LECTURES 5-6

Additive manufacturing and 3D Printing

3.1 Introduction

Additive manufacturing (AM) is the process of producing objects from computer-aided design (CAD) model data, usually adding layer upon layer. AM is also called 3-D printing, additive fabrication, or free-form fabrication. These new techniques give industry new design flexibility, reduce energy use, and shorten time to market.

Additive equipment can now use metals, polymers, composites, or other materials to “print” a range of functional components, including complex structures that may be difficult or impossible to manufacture by other means.

3.2 Benefits of Additive Manufacturing

AM process likely to play a role in future manufacturing capabilities. AM has the potential to minimize materials and energy usage, reduce waste, accelerate innovation, and compress supply chains. Listed below are some benefits of AM technology:

- **Innovation.** AM enables designs with novel geometries that would be difficult or impossible to achieve using CM processes.

- **Part consolidation.** The ability to design products with fewer, more complex parts rather than a large number of simpler parts may be the most important benefit of AM. Reducing the number of parts in an assembly may cut the overhead associated with documentation, production planning, and control, less time and labor is required to assemble the product, again contributing to a reduction in overall manufacturing costs.

- **Lower energy consumption.** AM can save energy by eliminating production steps, using less material and producing lighter products.
- **Less waste.** Reduce material needs and costs by up to 90%. AM can also avoidance of the tools, dies, and material scrap associated with CM processes.
- **Reduced time to market.** Items can be fabricated as soon as the 3-D digital description (3-D scanning or 3-D imaging to construct a Standard Tessellation Language [STL] file) of the part has been created, eliminating the need for expensive and time-consuming part tooling and prototype fabrication.
- **Light weighting.** With the ability to create complex shapes.

3.3 Biomedical Applications of Additive Manufacturing

- for customized implants and medical devices
- for fabrication of "smart scaffolds" and for construction of 3-D biological and tissue models using living biologics
- Creating computer-aided BAM, including modeling, analysis, and simulation of cell responses
- Making functional human tissues by using 3-D "bio printing" technology".

3.4 Challenges for Additive Manufacturing

To achieve a wider range of applications for AM, R&D efforts will need to overcome some key technical challenges, including the following:

- **Process control.** Feedback control systems and metrics are needed to improve the precision and reliability of the manufacturing process.
- **Tolerances.** Some potential applications would require micron-scale accuracy in printing.

- **Finish.** The surface finishes of products manufactured with additive technology require further refinement.
- **Scalability.** AM products are currently not performing for large-volume production.
- **Processing speed.** While low-volume production is faster than CM, higher volumes are considerably slower.
- **Electrical power.** Power variations and interrupts can impact the quality of the item produced.
- **Material compatibility.** Materials that can be used with AM technologies are currently limited. There is a need for new polymer and metal materials formulated for AM to provide materials properties, such as flexibility, conductivity, transparency and safety.

3.5. Difference between various AM techniques?

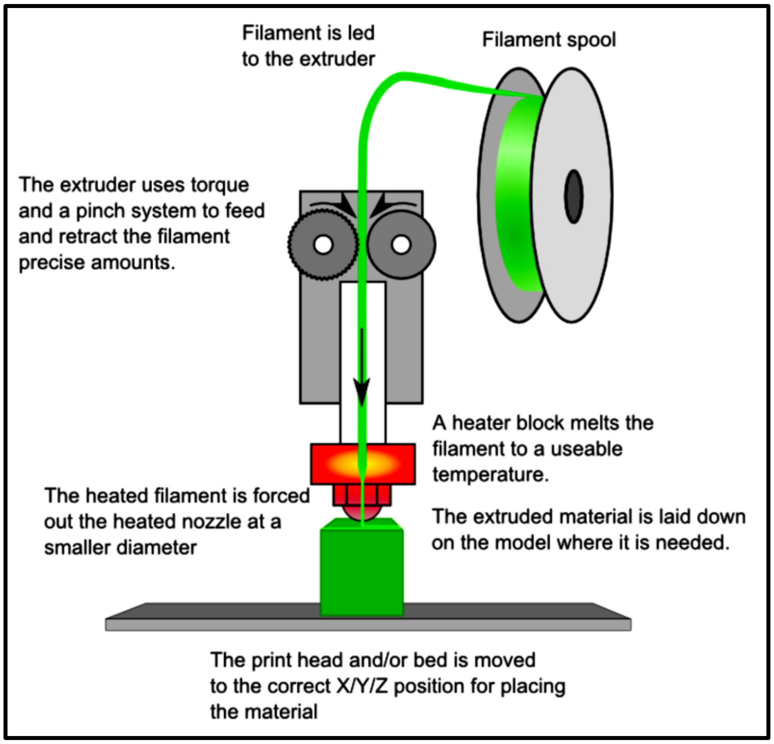
- Techniques used for creating layers;
- Techniques of bonding the layers together;
- Speed;
- Layer thickness;
- Accuracy Range of materials;
- Cost.

