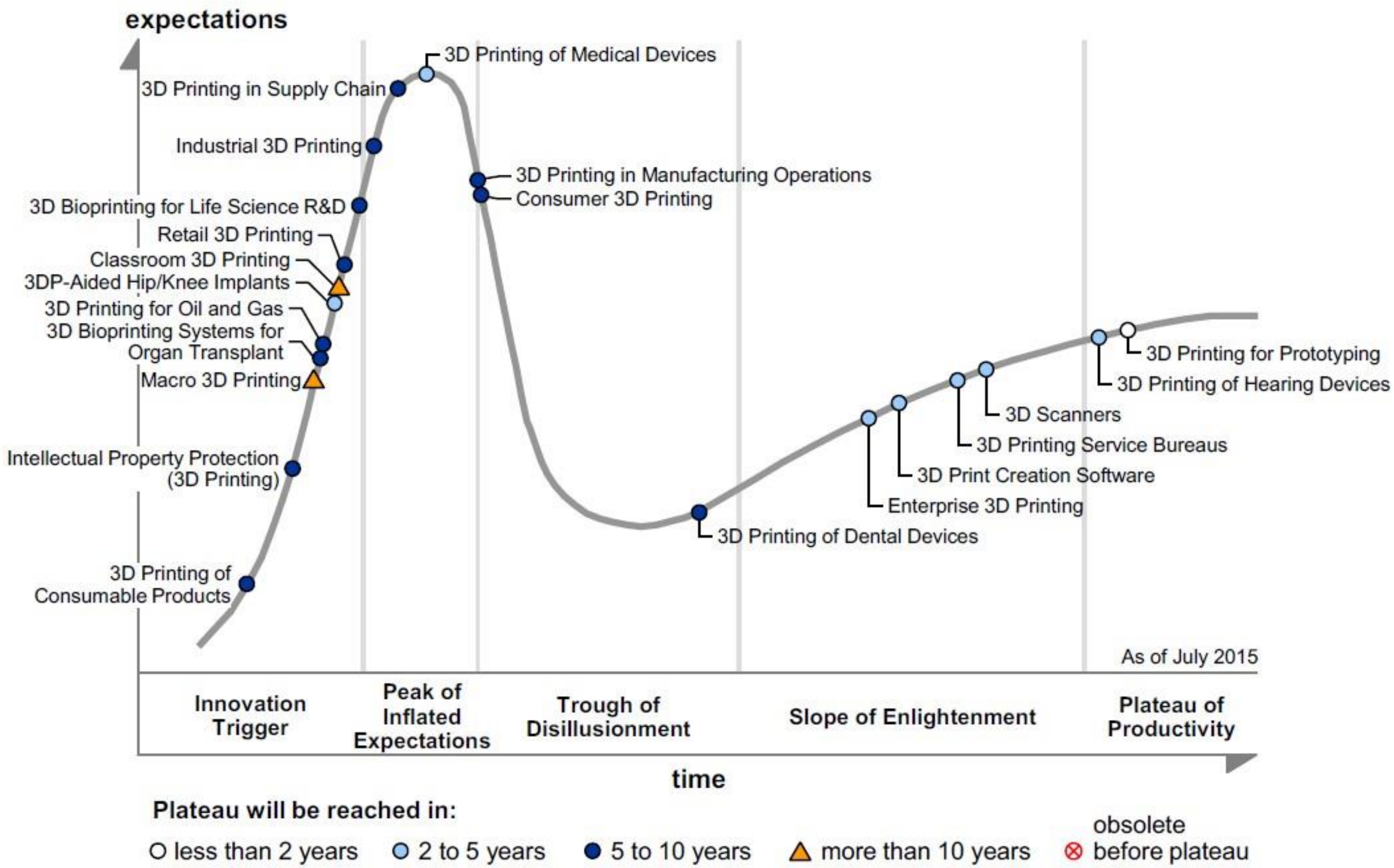


Hype cycle 2013



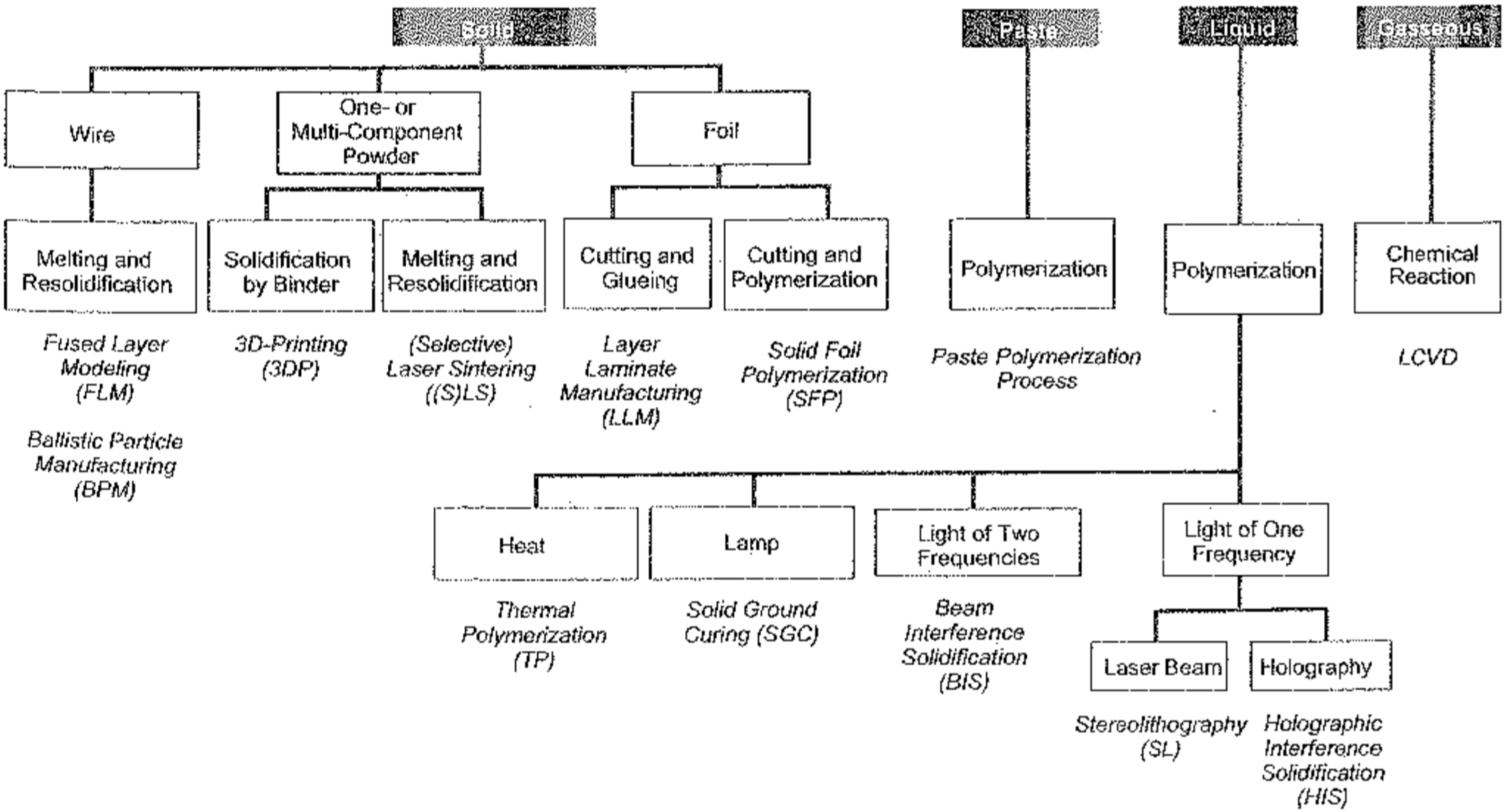
+ Hype cycle 2015

Figure 1. Hype Cycle for 3D Printing, 2015



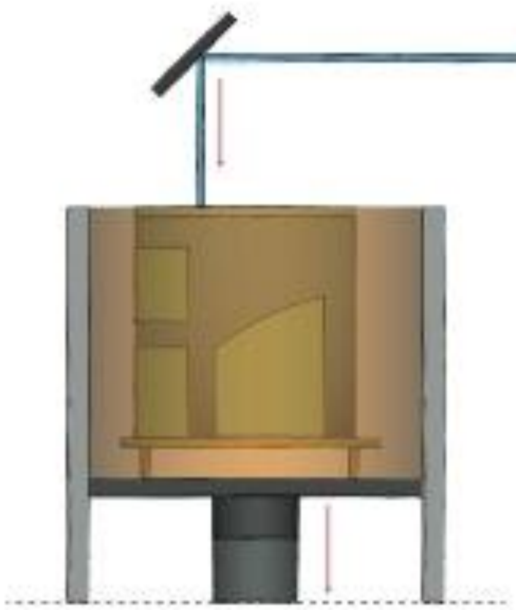
Source: Gartner (July 2015)

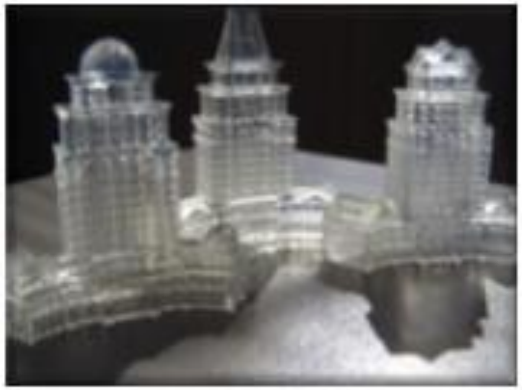
A possible classification



Available technologies

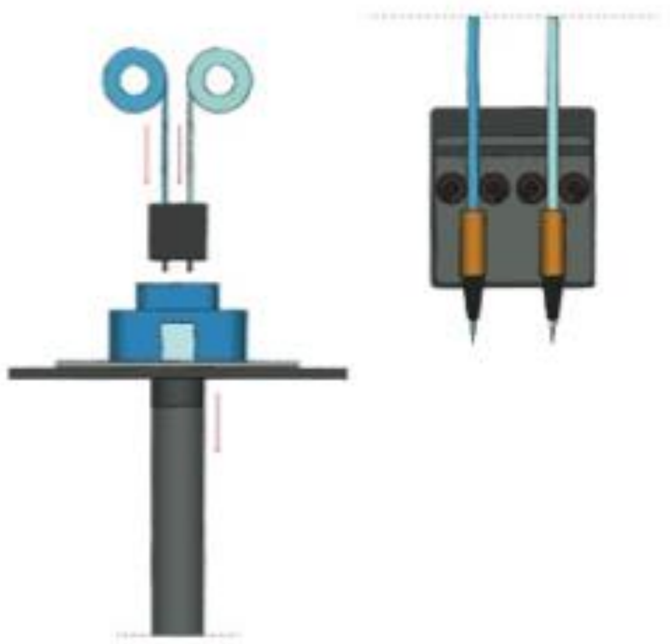
- Solidification of liquid materials
  - Photo-polymerization process





Available technologies

- Generation from the solid phase:
  - incipiently or completely melted solid materials, powder, or powder mixtures:
    - Extrusion (FDM),
    - Ballistic and
    - Sintering processes

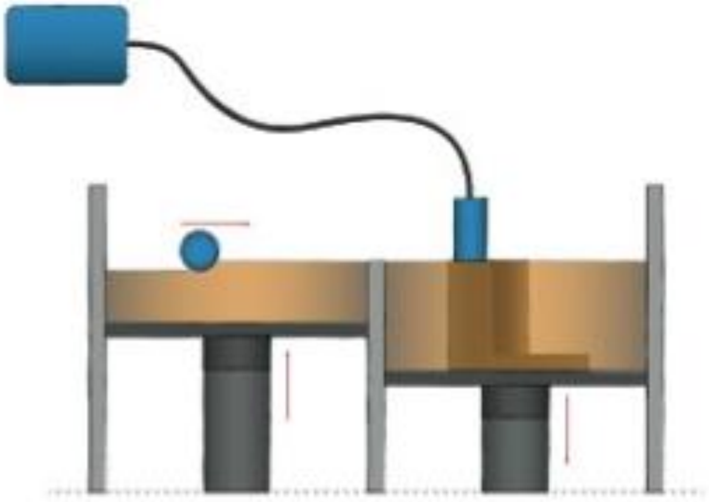


Available technologies

- Generation from the solid phase:
  - incipiently or completely melted solid materials, powder, or powder mixtures:
    - Extrusion (FDM),
    - Ballistic and
    - Sintering processes

