2006-02 CAD/CAM

# RP (Rapid Prototyping)

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2006-11-06

# NASA: Fabrication in Space

FDM1600 test at zero gravity
Johnson Space Center & Marshall Space Flight Center, 2000

# Requirements in Product Development

- Functional or aesthetic assessment
- Communication aids, visualization
- Assemblability checking

- 25 or 30% of product development budget are spent on physical prototypes and testing

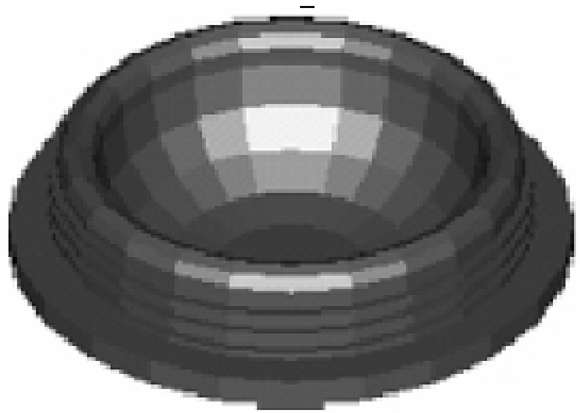
- Rapid Prototyping fabricates a part of arbitrary shape directly from CAD model by forming thin layers of the part layer by layer

# Introduction to RP

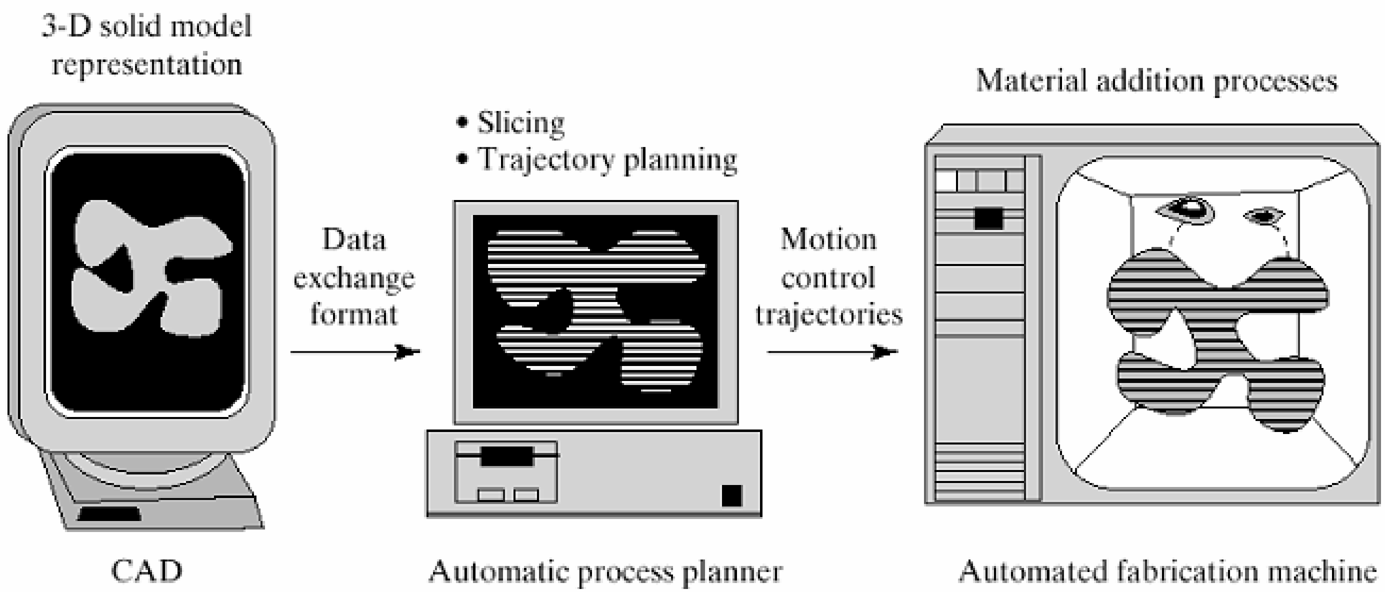
- Other name of RP
  - Layered Manufacturing
  - Rapid Prototyping and Manufacturing
  - Solid Freeform Fabrication (SFF)

- Group of related technologies that are used to fabricate physical objects directly from CAD data
- Add and bond materials in layers to form objects
- Offer advantages compared to classical subtractive fabrication methods

# Basic Idea



(a)

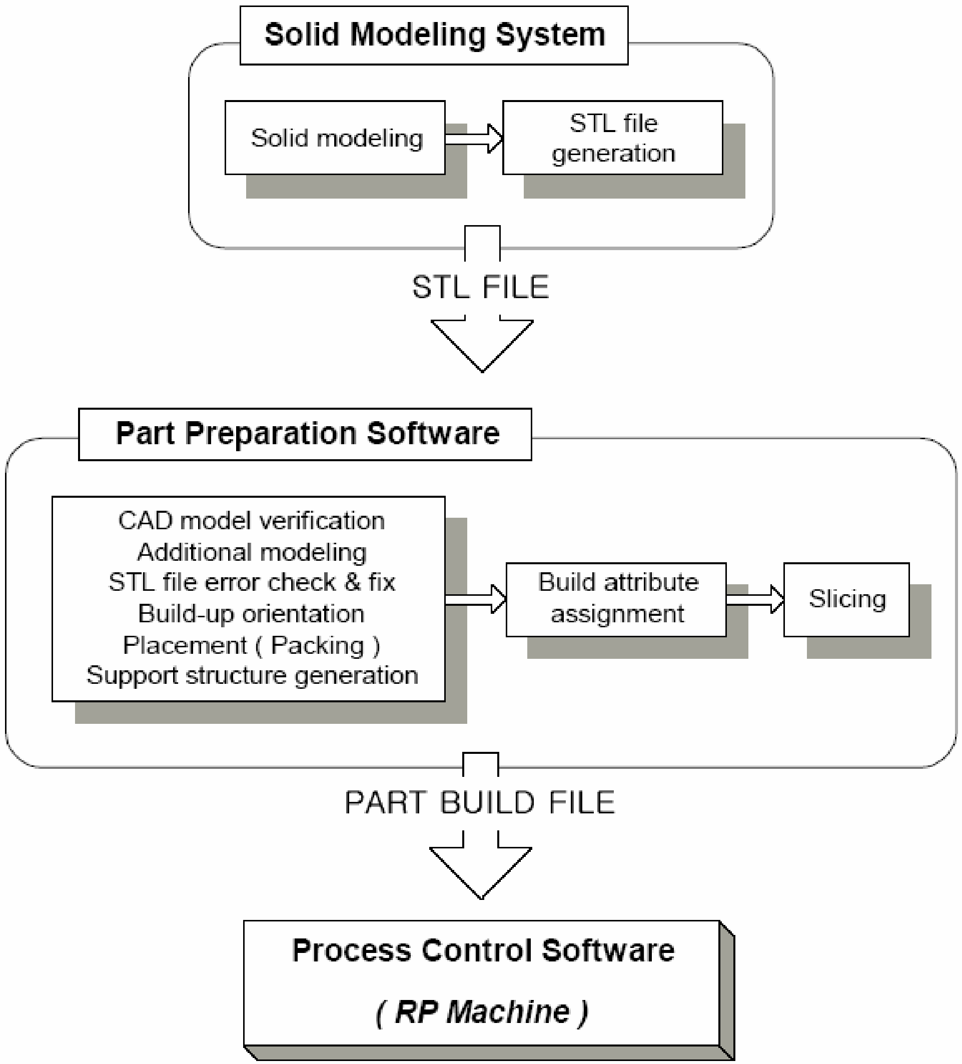



(b)

# Advantages of RP

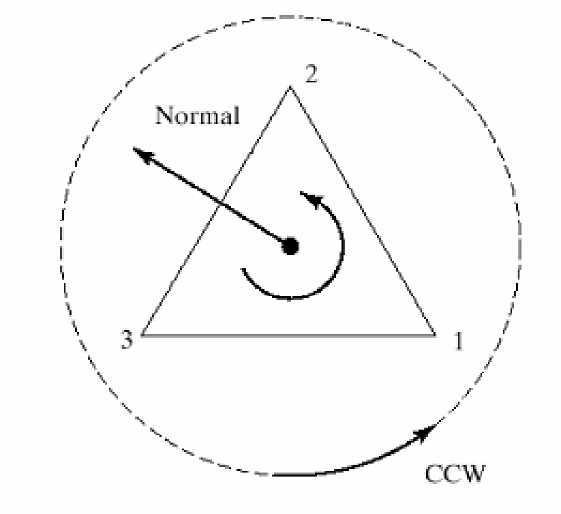
- No need to define a blank geometry
- No need to define set-ups and material handling
- No need to consider jigs, fixtures, and clamping
- No need to design mold and die

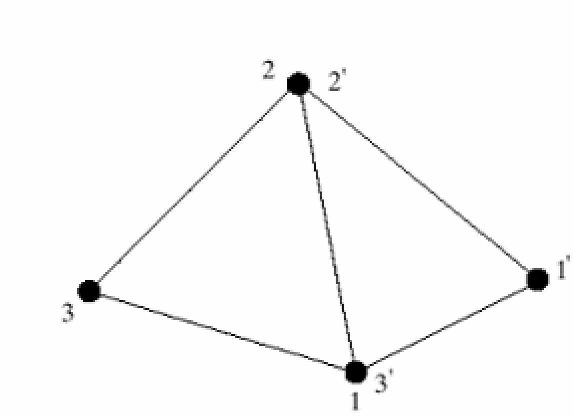
# General System Configuration of RP



# Stereo Lithography Process

- Geometry Input : STL file format
  - Developed for STereo Lithography
  - *De facto* standard for RP data
  - Most CAD systems support STL format



# Stereo Lithography Process (cont.)

- STL file formats

```
solid example
    facet normal 6.89114779E-02 -9.96219337E-01 -5.28978631E-02
    outer loop
        vertex 2.73239994E+01 1.08957005E+01 4.57905006E+01
        vertex 2.81019993E+01 1.09582005E+01 4.56250000E+01
        vertex 2.75955009E+01 1.09116001E+01 4.58456993E+01
    endloop
    endfacet
        :
        :
endsolid example
```

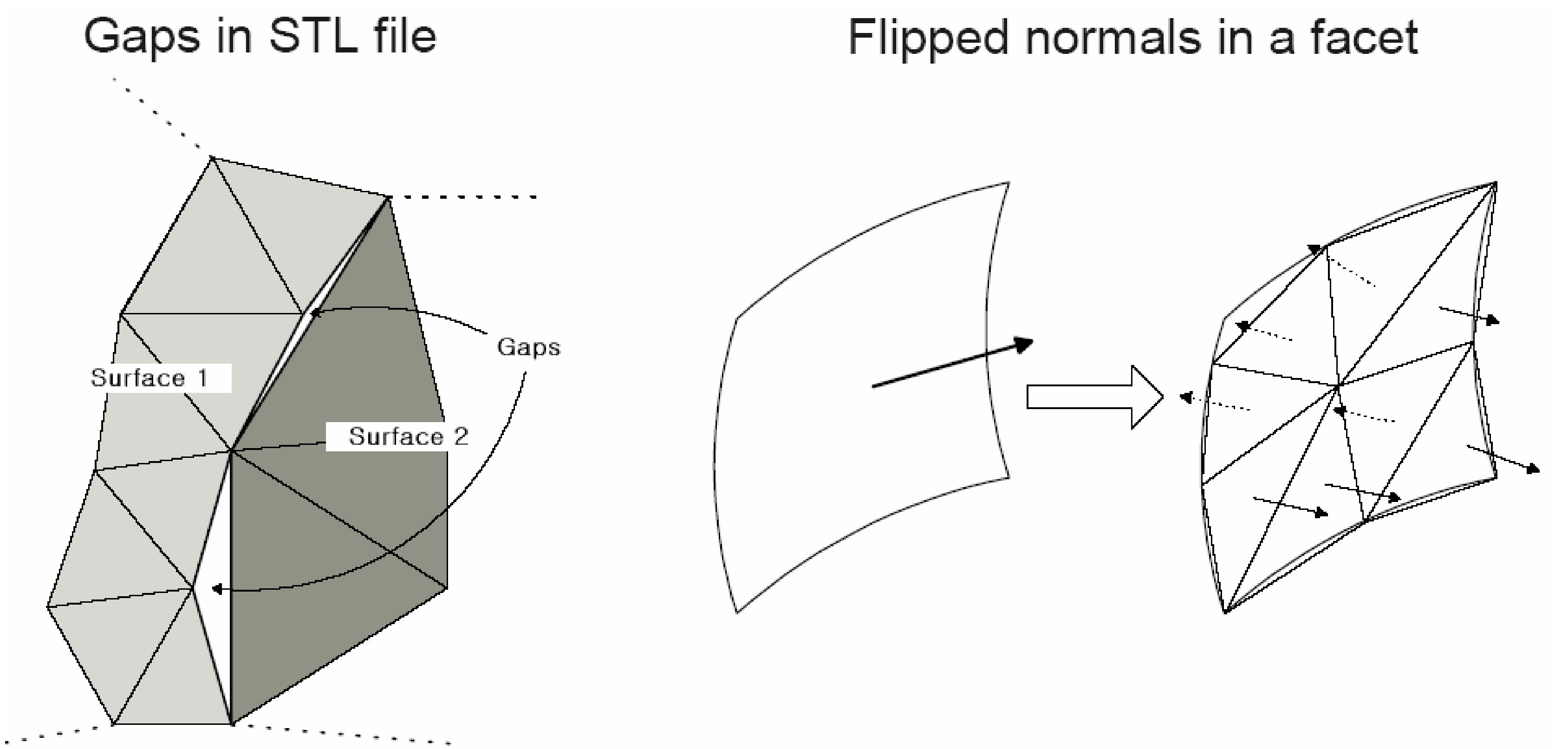
(a) ASCII

| Byte | Type | Description |
|---|---|---|
| 80 | String | Head information such as the CAD system used |
| 4 | Unsigned long integer | Number of facets |
| First Triangle Definition | | |
| 4 | Float | Normal x |
| 4 | Float | Normal y |
| 4 | Float | Normal z |
| 4 | Float | Vertex1 x |
| 4 | Float | Vertex1 y |
| 4 | Float | Vertex1 z |
| 4 | Float | Vertex2 x |
| 4 | Float | Vertex2 y |
| 4 | Float | Vertex2 z |
| 4 | Float | Vertex3 x |
| 4 | Float | Vertex3 y |
| 4 | Float | Vertex3 z |
| 2 | Unsigned long integer | Number of attributes bytes should be set to zero |
| Second Triangle Definition | | |
| | .. | |
| | .. | |

(b) Binary

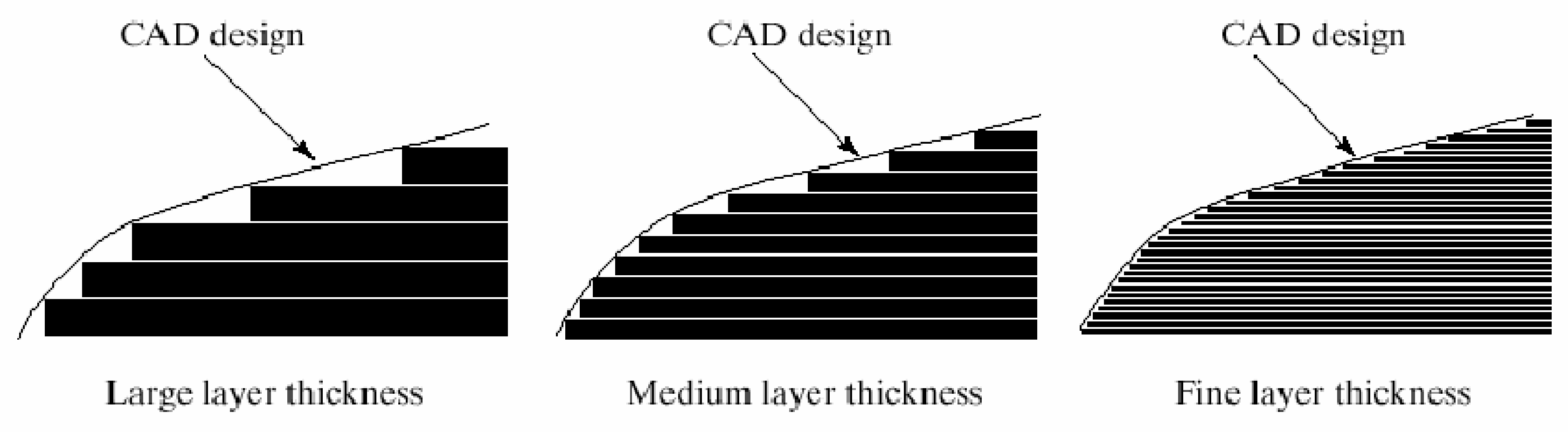
# Stereo Lithography Process (cont.)

