

Brza izrada prototipova i alata

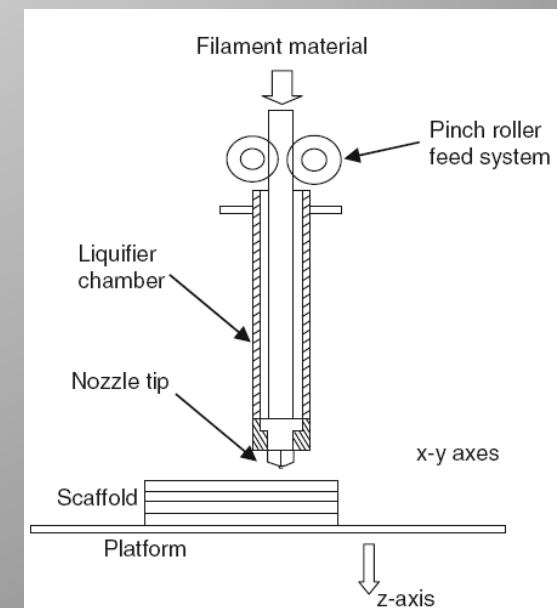
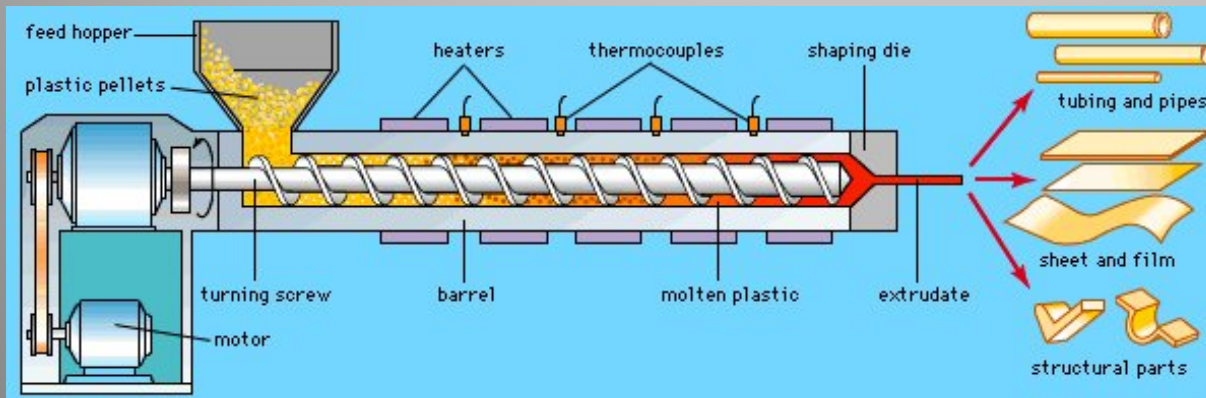
Nastavnik:
Prof. Dr Mladomir Milutinović

Asistent:
Dejan Movrin

Postupci na bazi čvrstih materijala

Postupci bazirani na principu ekstruzije

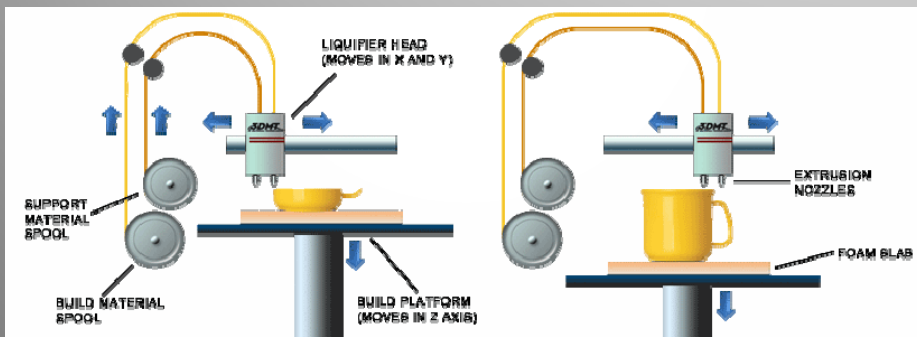
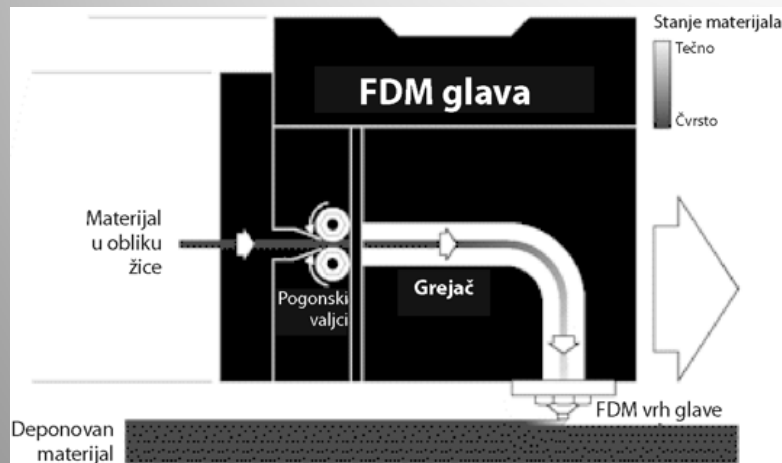
- Dopremanje materijala
- Topljenje materijala
- Postiskivanje materijala (pod dejstvom pritiska ili gravitacije)
- Ekstruzija
- Plotovanje u X-Y ravni
- Vezivanje i očvršćavanje materijala (hlađenjem ili hemijskim putem)
- Izrada potpornih struktura



Fused Deposition Modeling (FDM)

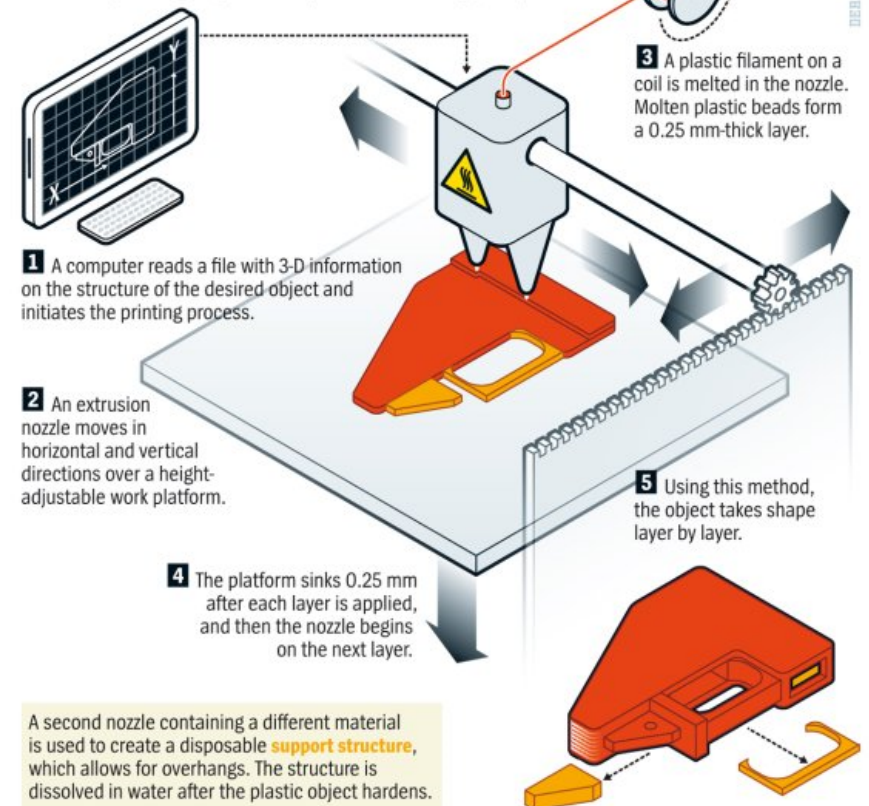
Modeliranje deponovanjem topljenog materijala

- Scott Crump, Stratasys Inc., Minesota, SAD
- Prvi komercijalni FDM sistem se pojavio 1992. godine - 3D modeler



Inside a 3-D Printer

How a 3-D printer using fused deposition modeling (FDM) works

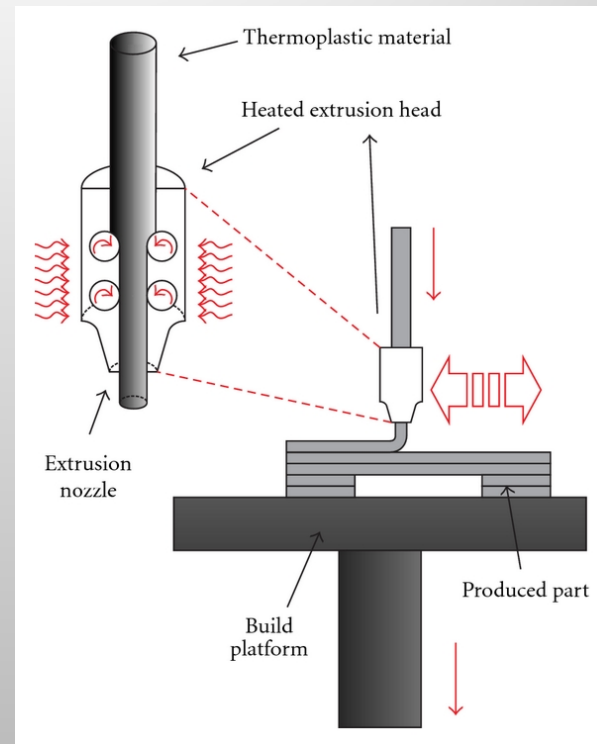




Fused Deposition Modeling (FDM)

Parametri procesa

- Vrste materijala
- Čvrstoća materijala
- Modul savijanja
- Viskoznost
- Prečnik žice
- Tačnost pozicioniranja glave
- Brzina deponovanja
- Zapreminski protok
- Prečnik mlaznice
- Temperatura
- Geometrija dela



Materijali: ABS (acrylonitrile butadiene styrene), Vosak, Elastomeri, Amorfni polimeri, Keramički materijali (pasta), **Metalni materijali (niska T_{top})**.

Prečnik mlaznice: 0,18mm

Razmak između mlaznice i platforme → Širina sloja 0,250 – 0,965 mm (2,5mm)

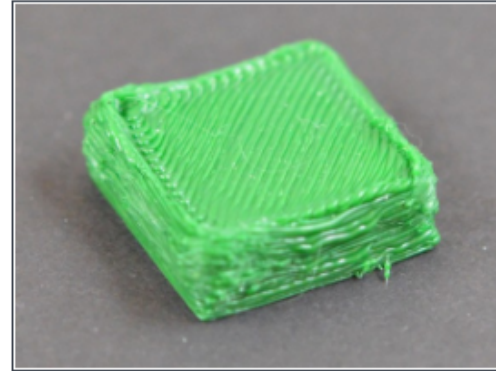
Debljina sloja: 0,2 – 0,25mm (0,125mm, 0,078 mm)

Temperatura: 0,5 veća T_{top} (70 °C za vosak i 270 °C za ABS termoplast)

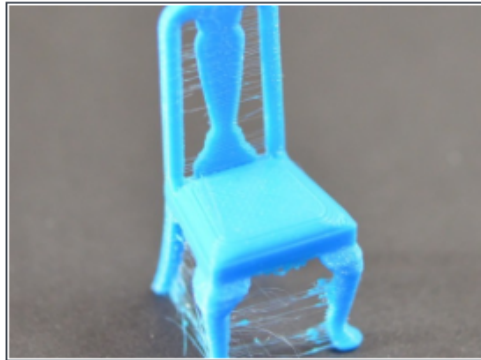
Vreme očvršćavanja: 0,1s



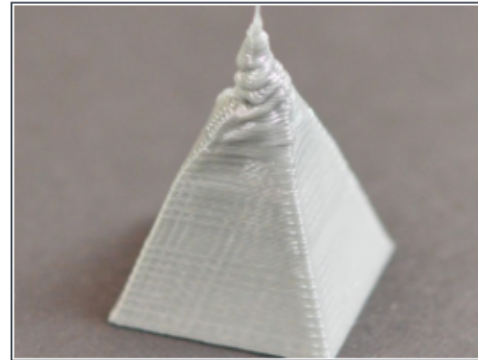
Under-Extrusion



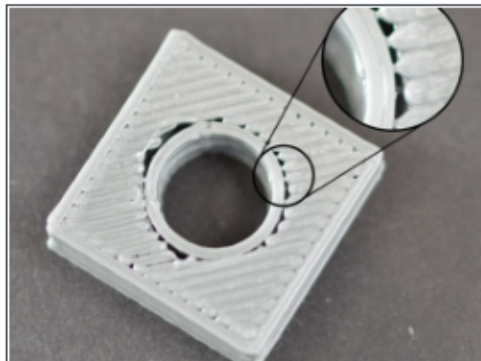
Over-Extrusion



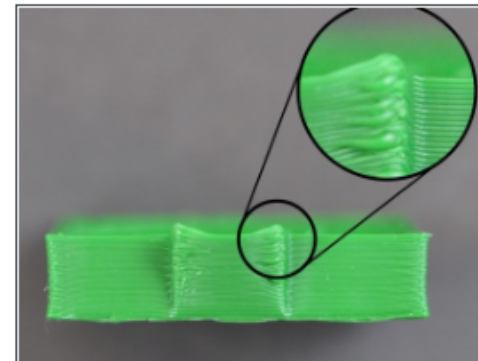
Stringing or Oozing



Overheating



Gaps Between Infill and Outline



Curling or Rough Corners

Fused Deposition Modeling (FDM)

Glavne prednosti

- ✓ Izrada funkcionalnih delova
- ✓ Minimum otpada
- ✓ Lako uklanjanje oslonaca
- ✓ Brza i jednostavna promene materijala
- ✓ Cena
- ✓ Lako i pogodno manipulisanje podacima
- ✓ Nema zagađenja okoline štetnim isparavanjima.
- ✓ Nije potrebno postprocesiranje modela
- ✓ Brza i laka instalacija sistema

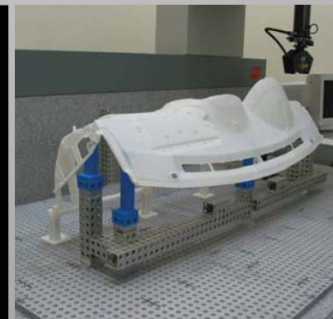
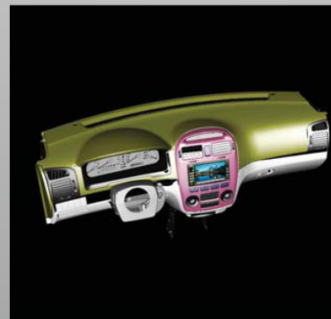
Nedostaci procesa

- Relativno niska tačnost delova
- Sporost procesa
- Nepredvidivo skupljanje

Fused Deposition Modeling (FDM)

Primena FDM

- ❑ **Modeli za konceptualizaciju i prezentaciju.** Modeli se mogu peskariti, bojiti, etiketirati i bušiti pa se može dobiti izgled krajnjeg proizvoda.
- ❑ **Prototipovi za dizajn, analizu i funkcionalna ispitivanja.** Mogu se proizvesti potpuno funkcionalni prototipovi od ABS plastike. Takvi delovi imaju 85% čvrstoće krajnjeg proizvoda. Zato se mogu sprovesti testiranja u eksploataciji, posebno za proizvode široke potrošnje.
- ❑ **Šabloni i master modeli za izradu alata.** Modeli se mogu koristiti za precizno livenje, livenje u pesku i livenje pod pritiskom



Fused Deposition Modeling (FDM)



How does FDM compare with traditional processes for Lamborghini Lab?

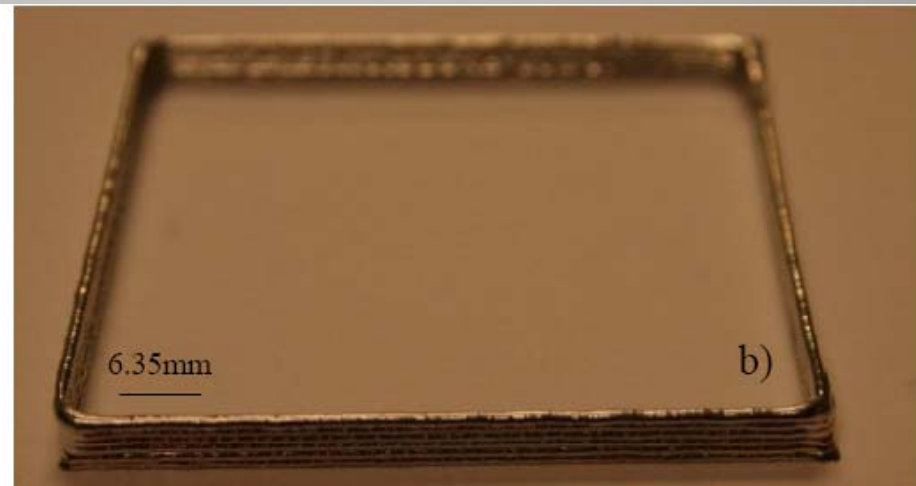
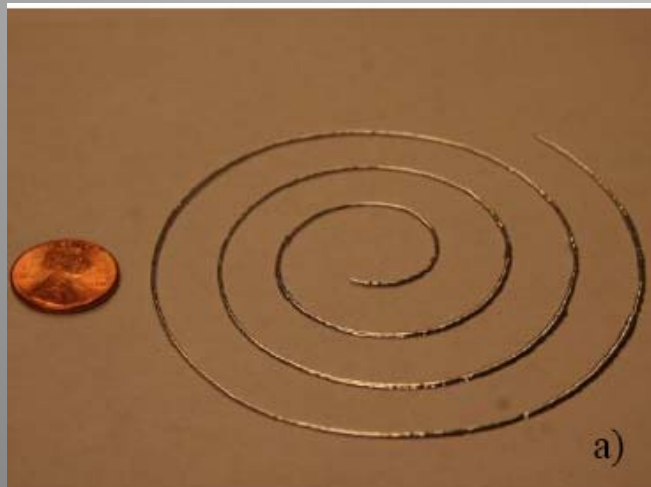
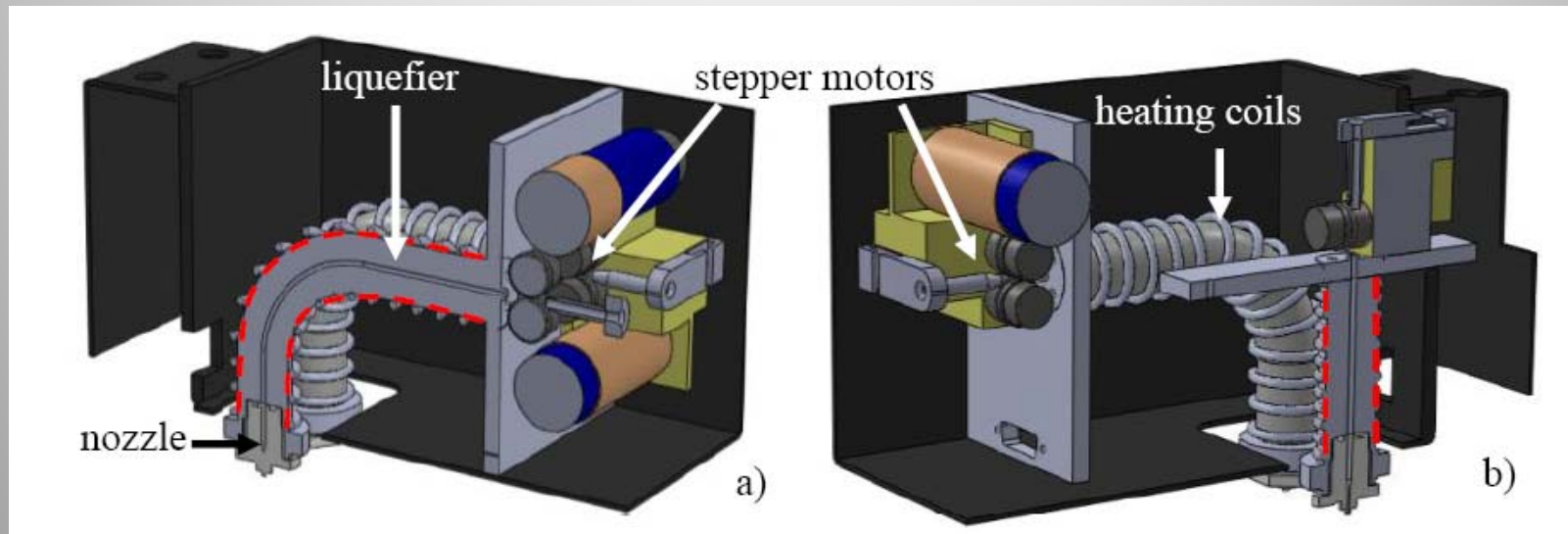
| Method | Cost | Lead Time |
|---------------------|----------------|---------------|
| Traditional process | \$40,000 | 120 days |
| FDM Technology | \$3,090 | 20 days |
| Savings | \$36,910 (92%) | 12 days (80%) |

Karakteristike FDM sistema firme Stratasys

| Model | Prodigy Plus | FDM Vantage SE | FDM Titan | FDM Maxum |
|--------------------------|---|--|--|--|
| Maksimalna veličina dela | 203x203x305 mm | 406x355x406 mm | 406x355x406 mm | 600x500x600 mm |
| Tačnost | ±0,127 mm | do 127 mm: ±0,127 mm preko 127 mm: ±0,038 mm/mm | do 127 mm: ±0,127 mm preko 127 mm: ±0,038 mm/mm | do 127 mm: ±0,127 mm preko 127 mm: ±0,038 mm/mm |
| Debljina sloja | fina – 0,178 mm standardna – 0,254 mm gruba – 0,33 mm | 0,127 do 0,254 mm | 0,178 do 0,356 mm | 0,178 do 0,356 mm |
| Materijal | ABS | ABS, polikarbonat | ABS, polikarbonat, polifenilsulfon | ABS, ABSi |
| Sistem izrade oslonaca | WaterWorks | WaterWorks, BASS | WaterWorks, BASS | WaterWorks |

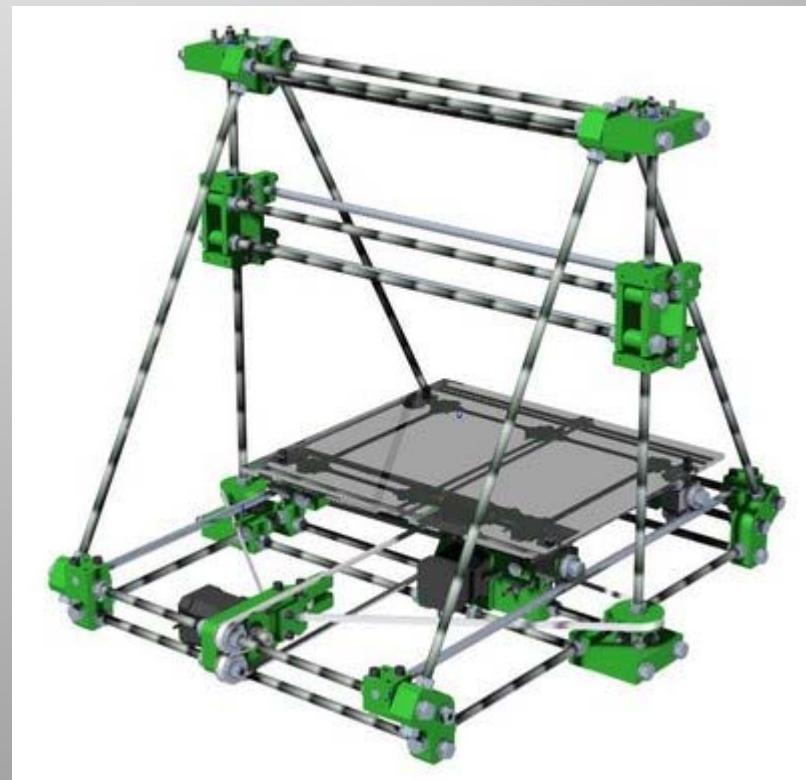
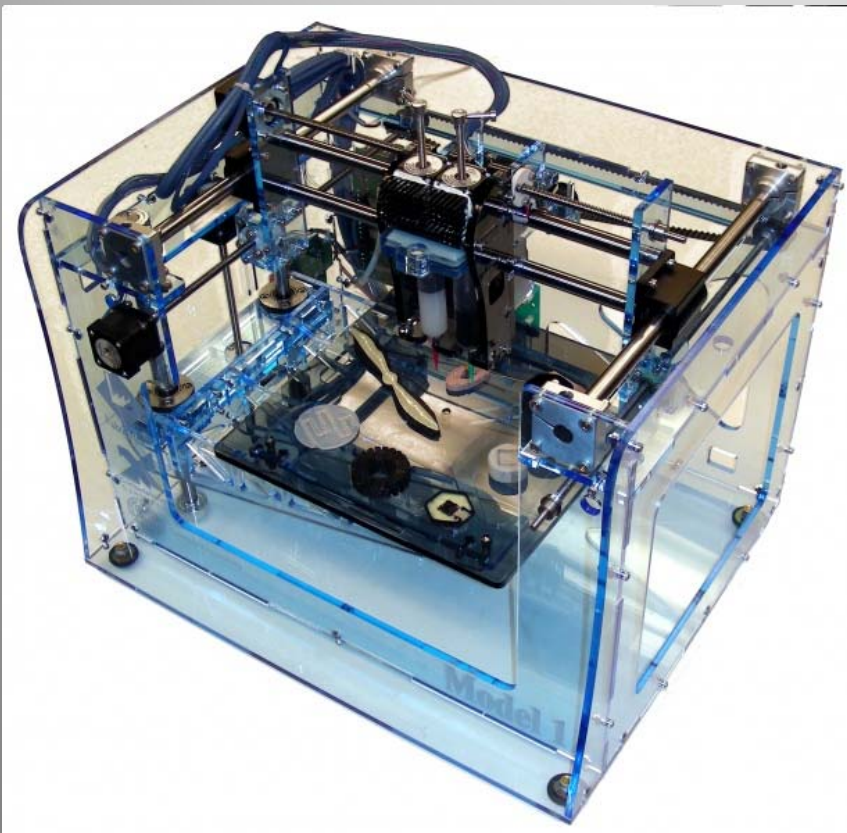


FDM Metala

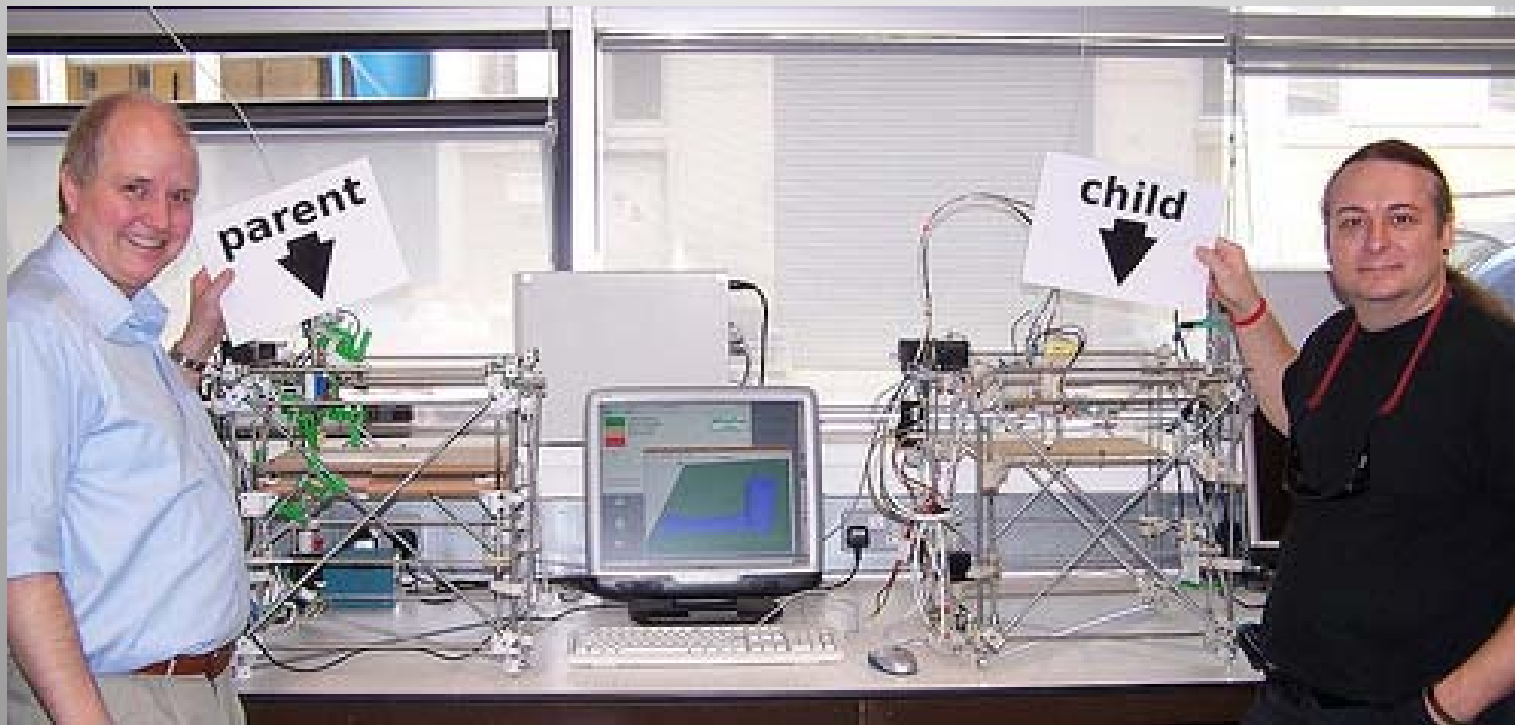


Do it Yourself FDM rapid prototyping (cost under \$5K)

- FAB@Home
- RepRap

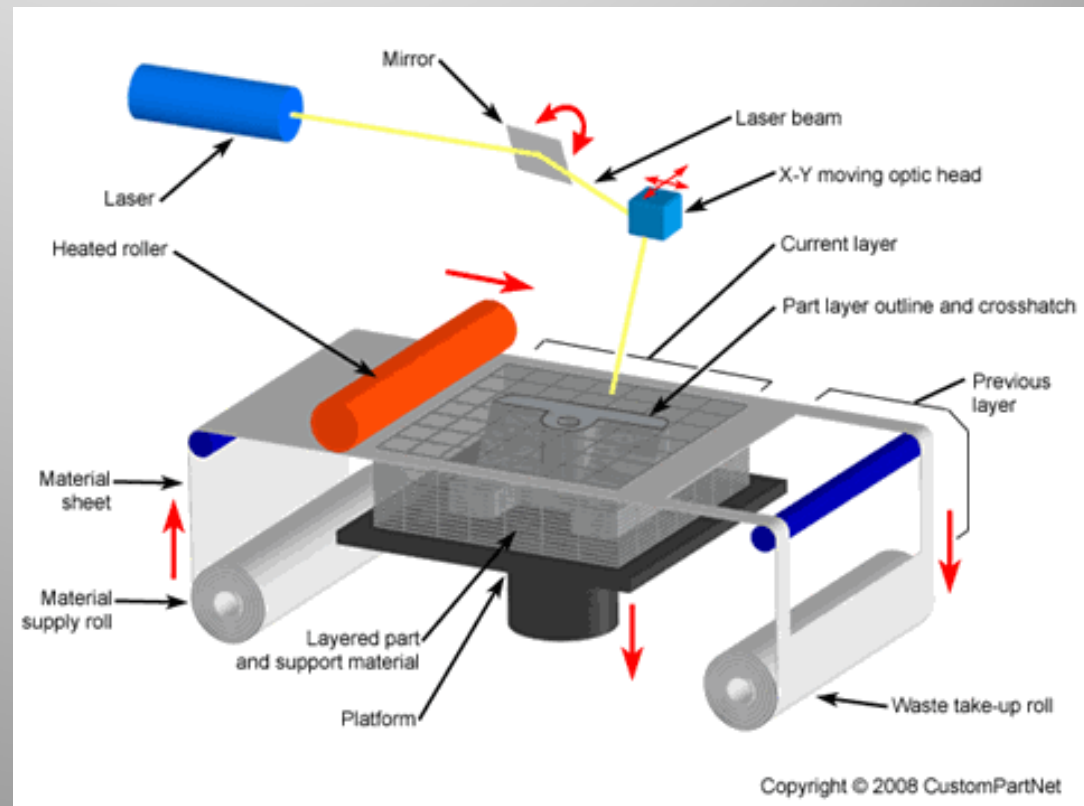


The Future ? Self-replication !



Laminated Object Manufacturing (LOM)

- Cubic and Helisys, 1991
- Laminirani objekat
- Veoma jednostavan postupak
- Solid Freedom Fabrication (SFF)

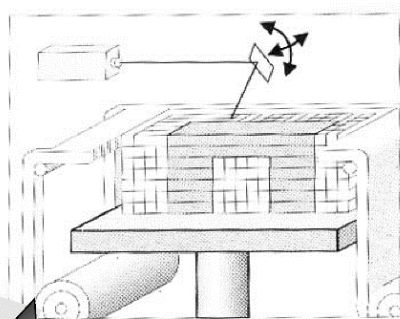


Laminated Object Manufacturing (LOM)

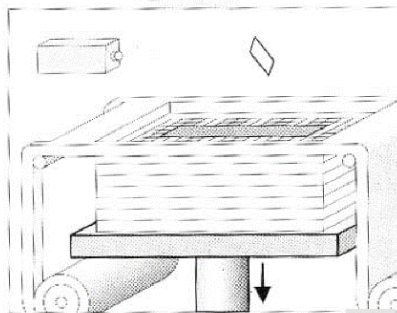
Faze procesa

Procesiranje

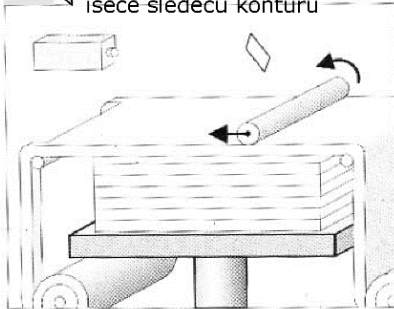
1. Isecanje konture laserskim zrakom



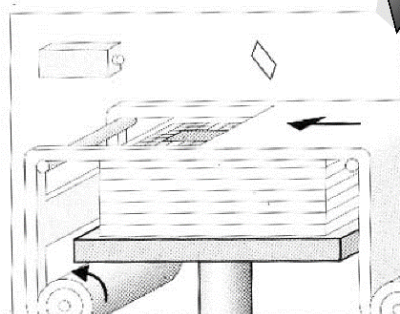
2. Spuštanje platforme za debljinu sloja



4. Premazivanje materijala lepkom pre nego što laserski zrak iseče sledeću konturu

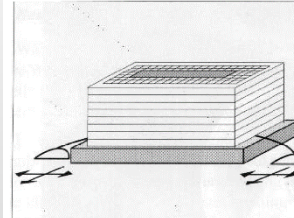


3. Dotur novog materijala



Post-Procesiranje

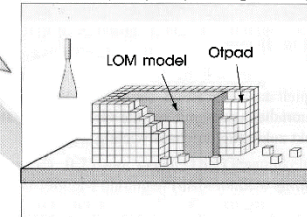
1. Skidanje sa platforme



2. Vađenje iz okvira



3. Odstranjivanje otpadnog materijala



(a)



(b)



Laminated Object Manufacturing (LOM)



Laminated Object Manufacturing (LOM)

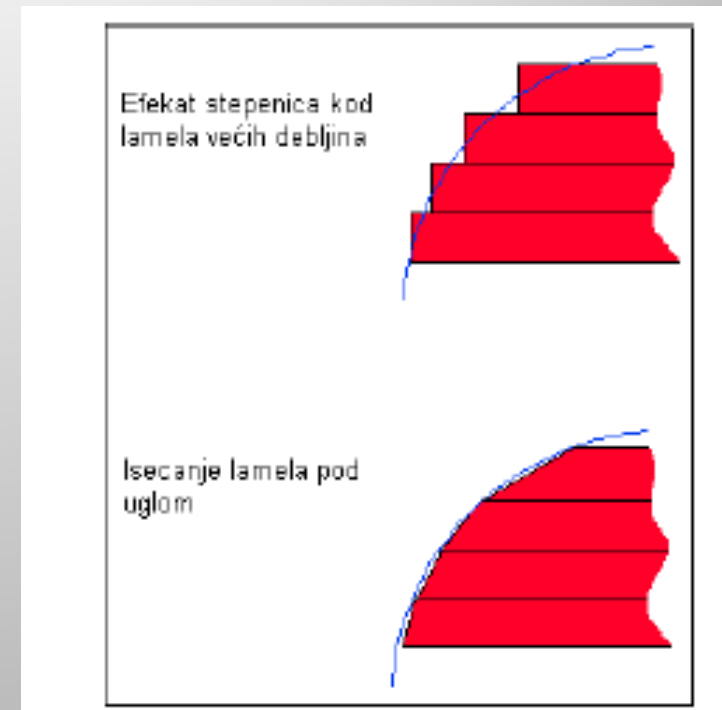
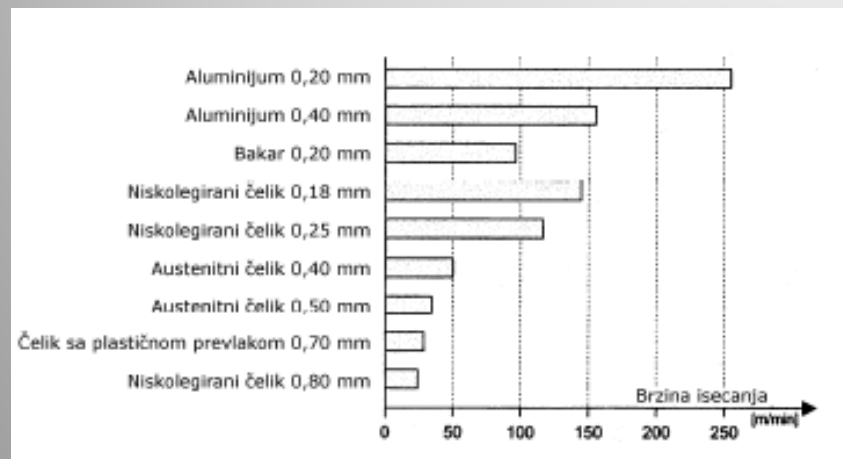
Glavne prednosti

- ✓ Široki spektar materijala
(papir, plastika, metal, keramika, kompoziti)
- ✓ Brzina
- ✓ Izrada delova velikih dimenzija
- ✓ Visoka tačnost u X, Y, Z parvcu (0.127 mm)
- ✓ Neosetljivost na skupljanje
- ✓ Nema potrebe za osloncima
- ✓ Nema zagađenja okoline
- ✓ Kratko vreme postprocesiranja modela
- ✓ Nema zaostalih napona

Nedostaci procesa

- Kontrola snage lasera
- Problem izrade delova sa tankim zidovima
- Čvrstoća (adhezija slojeva)
- Anizotropnost osobina
- Uklanjanje viška materijala iz otvora modela
- Nužno je lakiranje prototipa da bi se izbeglo upijanje vlage i time promena dimenzija
- Veliki otpadak materijala

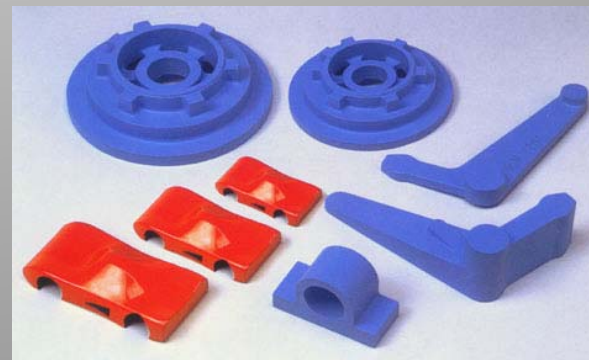
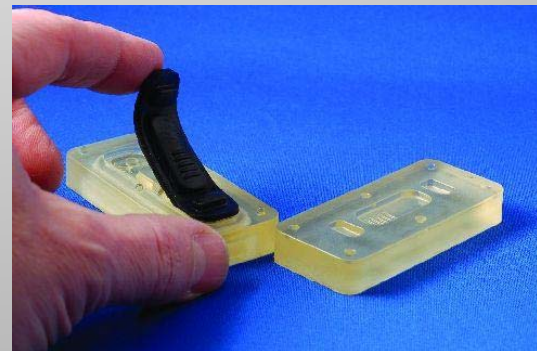
Laminated Object Manufacturing (LOM)



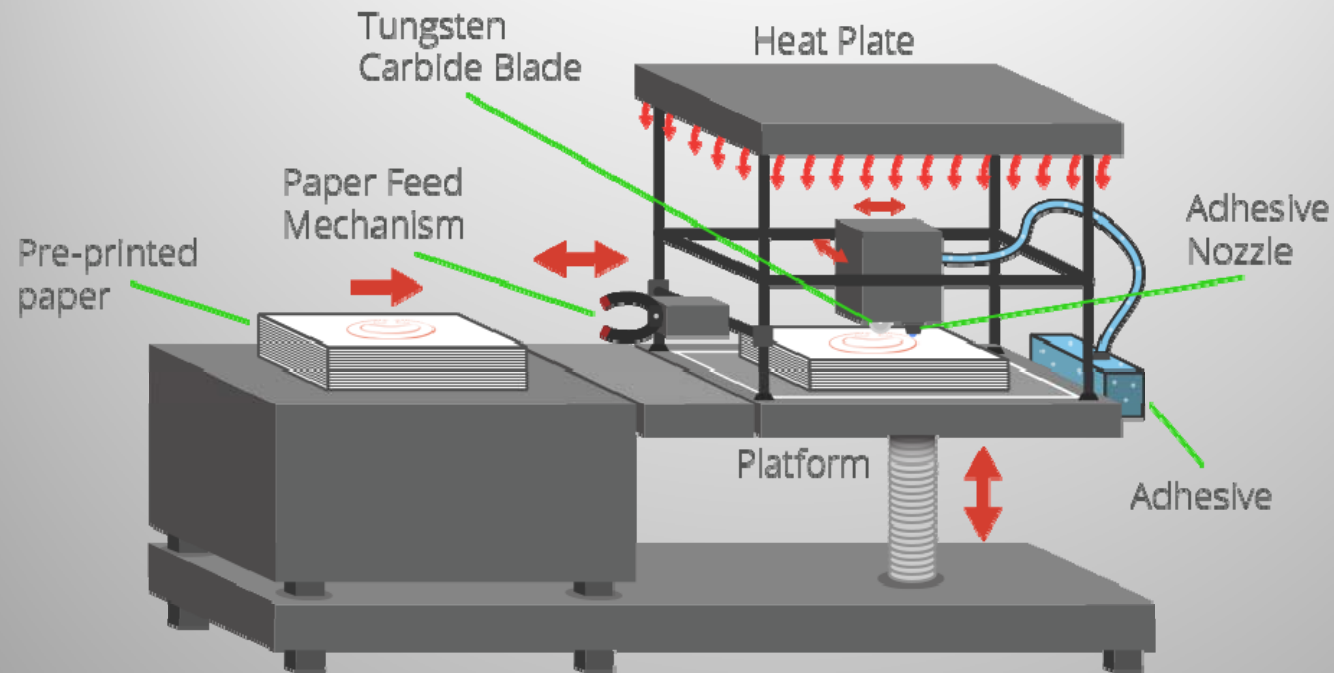
Laminated Object Manufacturing (LOM)


Primena LOM


- ❑ **Vizuelizacija objekata.** Objekti se obično proizvode u prirodnoj veličini i naknadno obrađuju i boje. Replika proizvoda.
- ❑ **Provera dizajna, uklapanja i funkcionalnosti.** Mogu se sprovesti bazična ispitivanja.
- ❑ **Izrada modela.** (precizno livenje, livenje u pesku, vakumsko livenje, injekciono presovanje, Modeli za oblikovanje alata za oblikovanje gume i silikona, sprej-metal itd.),
- ❑ **Rapid Tooling.** Alati za injekciono presovanje voska, poliuretana, silikona, epoksi, gume itd.

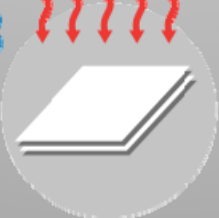



Selective Deposition Lamination (SDL)




- 

1 First sheet of paper is added to the platform
- 

2 The adhesive is added to the select areas of the paper
- 

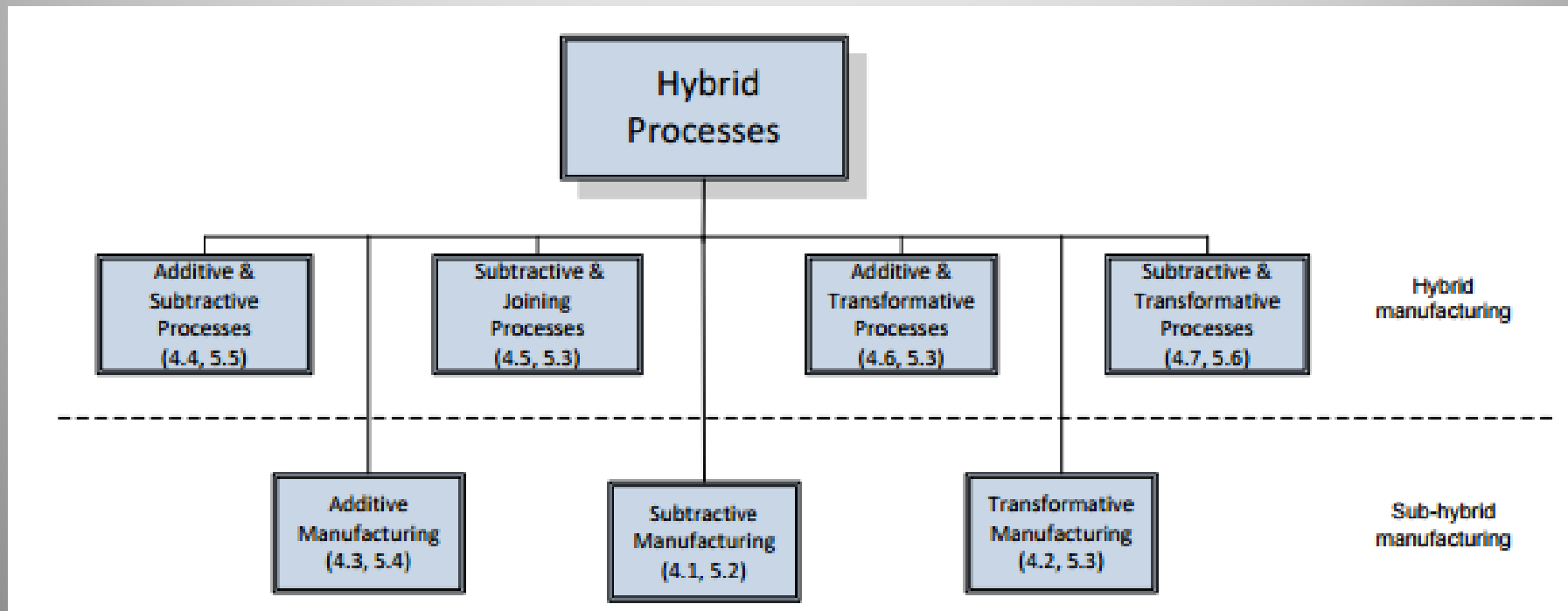
3 Heat & pressure is applied to help bond the paper
- 

4 A tungsten carbide blade cuts the paper one sheet at a time along the cut line
- 

5 This process continues until the model is finished

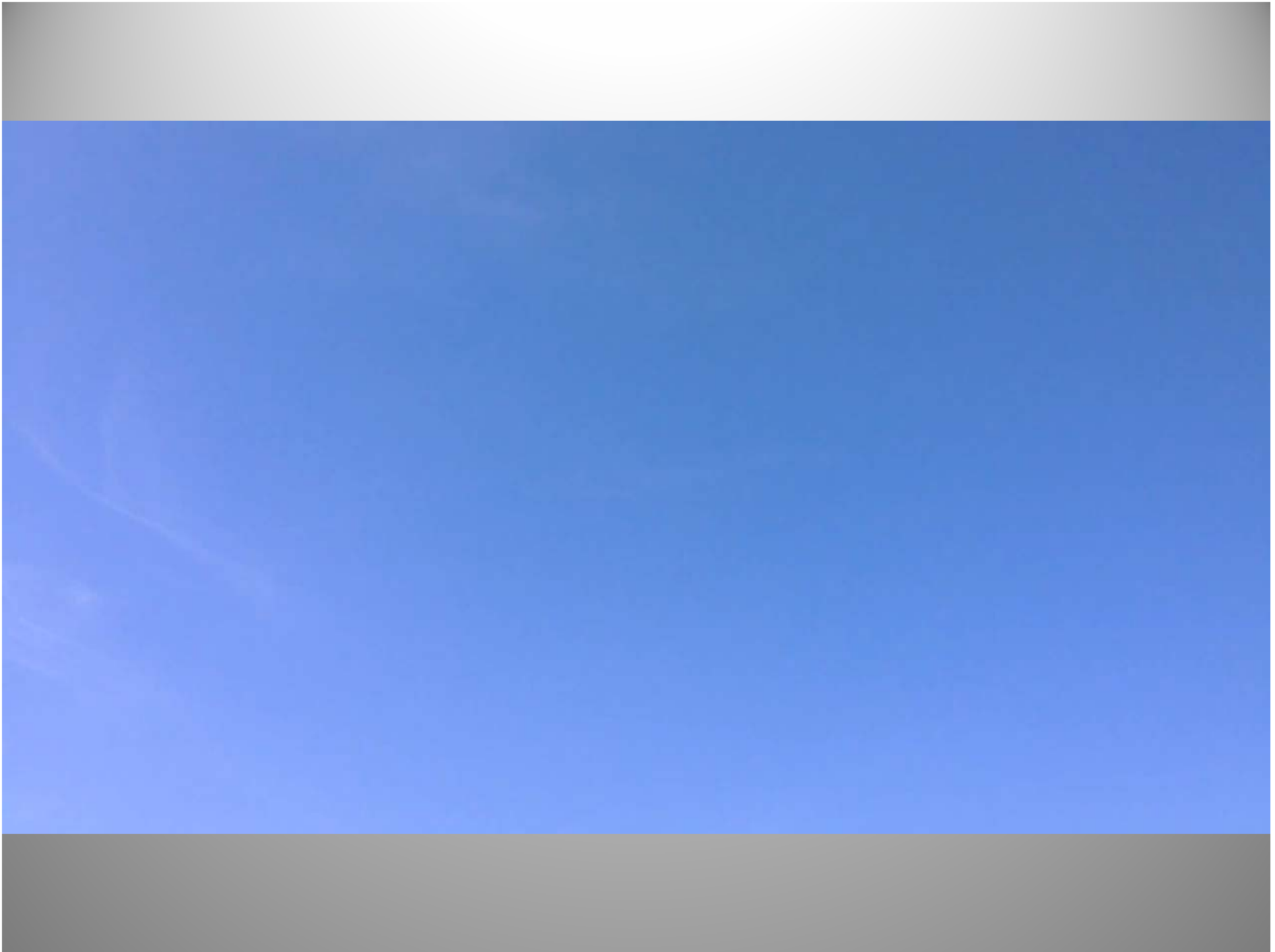
Hybrid manufacturing

Proces u kome se kombinuju dve ili više klasičnih tehnologija proizvodnje



The image features the word "SAUER" in a bold, white, sans-serif font, centered horizontally. The text is set against a dark blue background that has a subtle gradient, being slightly lighter in the center. Above and below the blue area are horizontal bands of a light gray color. The letters of "SAUER" are thick and have a slight drop shadow, giving them a three-dimensional appearance as if they are floating or attached to the surface.

SAUER





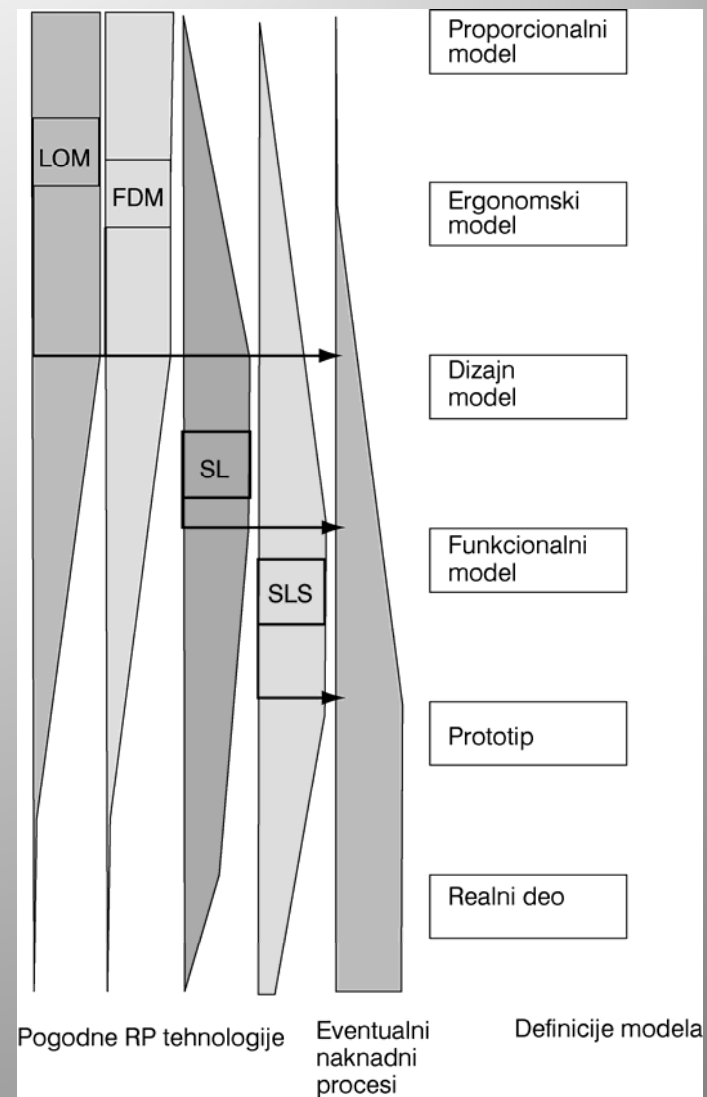
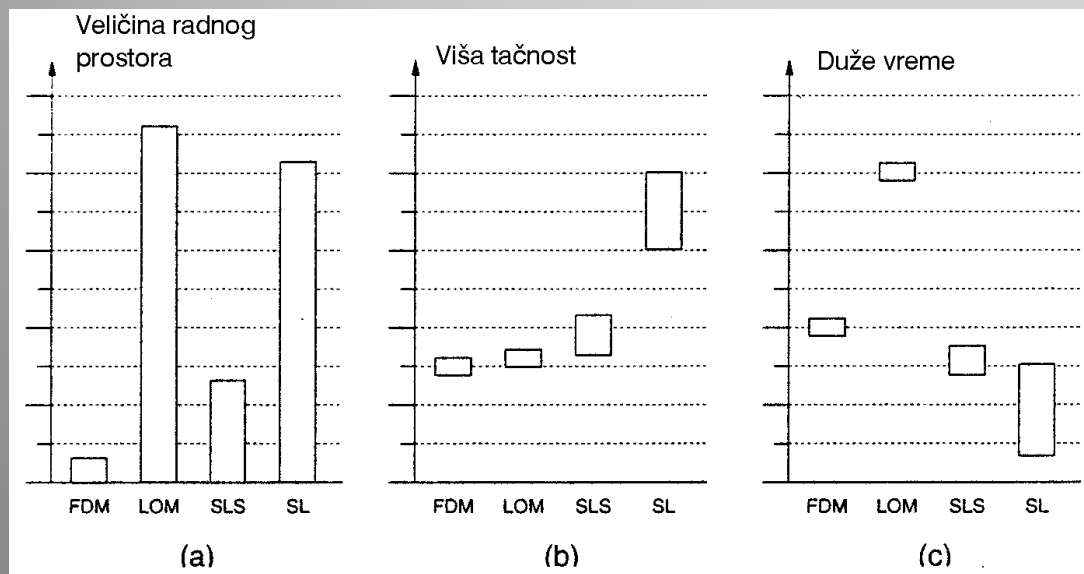
Automatic and semiautomatic
decomposition of parts into
features for additive/subtractive
operations definition



Komparacija RP tehnologija

Kriterijumi:

- veličina radne komore (modela)
- tačnost modela
- vreme izrade



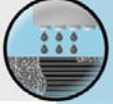
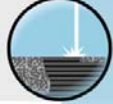
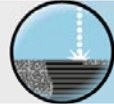





Komparacija RP tehnologija

| Karakteristika | POSTUPAK | | | | |
|---|---------------------|---|--|------------------------|--|
| | SL | FDM | SLS | 3DP | LOM |
| Postprocesiranje potrebno | da | ne | da | da | ne |
| Potpore potrebne | da | da | ne | ne | ne |
| Materijal | Epoksi smola, akril | ABS, MABS, vosak, elastomer, polietilen, poliamid | Najlon, metal, vosak, polikarbonat, polistirol | Keramika, metalni prah | Papir, plastika, keramika, drvo, tanak lim |
| Laser potreban | da | ne | da | ne | da |
| Debljina sloja (μm) | 50 | 125 – 250 | 76 | 177 | 76 – 203 |
| Tačnost (μm) | ± 100 | ± 127 | 51 | 127 | 127 |
| Maksimalne dimenzije dela (mm^3) | 500x500x 584 | 254x254x 254 | 330x380x 425 | 355x457x 355 | 813x559x 508 |
| Cena mašine (x 1000€) | 225 – 600 | 150 | 375 – 550 | – | 180 – 350 |

Komparacija RP tehnologija

| | | | | | | | |
|------------------------------|---|--|---|---|-------------------------------------|--|---|
| | Stereo-lithography | Wide Area Inkjet | Selective Laser Sintering | Fused Deposition Modeling | Single Jet Inkjet | Three Dimensional Printing | Laminated Object Manufacturing |
| Technology >> | | | | | | | |
| Representative Vendor >> | 3D Systems | | | Stratasys | Solidscape | Z Corp. | Cubic Technologies |
| General Qualitative Features | | | | | | | |
| Maximum Part Size (inches) | 20 x 20 x 24 | 12 x 8 x 8 | 12 x 12 x 12 | 24 x 20 x 24 | 12 x 8 x 8 | 20 x 24 x 12 | 32 x 22 x 20 |
| Speed | average | good | average to fair | poor | poor | excellent | good |
| Accuracy | very good | good | good | fair | excellent | fair | fair |
| Surface Finish | very good | fair | fair | fair | excellent | fair | fair to poor (depending on application) |
| Strengths | market leader, large part size, accuracy, wide product line | market leader, office okay, | market leader, accuracy, materials, | office okay, price, materials, | accuracy, finish, office okay, | speed, office okay, price, color, price | large part size, good for large castings, material cost |
| Weaknesses | post processing, messy liquids | size and weight, fragile parts, limited materials, part size | size and weight, system price, surface finish | speed | speed, limited materials, part size | limited materials, fragile parts, finish | part stability, smoke finish and accuracy |
| System Price | \$75-800K | \$50K | \$300K | \$30-300K | \$70K-80K | \$30K-70K | \$120-240K |
| Material Costs \$/pound | | | | | | | |
| plastics | \$75-110 | \$100 | \$30-40 | \$115-185 | \$100 | | \$8 |
| metal | | | \$25-30 | | | | |
| other | | | \$5 (foundry sand) | | | starch: \$0.35 / cu in plaster: \$0.80 / cu in +infiltrant | \$5.8 (paper) |

Komparacija RP tehnologija

| Materials | Technologies | | |
|--|---|--|--|
| | Parts built through polymerization | Parts built through bonding agent | Parts built through melting |
| Ceramic | |  BJ |  LM |
| Metal | | |  EBM |
| Sand | | | |
| Plastic |  SL  PJ | |  FDM  LS |
| Wax | | |  MJ * |
| <div> <div>Lower</div> <div>Durability</div> <div>Higher</div> </div> <div> <div>Smoother</div> <div>Surface finish</div> <div>Rougher</div> </div> <div> <div>Higher</div> <div>Detail</div> <div>Lower</div> </div> <div> <div>Prototypes Indirect processes</div> <div>Application</div> <div>Functional parts</div> </div> | | | |

* MJ achieves smooth surface finish and high detail

Komparacija RP tehnologija sa konvencionalnim tehnologijama za generisanje modela

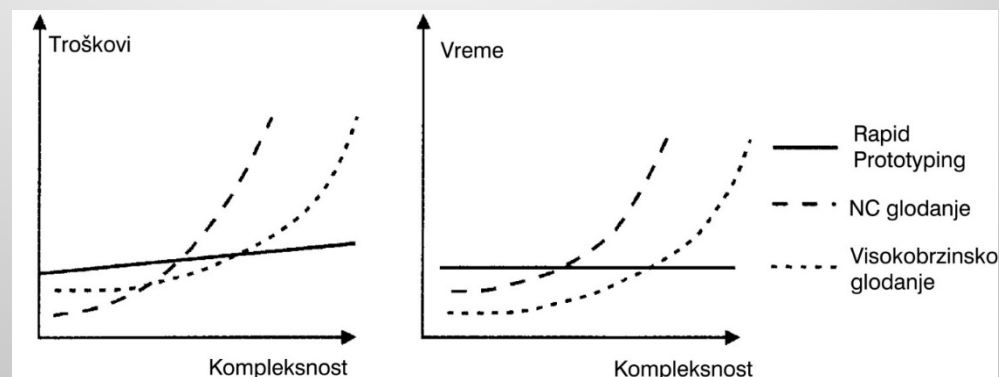
Materijal

Alati

Konstrukcija prototipa

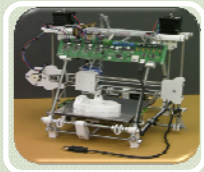
Kompatibilnost

Tačnost

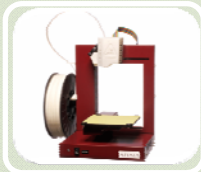


| | SLA | SLS | Poly-Jet | FDM/FFF | Binder Jetting | CNC | Injection Molding | Forming | Joining |
|---------------------|-----|-----|----------|---------|----------------|-----|-------------------|---------|---------|
| Cost- Low Volume | ✓ | ✓ | ✓ | ✓ | ