Future Trends in Additive Manufacturing and Space Applications

James F. Bredt, Ph.D
CTO, Viridis3D LLC
Cofounder, Z Corporation
Aug 2013

Massachusetts Institute of Technology

Who Am I?

- Cofounder of Z Corporation
  - Chief of Materials Development
  - Created many of the software algorithms for full-color 3DP
  - Left in 2005 to work at MIT
- CTO of Viridis3D
  - Develop materials and processes for industrial 3D Printing
  - Presently working on a robot-based 3D Printer for ceramics and foundry applications
- MIT: Research and teaching in Materials Science
- James H. Bredt was my father
  - Program Administrator at NASA in the 70's and 80's
  - Worked on Manufacturing in Space
  - Worked on Environmental Controls for long-term missions.
  - Source of several of the metaphors I may use in this talk

Massachusetts Institute of Technology

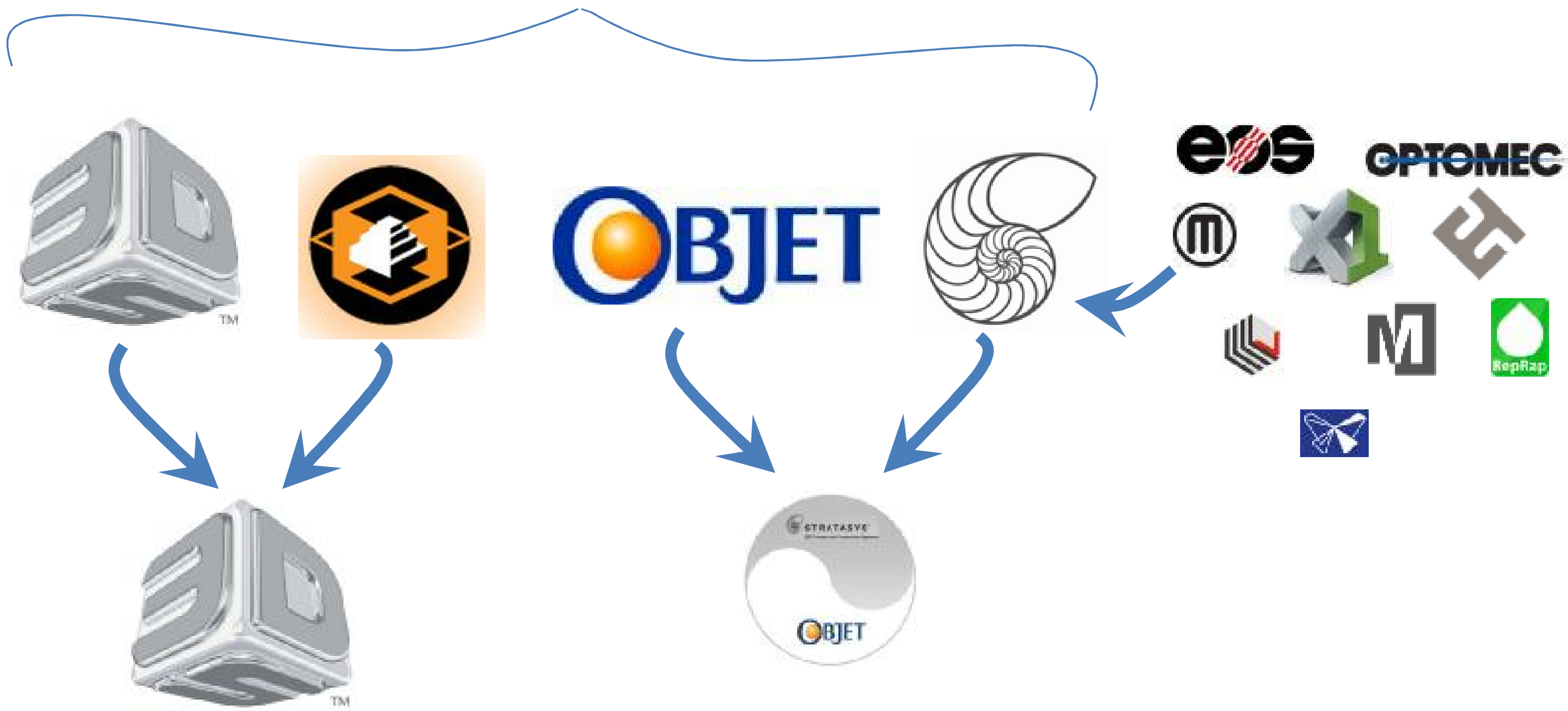
Viridis3D LLC

Outline

- AM Industry Trends
- Innovation in AM
- Review by Technology
- Conclusions

2012-13 Industry Consolidation

~ ¾ of Market Share



Corporate Acquisitions are NOT Good for Technological Innovation!

Massachusetts Institute of Technology

Viridis3D LLC

Low-End Race to the Bottom

Explosion of low-cost AM systems are attracting attention of large players.

ca. 2007

ca. 2010

2013

Innovation is being directed towards cheaper equipment, not to expanding capabilities.

Massachusetts Institute of Technology

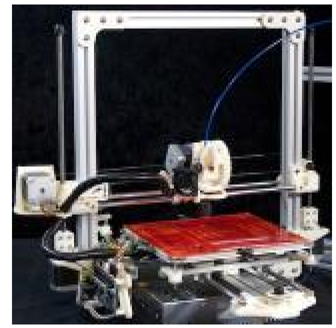
Viridis3D LLC

Tissue Engineering

Low-end systems are getting adapted where possible in R&D efforts

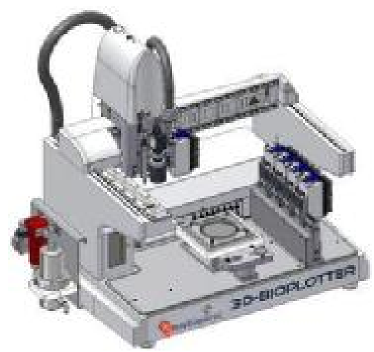
Princeton

Mott Children's Hospital



U. Manchester

Cornell



Envision TEC

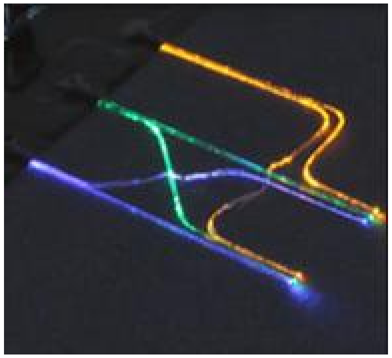
U. Iowa

Massachusetts Institute of Technology

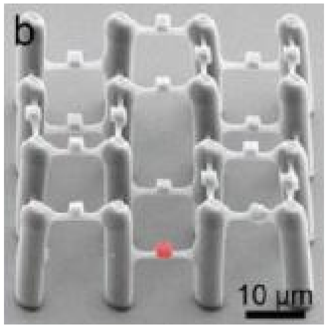
Viridis3D LLC

Biomimetics, Soft Robotics, Heterostructures

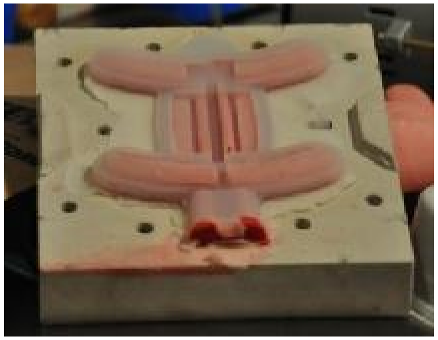
OptoMEC



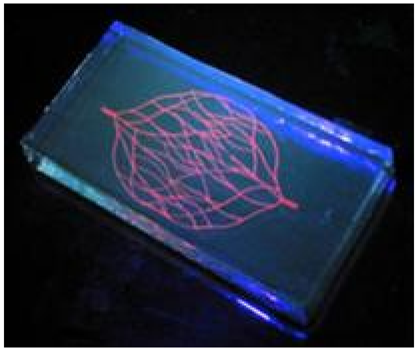
Harvard Lewis Grp.



Nanoscribe



Borgatti



Harvard Lewis Grp.