3.6. The Main 3D Printing Technologies

3.6.1 Fused deposition modeling (FDM)

- **Filament is made of thermoplastic materials**
    - Acrylonitrile butadiene styrene (ABS)
    - Polylactide (PLA) – biodegradable!
    - Many new materials

- **Dual extruder machines exist**
  - Temporary support structures can be made from water-soluble material
  - Two colors
- **Fused Deposition Modeling – Clones**
  - MakerBot
  - Delta 3D Printer
  - Ultimaker
  - Cube from 3D Systems
  - And many others



3.6.2 Stereolithography (SLA)

- SLA uses liquid photo-reactive resin
- Laser beam traces one layer on the surface of the resin
- Laser light cures and solidifies parts it hits
- The platform descends by one layer
- Support structure
  - thin support lattice can be broken off

3.6.2.1 Stereolithography – 3D Systems

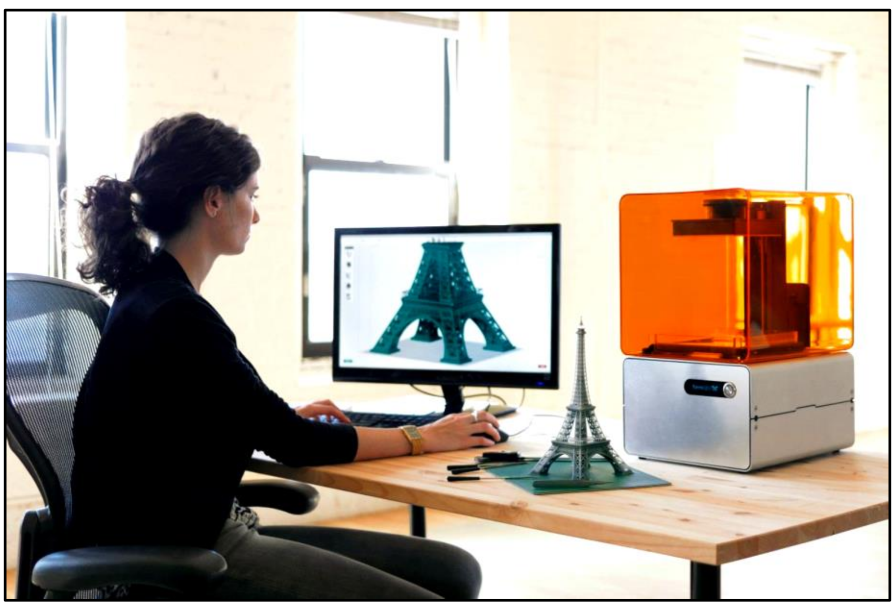
- Two main families

- ProJet
- iPro

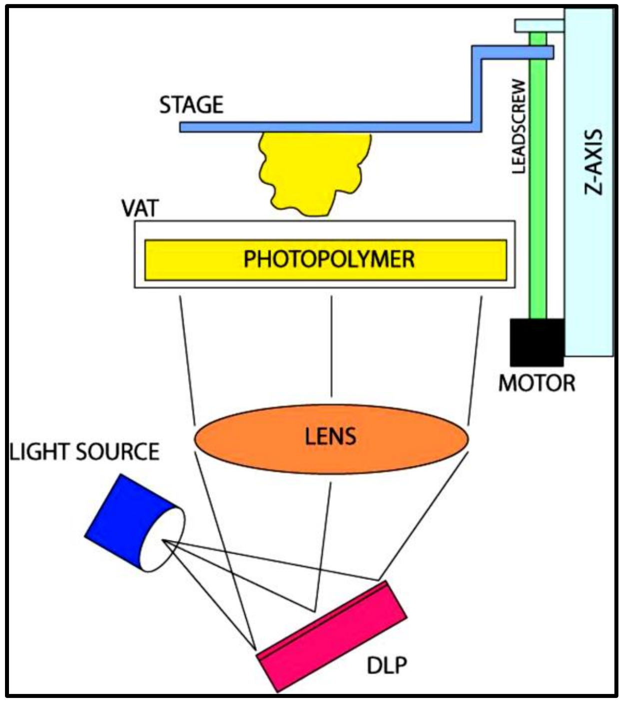
- Build volume: varies, can be very large
- Resolution up to 0.05mm
- Materials (only one can be used):
  - photopolymers
  - clear, opaque, temperature resistant, ceramic-like, abs-like

3.6.2.2 Stereolithography – Clones

- Formlabs
  - –Smaller build volume
  - –Similar resolution
  - –Much less expensive



3.6.3 Digital Light Projector (DLP) 3D Printing



- DLP 3D also uses liquid ultraviolet curable photopolymer resin
- DLP exposes and solidifies one layer at a time on the surface of the resin
- The Z-axis moves by one layer

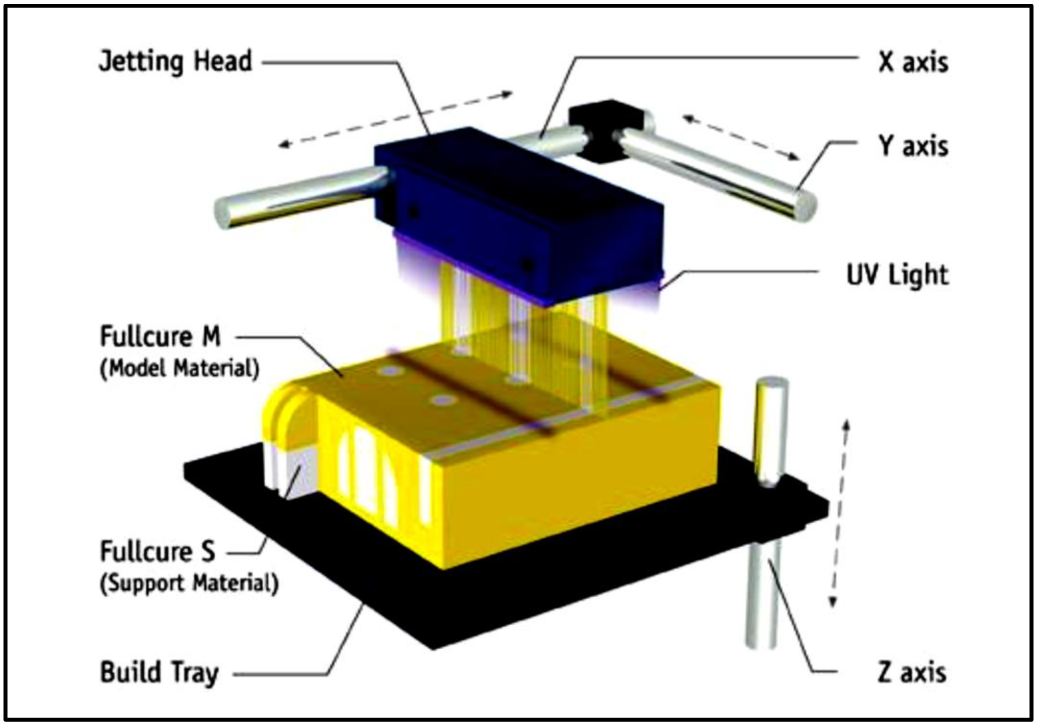
3.6.3.1 DLP 3D Printing Features

- Similar to SLA
  - laser + mirror is replaced by a projector
- Simple design
  - only one degree of freedom
- Faster than SLA
  - exposes one layer at a time
- Materials
  - same as SLA
- No additional support material
  - Lattice structure similar to SLA