- Typical Errors in STL file



# Stereo Lithography Process (cont.)

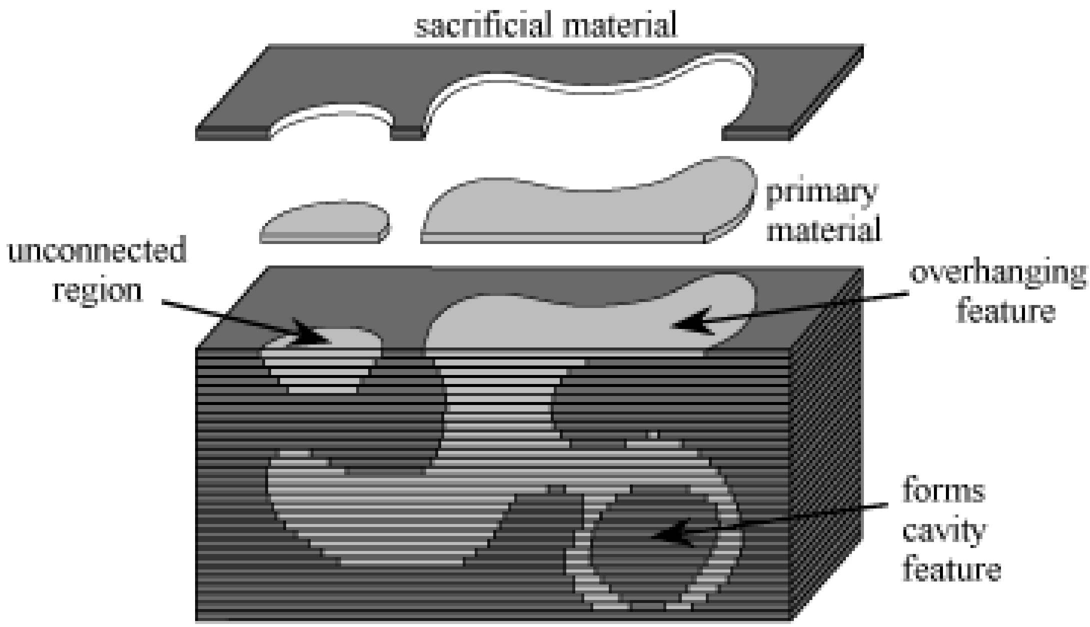
- Stair-Step Effect



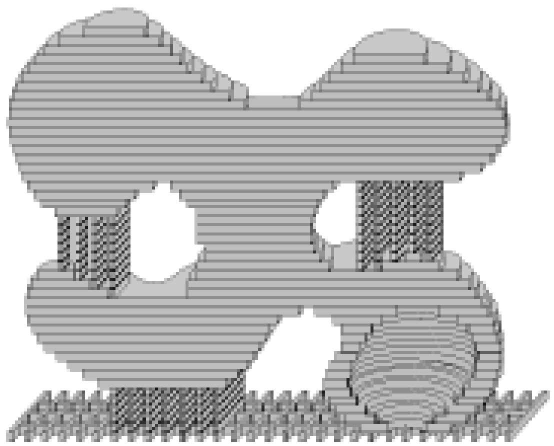

***Surface roughness vs. build time***

# Stereo Lithography Process (cont.)

- Support Structures



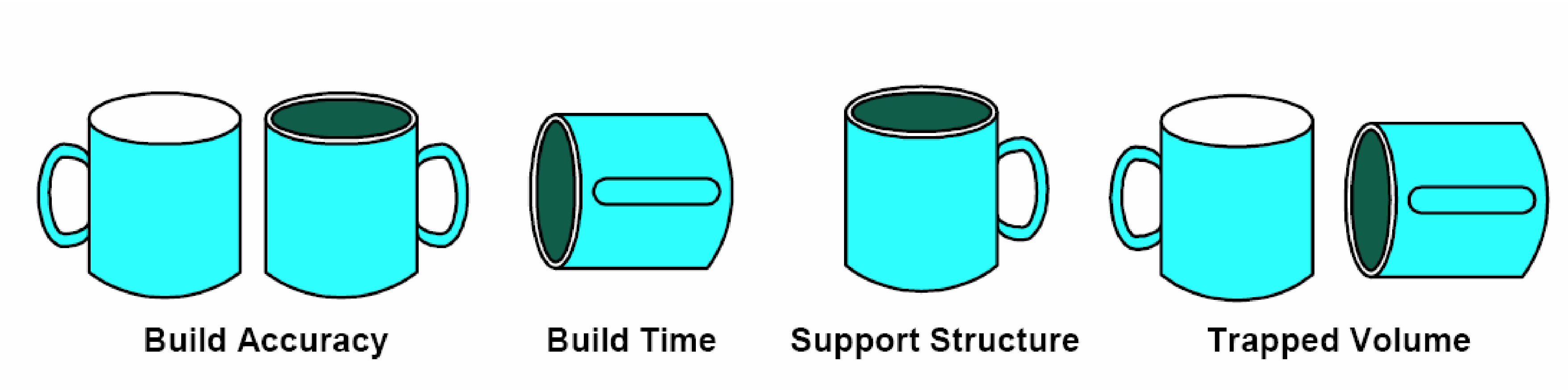

a. Complementary support.



b. Explicit support.

# Stereo Lithography Process (cont.)

- Post-processing
  - Determination of Build-up direction
    - Accuracy
    - Build-up speed
    - Trapped volume
    - Necessity of support structure



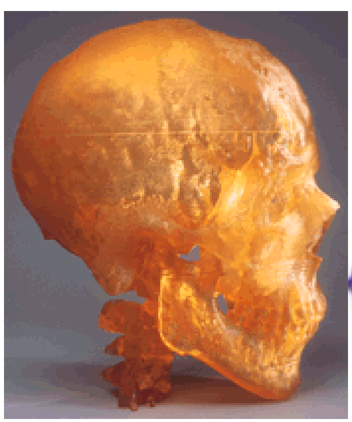
# Issues in RP

- Accuracy and Surface Finish
- Material
  - Stereo Lithography Resins
  - Metals
  - Ceramics and Paper
- Cost
  - Equipment
  - Maintenance
- Time

# 1. Stereo Lithography Apparatus (SLA)

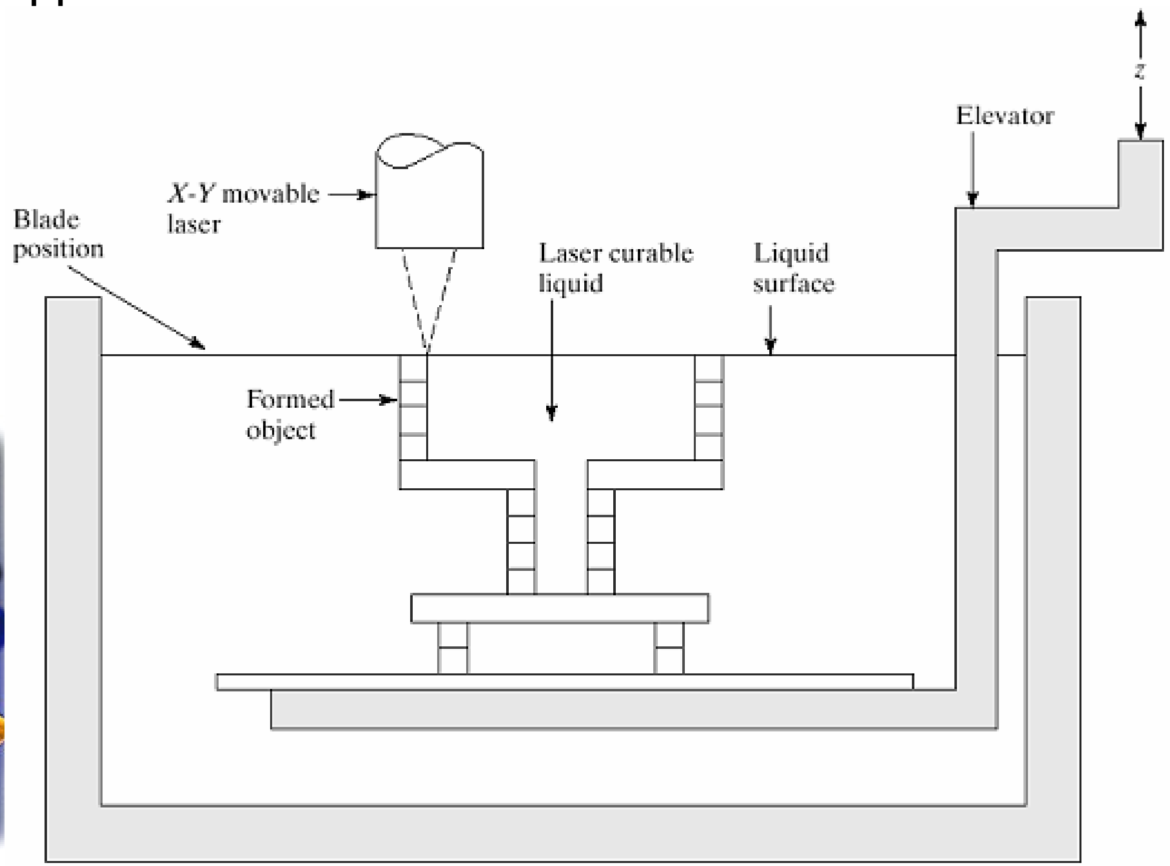
- Developed by 3D Systems, Inc
- Laser beam will scan the surface following the contours of the slice
- Commercial machines & Applications

SLA-3500



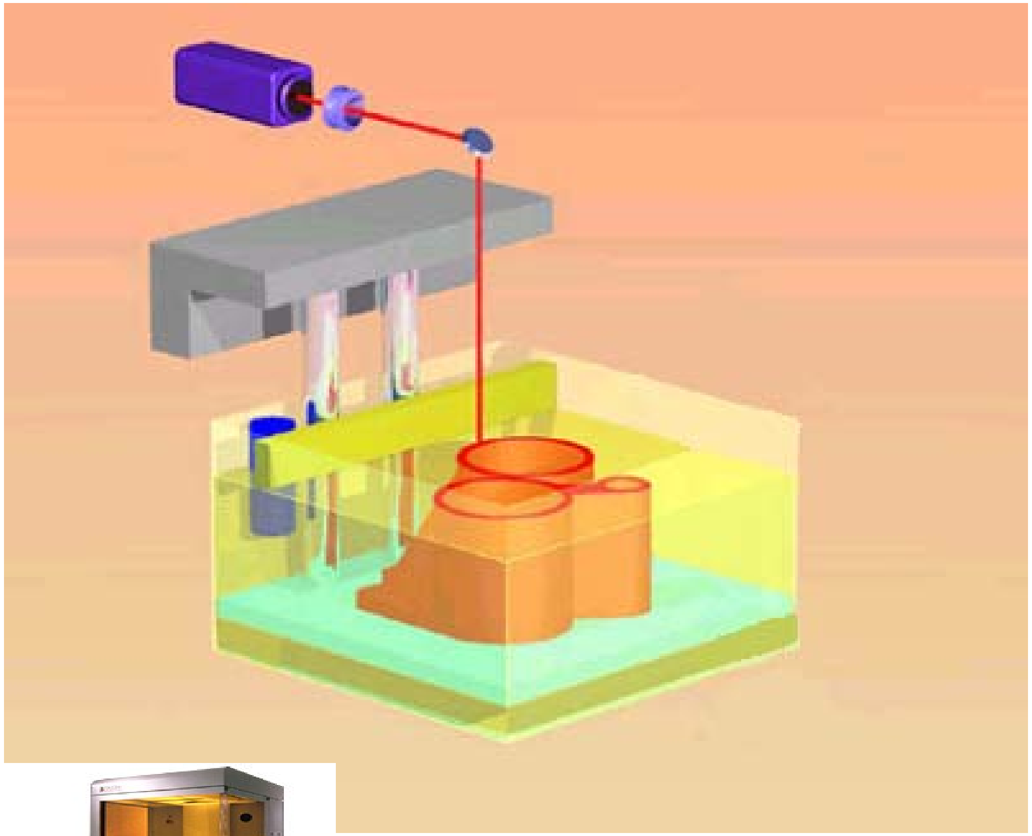
Skull

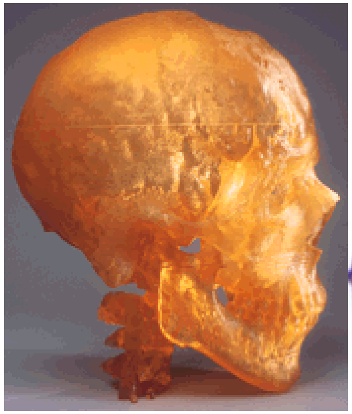
Manifold



# 1. StereoLithography Appratus (SLA)

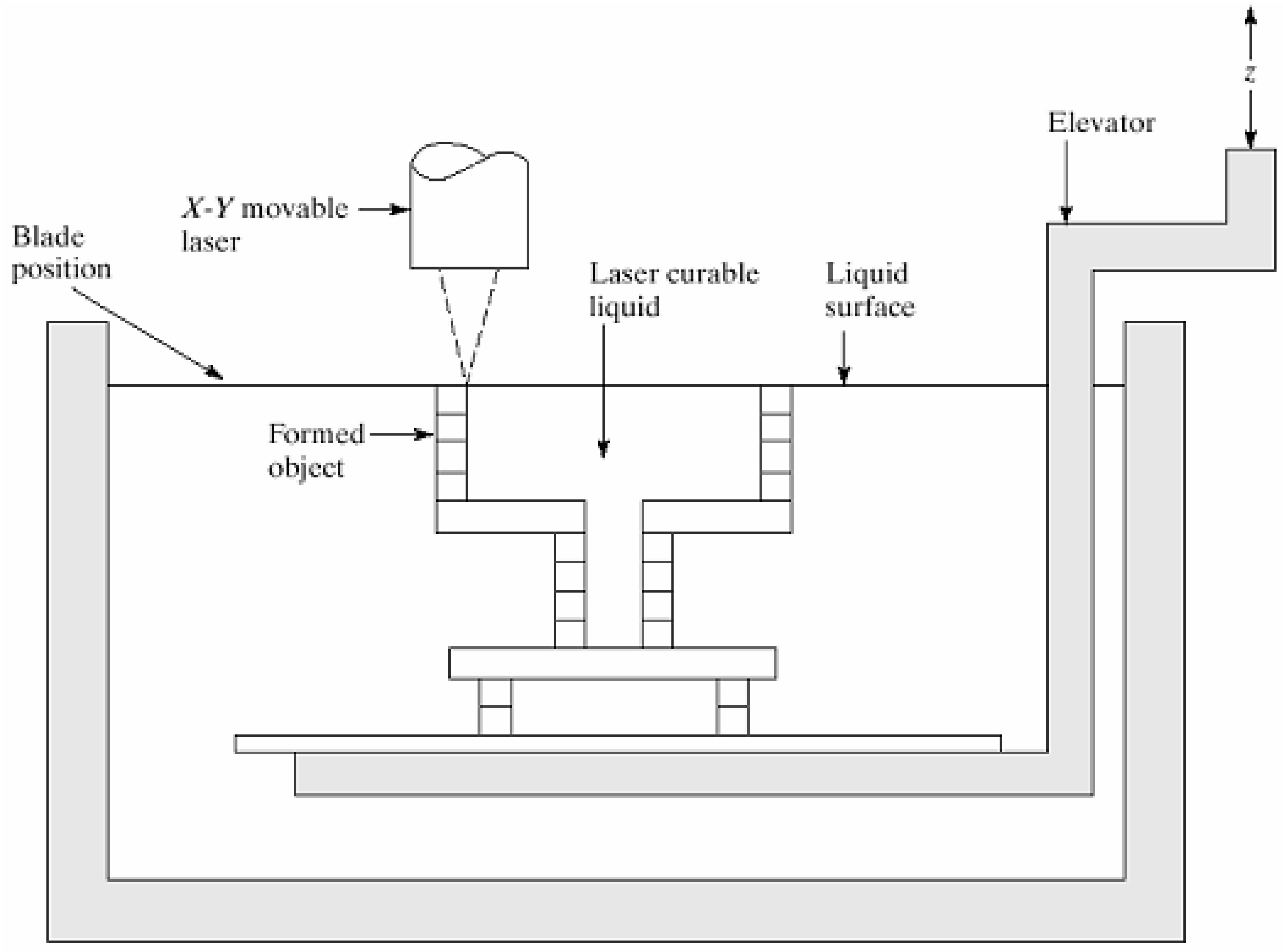
- Developed by 3D Systems, Inc
- The laser beam will scan the surface following the contours of the slice.





SLA-3500

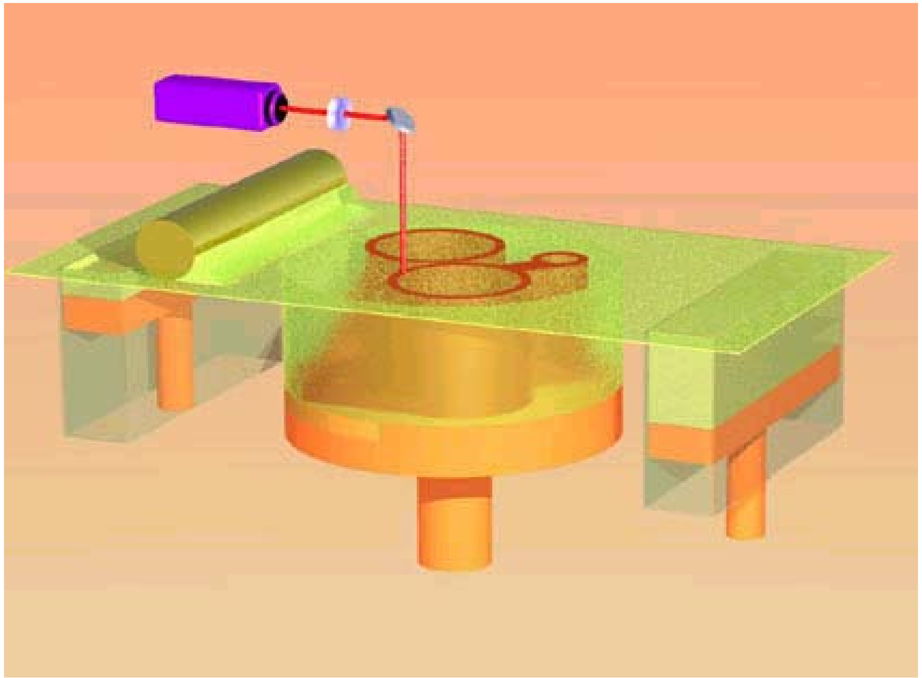
# SLA(SL)



z
Elevator
X-Y movable laser
Blade position
Laser curable liquid
Liquid surface
Formed object

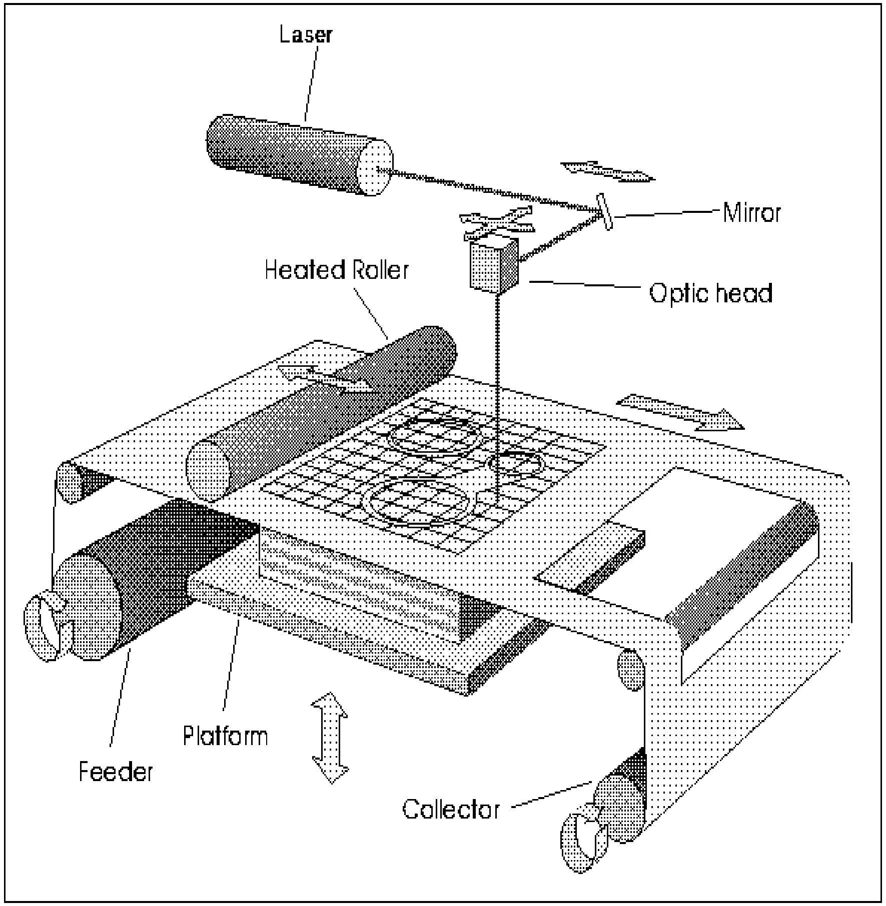
# 2. Selective Laser Sintering (SLS)

- Developed  by The University of Texas at Austin
- Powders are spread over a platform by a roller.
- A laser sinters selected areas causing the particles to melt and then solidify.

