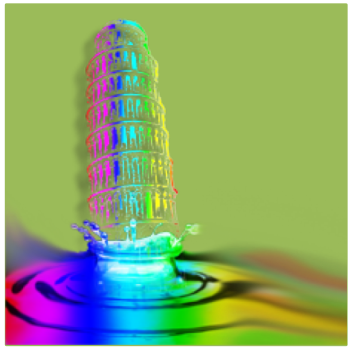
CENTRO E. PIAGGIO
Bioengineering and Robotics Research Center

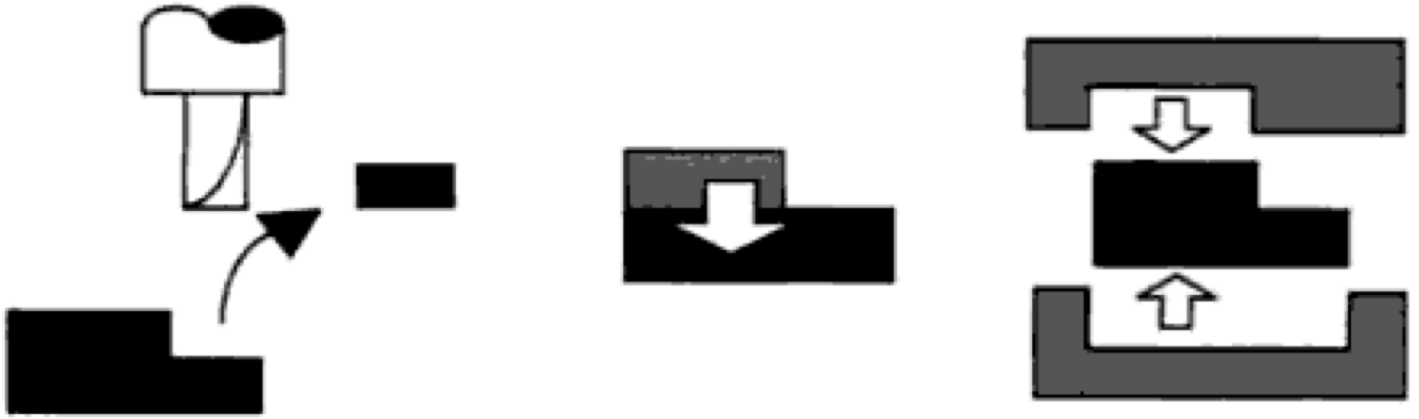


Additive manufacturing:

PROCESS WORKFLOW

Deacutis.aurora@gmail.com

Building 3D object



Subtractive

Additive

Formative

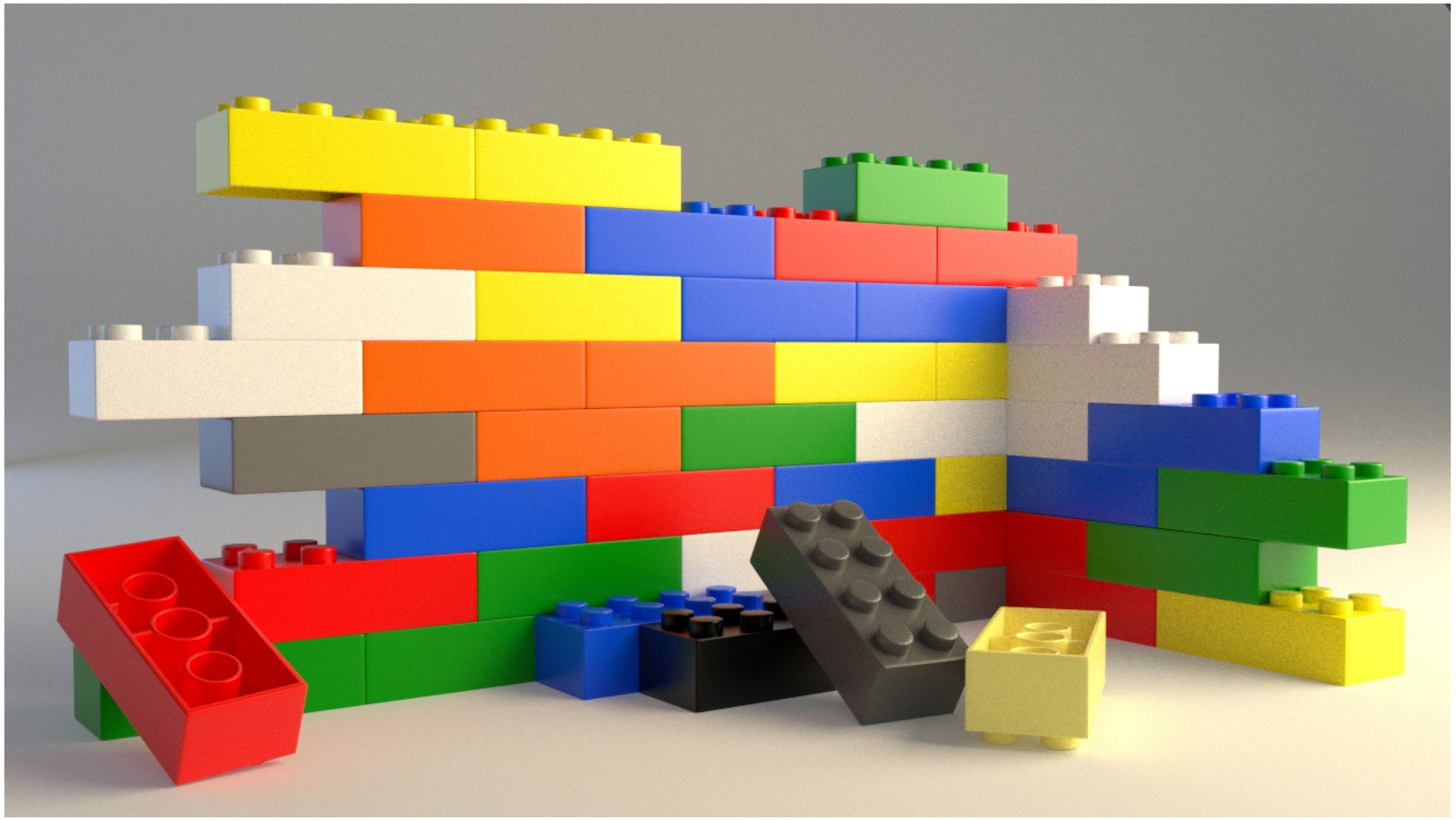
Building 3D object: subtractive

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

Building 3D object: formative

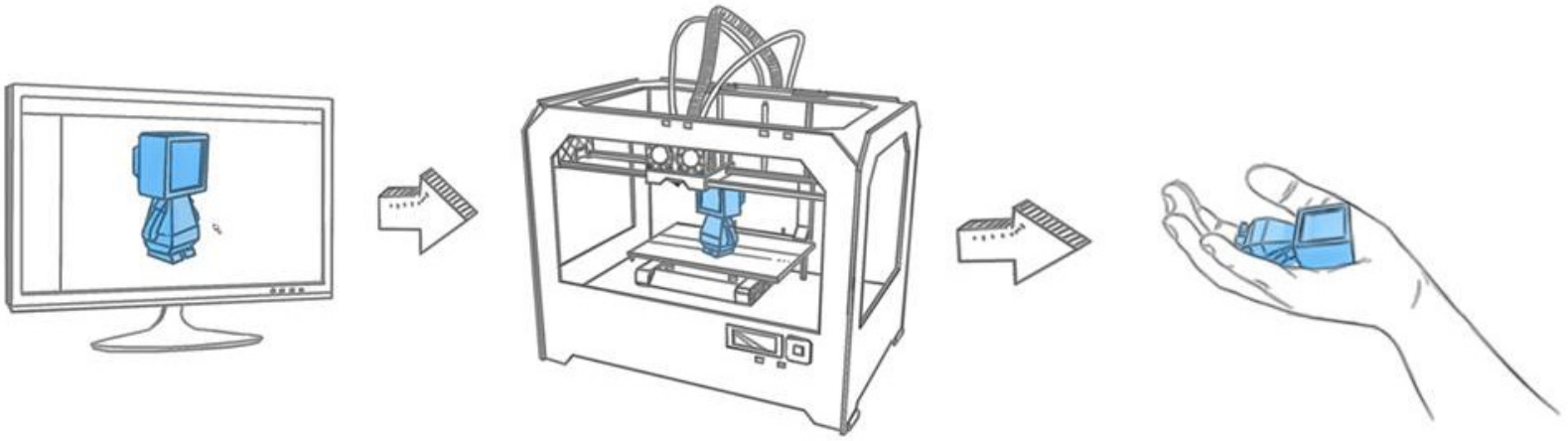
- Bending
- Forging
- Electromagnetic forming
- Plastic injection molding
- …

Building 3D object: additive



Additive Manufacturing (AM)

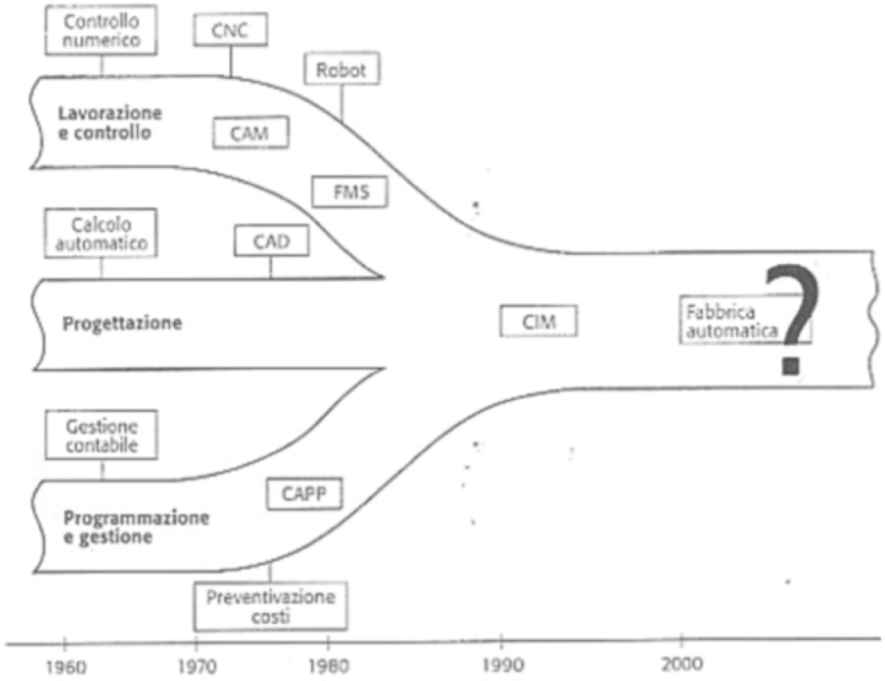
- The process of joining material to make object from 3D a digital model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.



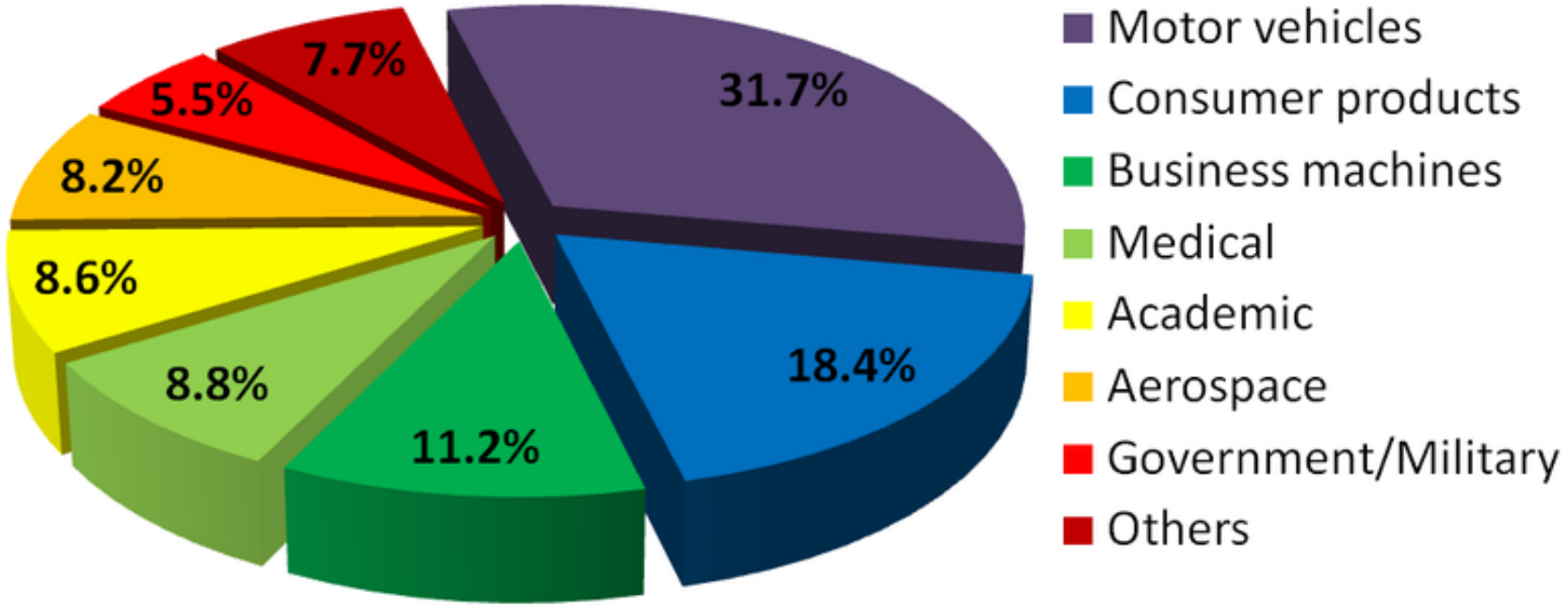
AM = Rapid Prototyping (RP)

Computer aided technologies (CAx)

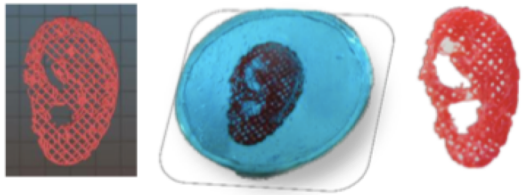
- CAD – Design
- CAE – Engineering
- CAM – Manufacturing
- CAPP – Process Planning
- CIM – Computer Integrated Manufacturing

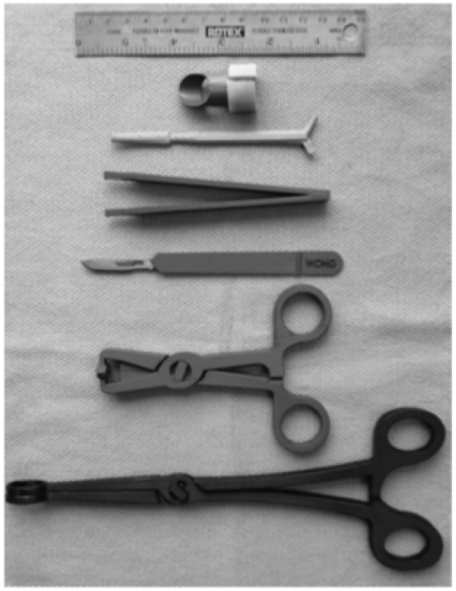


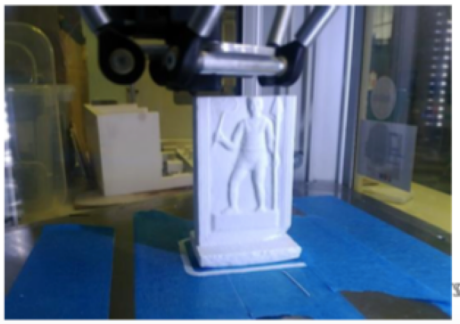
Additive manufacturing by Industry Sectors

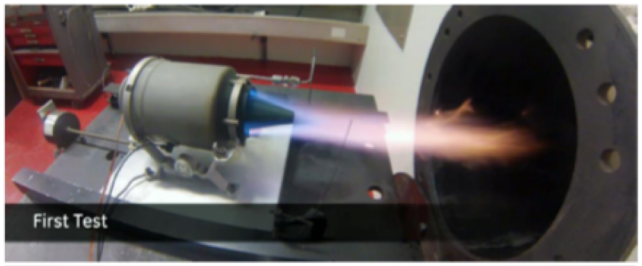


Additive manufacturing what?









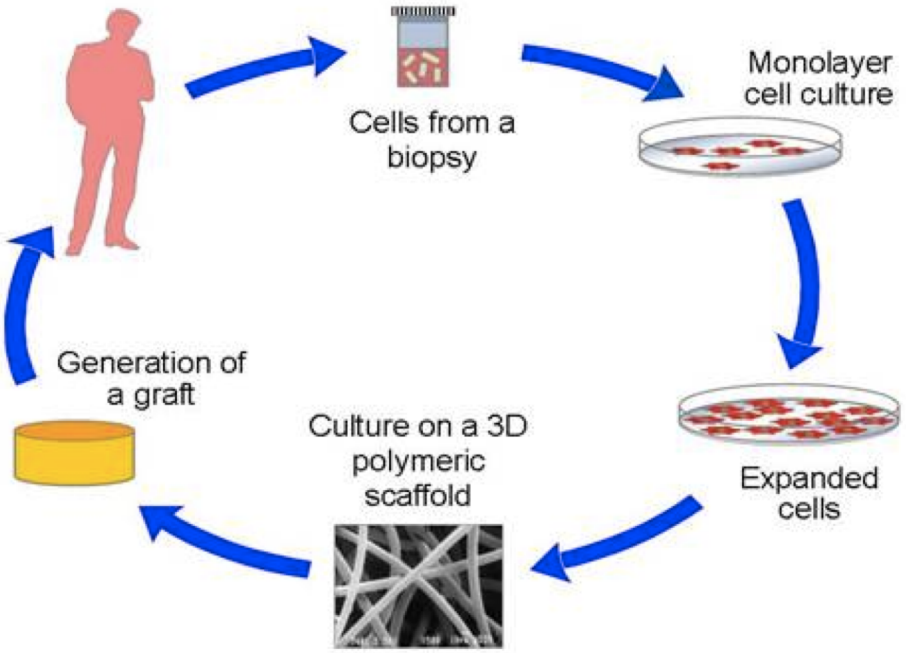
MEDICAL APPLICATION OF RAPID PROTOTYPING

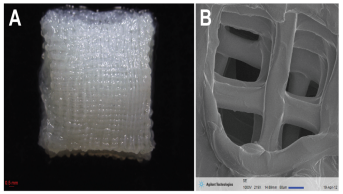
Prosthetics

Surgery (1of2)

Surgery (2of2)

Tissue Engineering-scaffold fabrication

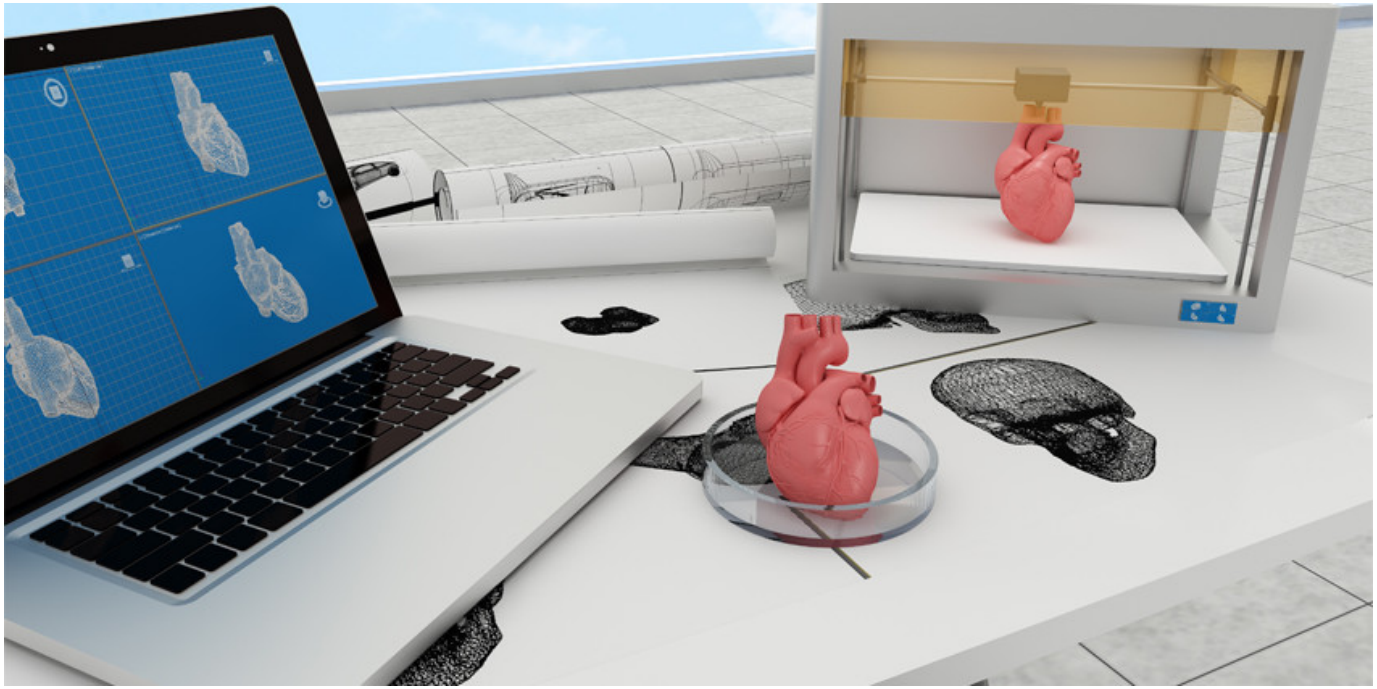




Scaffold is a **temporary** 3D polymeric structure that **mimics** the **mechanical**, **structural**, and **biochemical** properties of the extracellular matrix (ECM) of natural tissue supporting 3D tissue growth

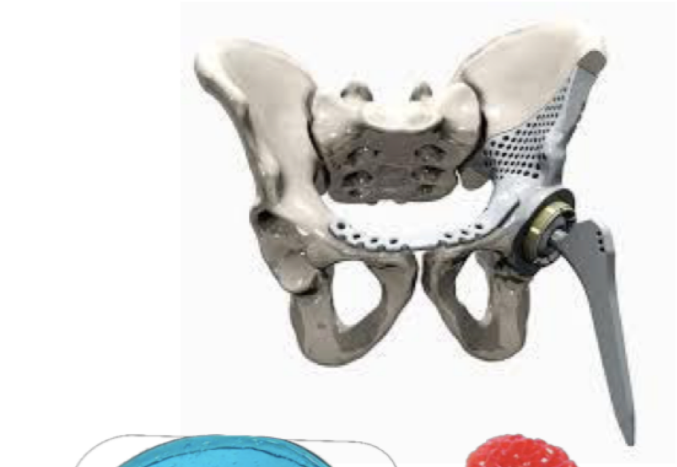
RP in TE: biofabrication

The automated generation of biologically functional products with structural organization **from living cells, bioactive molecules**, **biomaterials**, **cell aggregates** such as micro-tissues, or hybrid cell-material constructs, through Bioprinting or Bioassembly and subsequent tissue maturation processes.

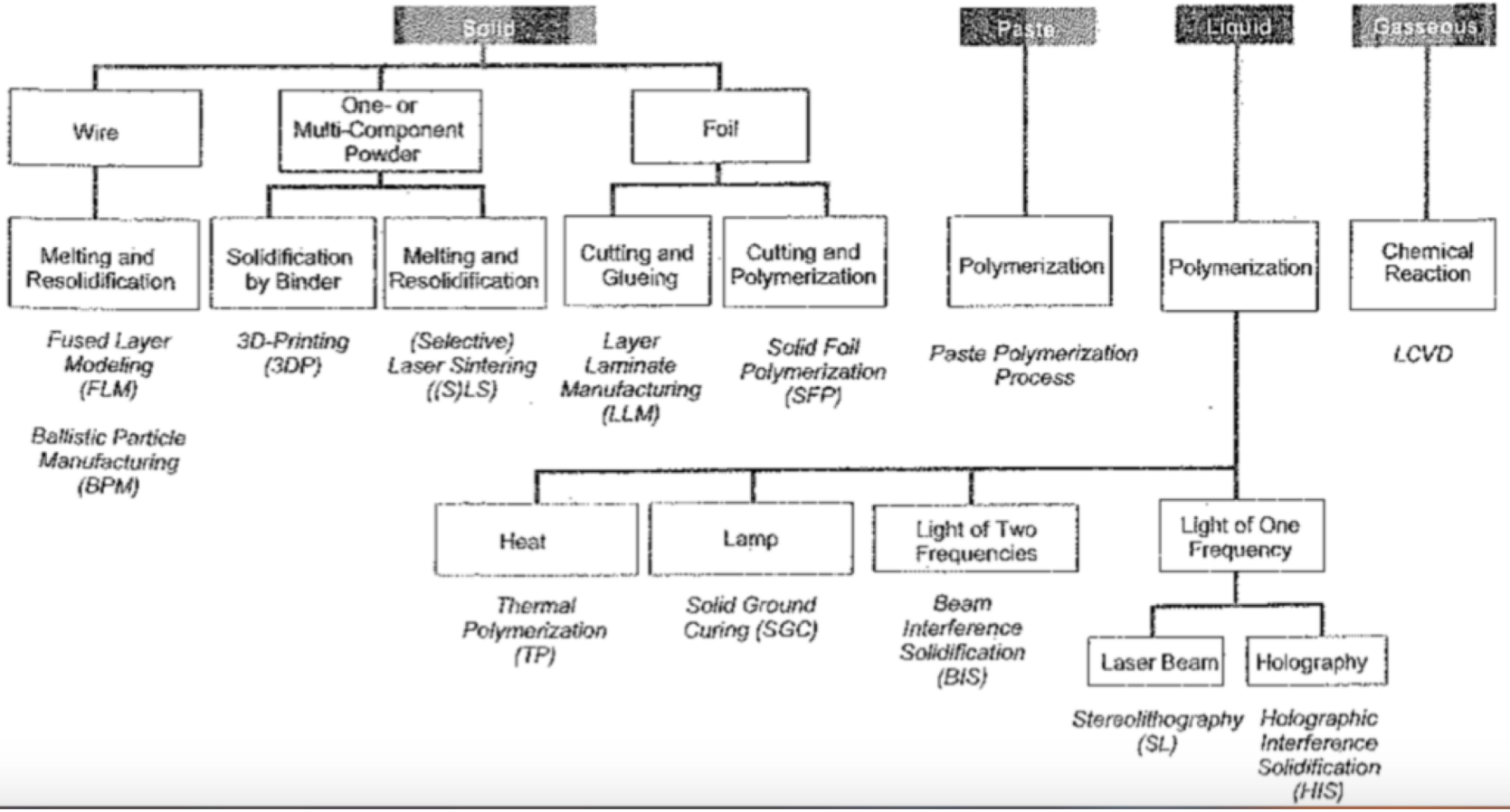


Additive manufacturing using...

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



A possible Classifcation



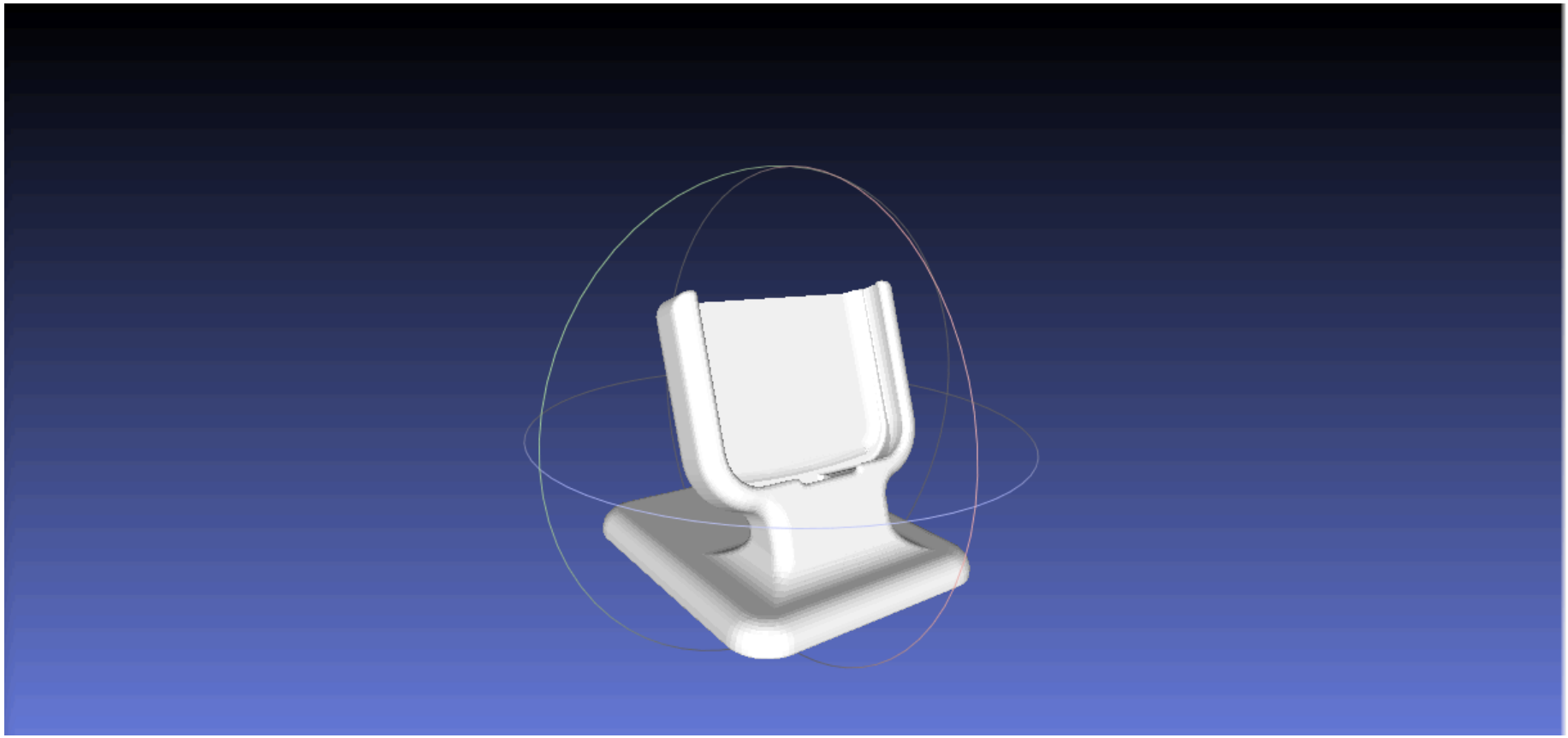
ASTM/ISO 52900 classification

- 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.

Additive manufacturing (or RP) Process Flow

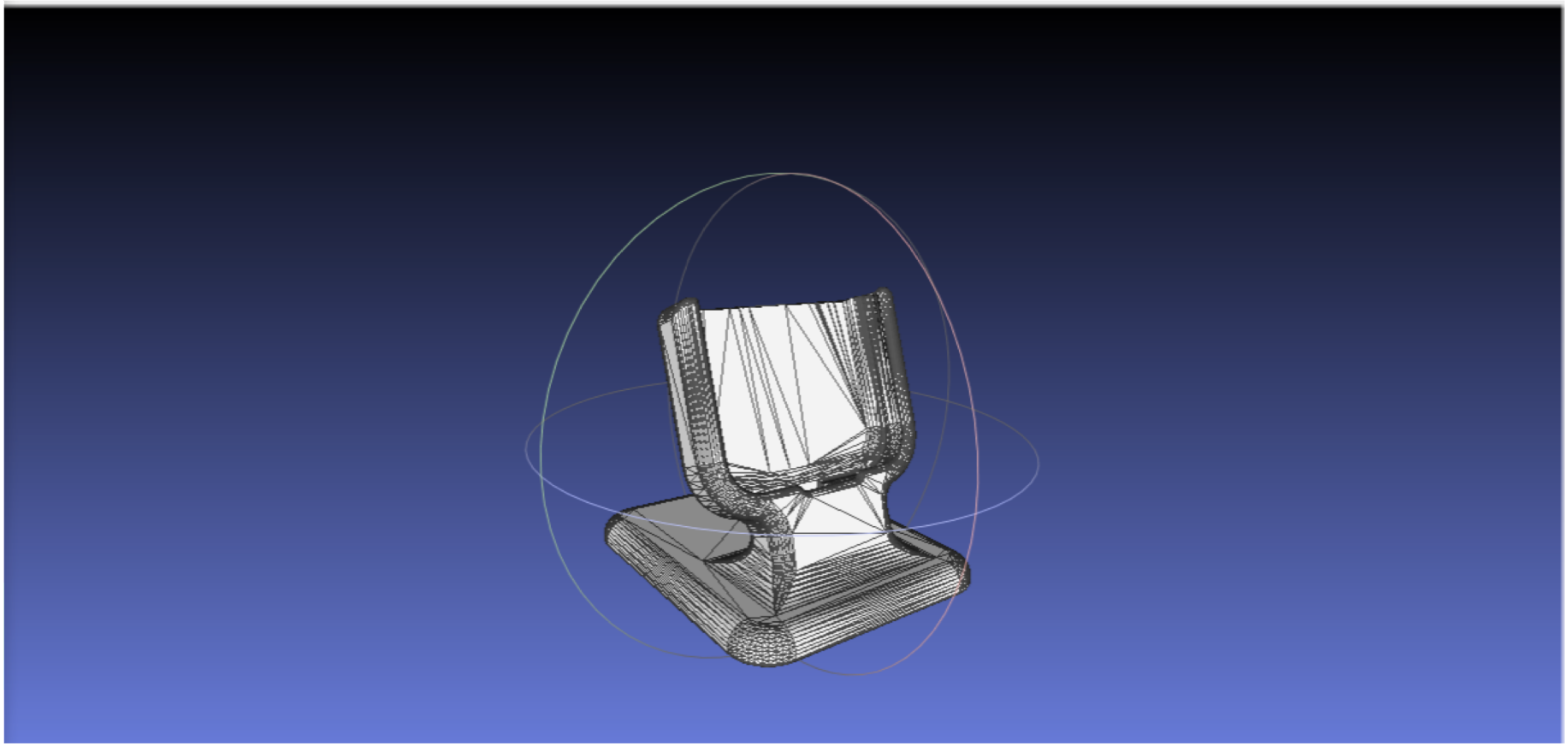
- Solid Modelling
- Generation of exchange format file
- Support Generation
- “Slicing” of the Model
- Model Physical Build up
- Clean-up and Post Curing
- Surface Finishing

from idea to design



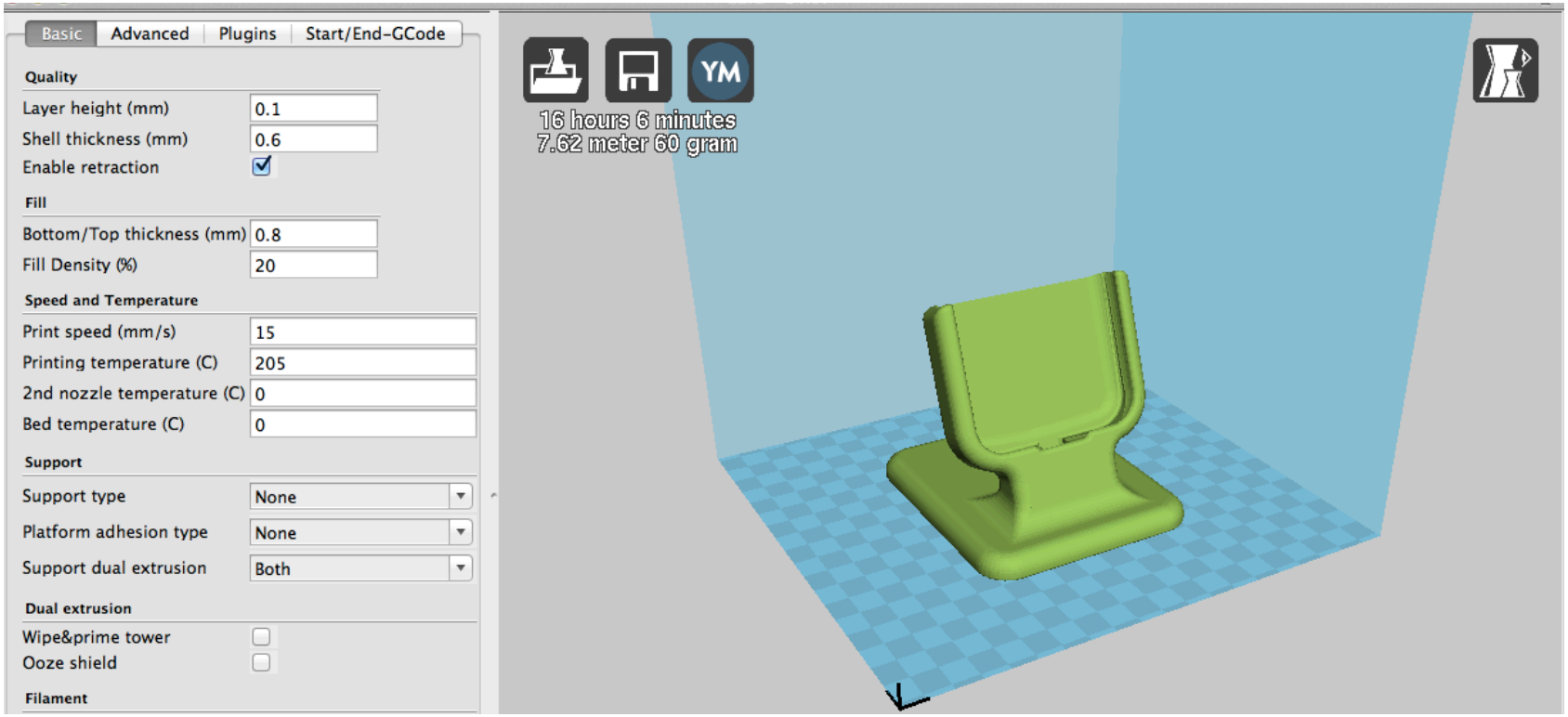
3D model
CAD (computer aided design)

from idea to design



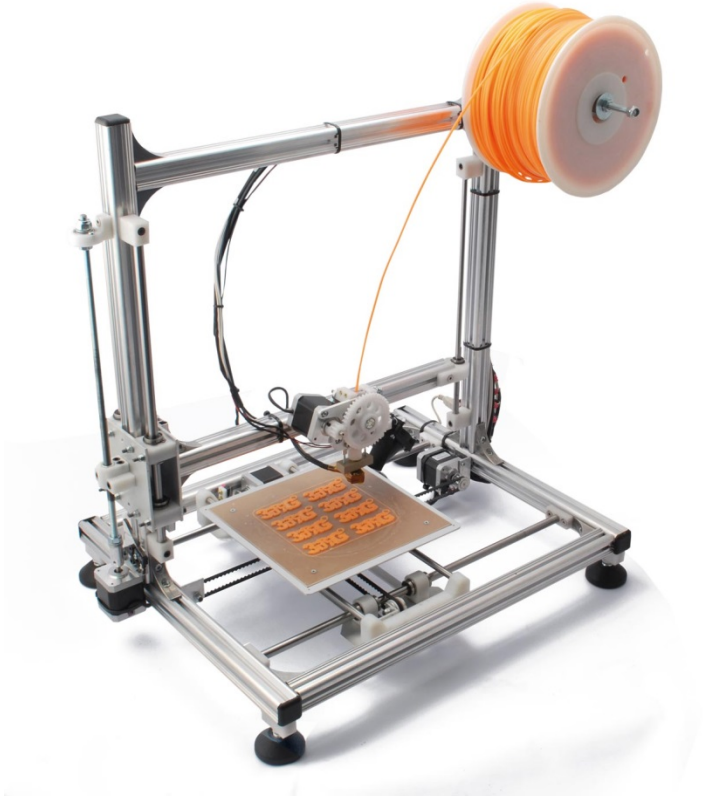
.STL representation

from design to object



- Support Generation
- “Slicing” of the Model
- Toolpath generation

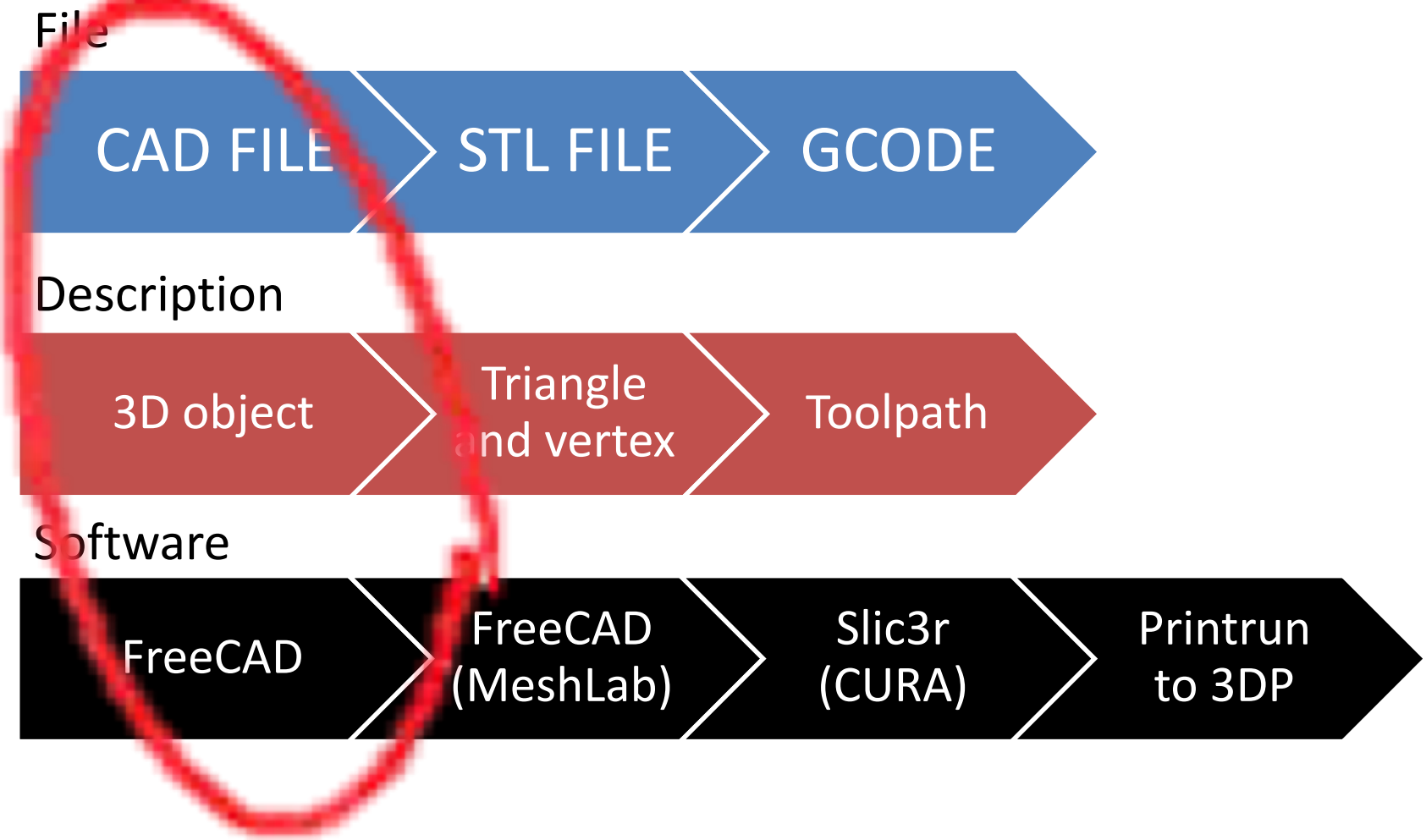
from design to object



Model Physical Buildup

from design to object

Additive manufacturing (o RP)
Process Flow: solid modeling



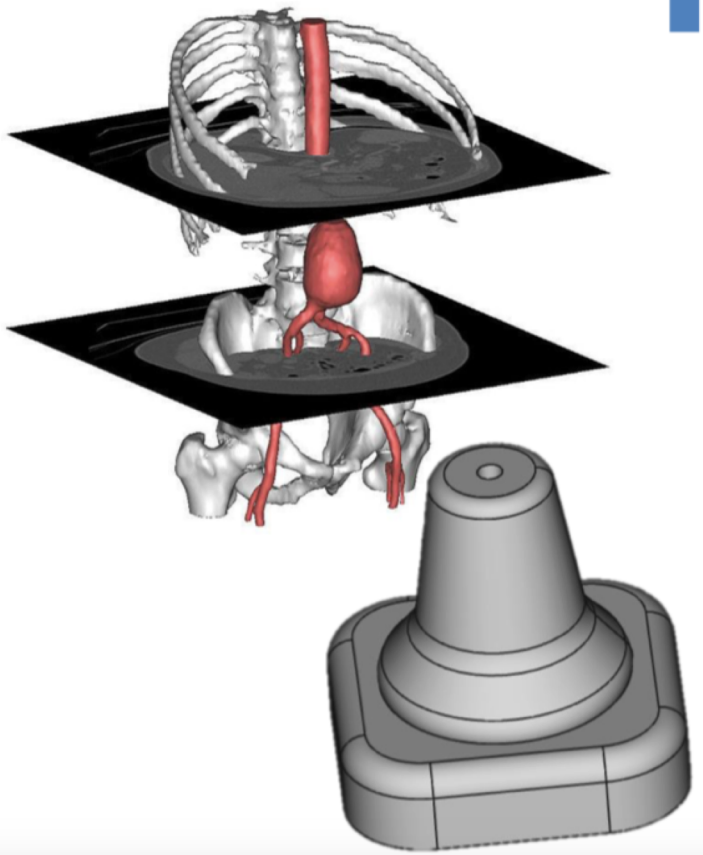
3D DATA SOURCE

3D data source: CAD model (1)