Available technologies

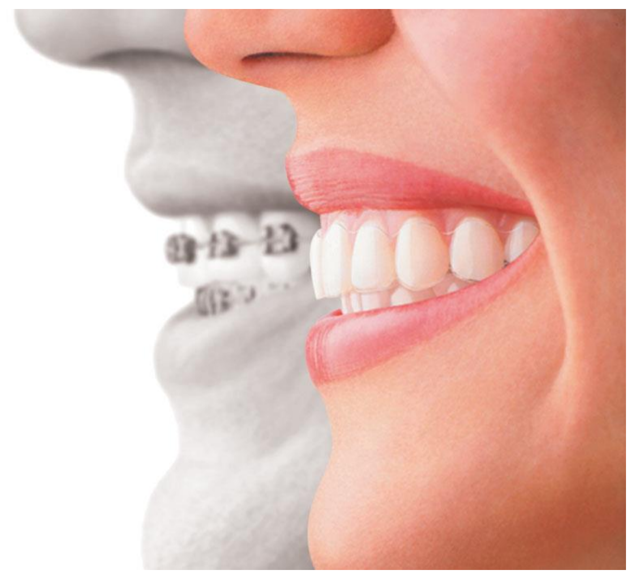
- Generation from the solid phase:
  - Conglutination of granules or powders by additional binders
    - 3D inkjet printer



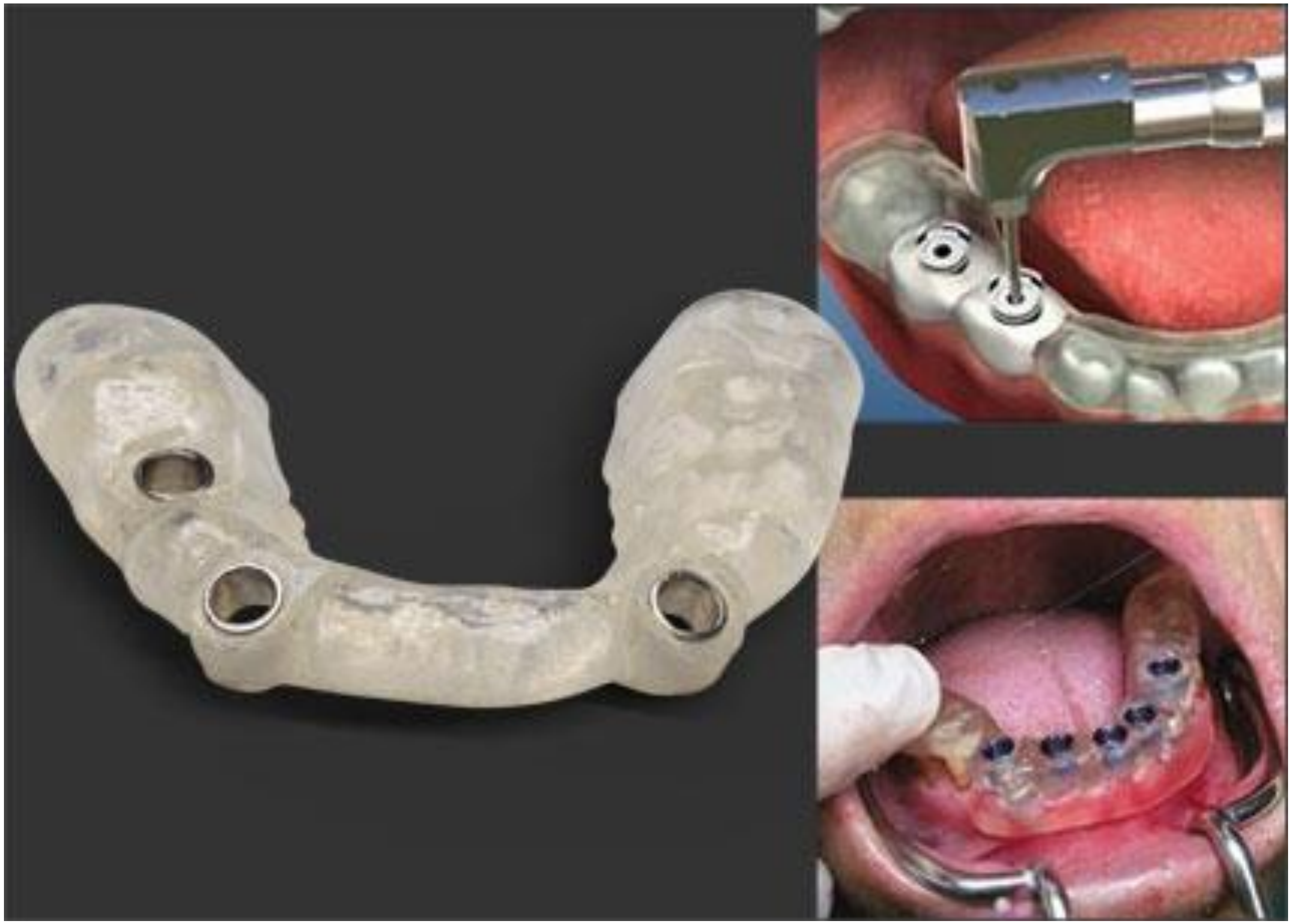
MEDICAL APPLICATION OF RAPID PROTOTYPING

Invisalign Orthodontic Aligners

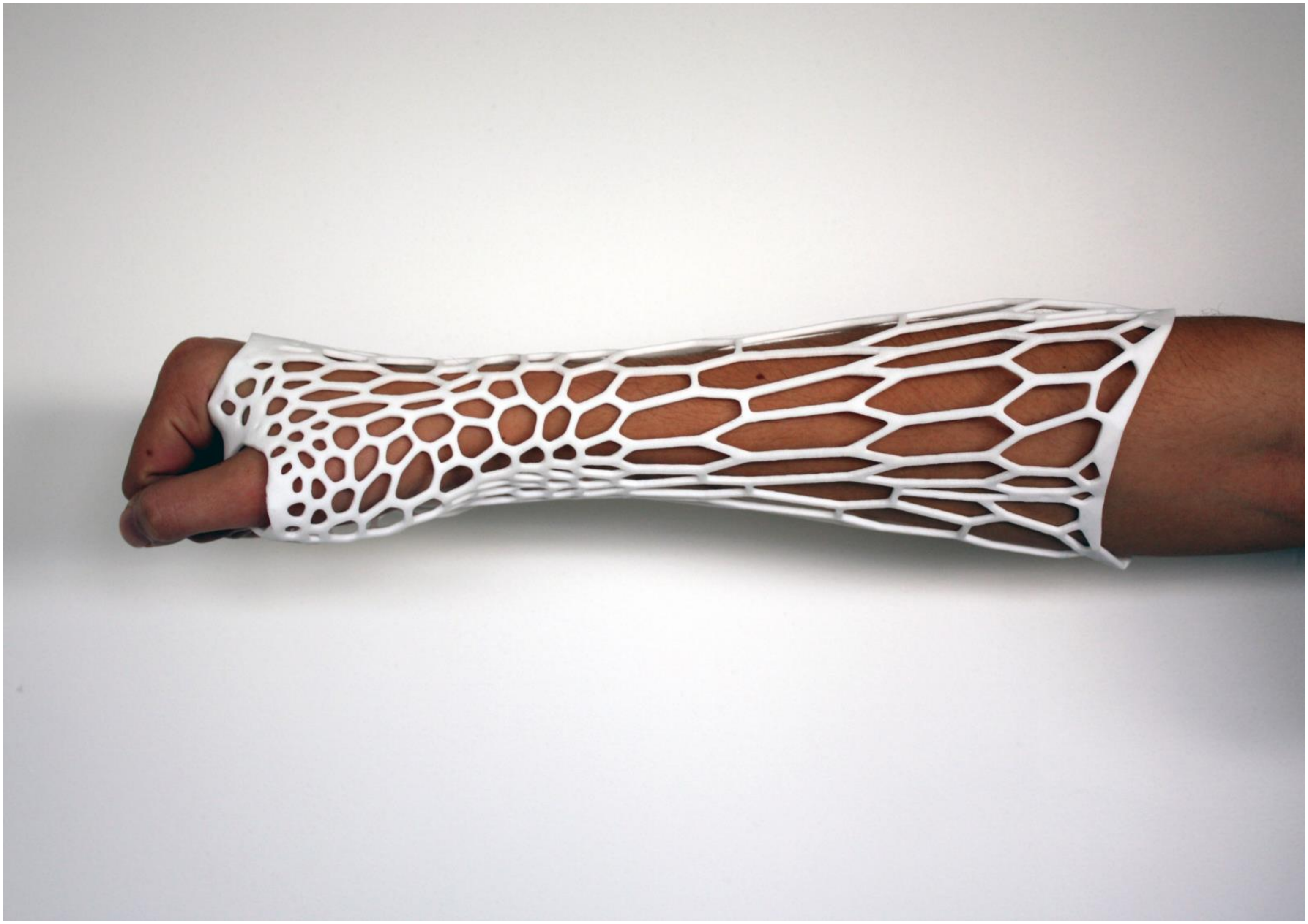
- An aligner for orthodontic use manufactured using a combination of rapid tooling and thermoforming.