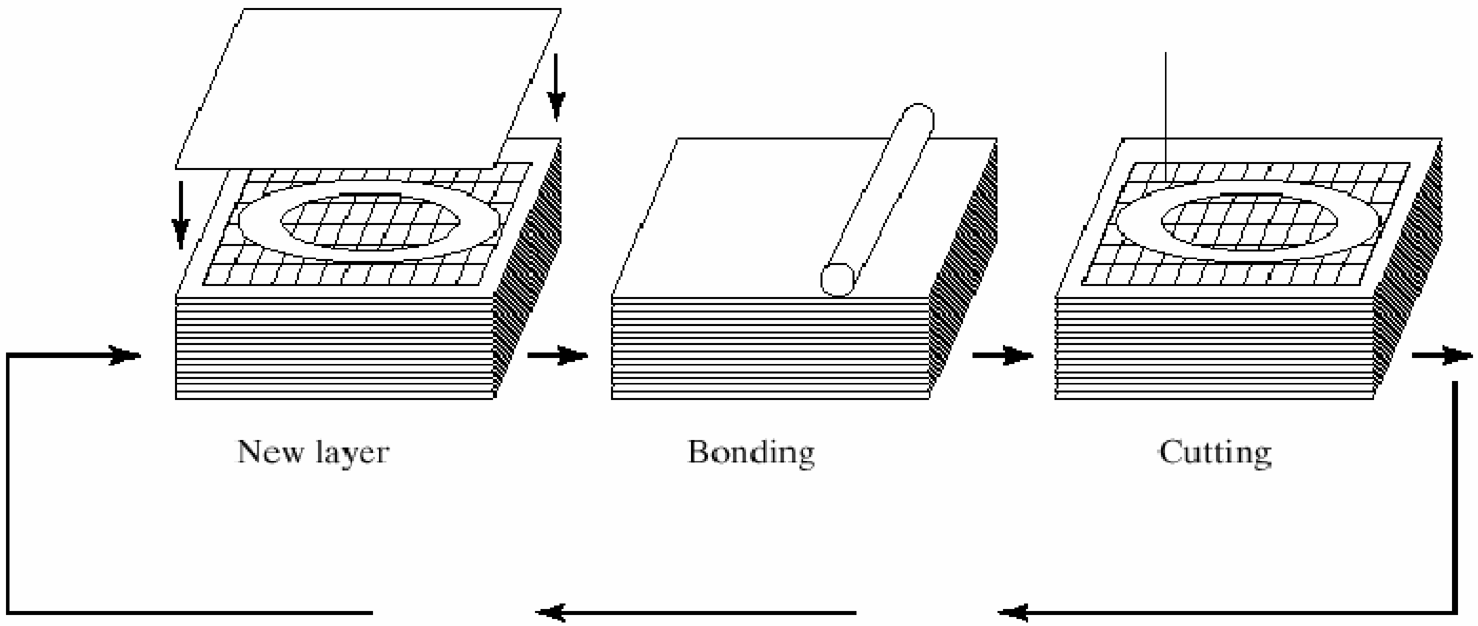


# 3. Laminated Object Modeling (LOM)

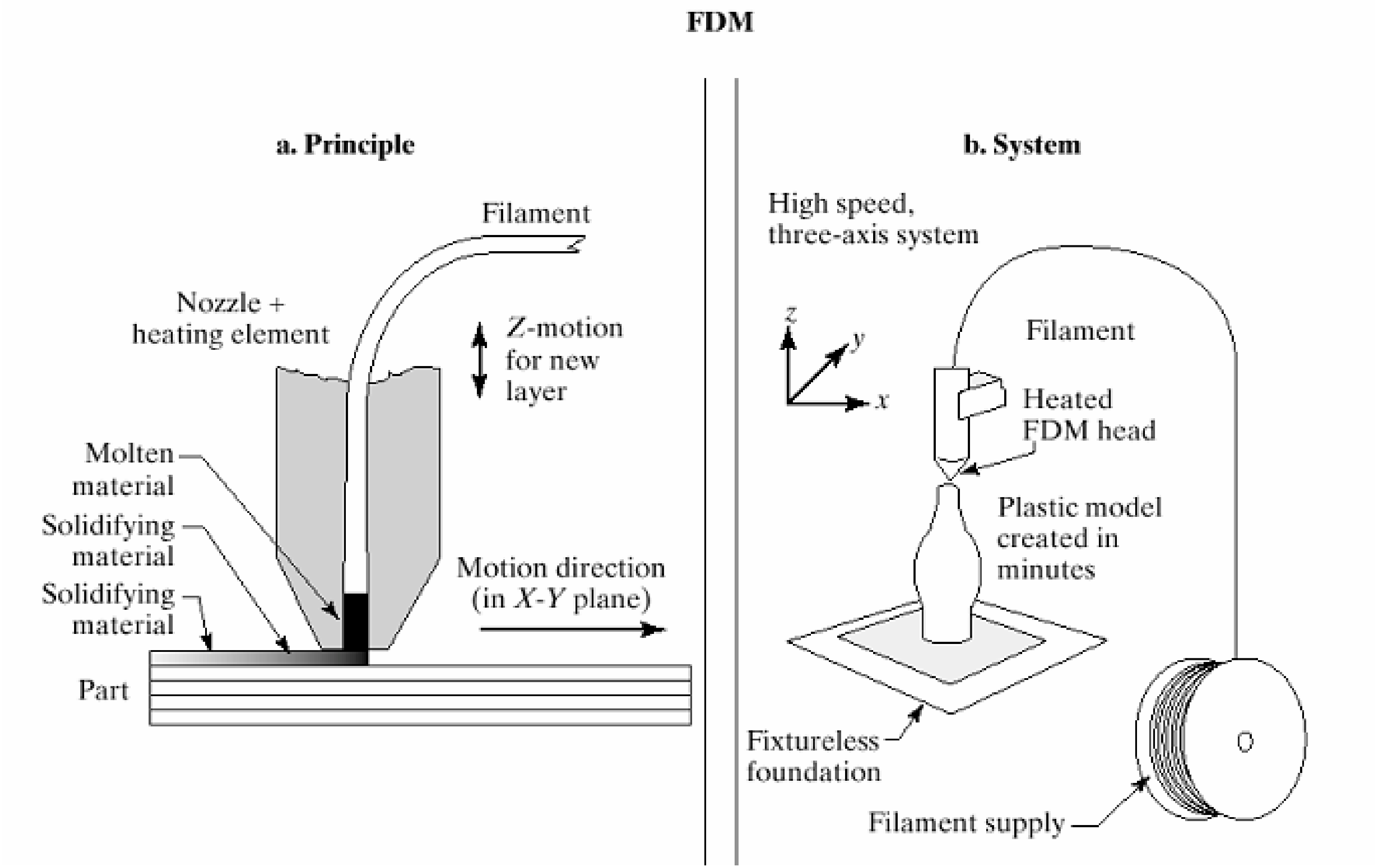
- Developed by Helysis
- The undersurface of the foil has a binder that when pressed and heated by the roller causes it to glue to the previous foil.
- The foil is cut by a laser following the contour of the slice.



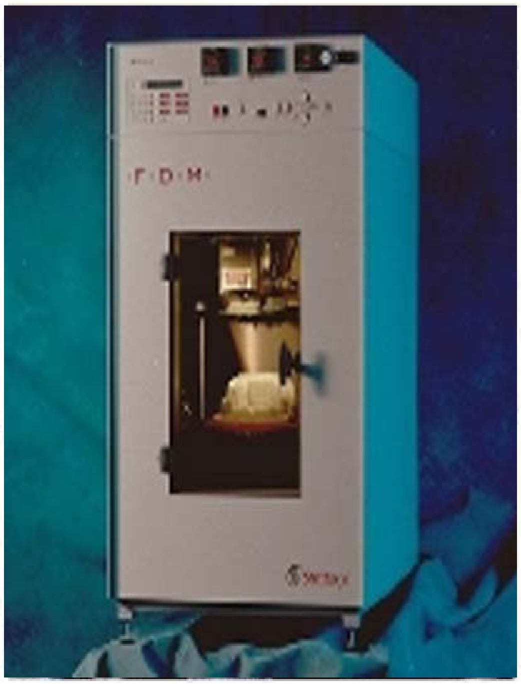
# LOM process

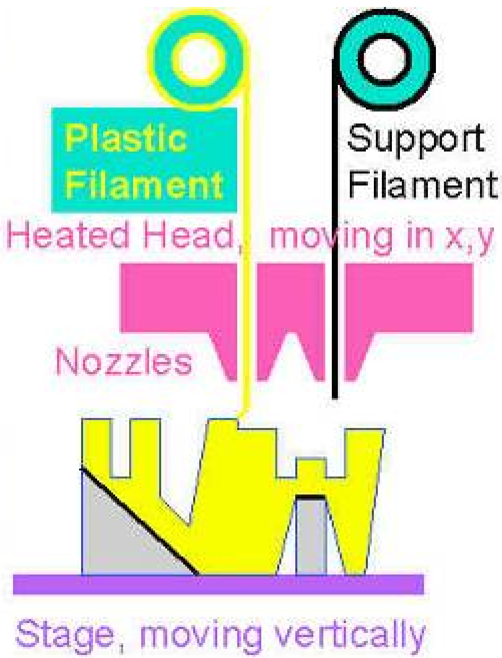


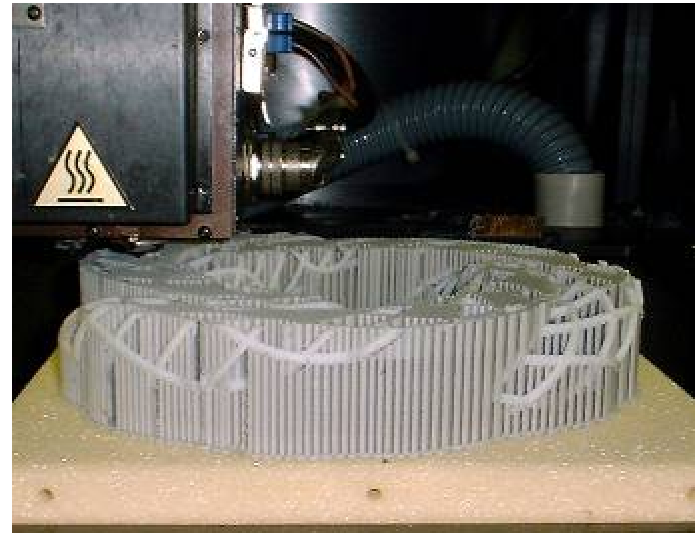
# 4. Fused Deposition Modeling (FDM)



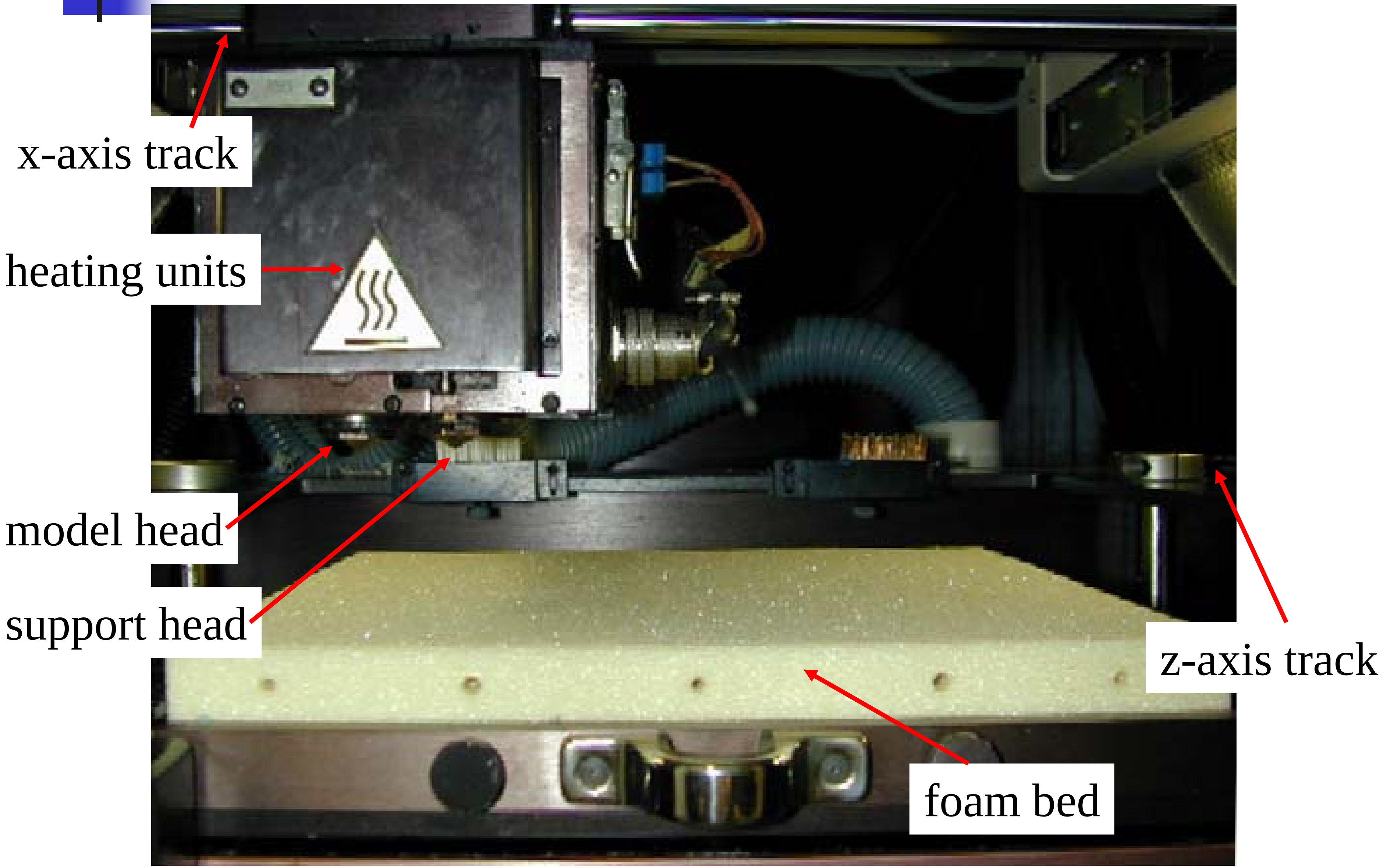
# Fused Deposition Modeling (FDM)