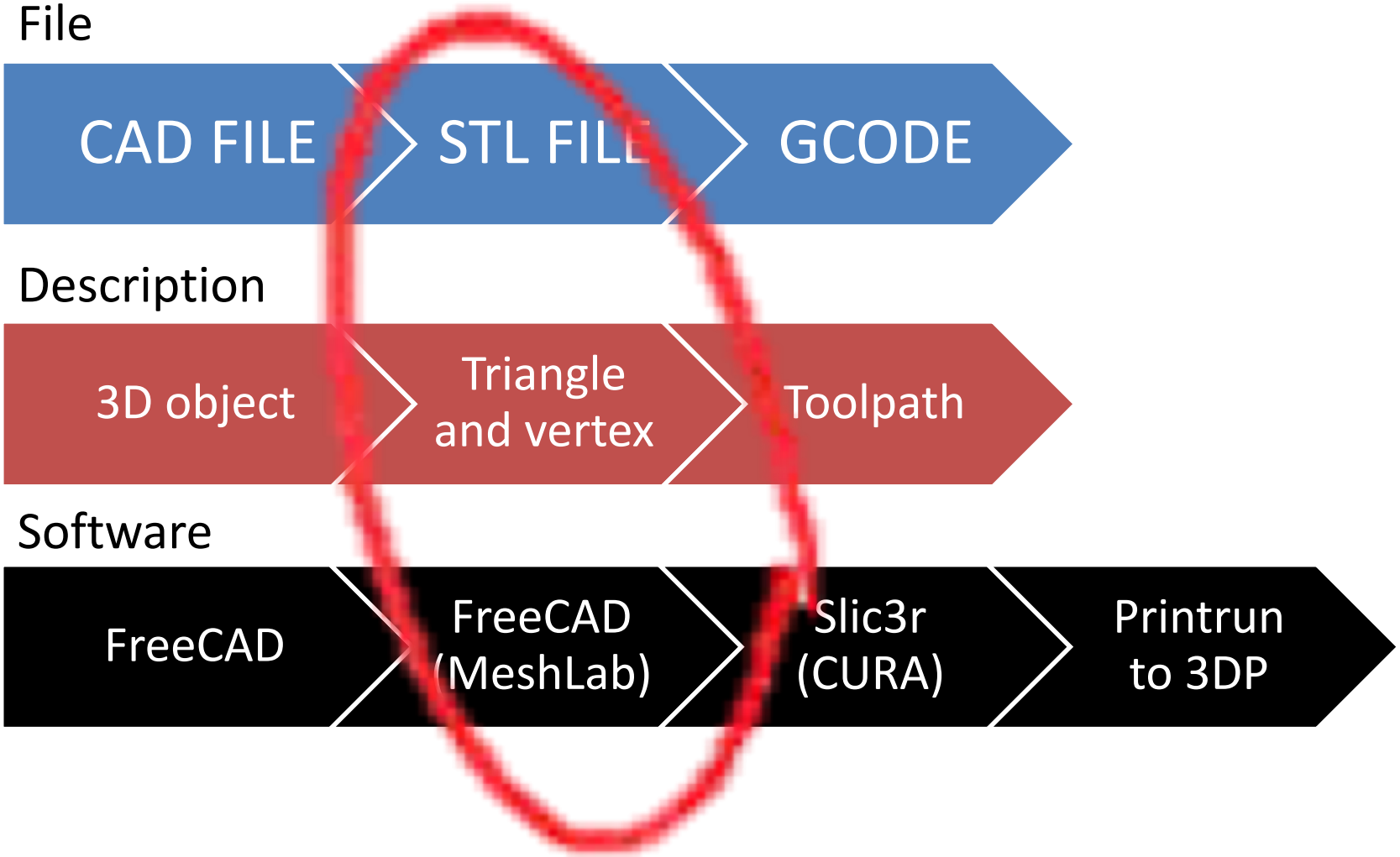
Dimensions of CAD Elements	Elements	Type of CAD Model
0D	Point	Corner Model
1D	Line	Edge Model
2D	Surface	Surface Model
3D	Solid/Volume	Solid or Volume Model

3D data source: CAD model (2)

- Representation of a volume
  - CAD model
    - Your specific design
    - Web repository (http://www.thingiverse.com, https://www.youmagine.com, https//3dprint.nih.gov, http://www.appropedia.org, http://opensourceecology.org, http://reprap.org)
  - Instruments output
    - Segmentation of medical Images (Tomographic Data: CT scan, RM scan)
    - Surface scanning (Laser)

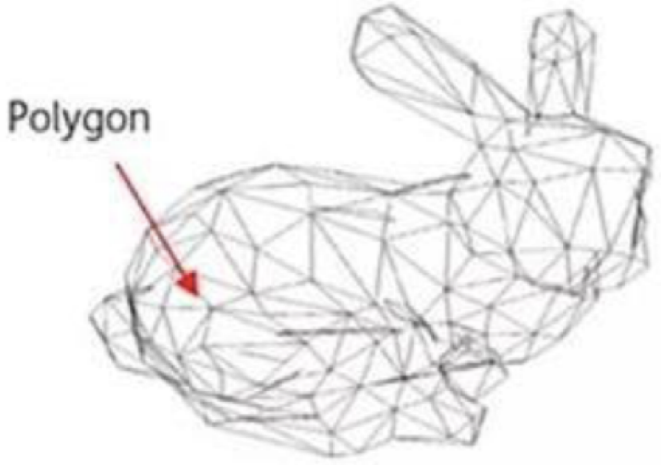


Additive manufacturing (o RP) Process Flow: exporting exchange format



CAD EXCHANGE FORMATS

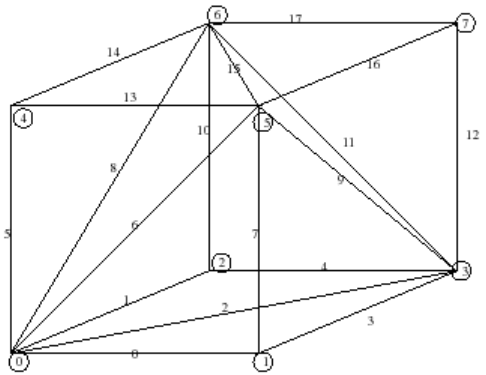
- Exchange format allow CAD systems to interface with 3-D system AM machines
- Exchange formats for exporting 3D models:
  - Polygon-based representations if the surface of the model
  - The most widespread is the .STL representation

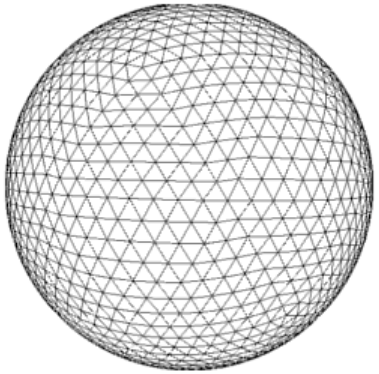


(a) Polygon-based representation

What is an .STL (StreoLiThography) file ?

- This format describes **only the surface geometry of a three-dimensional** object without any representation of colour, texture or other common model attributes.
- The main purpose of the STL file format is to **encode the surface geometry** of a 3D object. It encodes this information using a simple concept called **“tessellation**”.
- The basic idea was to tessellate the 2 dimensional outer surface of 3D models using triangles (also called “facets”) and store information about the facets in a file.
- Accuracy on a .STL files depends on the triangle sizes (Smaller facets produce a higher quality surface)

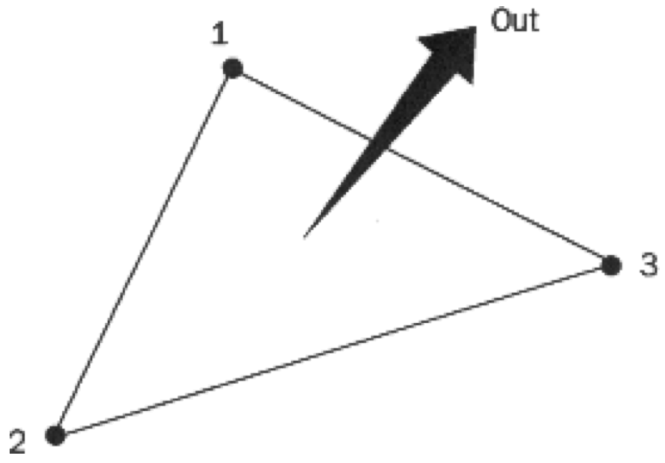




How does an STL file store information about triangle facets?

- The STL file format provides two different ways of storing information about the triangular facets that tile the object surface. These are called the *ASCII encoding* and the *binary encoding*.

- In both formats, the following information of each triangle is stored:
  - The coordinates of the vertices;
  - The components of the unit normal vector to the triangle. (The normal vector should point outwards with respect to the 3D model)



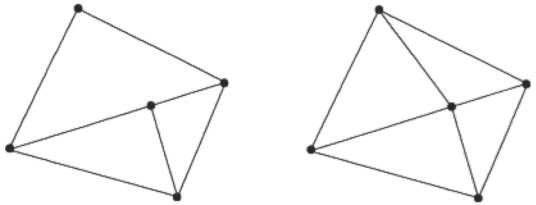

```
endsolid <name>
```

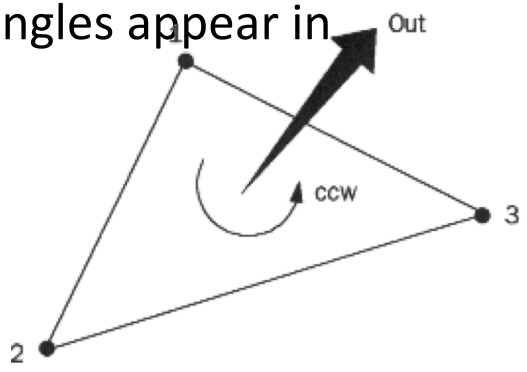
```
facet normal nx ny nz
    outer loop
        vertex v1x v1y v1z
        vertex v2x v2y v2z
        vertex v3x v3y v3z
    endloop
endfacet
```

```
solid <name>
```

Rules for the STL format

- The **vertex rule** states that each triangle must share two vertices with its neighboring triangles*;*
- The **orientation rule says** that the orientation of the facet (i.e. which way is “in” the 3D object and which way is “out”) must be specified in two ways:
  - The direction of the normal should point outwards.
  - The vertices are listed in counterclockwise order when looking at the object from the outside (*right-hand rule*)
- The coordinates of the triangle vertices must all be positive→ triangles lives in the all-positive octant of the 3D Cartesian coordinate system.
- The triangle sorting rule recommends that the triangles appear in ascending z-value order**.**