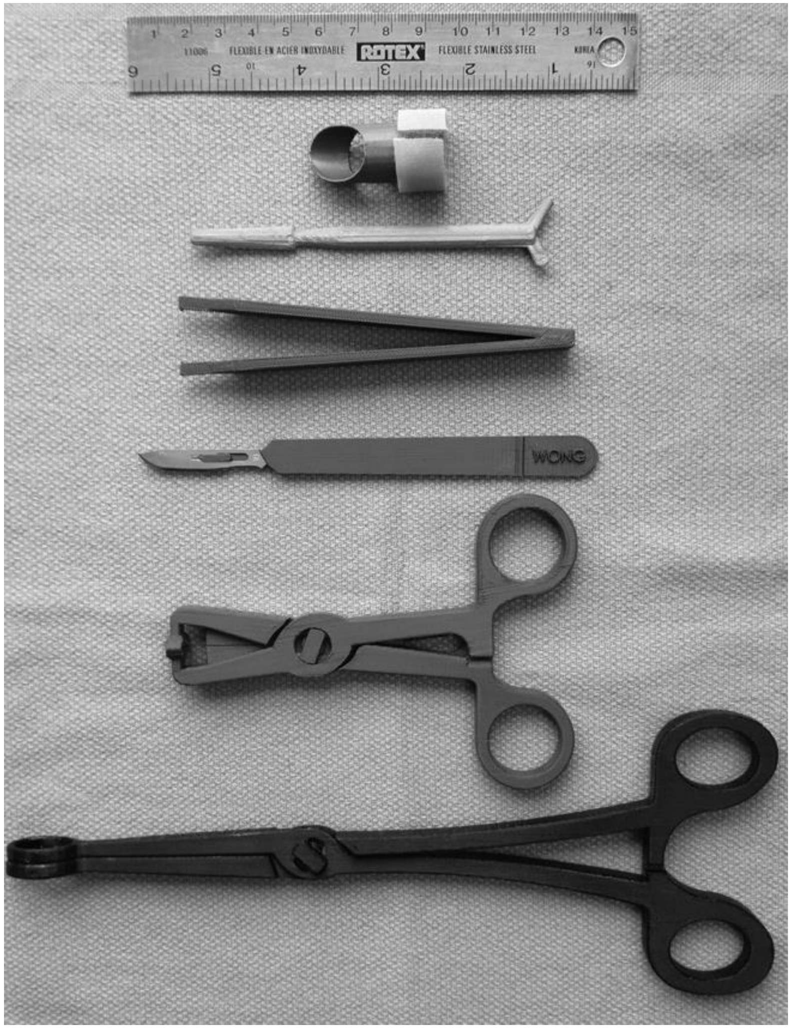
Drilling guide for dental implants



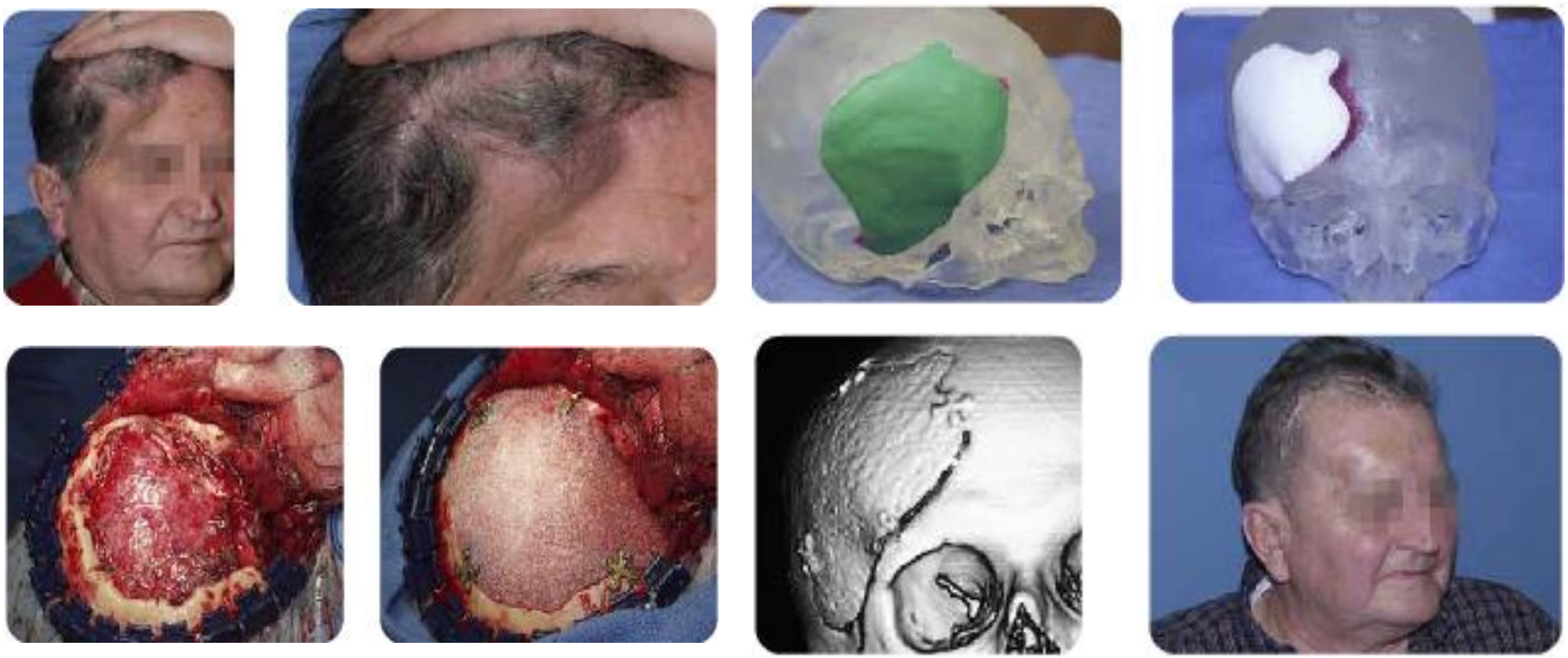
3D printed cast



Surgical instruments for space missions



Surgery

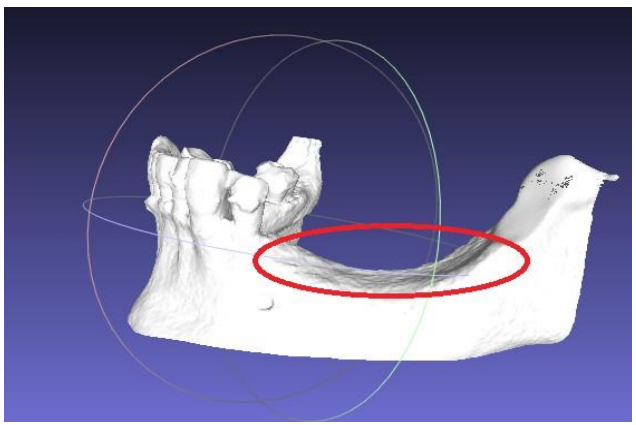


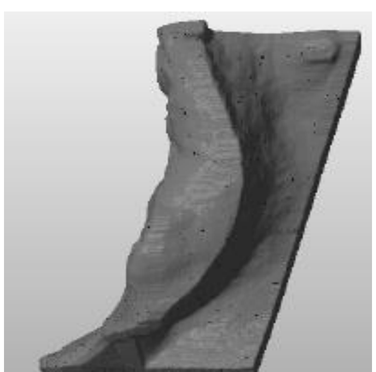
Surgery




Patient-specific indirect additive manufacturing

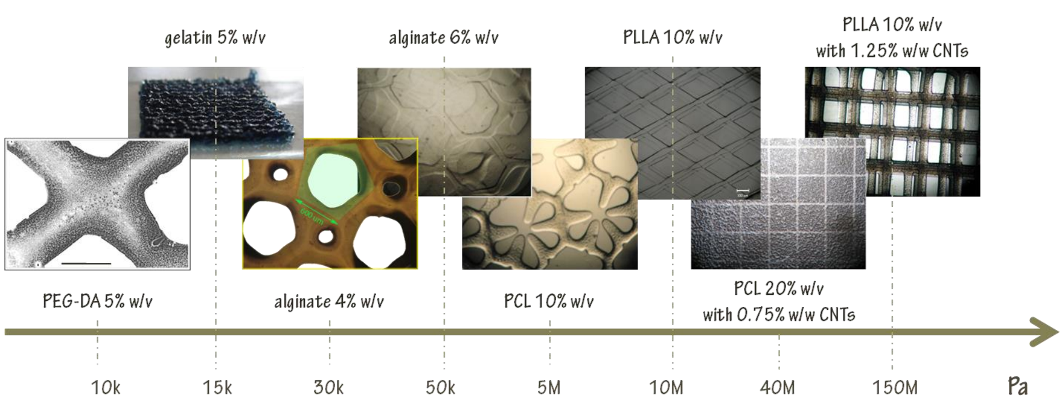
- *Soluble patient-specific molds for custom medical implant – from CT scan to the final object*





Tissue Engineering - Biofabrication

- Living cells are extracted from patients and seeded onto a carrier (scaffold) which accomodates and guides the growth of new cells in 3D within laboratory environment.