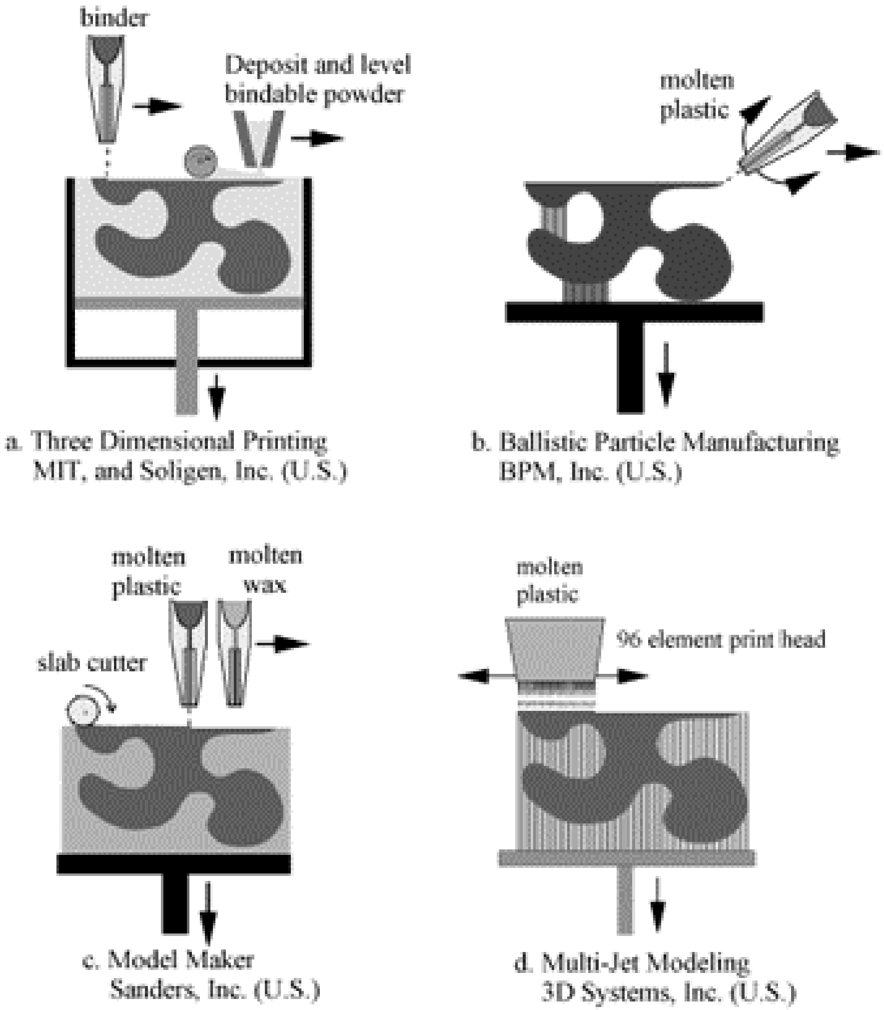



# FDM head


x-axis track
heating units
model head
support head
z-axis track
foam bed

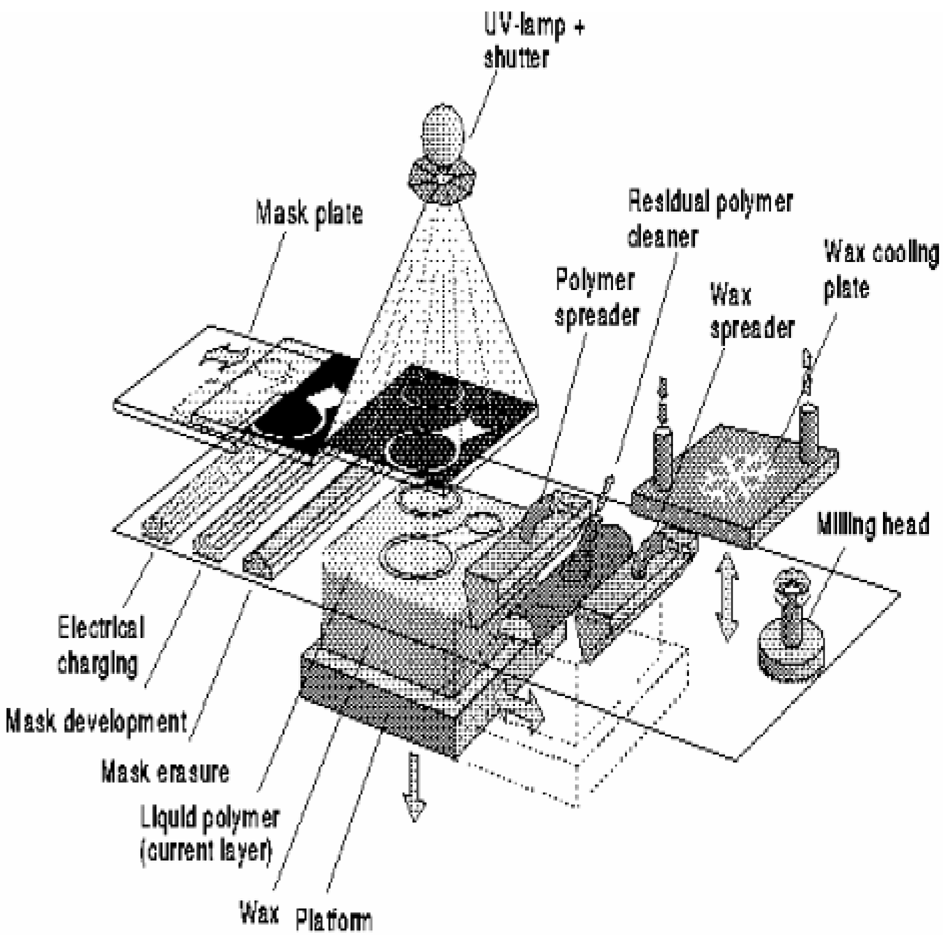
# 5. 3D Printers

- Developed at MIT
- Parts are built upon a platform situated in a bin full of powder material.

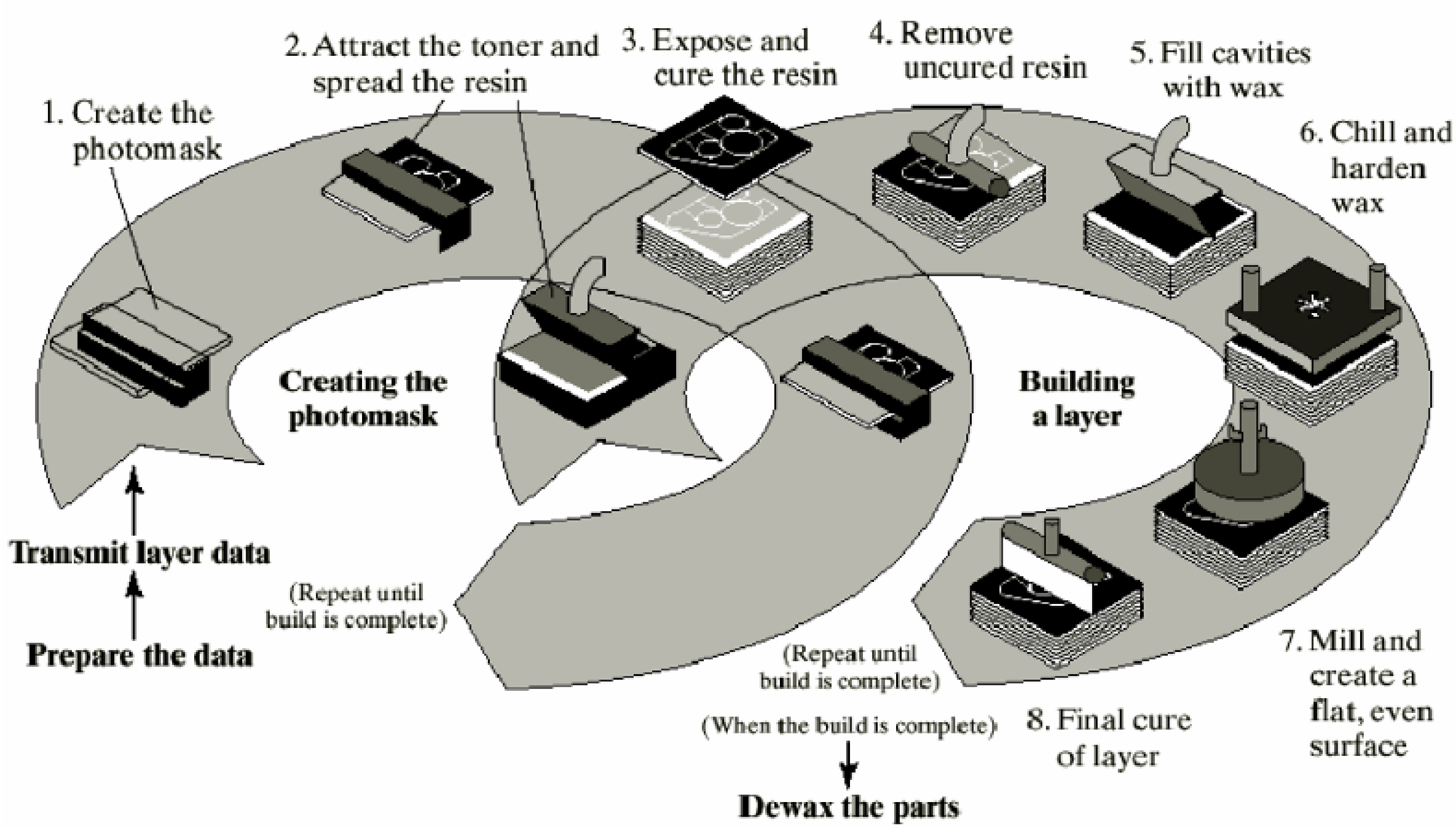


# 6. Solid Ground Curing (SGC)

- Developed and commercialized by Cubital Ltd. (Israel).
- Uses a Photopolymer, sensitive to UV-light.
- The vat moves horizontally as well as vertically.
- The horizontal movements take the workspace to different stations in the machine.



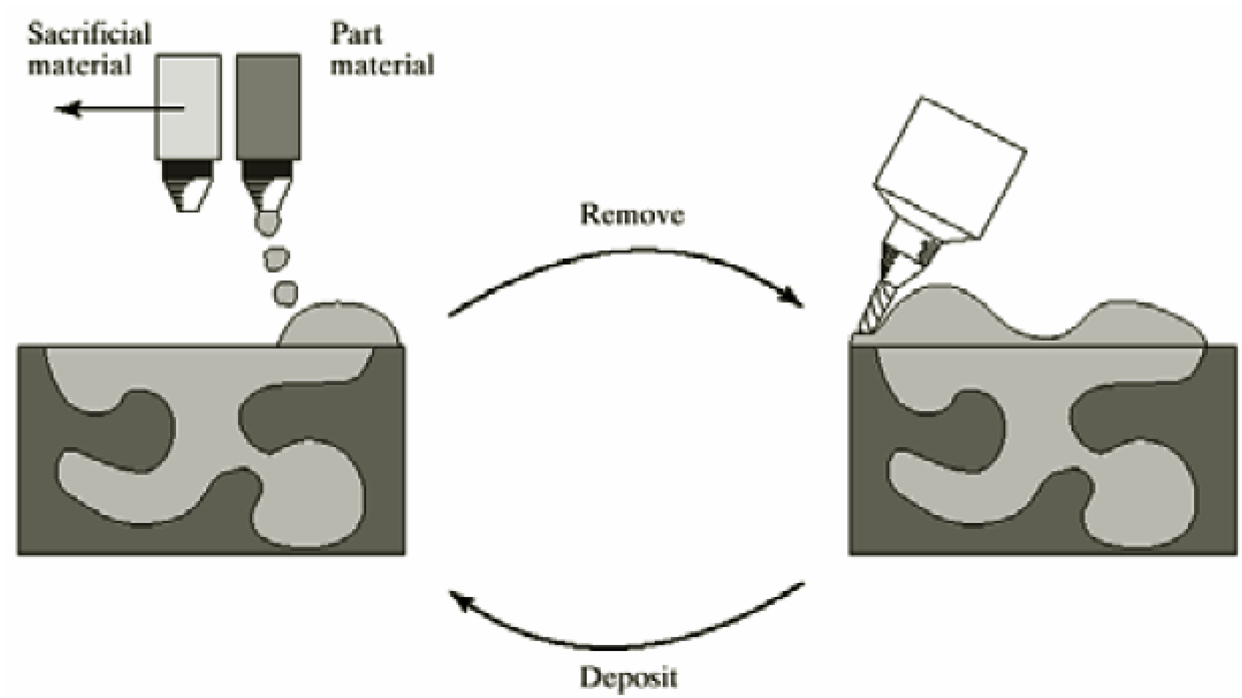
# SGS Process



1. Create the photomask
2. Attract the toner and spread the resin
3. Expose and cure the resin
4. Remove uncured resin
5. Fill cavities with wax
6. Chill and harden wax
7. Mill and create a flat, even surface
8. Final cure of layer
Creating the photomask
Building a layer
Transmit layer data
Prepare the data
(Repeat until build is complete)
(Repeat until build is complete)
(When the build is complete)
Dewax the parts

# 7. Shape Deposition Manufacturing (SDM)

- Developed by Stanford University/CMU
- Uses deposition and milling
- Provides good surface finish



# Issues in RP Materials

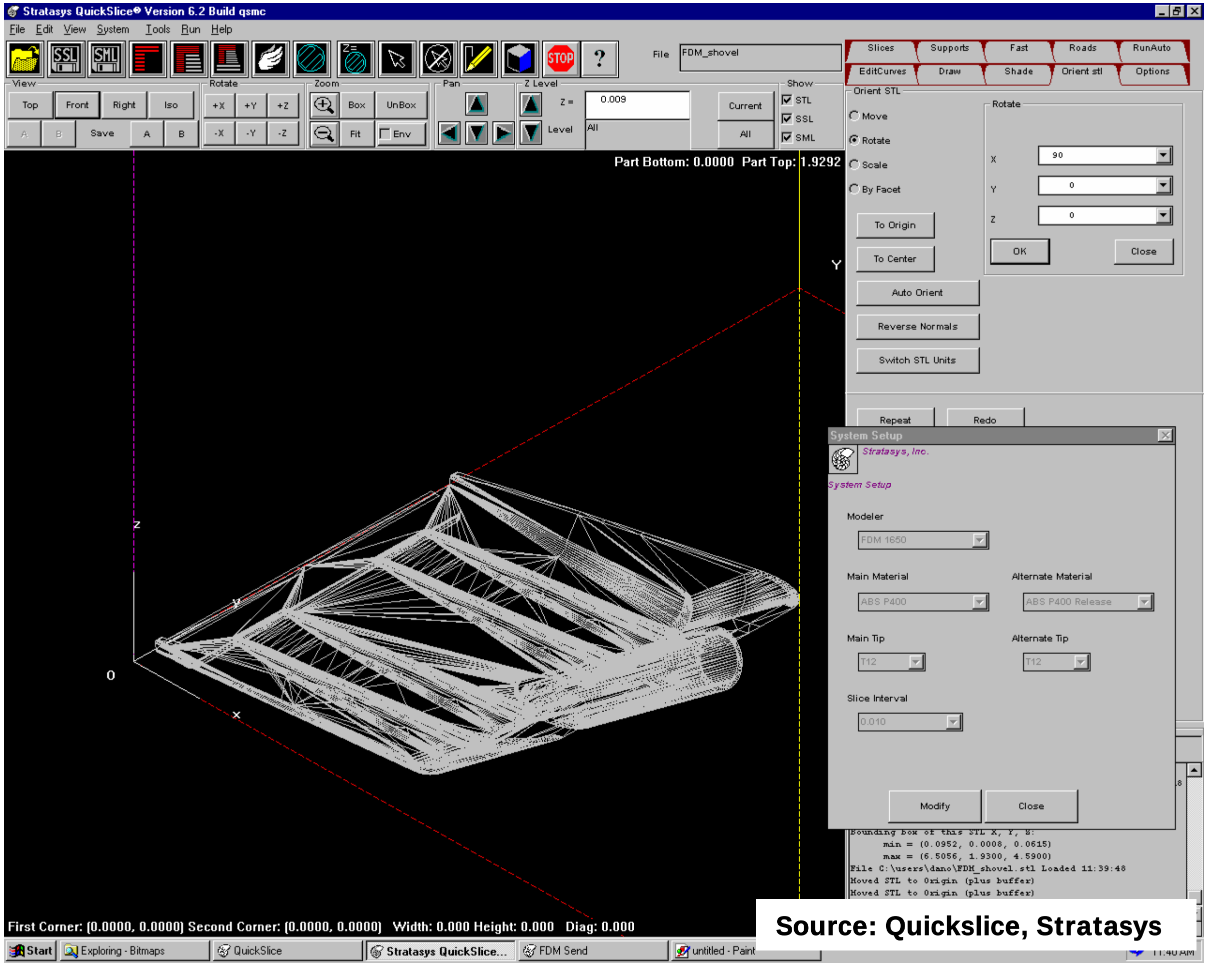
- Rapid Fabrication of functional parts
  - Structural
  - Optical
  - Surface Roughness
  - Electrical
  - Thermal
  - Color
  - … … …

# FDM Software – Three Levels

- **STL file** – Tesselated Stereolithography file – export from solid modeling package
- **SSL file** – Sliced Layer File, Support Calculation – Proper part orientation can drastically affect build time, support requirements, and part strength
- **SML file** – Rastors, Build Parameters, time estimation

# STL File – Collapsible Shovel Head

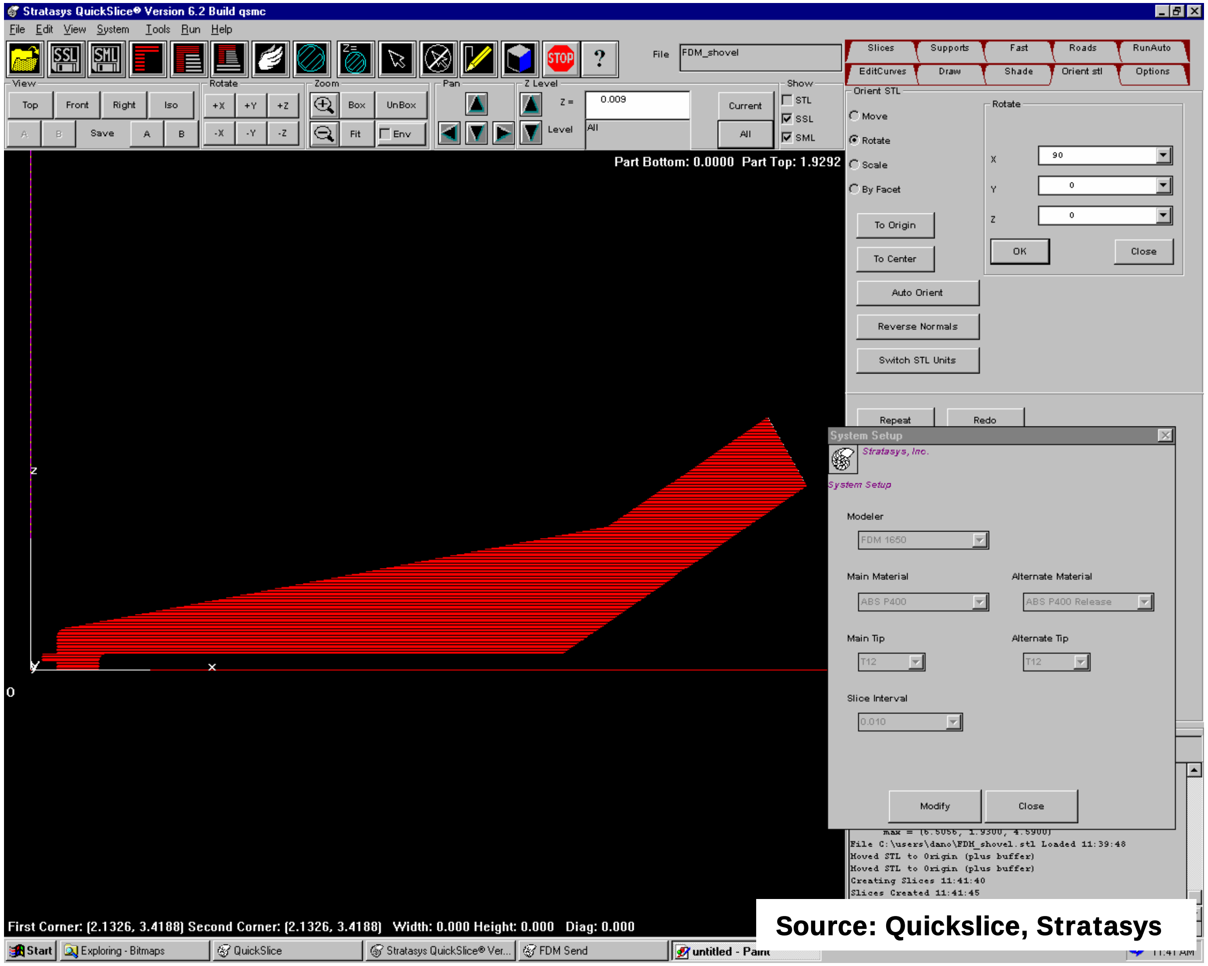
- Tesselated (Triangulated) format
- Standardized Export Type
- Quickslice Layout