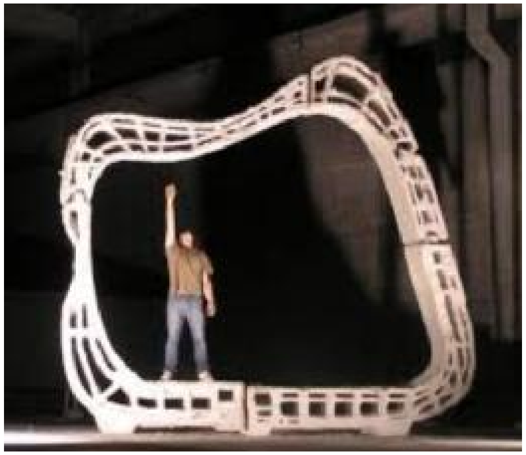
Indiegogo

Massachusetts Institute of Technology

Viridis3D LLC

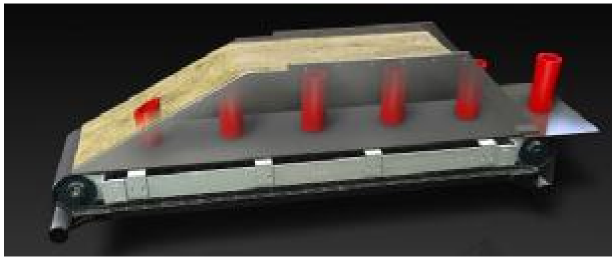
Industrial 3D Printing

Smaller companies are finding a niche in the industrial market neglected by large players.

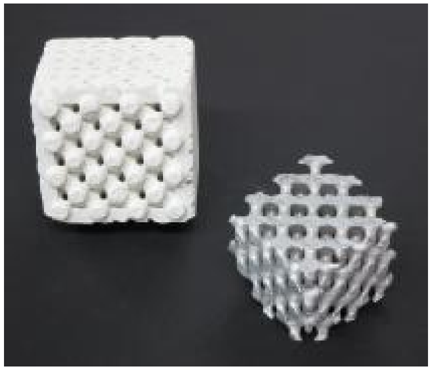


D-Shape

EOS



VoxelJet



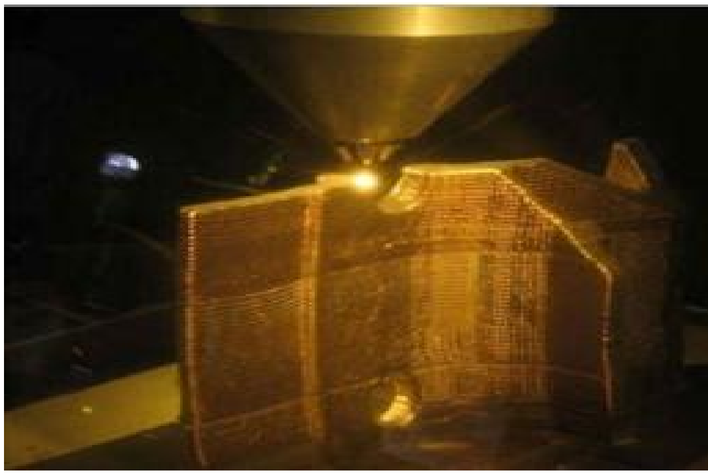
Viridis3D

Massachusetts Institute of Technology

Viridis3D LLC

Review of Trends by Technology

…and applications in space…



…either on a space station or on Moon base.

- Operation in zero G or with Moon gravity
- Large-scale production must be in the vacuum
- Raw material sources might include metallic asteroids, materials refined from Moon dust
- Biopolymer from algae farm or food processing

Massachusetts Institute of Technology

Viridis3D LLC

How Do You Invent a 3D Printer?