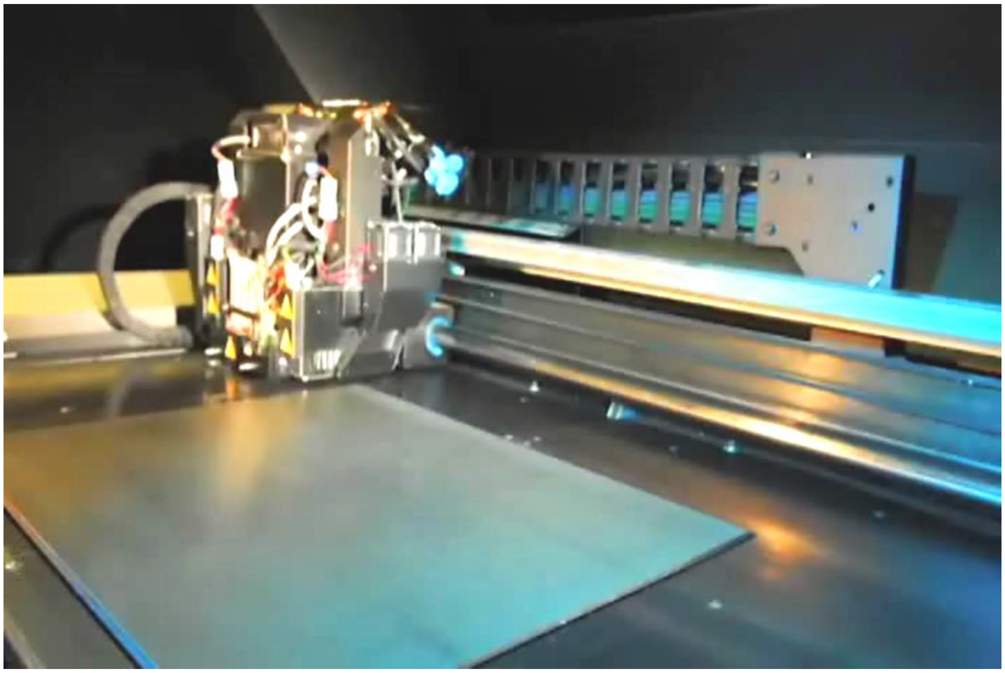
3.6.4 Photopolymer Phase Change Inkjets (PolyJet)

Inkjet printhead jets liquid photopolymer and support material

- UV light cures photopolymer and support material
- Excess material is removed using a roller
- The platform descends by one layer



Printing Process



3.6.4.1 Photopolymer Phase Change Inkjets Features

•Similar to SLA

–Also uses photopolymers

•The only technology supporting multiple materials

–Currently two + support material

•Materials

–Photopolymers only

–Can be mixed before curing -> graded materials

–Soft, rigid, opaque, transparent, different colors

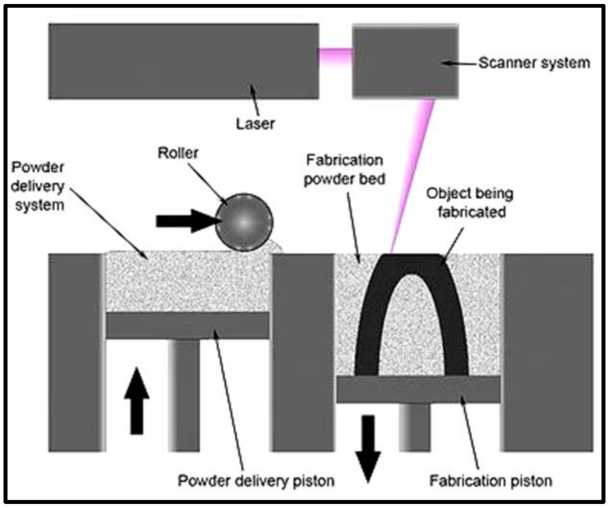
3.6.5 Selective laser sintering (SLS)