4D printing

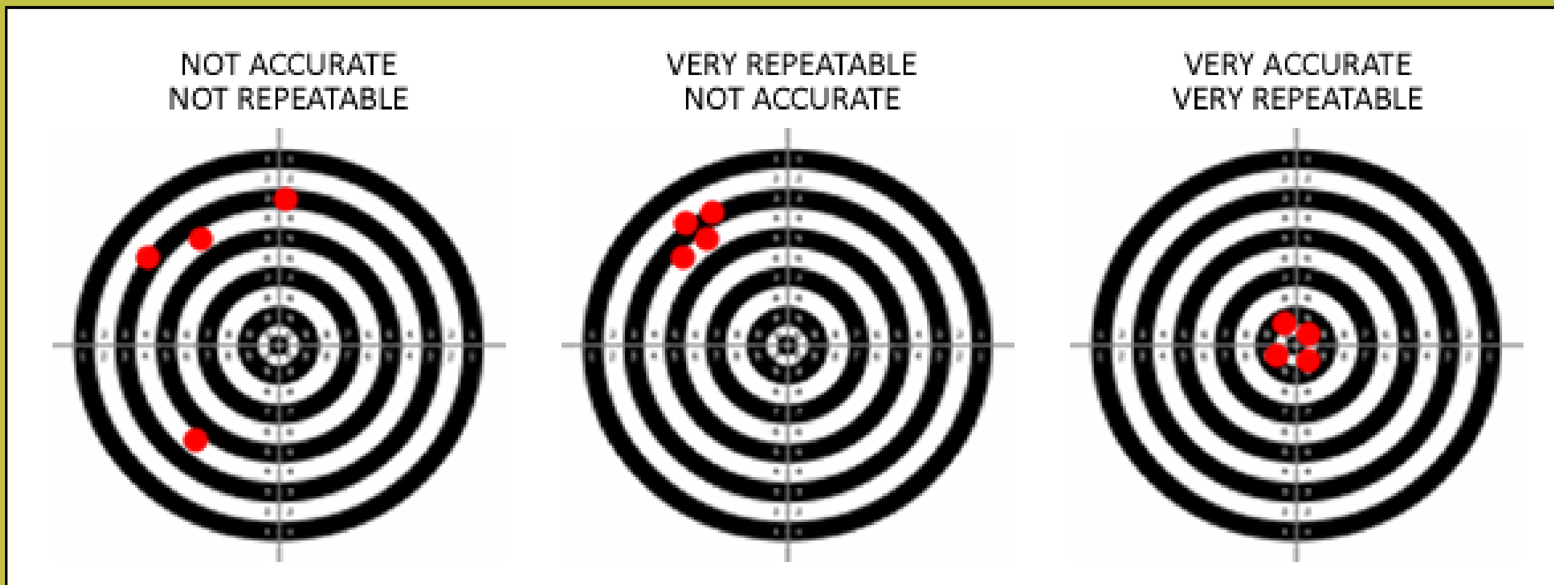
- https://vimeo.com/58840897

GENERAL CONSIDERATION ON ADDITIVE MANUFACTURING TECHNOLOGIES

Materials

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

Accuracy-repetability-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

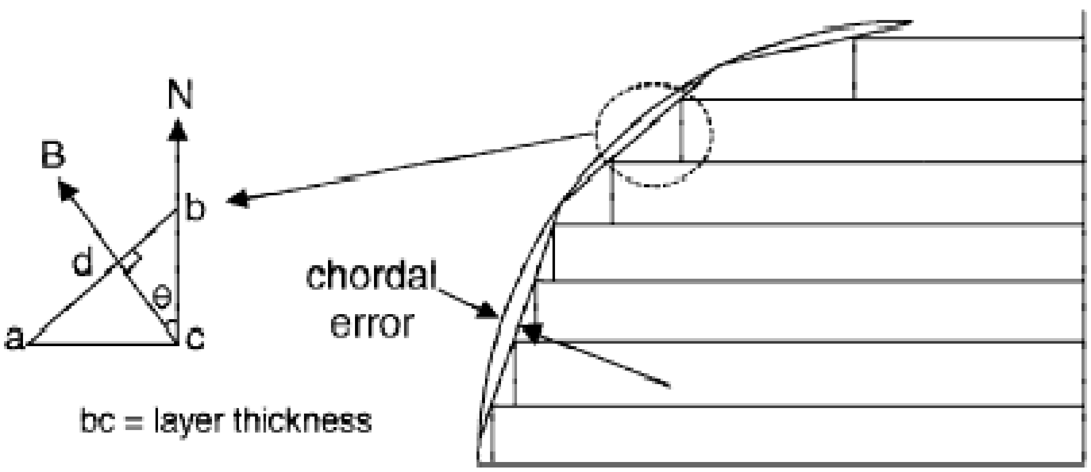
RESOLUTION
The smallest degree of movement that a scale can detect

Features of AM Systems

	Layer thickness(mm)	Accuracy (mm)
Stereolithography (SLA)	0.05 - 0.3	0.01 - 0.2
Layered Object Manufacturing (LOM)	0.1 - 1	0.1 - 0.2
Fused Deposition Modelling (FDM)	≈0.05	0.130 - 0.260
Selective laser sintering (SLS)	≈0.08	0.03 - 0.4
Solid ground curing (SGC)	0.01 - 0.15	0.05 - 0.5