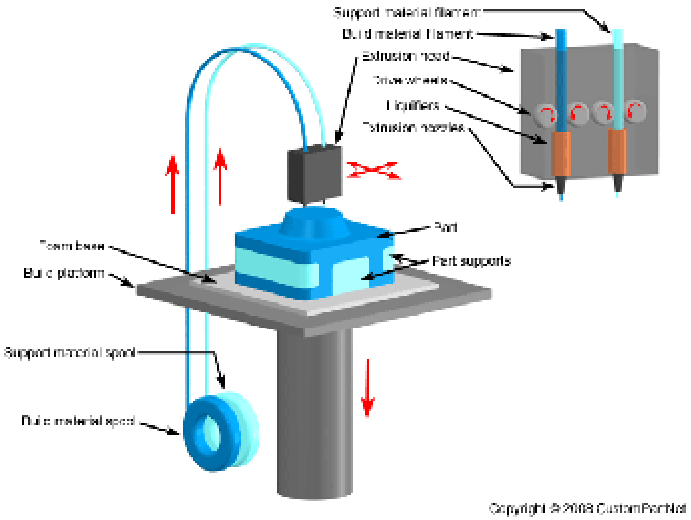
Material Dispenser

Manipulator

FANUC

- Select class of materials, accuracy and build size
- Select or invent dispenser
- Refine material selection to achieve best performance
- Manipulator follows from size, accuracy, and environmental requirements

Fused Deposition Modeling



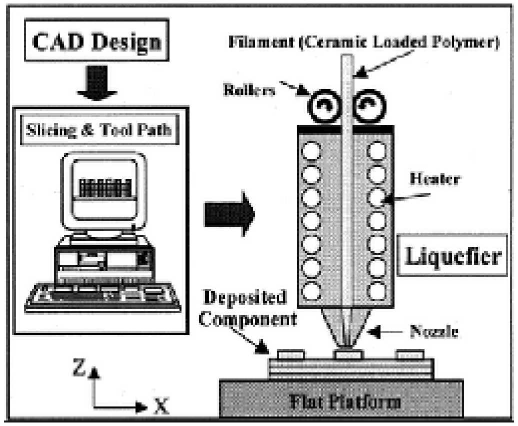
CustomPartNet

futuristicnews.com

- Most people who have heard of '3D Printing' think this is it.
- Build material is thermoplastic supplied as a filament
- Extrusion head travels over platen dispensing a bead
- Requires supports, may be different material from build

Process Features

- ABS, PLA, polyamide, acrylic, wax.
- Ceramic and metal powders as fillers
- Build rate: ~0.5 in/hr
- Build size: up to 36x24x36”
- One of the few methods that gives plastic parts at nearly full density
- Has already been flown in space
- Some materials might work in vacuum
- Materials such as PLA and cellulosics could be available from food proc.



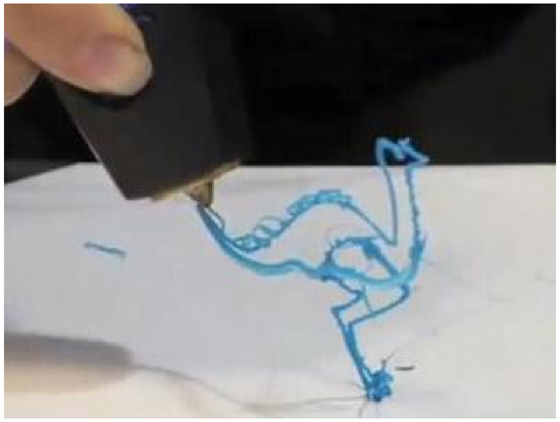
JECS 21, 1485-1490 (2001)

Companies: Stratasys, HP, Beijng Yinhua

Low-end FDM

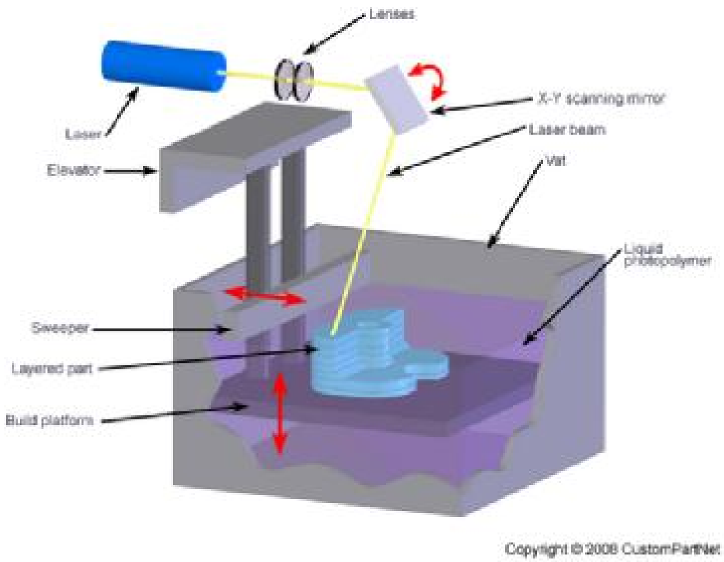
- Presently driving the AM industry.
- Systems costing less than $5000
- Kits as low as $75
- Size typically 4-6 in.
- Same materials as high-end FDM
- Companies: Stratasys (acq. of MakerBot) 3Doodler, Fabbster, 3D Systems (BitsFromBytes) RepRap, Fab@Home, Delta Micro Factory, and dozens of others