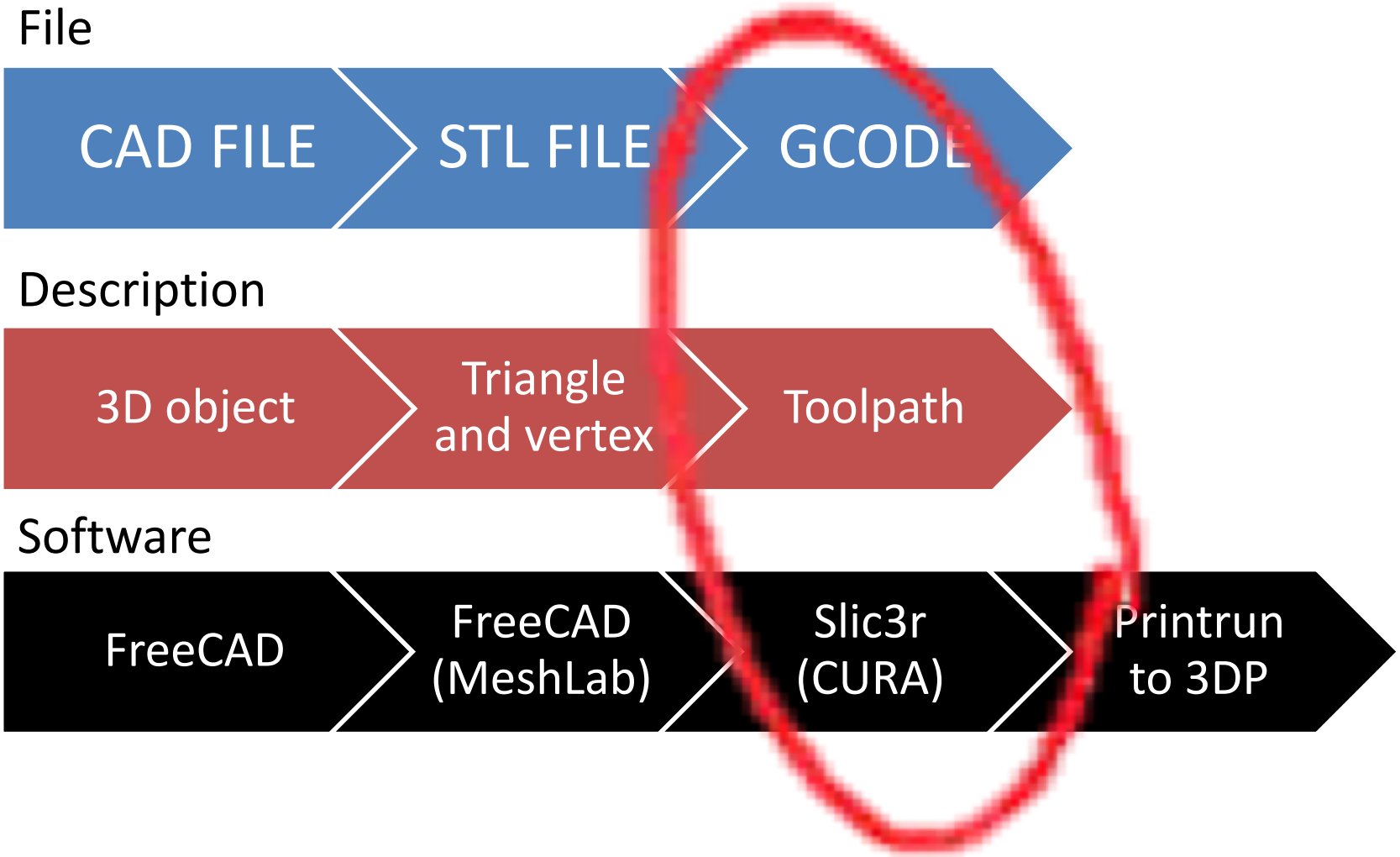
Are there any alternatives to the STL File Format?

- **More tha 30 types…:**
  - OBJ file format→which can store color and texture profiles.
  - PLY→originally used for storing 3D scanned objects.
  - AMF→
- **<u>BUT WHY .STL IS THE PREFERRED?</u>**
  1. **Simpler:** leading to smaller **file sizes** and **faster processing.**
  2. **Universal**: STL it is universal and supported by nearly all 3D printers.
  3. **Mature ecosystem**: Most 3D printable models you can find on the internet are in the STL file format

FROM CAD TO CAM

PREPARING THE 3D MODEL TO PRINT…

Additive manufacturing (o RP) Process Flow: From CAD to CAM



Processing of *.stl file

1. Check the *.stl files
2. Add the support material
3. Conver the *.stl files into instruction for the AM machine (GCode file)
    - Setting of all RP parameter

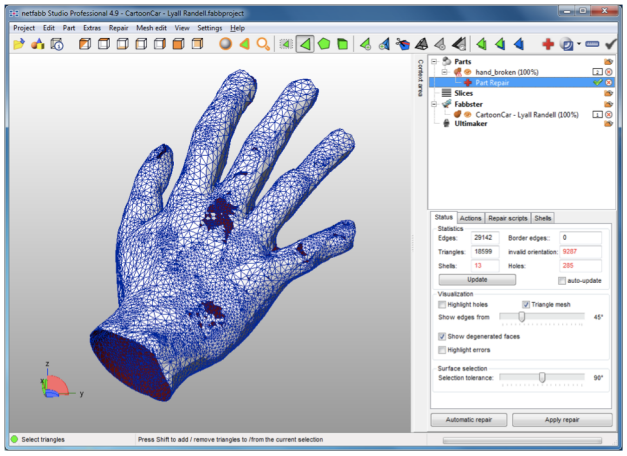
Checking and repairing the .STL file

- There are several programs which can help with repairing a broken STL file.

Rhinoceros 5

Meshlab

netfabb®

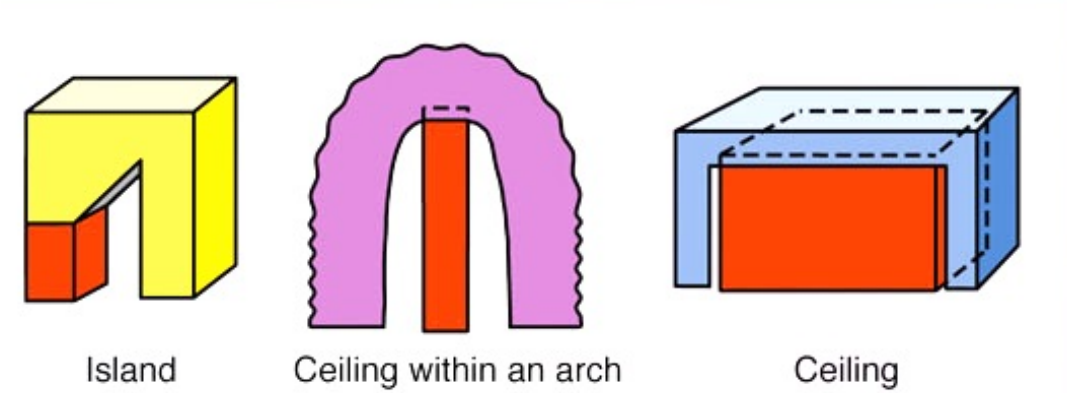


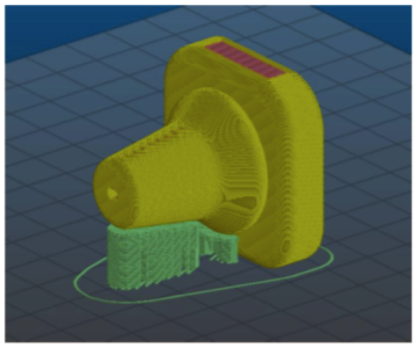
Adding Support material…

- Some solid freeform fabrication 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.

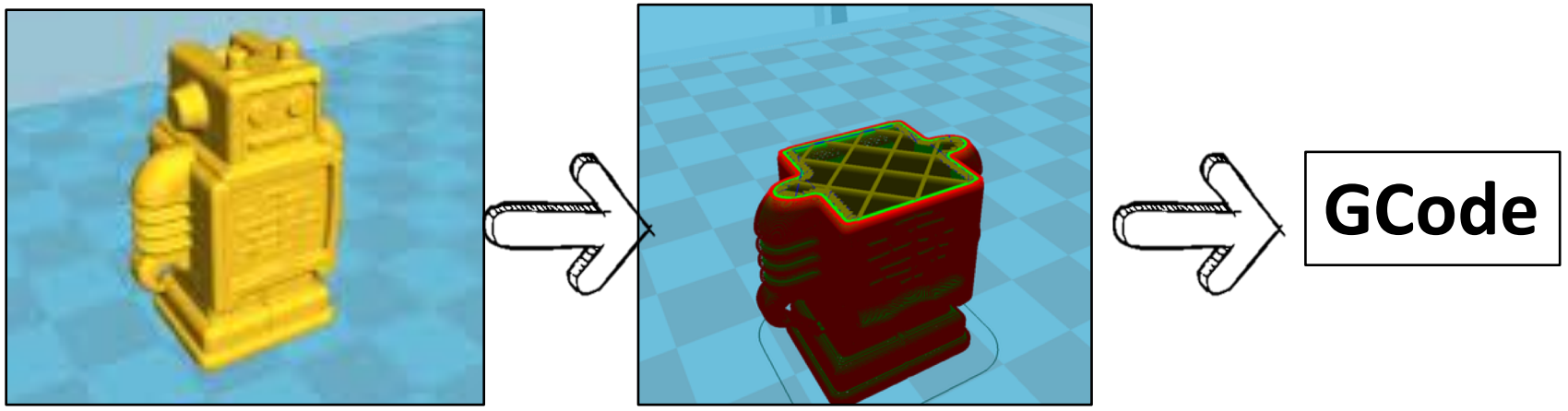
Support generation

- Support generation may depend on
  - objects orientation,
  - on the specific AM technique
  - manufacturing technology
- Supports are generated using a dedicated slicer software





Slicing the model



Cura
Powered by Ultimaker

Slic3r
G-code generator for 3D printers

Skeinforge

G-CODE

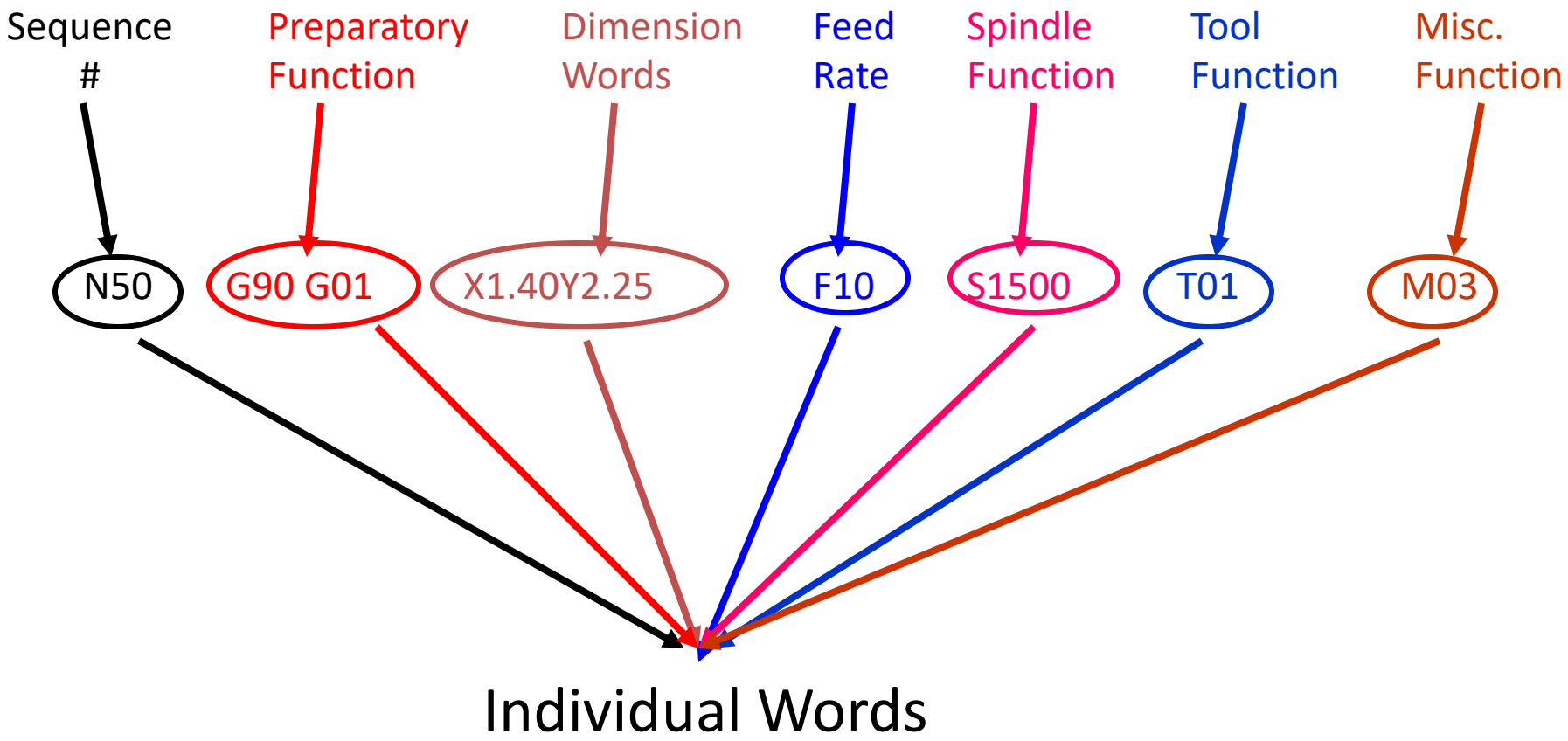
- G – Code Programming
- Originally called the “Word Address” programming format.
- Processed one line at a time sequentially.