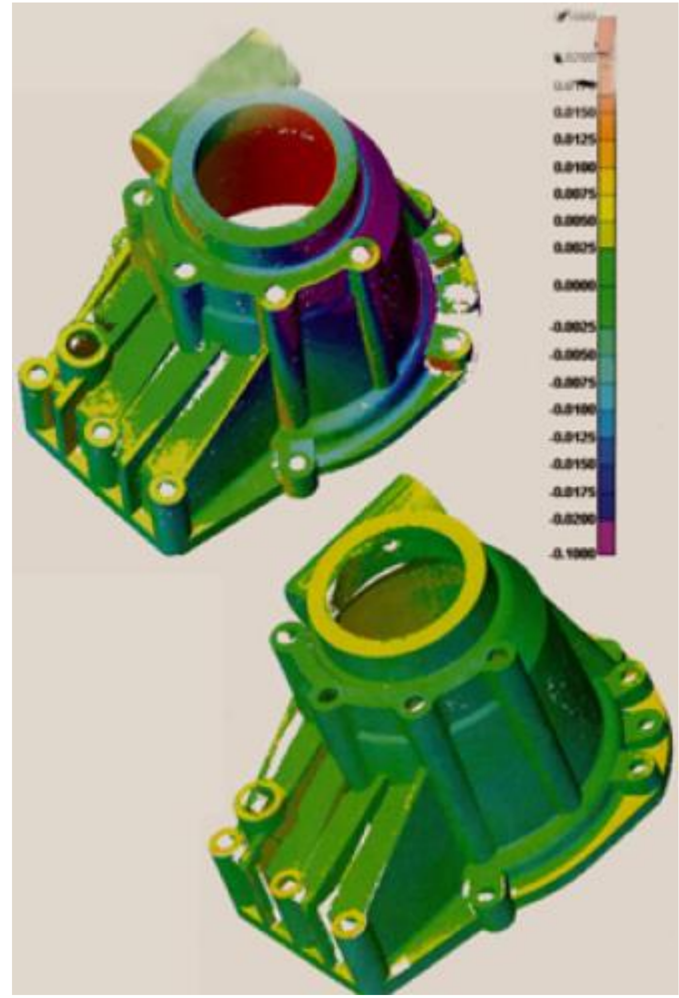
Drawbacks of AM

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



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

- 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

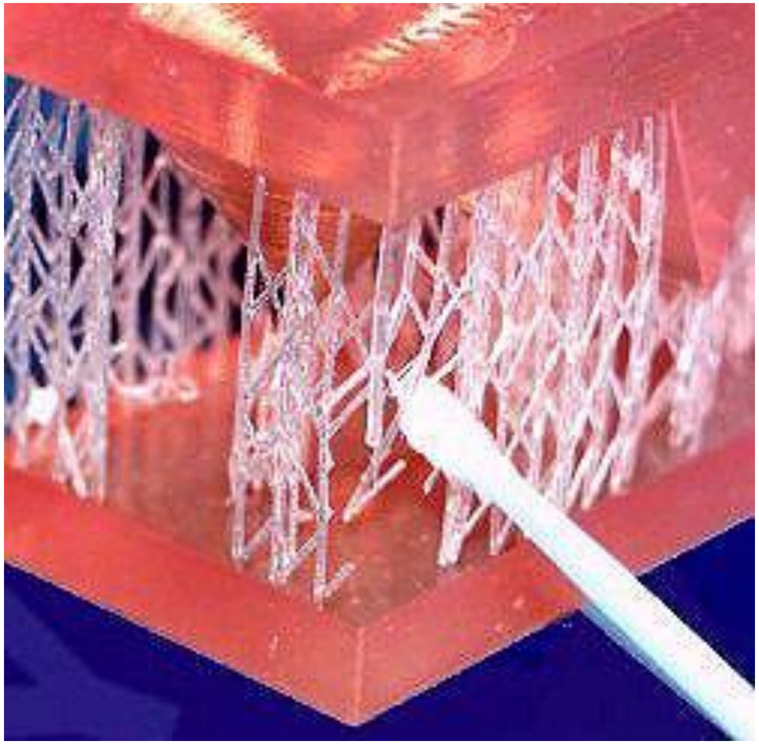
Drawbacks of AM

- Costs and time due to secondary operations
  - Post Curing (Stereolithography)
  - Inflintration, 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 (FDM).

Support structure, stereolithography.



Drawbacks of AM

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

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

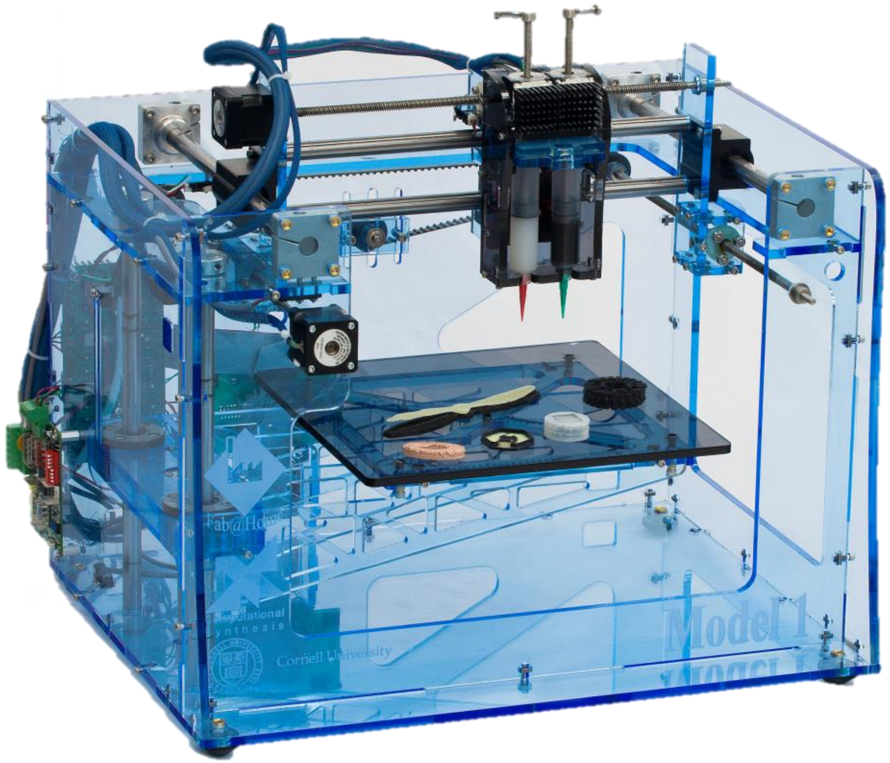
Cost - Vendors

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

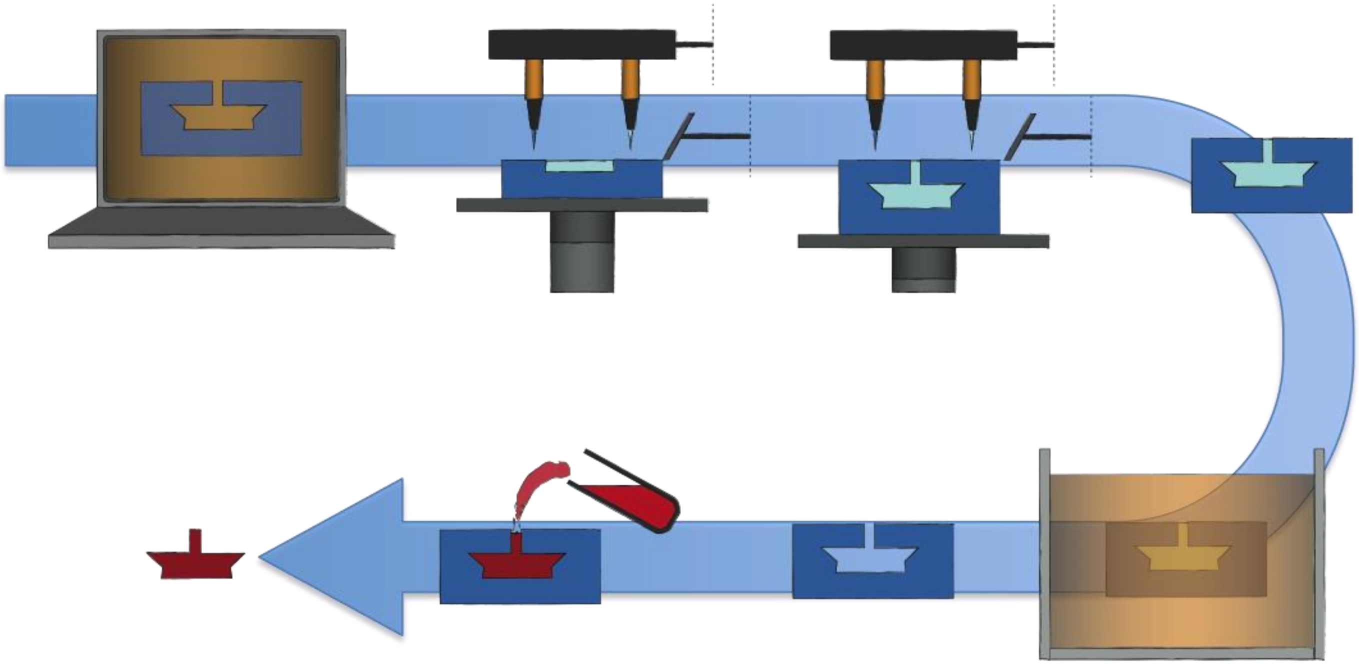
- https://www.stratasysdirect.com/

- https://www.3dhubs.com/

INDIRECT RAPID PROTOTYPING (RAPID TOOLING)