Delta Micro Factory



3Doodler

Stereolithography

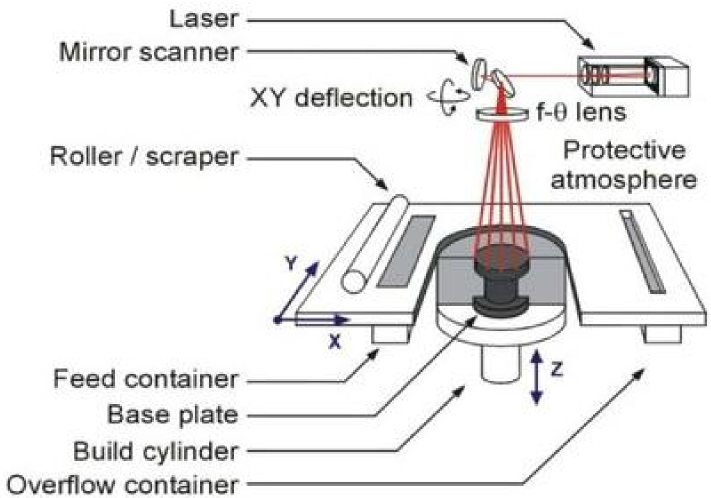


howstuffworks.com

- Build material is liquid photopolymer in tank
- Laser spot travels over top surface, curing polymer in layers.
- Ceramic and metal fillers are being explored
- Requires gravity, atmosphere. Petrochemical & have strong odor.

Companies: 3D Systems, FormLabs CMET, TNO

Laser Sintering/Melting



KU Leuven

EOS

- Build material is powder in a leveled bed.
- Laser spot melts (or sinters) powder grains in layers
- Bed is lowered in steps, and powder is spread by roller.
- Layers are supported during build by unbound powder

Process Features

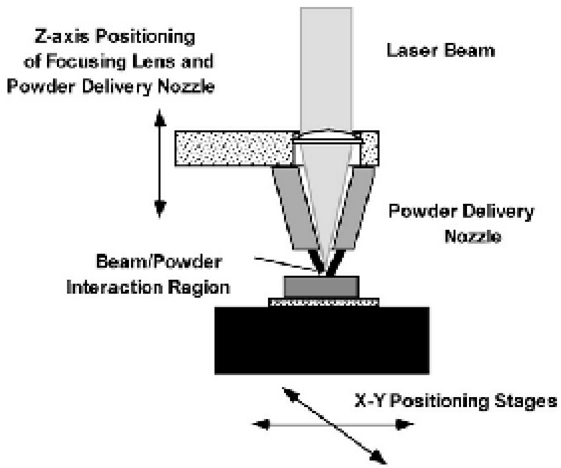
- Fully dense stainless steels, tool steels, nickel alloys, Co-Cr, Ti, Cu, Al
- Best mechanical strength
- Polymers: ABS, Polyamide, PEEK
- Build rate ~ 5 mm^3/sec
- Build size: 10x10x12” (metals)
- Up to 22x22x30” (plastics)
- Requires gravity
- Metals probably work BETTER in vacuum