Source: Quickslice, Stratasys

# SSL File – Unsupported, Front View

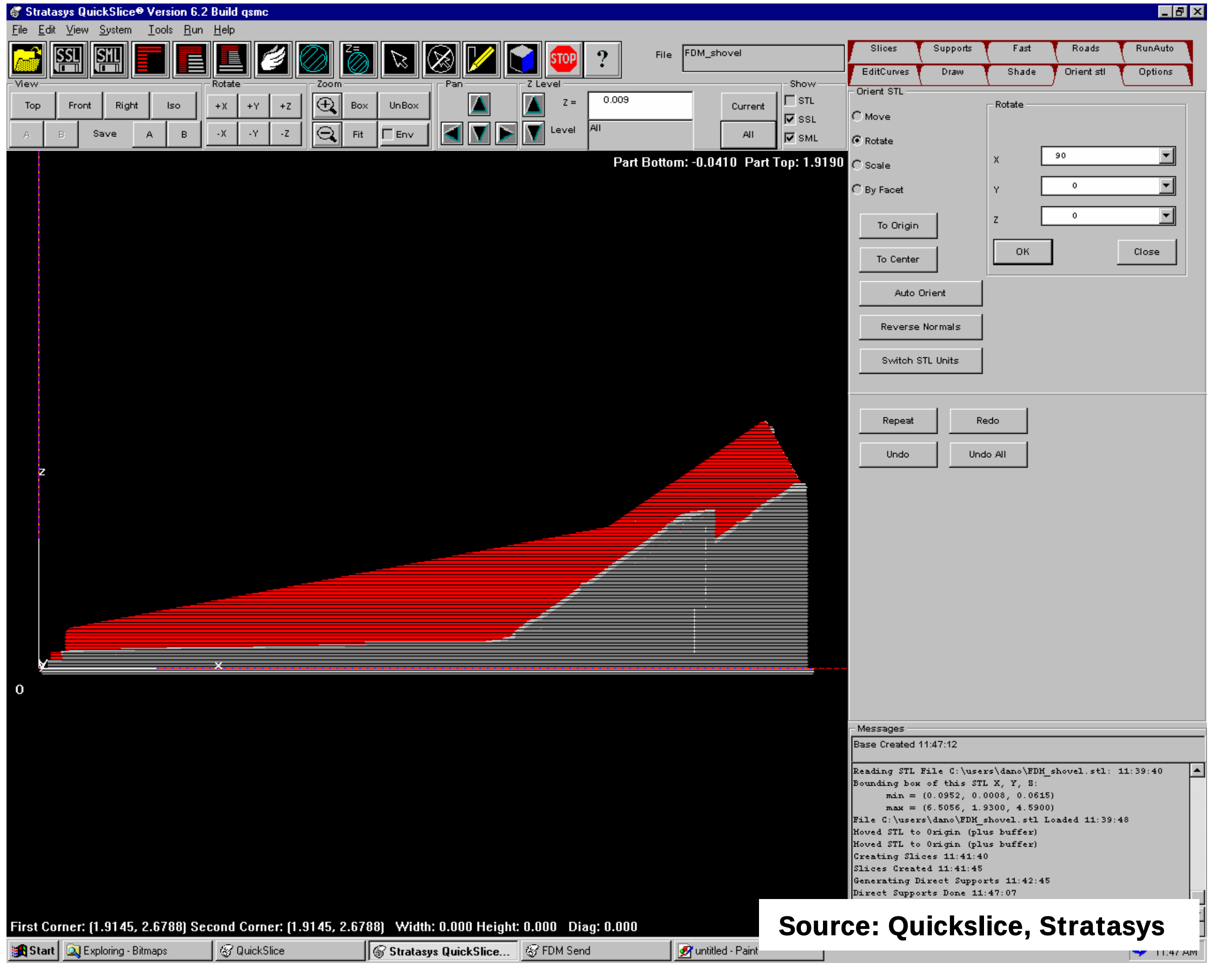
- Vertically Sliced File
- Orientation Important!
- Unsupported Material will fall




Source: Quickslice, Stratasys

# SSL File – Supported, Front View

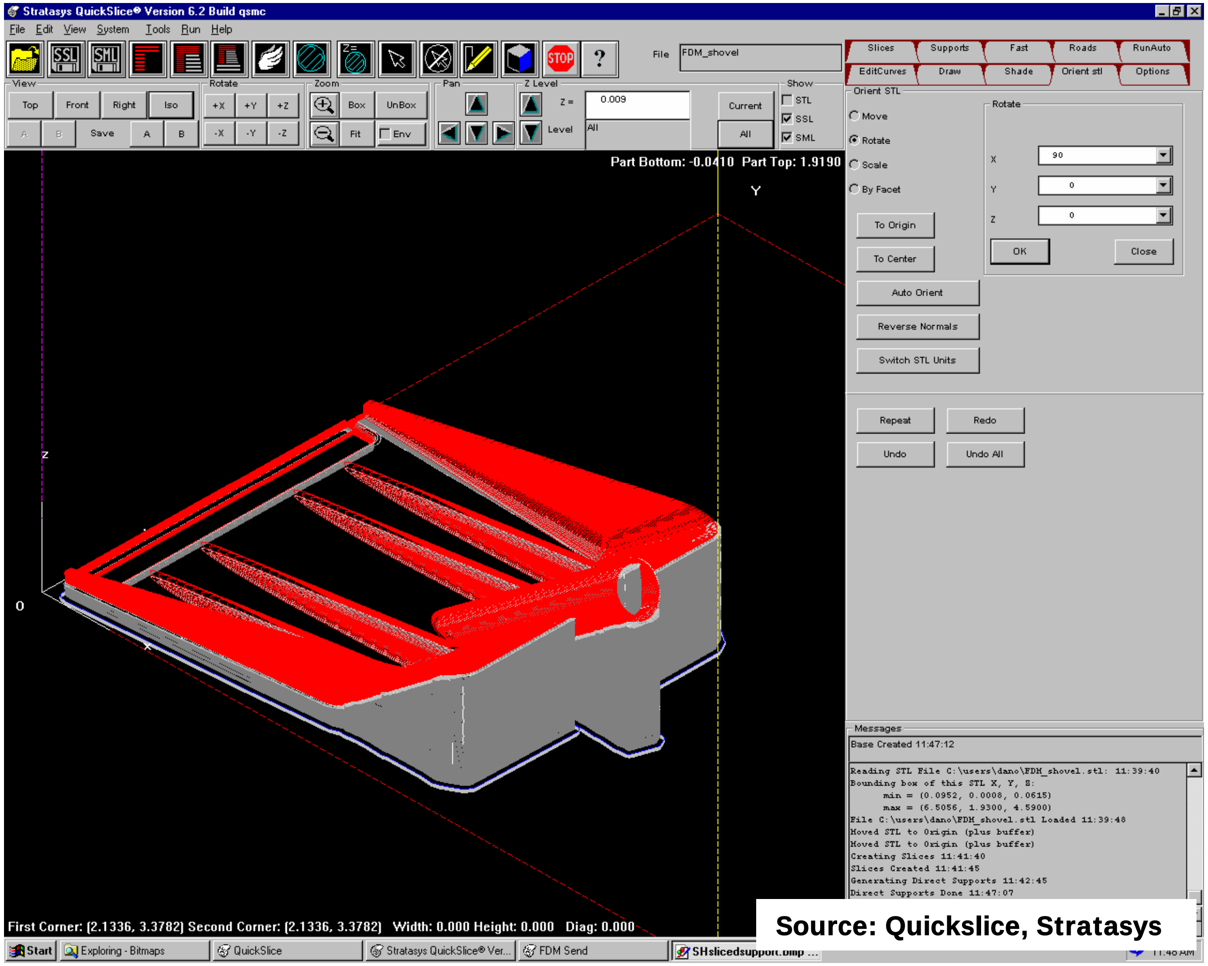
- Support Calculation
- 45° Support rule
- Foam Substrate
- Foam Irregularities




Source: Quickslice, Stratasys

# SSL File – Supported, Isometric View

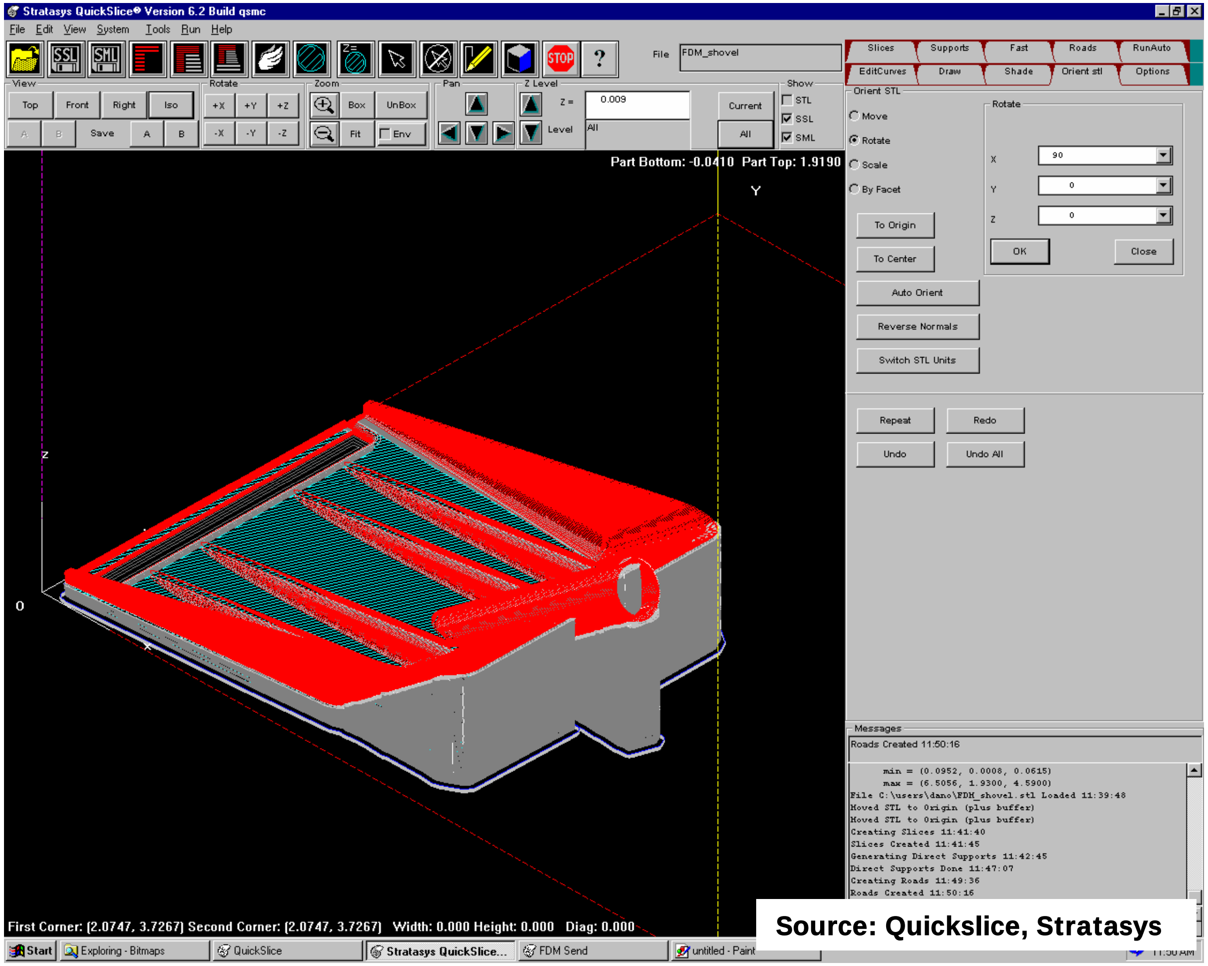
- Support Base (Blue)
- Removing Support Material
- Calculation and Removal can be time intensive



Source: Quickslice, Stratasys

# SML File – Supported, Isometric View

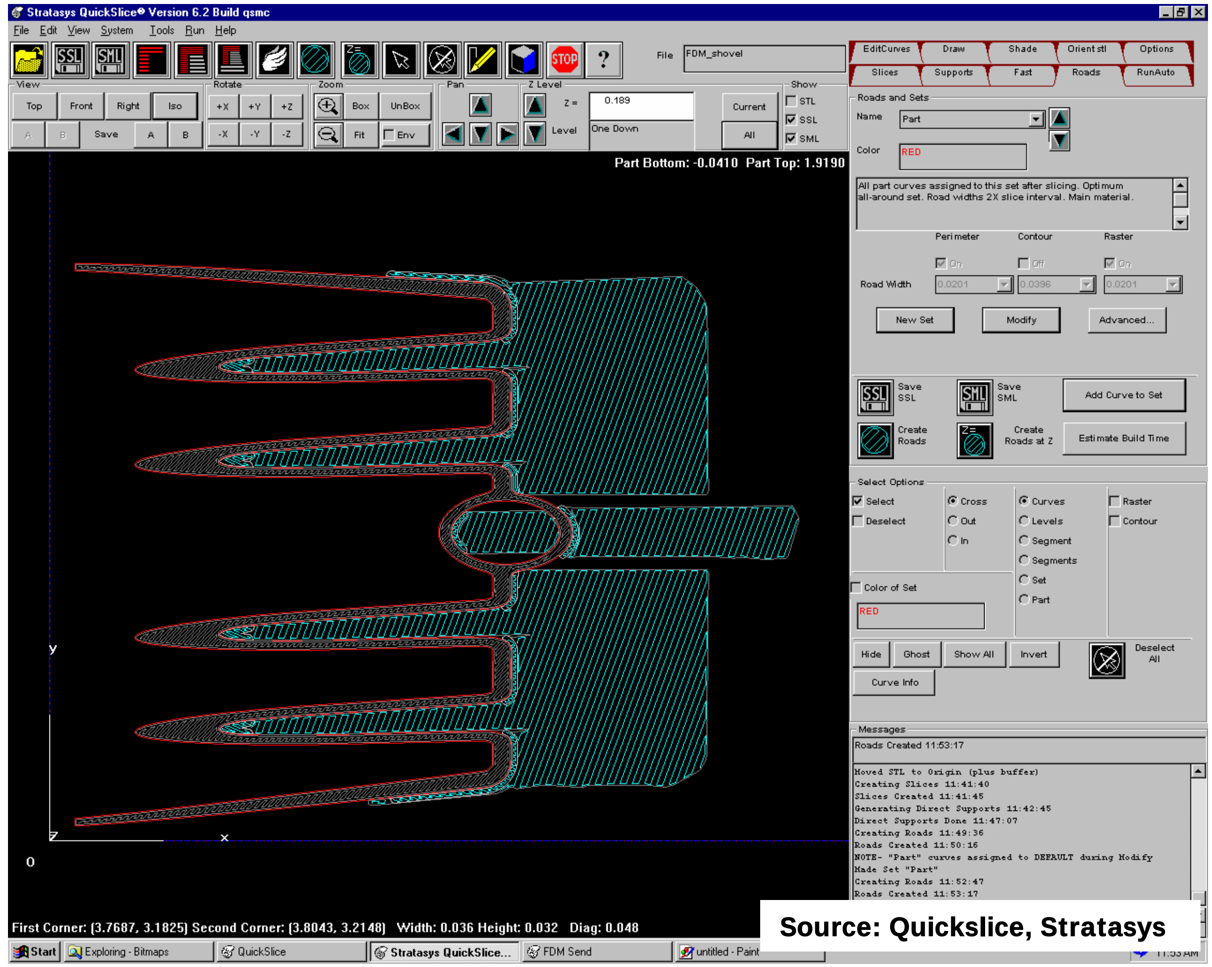
- Road Generation
- Colored Layer of SSL file determines road orientation
- Road type and orientation strongly affects build time and part strength




**Source: Quickslice, Stratasys**

# SML File – Supported, Top Layer

- Rastors oriented at 45° angle (FDM material behaves like a composite)
- Note loose fill of support material – easier to break and quicker to build

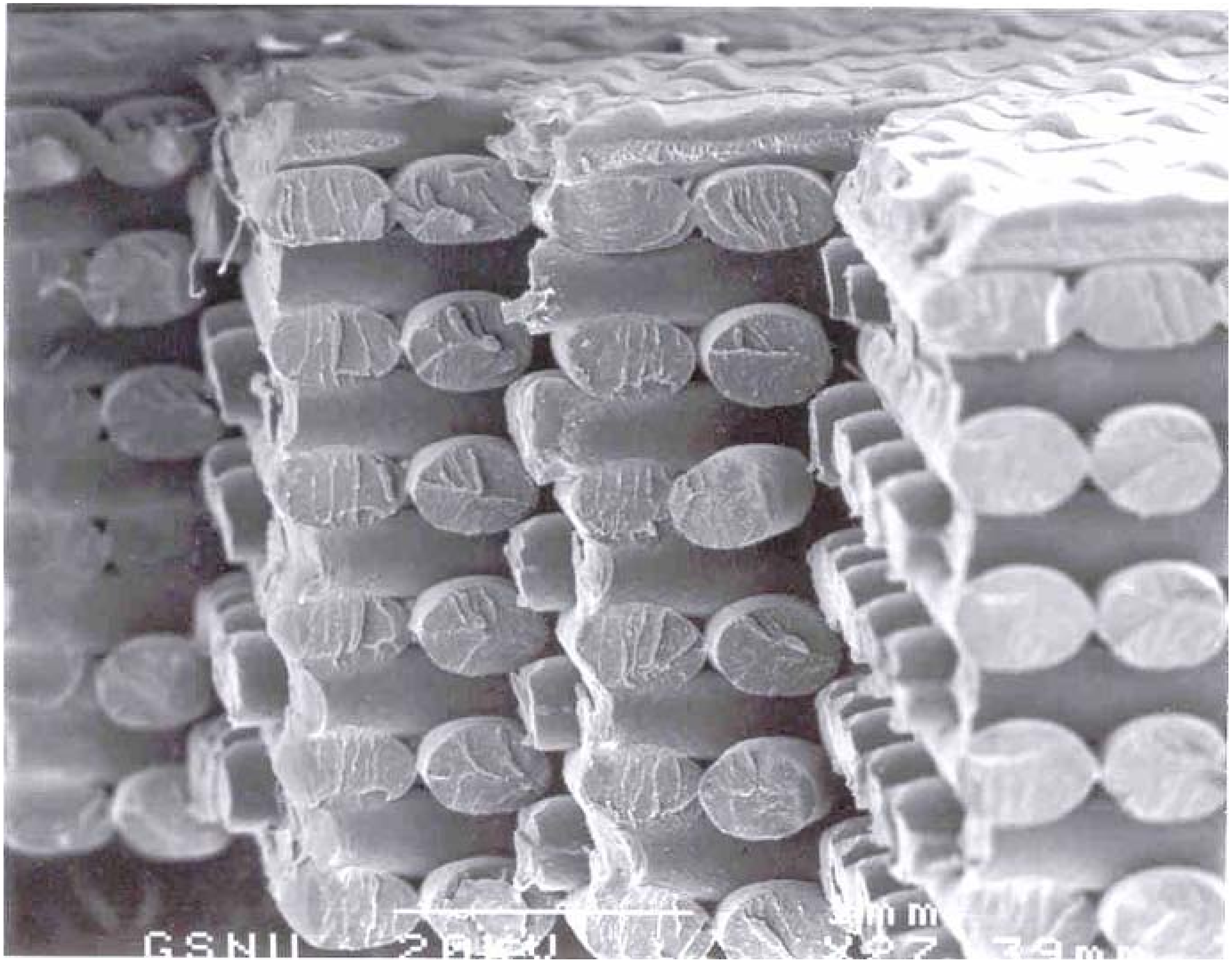



**Source: Quickslice, Stratasys**

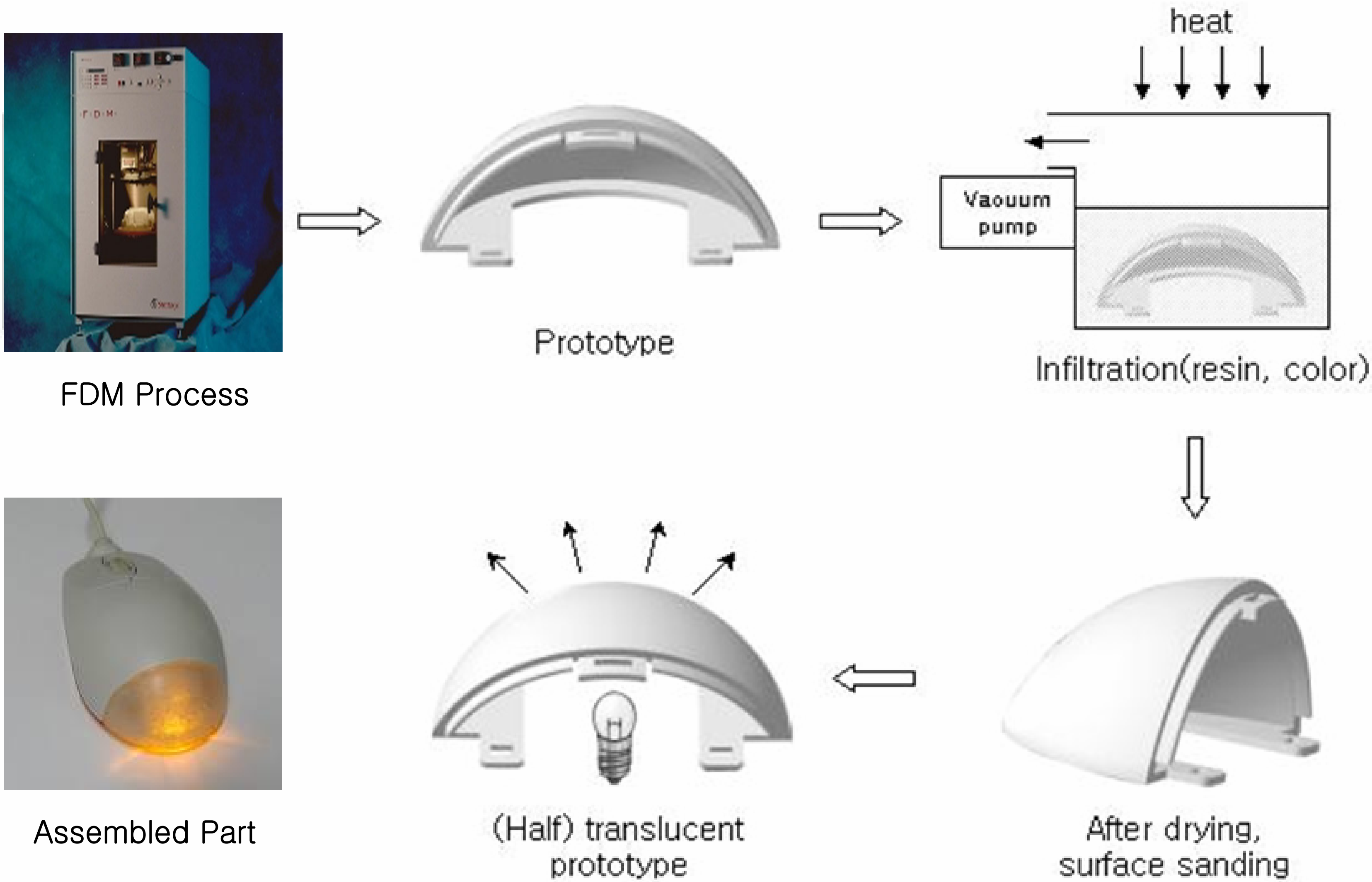
# FDM Build Parameters - Software

- Perimeters, Contours, Rastors  (Road type)
  - Perimeter: Follows outer shape of current slice-ideal for cosmetic outer surface
  - Contour:  Follows shape of perimeter on part interior – not commonly used as it leaves gaps
  - Rastors: Standard back and forth part fill – adds strength to part, composite theory (rastor angles)
- Road width - Dependant on nozzle size and feed rate – ranges from .012 to .0396 for T12 nozzle
- Air Gap – gap between roads – allows for tightly fused, strong surface, or sparse, quick building fill

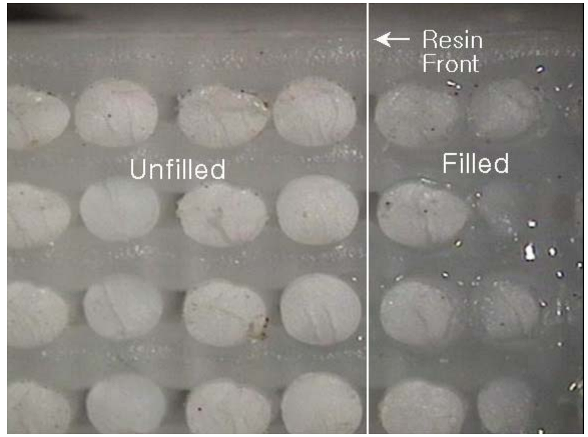
# Micro Structure of FDM



# PartPost-process of FDM



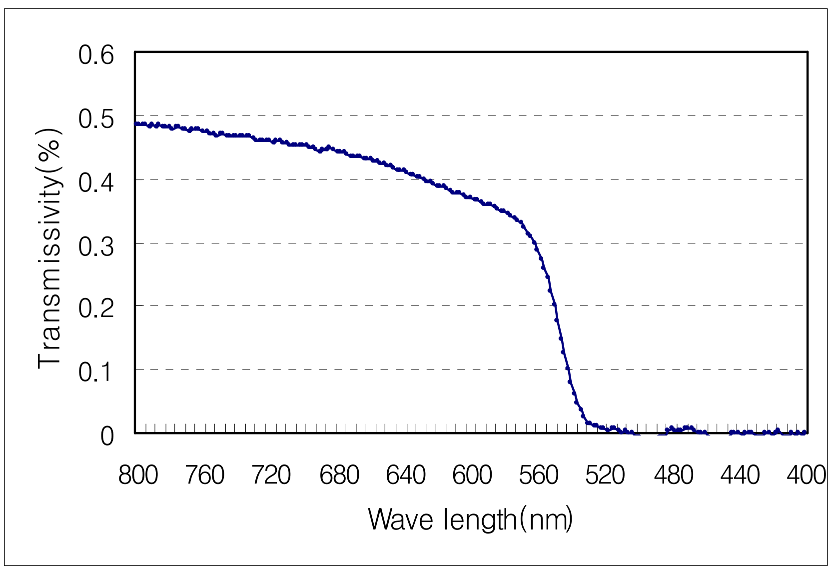
# Resin Infiltration

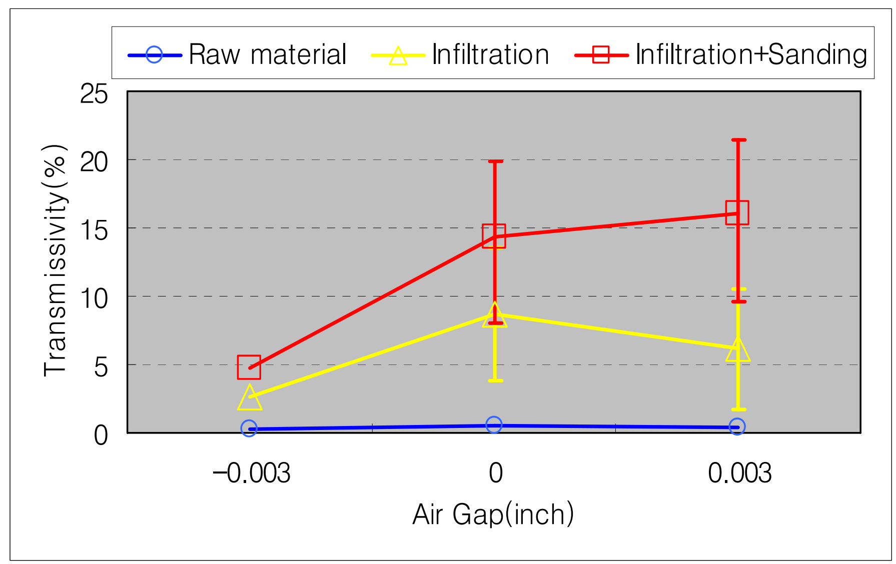



**Raw FDM ABSi**

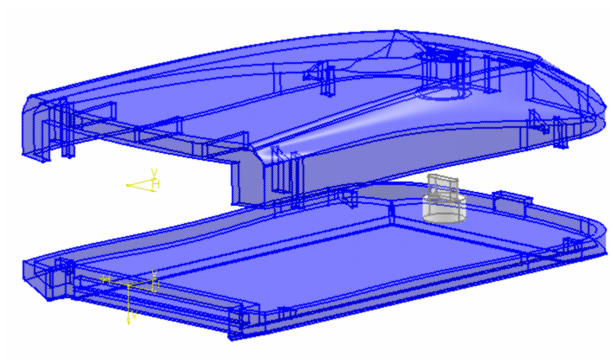
**During Infiltration**

**After Infiltration**



# Flash Memory Reader

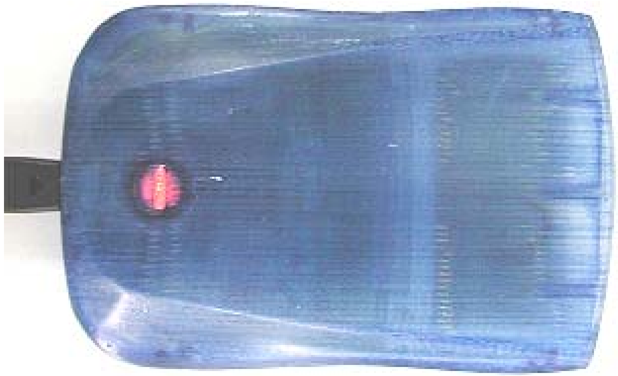


CATIA modeling:

5 hours

FDM process:

10 hours

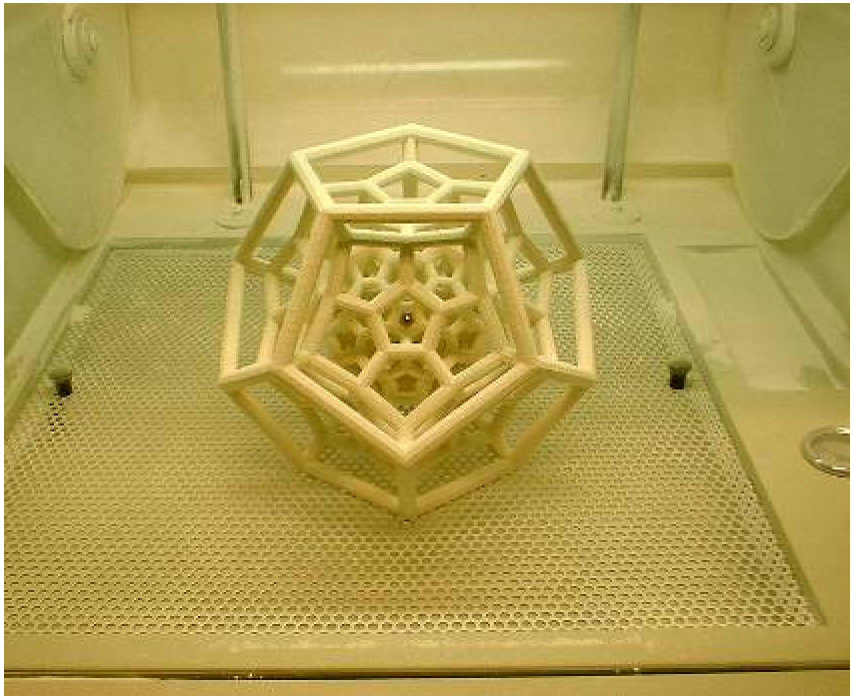


Post-process : 24 hours

Total prototyping time : 39 hours

# Gallery

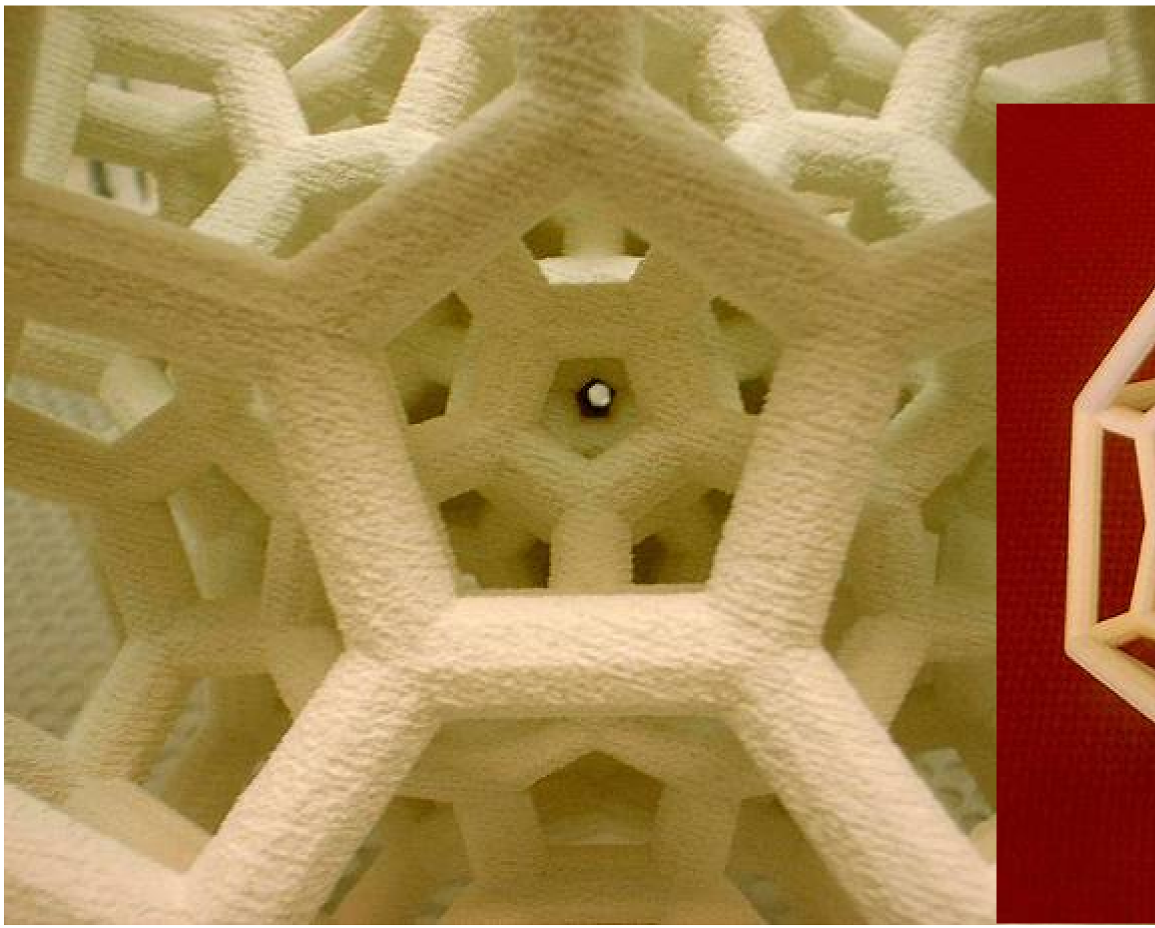
- Z- corp (3D Printer)

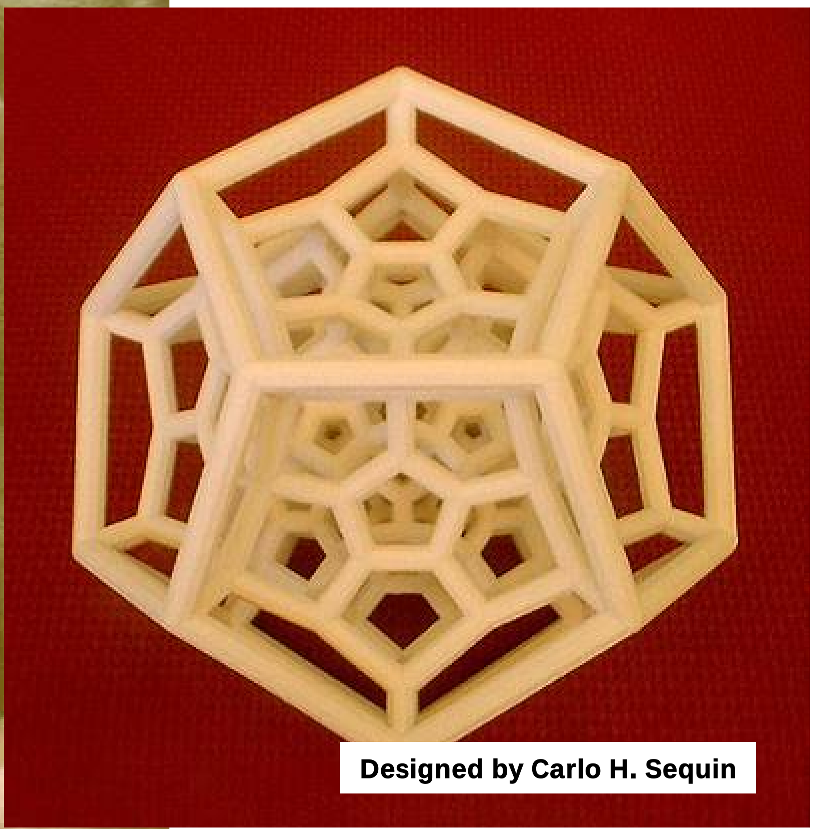


Designed by Carlo H. Sequin

# Gallery (cont.)

- Z- corp (3D Printer)





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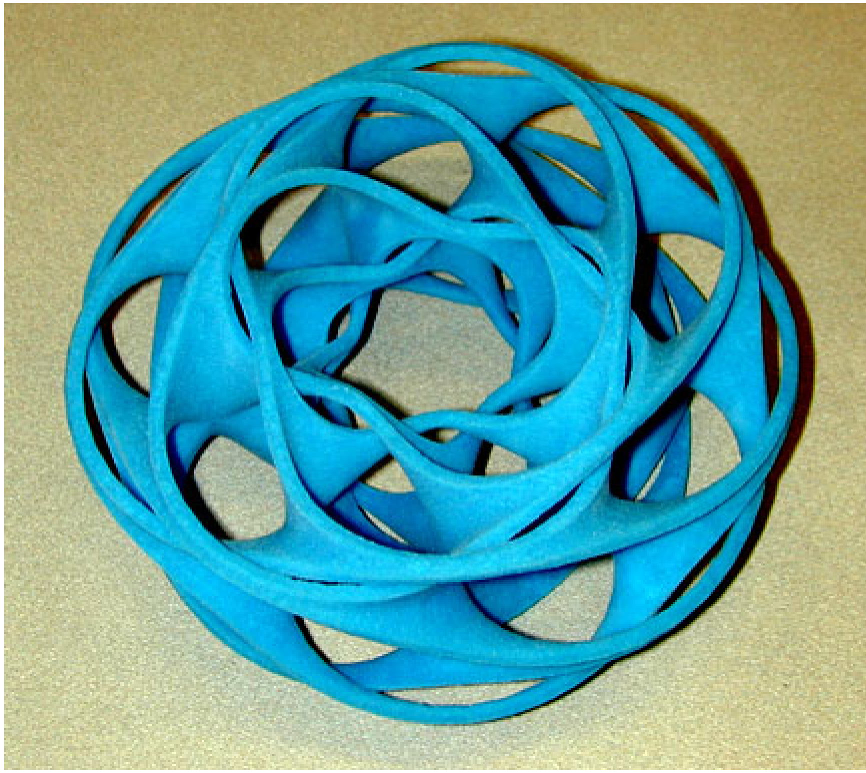
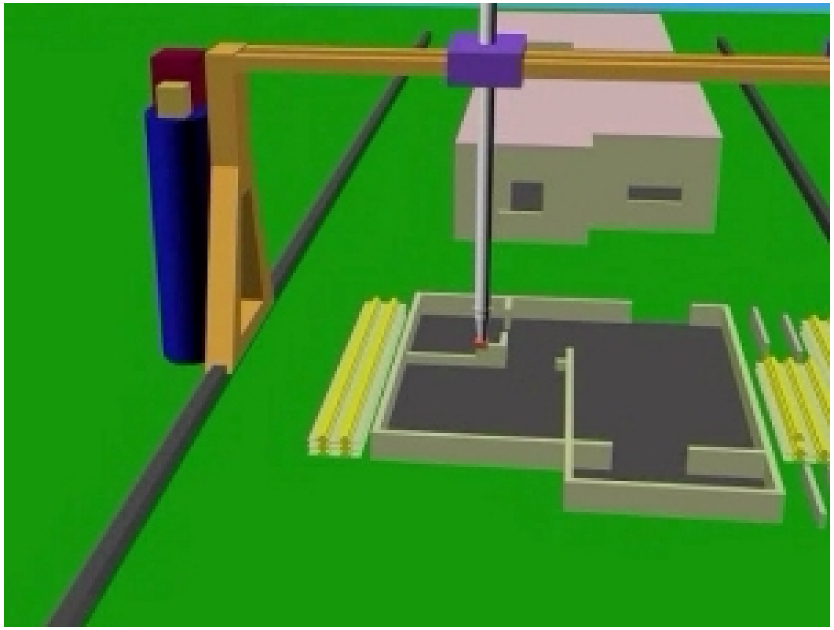
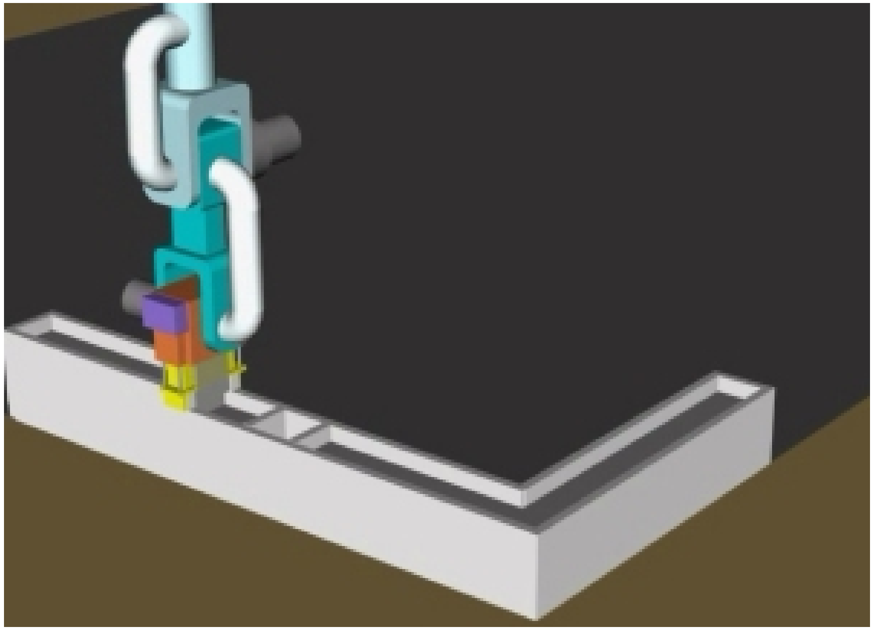


**Designed by Carlo H. Sequin**

# Applications

- Architectures

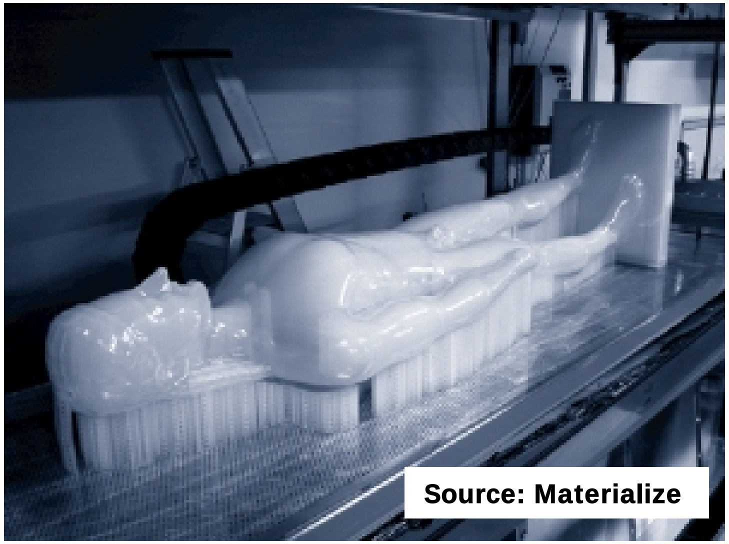




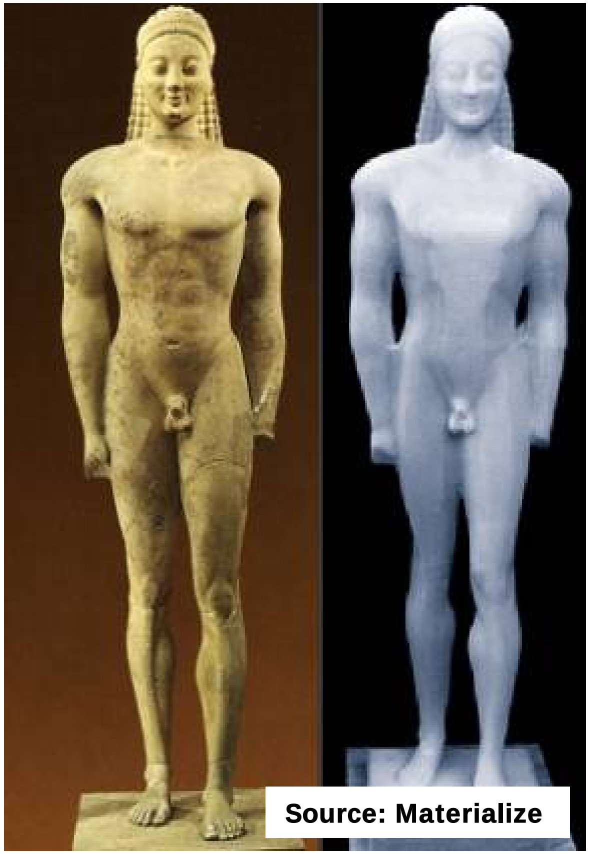
A machine mounted on rails might be used to build multiple houses.

# Applications (cont.)

- Materialization of arts




Lifting the kouros out of the Mammoth.




The original Volomandra Kouros and the SLA replica

# Applications (cont.)

- Micro component

Micro robot by Sandia Lab

# Applications (cont.)

- Rapid Tooling (RT)

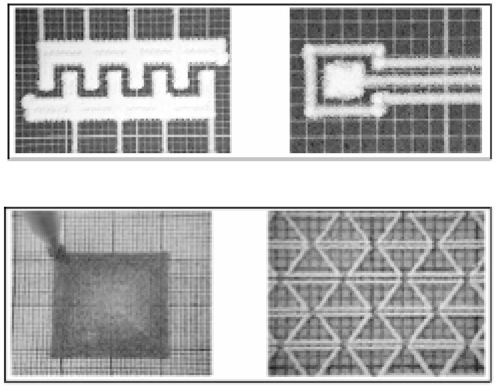

DTM's RapidTool™ process for rapid mold making

Core and cavity sets produced by RapidTool ™

# Applications (cont.)

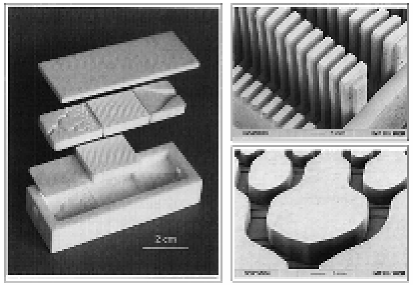
- Other Examples

## Patterning with Ceramic



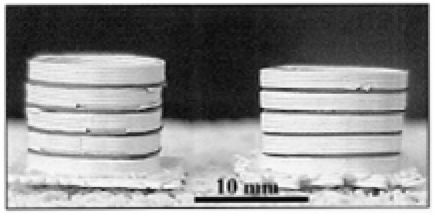
P. Kumar *at al,* Ann Arbor

## Microreactor

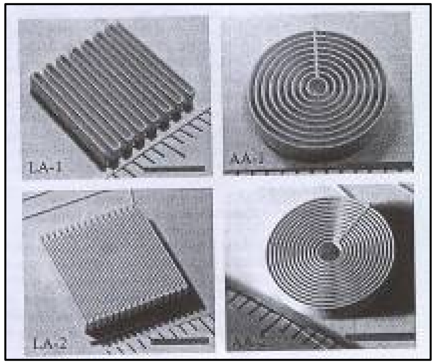


R. Knitter *at al.*
RP Journal

## Sensor and Actuator



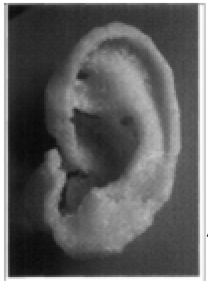

Electrode ; A. Safari *et al*. IEEE




PZT Sensor ; J. E. Smay *et al*. J. Am. Ceram. Soc.

## Artificial Bone and Ear

Artificial bone



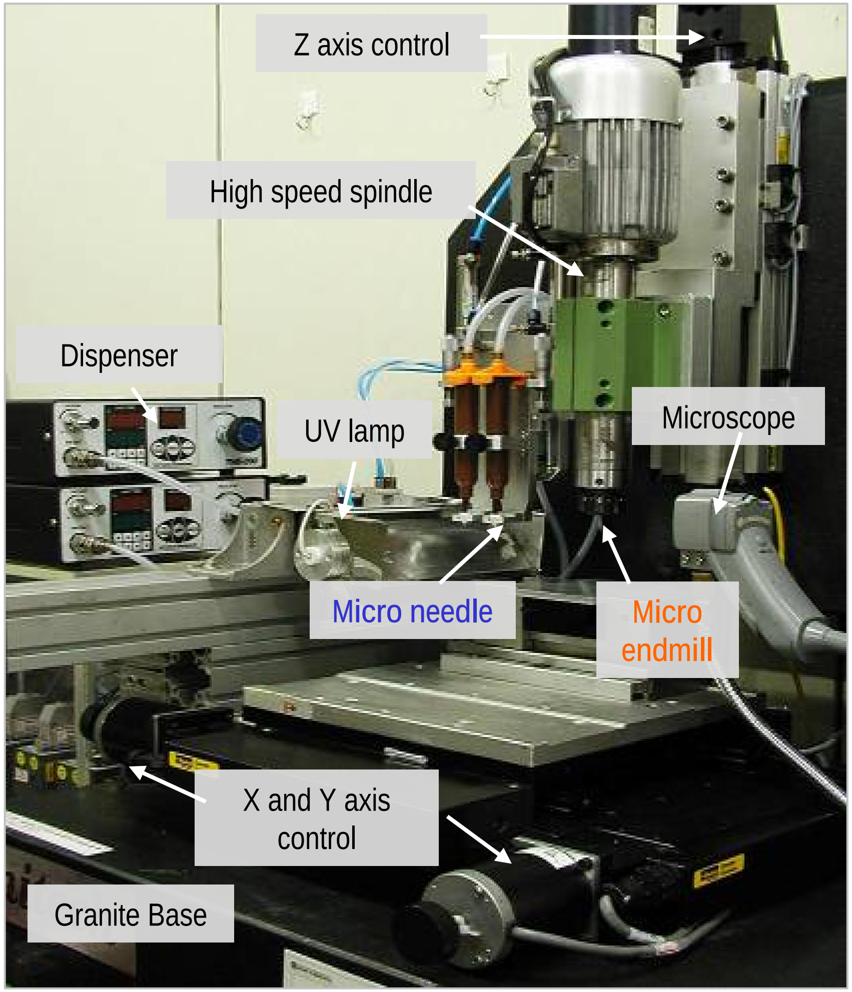
Y. Tan *et al.*
Am. Ceram. Soc.

Artificial ear

Bio-compatible Material

# Hybrid RP System

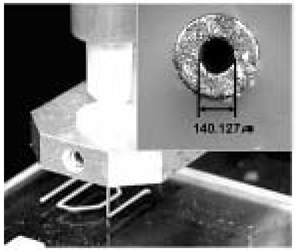
- Hardware



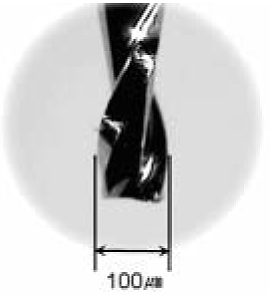

✓ ***Deposition; Rapid Prototyping***

✓ ***Cutting; Milling***

✓ ***Hybrid; Both***




*Micro needle*



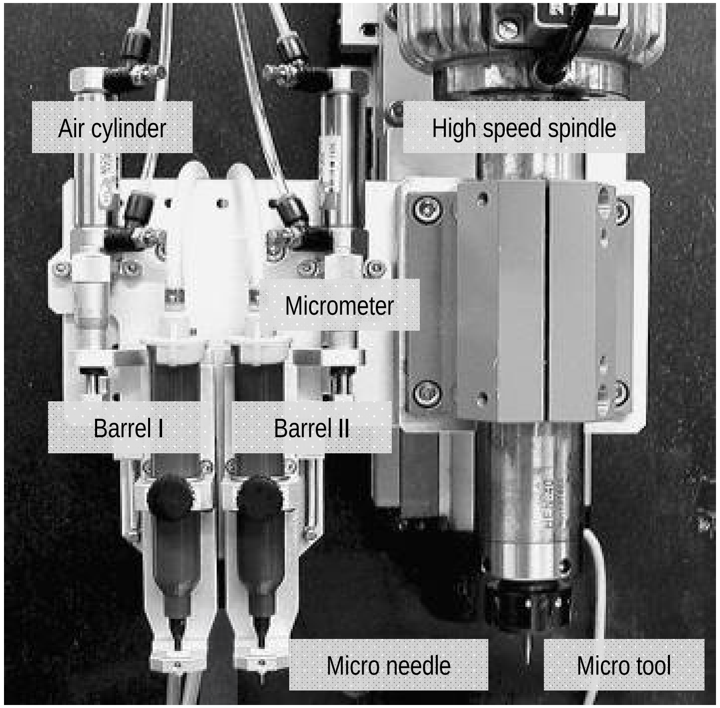

*Micro endmill*

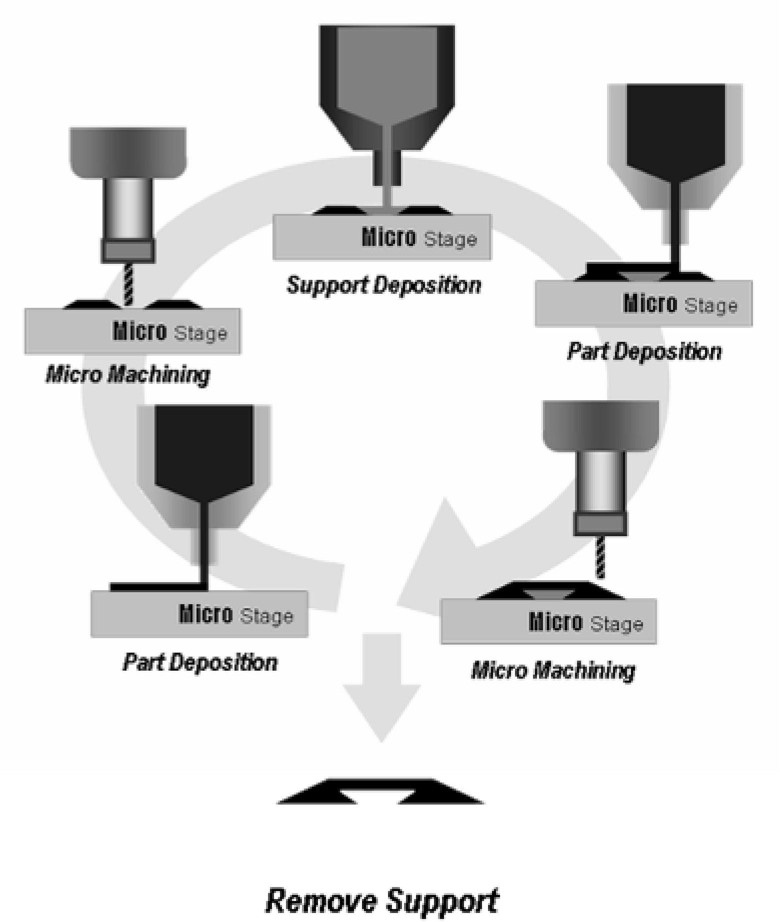
**SPECIFICATIONS**

| | |
|---|---|
| 3 Axes-stage | **1㎛ resolution** |
| Dispenser | **15 ~ 700 kPa** |
| Micro needle | **$\phi$ 140 ㎛ ~ $\phi$ 800 ㎛** |
| Micro tool | **$\phi$ 100 ㎛ ~ $\phi$ 1000 ㎛** |
| High speed spindle | **Max. 46,000rpm** |
| UV curing system | **0 ~ 400 W, $\lambda$ = 365 ㎚** |
| Controller | **PMAC (Multi-tasking board)** |

# Hybrid RP System (cont.)

- Hybrid process: depositing + machining

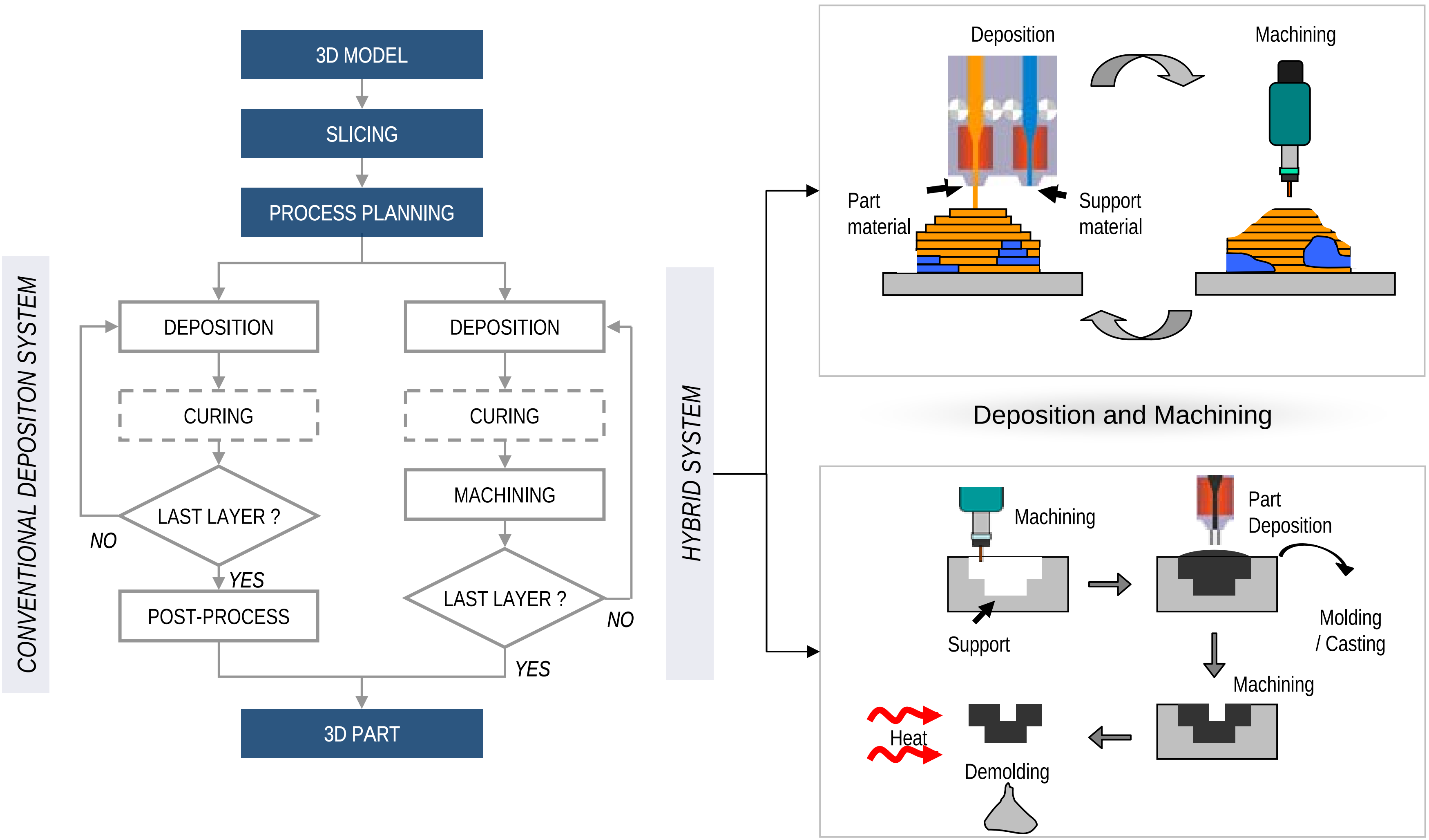



Conceptual process of NCDS

# Hybrid RP System (cont.)

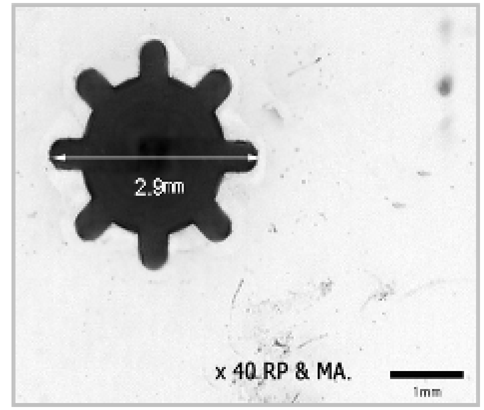
- Process planning



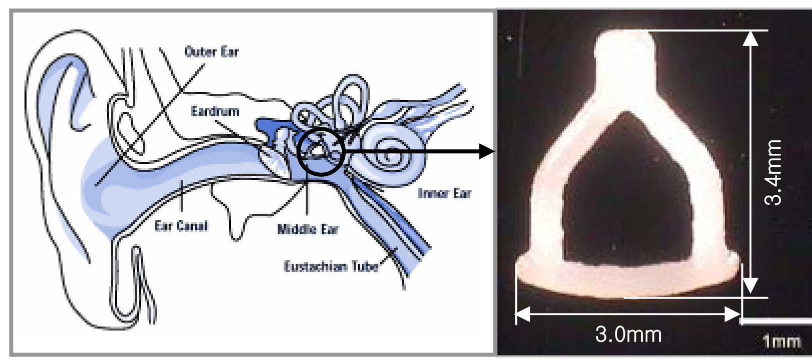
# Nano composite parts

- Micro Gear
  - A gear geometry with $\phi$ 2.9mm was fabricated
  - 5wt% MWCNT + Acrylic resin
  - Dispensing process using $\phi$300μm needle
    micro milling using $\phi$100μm flat endmill
- Stapes
  - The smallest bone in human body, width 2.5mm / height 3.5mm
  - 40wt% Hydroxyapatite + Acrylic resin
  - Dispensing process using $\phi$140μm needle
    micro milling using $\phi$100μm flat endmill
  - Mold (using wax) machining → part deposition
    → surface machining → demolding
- Fabrication time

| Parts | Average Time (min) |
|---|---|
| Micro Gear | 2 |
| Stapes | 15 |



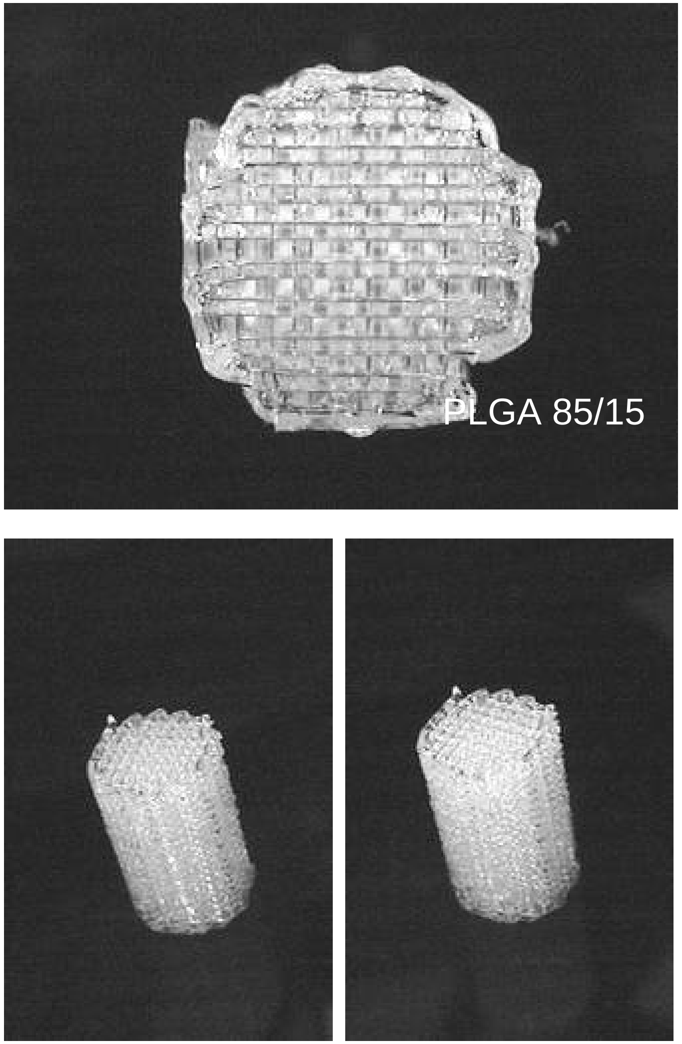

Microscope picture of microgear

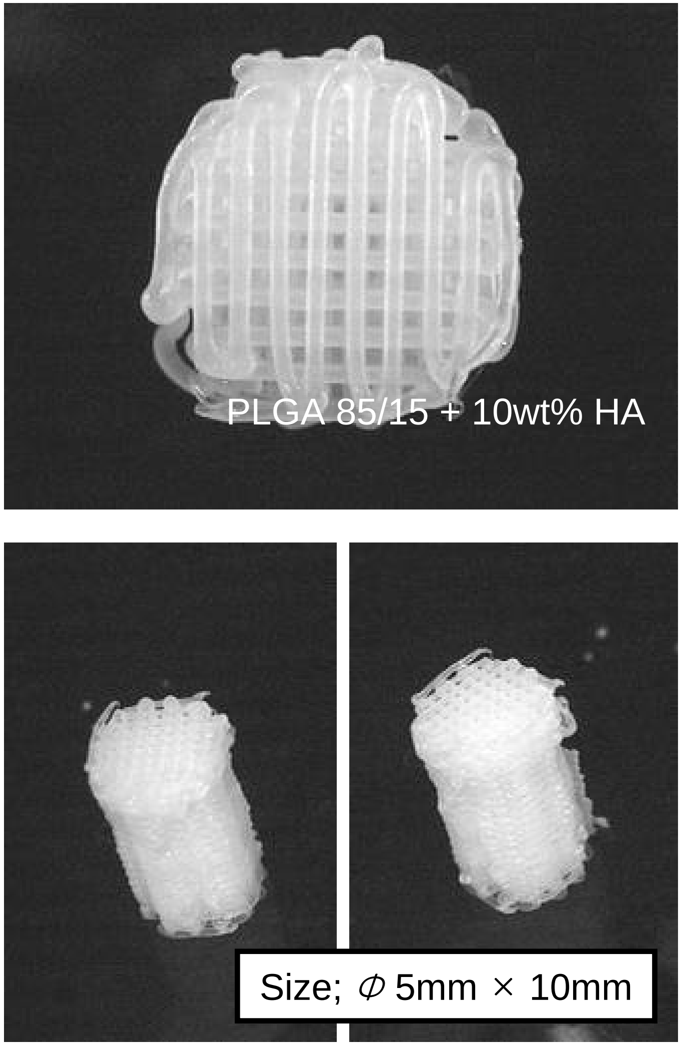



Geometry of stapes

# Scaffold for Bone Growth

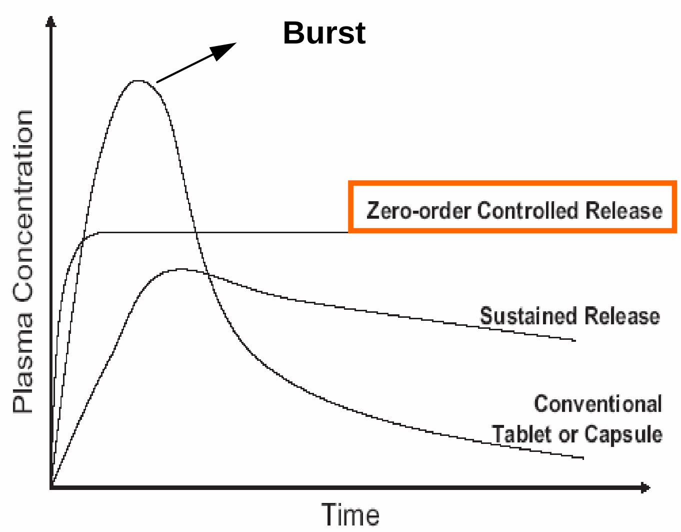
- Bio-degradable polymer

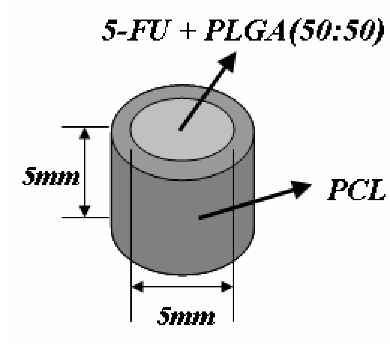


# Drug Delivery System (DDS)

- Specimen for Zero-order Release Test

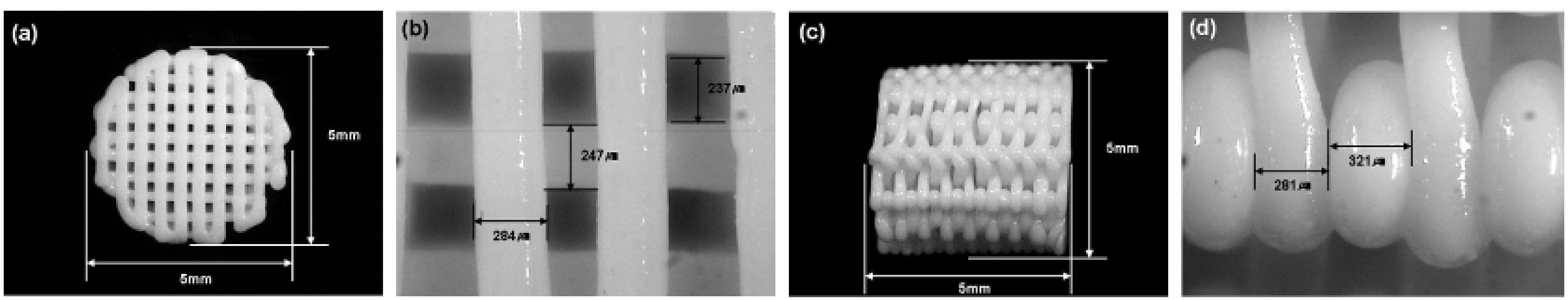




Fabricated container and drug delivery device

- Scaffold Shape of DDS (Controlled Pore Size)




Fabricated drug delivery device of scaffold shape (15layers, $[0^{\circ}_{8}/90^{\circ}_{7}]$, 5mm×5mm)