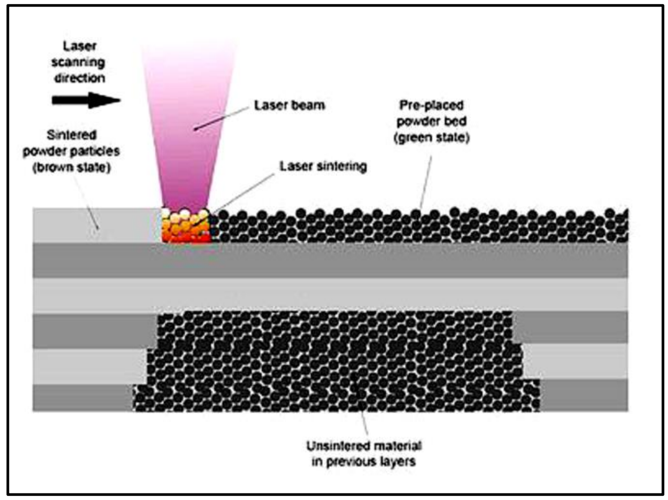
–Direct metal laser sintering (DMLS)

SLS and DMLS use a bed of small particles (made of plastic, metal, ceramic, or glass)

•High-power laser traces one layer on the surface of the powder bed fusing the particles

•The platform descends by one layer and more material is added





3.6.5.1 SLS & DMLS Features

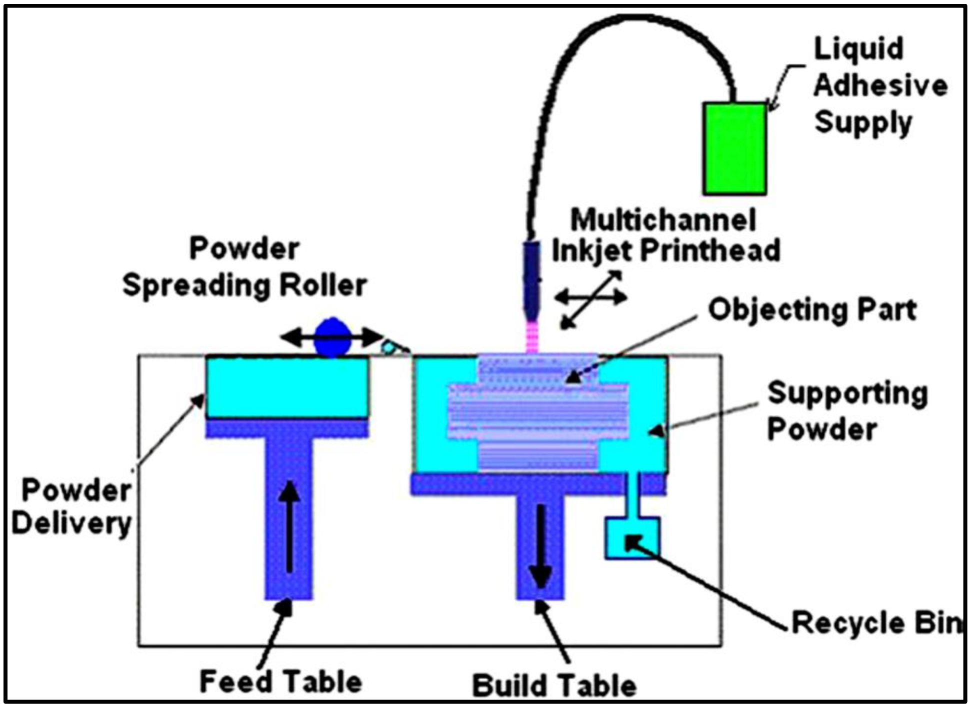
- •Laser and scanner system
  - –Similar do SLA but laser is more powerful
- •Bulk material can be preheated
  - –Reduces the required energy to melt it
- •Materials
  - –One material at a time
  - –Glass, polymers (e.g., nylon, polysterine), metals (e.g., steel, titanium, alloys), ceramic
- •Does not require support structure
  - –Overhangs are supported by powder material