EOS

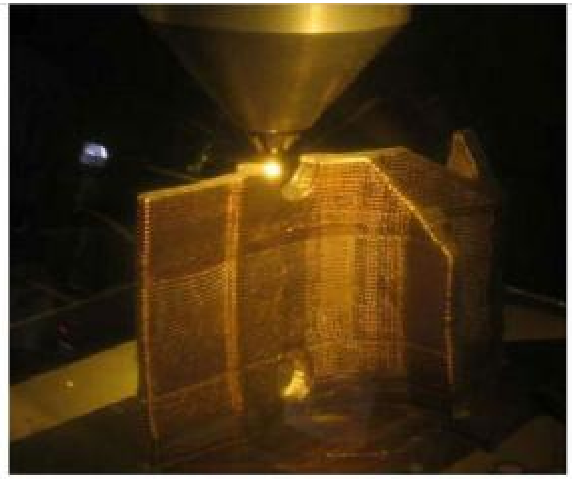
Schneider Prototyping

Companies: 3D Systems, EOS, Concept Laser, Realizer, Phenix, MTT, Arcam (E-beam)

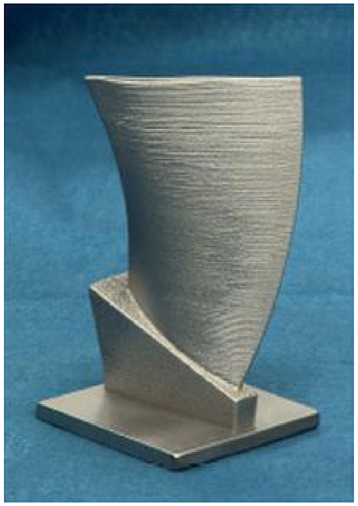
Laser Cladding



Stratonics, Inc



Stratonics, Inc



Sandia

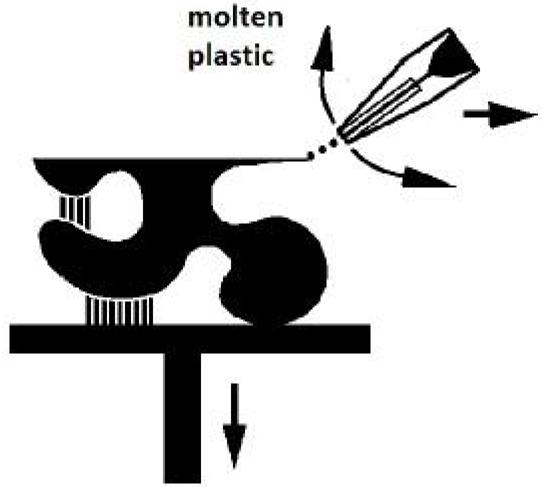
Metal powders applied in stream to laser spot on substrate

System is robotic, no powder bed. Parts up to 3 meters.

Zero G, vacuum operation might be feasible

Companies: Optomec, POM

Ballistic Particle Manufacturing



Droplets of molten polymer are shot from a DOD printhead onto a substrate using a 6-axis robot.

No size limitation, but build rate is very slow.

Possible applications with metals, should work in zero G, vacuum.

Companies: None – BPM Inc. failed in 1997

Inkjet on Platen

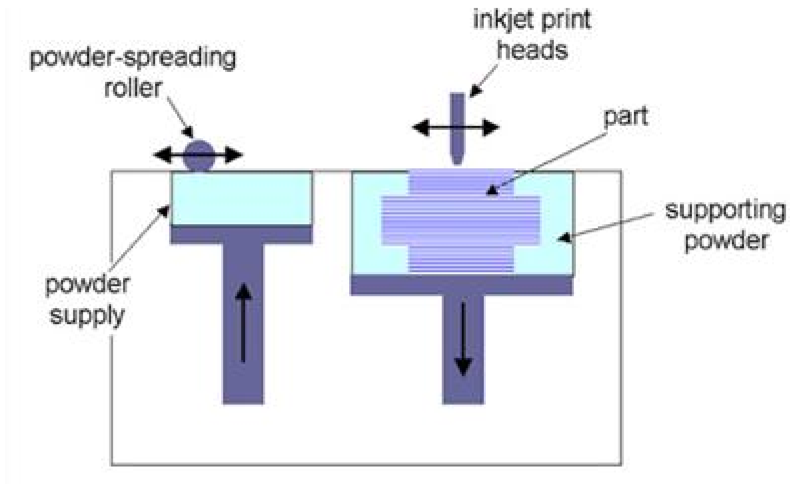
- Material is photopolymer liquid dispensed through an inkjet printhead. Cured with UV lamp
- Acrylics, epoxies, elastomers.
- Features ~.001 in.
- Build size: up to 20x15x8”
- Build rate ~1 in/hr
- Can build functionally gradient parts, such as elastomers with varying stiffness.
- Can work in zero G
- Requires atmosphere, ventilation.