Word address format

- Word address was developed as a tape programming format.
  - Another name for “word address” is “variable block” format, so named because the program lines (blocks) may vary in length according to the information contained in them.
  - Earlier tape formats required an entry for all possible machine registers. In these earlier formats, a zero was programmed as a null input if the register values were to be unaffected, but in work address, the blocks need only contain necessary information. Although developed as a tape format, word address is used as the format for manual data input on many CNC machines.

- <u>Addresses</u>
  - The block format for word address is as follows:
  - N … G … X … Y … Z … I … J … K … F … H … H … S … T … M …
  - Only the information needed on a line need be given. Each of the letters is called an address (or word)

Common Format of a Block



G-Code

```
;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
```

Word address

- Reserved Code Words Worksheet
  - N – Sequence or line number
  - G – Preparatory function
  - …
- Dimension Words:
  - X
  - Y
  - Z

Word Address (1of3)

- N – Sequence or line number
  - A tag that identifies the beginning of a block of code. N numbers are ignored by the controller during the program execution. It is used by operators to locate specific lines of a program when entering data or verifying the program operation.

- G – Preparatory function
  - G words specify the mode in which the milling machine is to move along its programmed axes. Preparatory functions are called prep functions or, more commonly **G codes**

Word Address (2of3)

- Dimension Words
  - X – Distance or position in X direction
  - Y – Distance or position in Y direction
  - Z – Distance or position in Z direction

- M – Miscellaneous functions
  - M words specify CNC machine functions not related to dimensions or axial movements.

Word Address (3of3)

- **F – Feed rate (inches per minute or millimeters per minute)**
  - **Rate at which cutting tool moves along an axis.**
- **S – Spindle speed (rpm – revolutions per minute)**
  - **Controls spindle rotation speed.**
- **T – Tool number**
  - **Specifies tool to be selected.**

G Word

- G words or codes tell the machine to perform certain functions. Most G words are modal which means they remain in effect until replaced by another modal G code.

Common G Codes

- G00 – Rapid positioning mode
  - Tool is moved along the shortest route to programmed X,Y,Z position. Usually NOT used for cutting.
- G01 – Linear Interpolation mode
  - Tool is moved along a straight-line path at programmed rate of speed.

- G02 – Circular motion clockwise (cw)
- G03 – Circular motion counter clockwise (ccw)

M Word

- M words tell the machine to perform certain machine related functions, such as: turn spindle on/off, coolant on/off, or stop/end program.

Additive manufacturing Process Flow

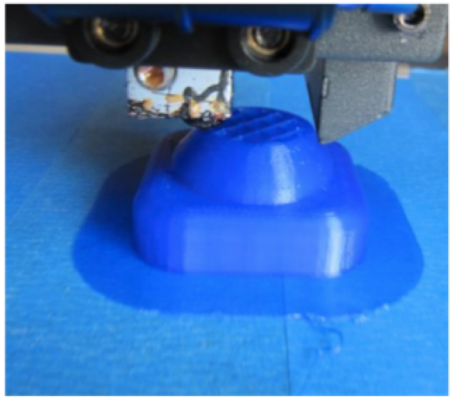
File

Description

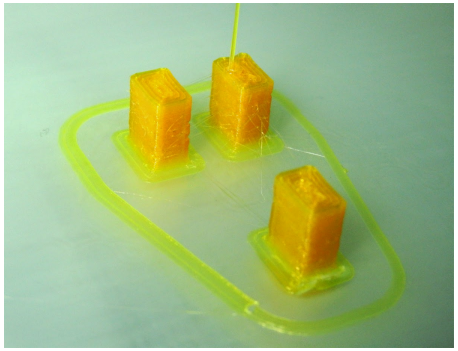
Software

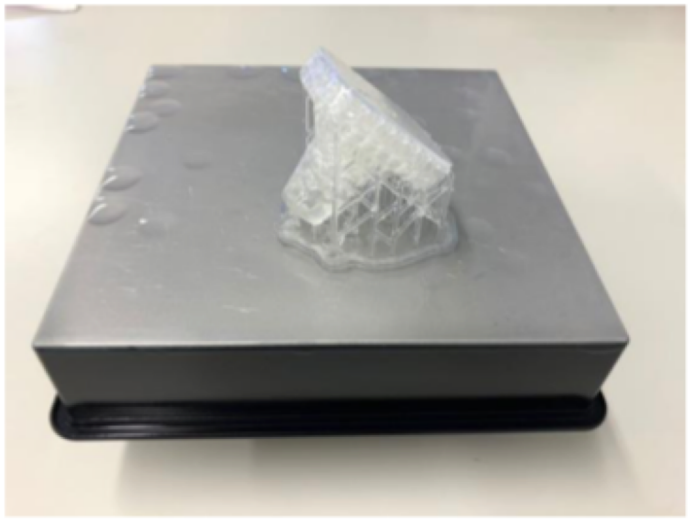
Model Physical Buildup: form GCode to printing. . .

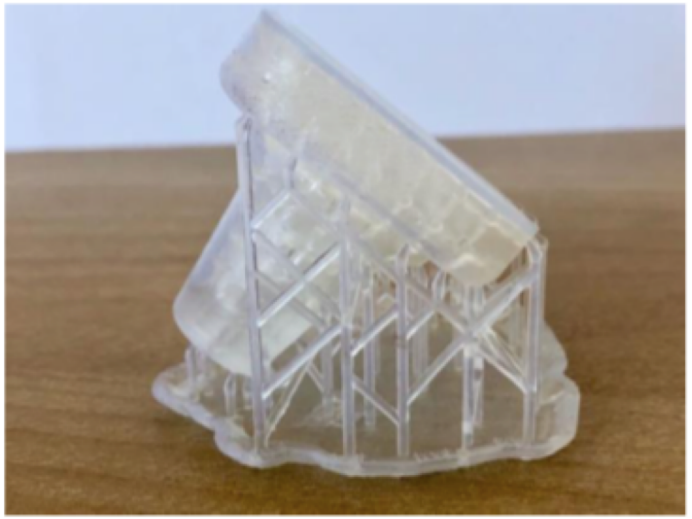
GCode



Clean up & Post treatments



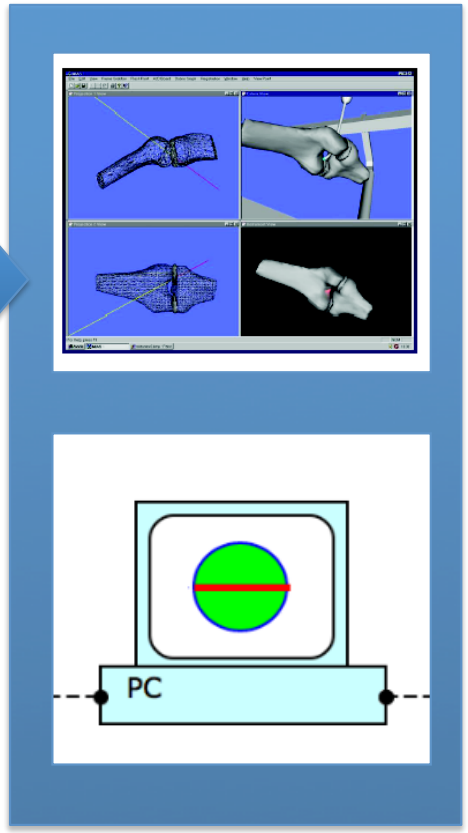




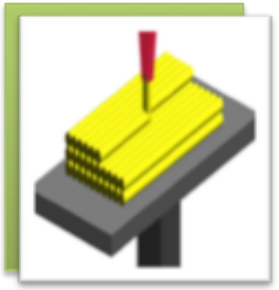
FROM MEDICAL IMAGES TO STL

Additive manufacturing Process Flow

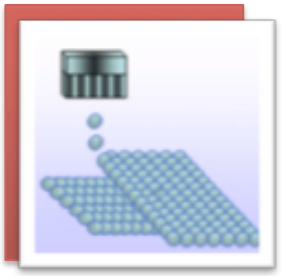
Image acquisition



CAD/CAM system



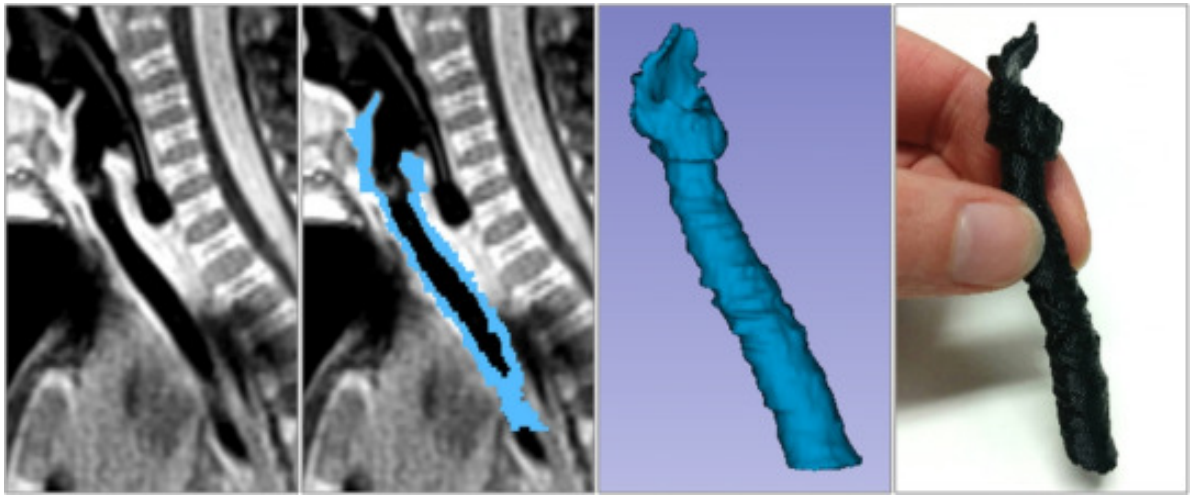
Direct writing



Inkjet based

Segmentation

- Segmentation subdivides an image into its constituent regions or objects.