Indirect Rapid Prototyping (iRP)

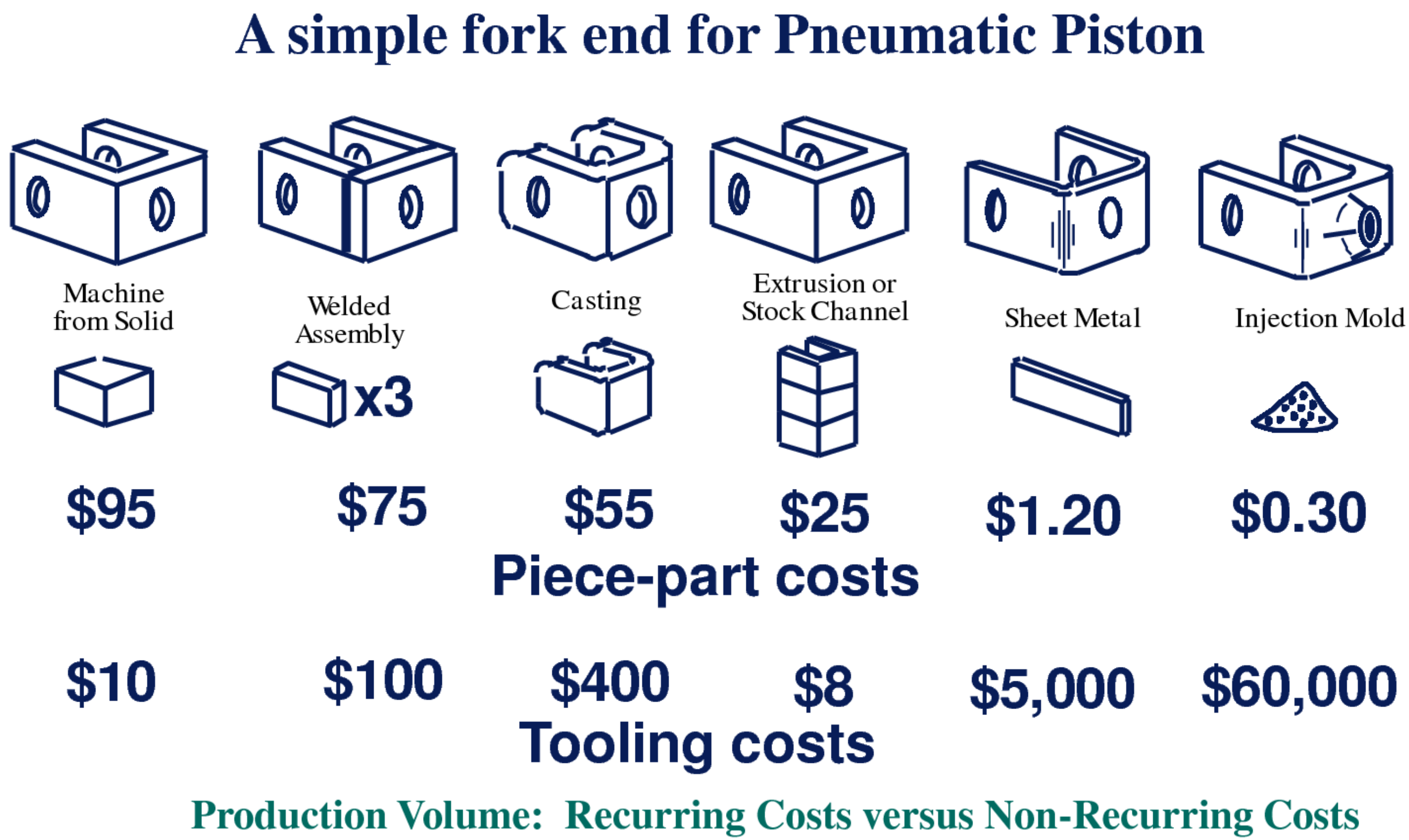
- Molds fabricated with RP devices (CAD/CAM)
- Casting of the desired (bio-)material
- Extraction of the final object



DW Hutmacher et al., Trends in Biotechnology, 22(7):354 – 362, 2004

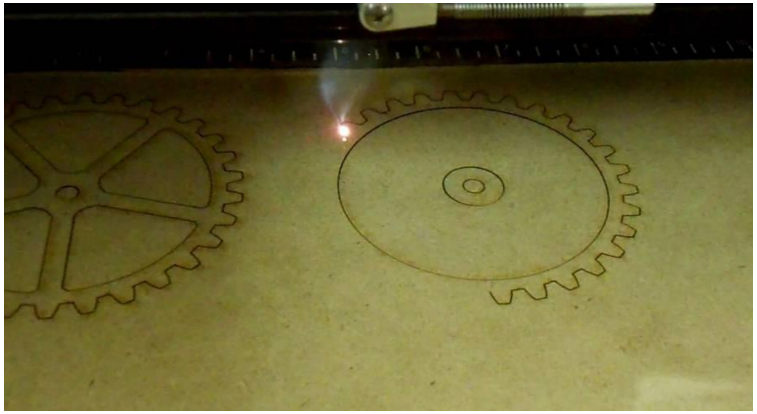
IS IT A GOOD CHOICE TO 3DPRINT EVERY OBJECT?

Design for manufacture



Subtractive technologies

- Laser cutter
- CNC milling machines



NC Machining & Rapid Prototyping

- Numeric control machines requires a skilled operator to set up the maching specifying:
  - tools,
  - speeds,
  - raw materials.
- NC Machining allows:
  - a wide range of materials
  - better accuracy
  - to reveal manufacturing limits in a given design.

Additive Manufacturing vs Subtractive Manufacturing

- AM can not become complete replacement for the SM (Milling, Turning, EDM etc.)
- AM technologies are instead complementary for:
  - complex or intricate geometric forms,
  - simultaneous fabrication of multiple parts into a single assembly,
  - multiple materials or composite materials in the same part.
- Thus, AM is the enabling technology for controlled material composition as well as for geometric control.

Environmental and health issues