Company: Objet (merged 2013 with Stratasys)

Objet

Inkjet on powder

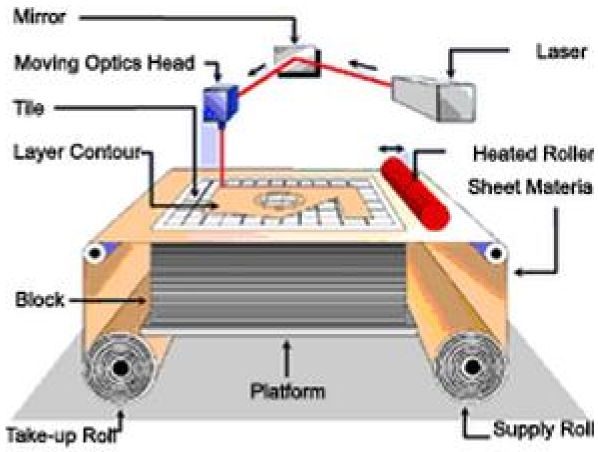
- Powdered substrate bonded by solvent printed through inkjet printhead.
- Filled polymers, resin-bonded sand, metals (EX One)
- Ceramics, refractories, cements (Viridis)
- Build rate: ~2 in/hr (ZCorp)
- Size: Up to 80x120x40" (VoxelJet)
- Robotic system available soon(Viridis)
- Powder-based system requires no support structures
- Requires gravity, atmosphere.



ZCorp

Companies: 3D Systems (acq. ZCorp 2012), EXOne, VoxelJet, Viridis3D

Laminated Object Manufacturing



Helisys


3Dprintingindustry.com

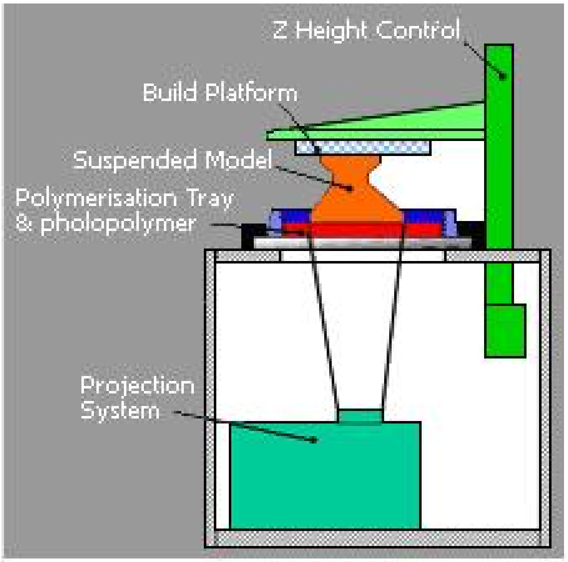

MCOR

- Adhesive-coated paper is laminated onto a growing stack.
- A laser or cutting tool carves the contours of each layer.
- Unused material is diced into cubes and removed after.
- Very fast & reliable machine, materials not too specialized
- Full color is available, first since ZCorp in 2001.
- Can work in zero G, doesn't require atmosphere.

Companies: MCOR, Helisys (closed)

Digital Light Processing

- Photopolymer bath cured by projected light
- Layers cured against window at bottom of tank.
- Platform is stepped upwards.
- Simple, reliable architecture
- Build rate ~1 in/hr.
- Resolution determined by pixel size of projector
- Fine features for jewelry pattern making
- Ceramic-filled resins are possible
- Might be feasible in zero G
- Requires ventilation



thecastinghaus.com

Jan Boon

Company: EnvisionTEC

Envisiontec

Massachusetts Institute of Technology

Conclusion

- Several technologies are feasible for making plastic replacement parts in space
- Robotic systems best for building large structures
- Metal powder or wire-feed machines building of large structures (e.g. rockets) could work very well in vacuum
- To detach raw material supply from Earth, need metals source:

  Asteroid or electro-refining of Moon rock