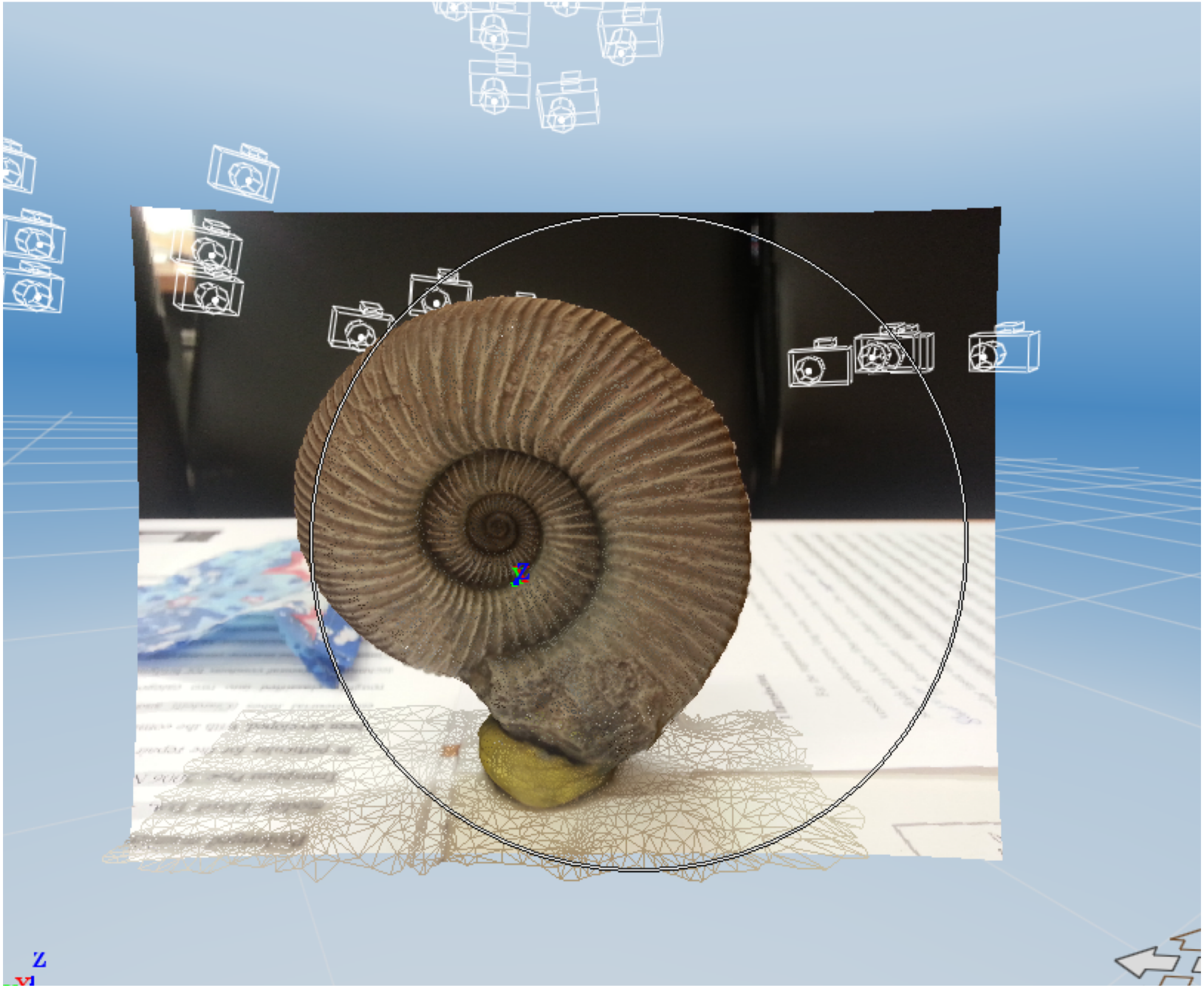


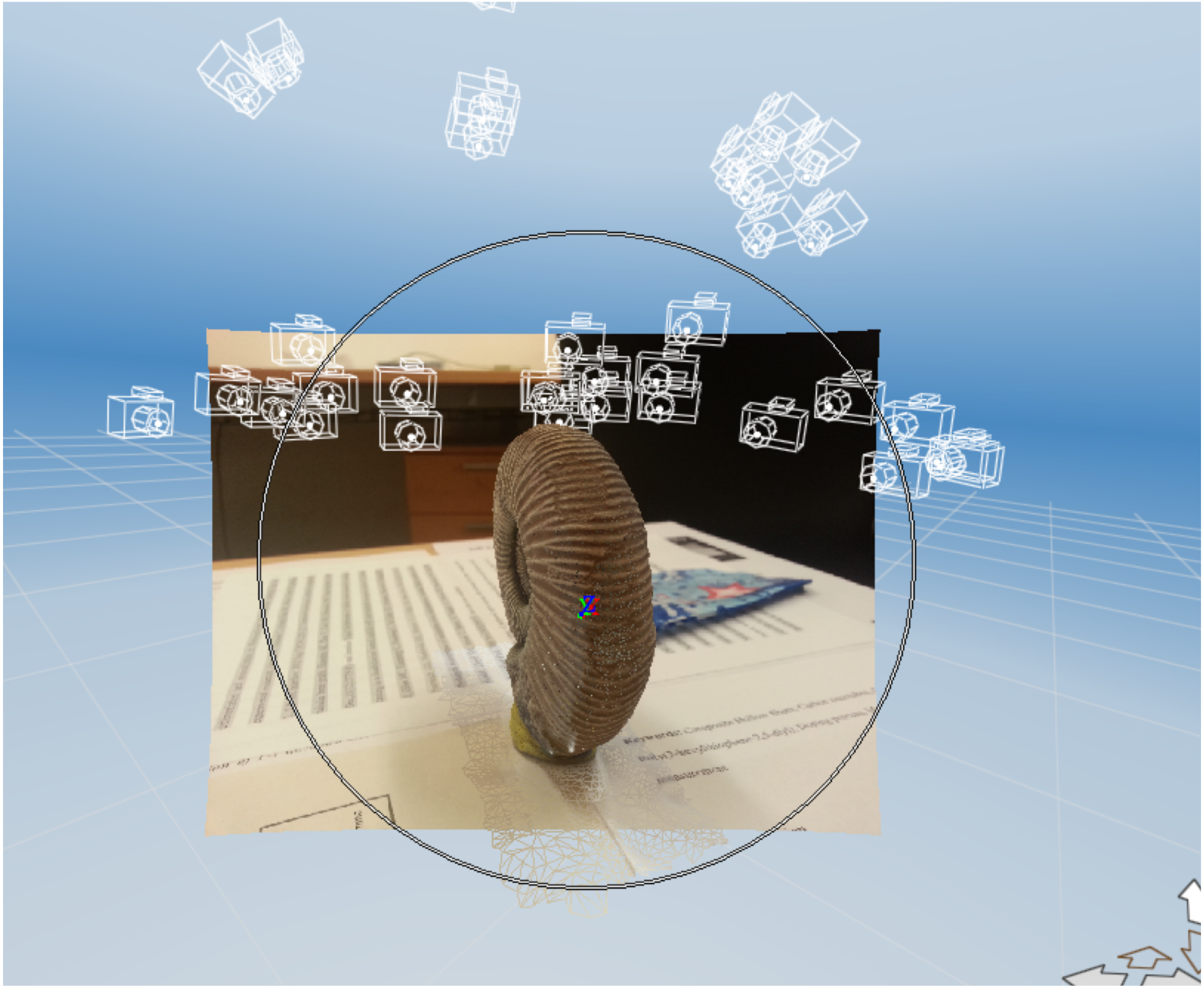
Software

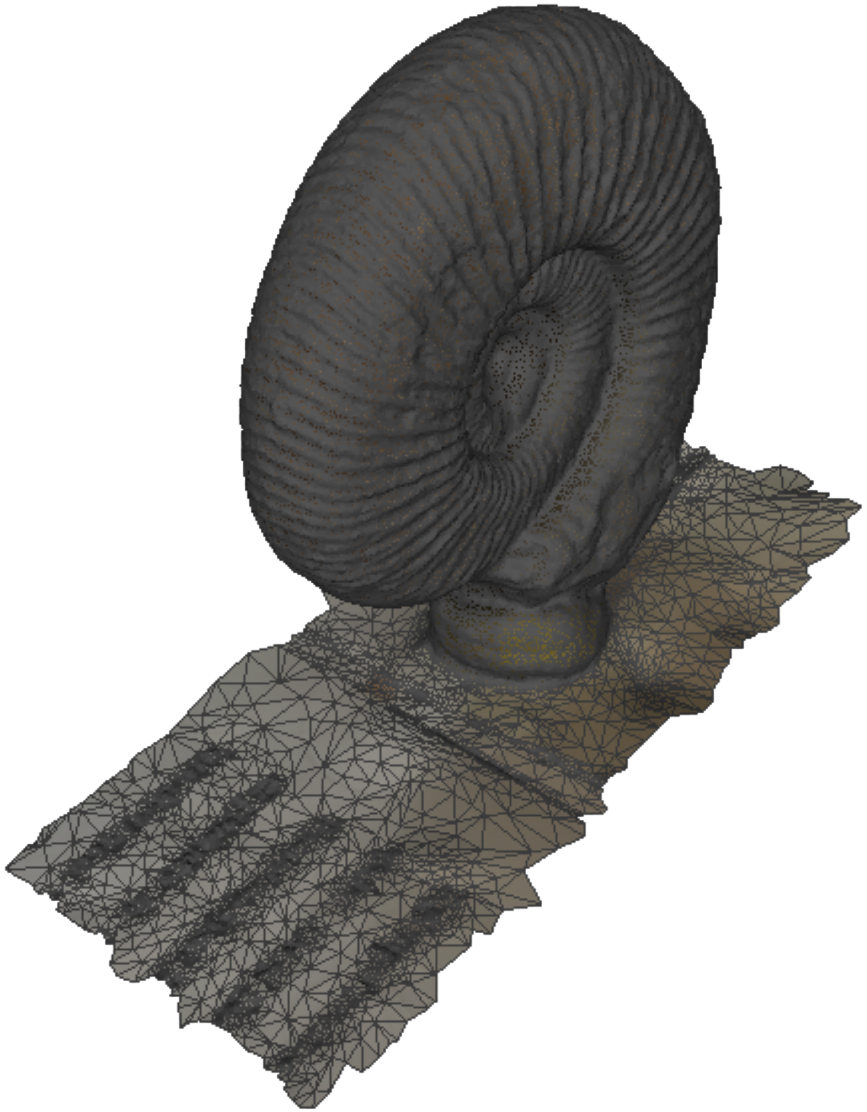
- OsiriX (www.osirix-viewer.com)
- 3DSlicer (www.slicer.org)
- ImageJ (rsb.info.nih.gov/ij)
- MIPAV (mipav.cit.nih.gov)
- itk-SNAP (www.itksnap.org)

Use of 123DCatch

FROM A SCAN TO A 3D MODEL


Z
Z
Y





Now you get ready to print..

- Download a CAD software
  - Prepare your CAD model

- Download a slicing Software
  - https://ultimaker.com/en/products/cura-software

Next time…

- Introduction to slicing with Cura