3.6.6 Plaster-based 3D printing (PP)

–Powder bed and inkjet head 3D printing

This method uses a bed of small plaster particles

- Inkjet printhead prints with liquid adhesive (possibly colored), one layer on the surface of the powder bed fusing the particles
- The platform descends by one layer and more material is added



3.6.6.1 Plaster-based 3D Printing Features

- Similar to SLS and DMLS
  - Also uses granular materials
  - Uses inkjet printhead instead of laser
  - Glues particles instead of melting them
- Does not require support structure
  - Overhangs are supported by powder material
- The only technology supporting full-color printing
- Materials
  - Plaster only
  - Color can be applied (typically on/near the surface)
- Brittle, requires post-processing

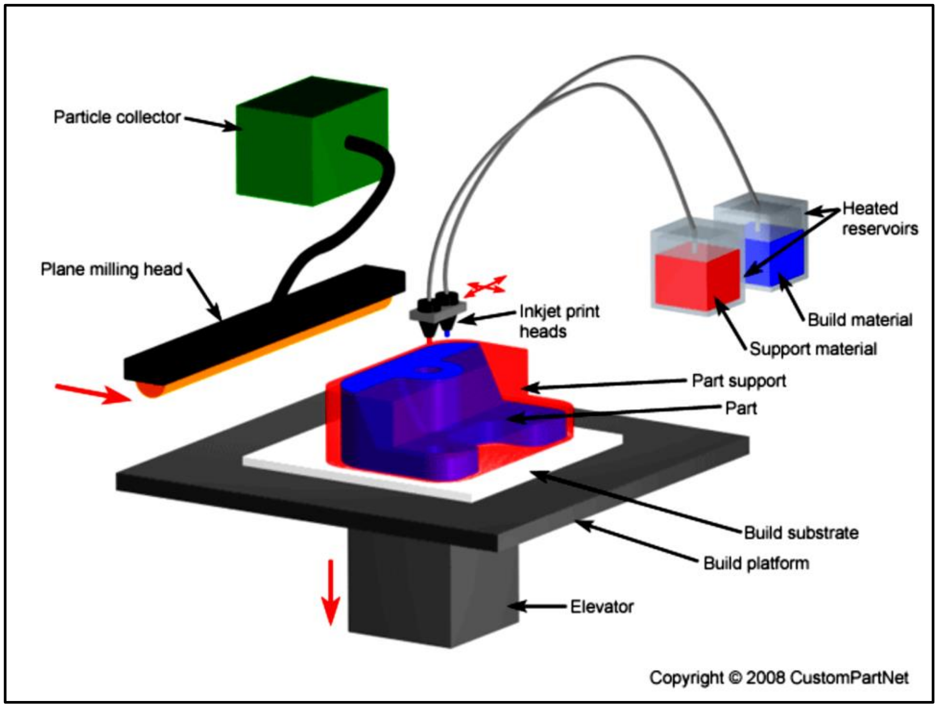
3.6.7 Thermal Phase Change Inkjets

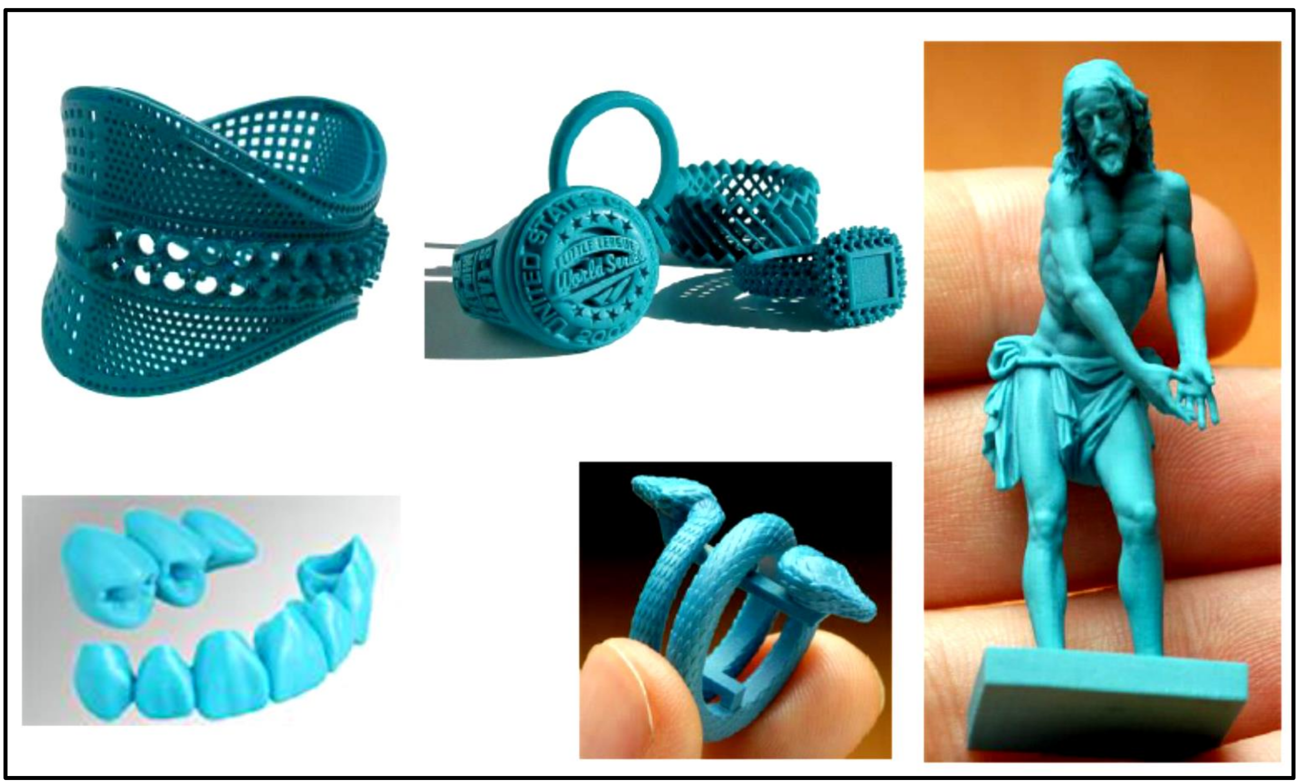
- Inkjet printhead jets heated liquid plastic and support material (wax)
- Material droplets solidify as they cool down
- Excess material is removed using a milling head to make a uniform thickness layer
- Particles are vacuumed away
- The platform descends by one layer

3.6.7.1 Thermal Phase Change Inkjets Features

- Extremely high resolution
- Slow printing time
- Materials
  - Limited: plastics and waxes
- Support material
  - Wax: easy to remove

- Manufactured objects are used as casting pattern but almost never as final functional parts

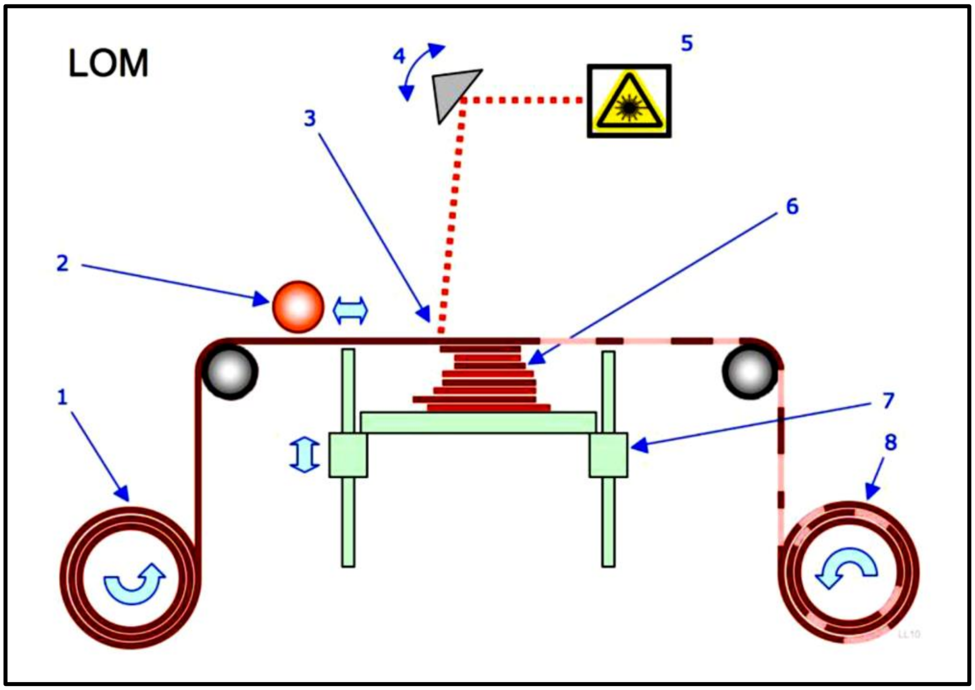




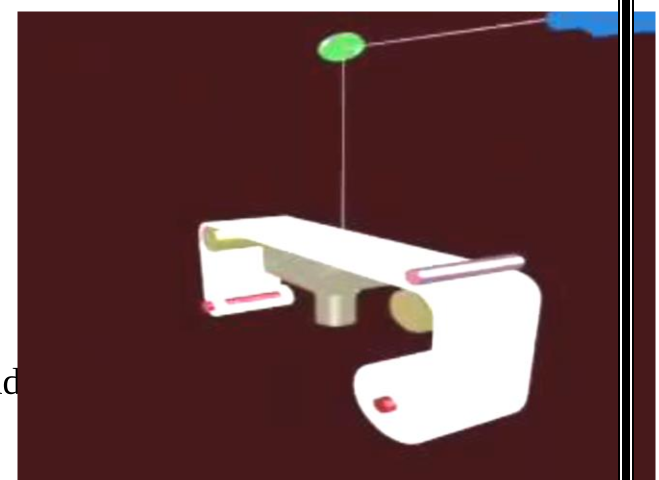
3.6.8 Laminated object manufacturing (LOM)

Sheet is adhered to a substrate with a heated roller

- Laser traces desired dimensions of prototype
- Laser cross hatches non-part area to facilitate waste removal
- Platform with completed layer moves down out of the way
- Fresh sheet of material is rolled into position
- Platform moves up into position to receive next layer



1 Foil supply. 2 Heated roller. 3 Laser beam. 4. Scanning prism. 5 Laser unit. 6 Layers. 7 Moving platform. 8 Waste



3.6.8.1 Laminated Object Manufacturing Features

- Inexpensive – low material cost
- Print resolution is lower than other methods
- Color can be added using additional printhead
- Materials

– Paper (most common), plastics, composites, metal, ceramics

- Support material

– Same material can be used as support






Acronym	
AM	Additive Manufacturing
AMF	Additive Manufacturing File Format
ASTM	American Society for Testing and Materials
CAD	Computer-Aided Drawing
DMLS	Direct Metal Laser Sintering
EL	Engineering Laboratory
ISO	International Organization for Standardization
LOTAR	Long Term Archiving and Retrieval
LTA	Long Term Archiving
NAMII	National Additive Manufacturing Innovation Institute
NIST	National Institute of Standards and Technology
PICAM	Product Information for Composites and Additive Manufacturing
PDM	Product Data Management
SIMCA	Systems Integration for Manufacturing and Construction Applications
STEP	Standard for the Exchange of Product model data
STL	Stereolithography File Format
UV	Ultra-violet
XML	eXtensible Markup Language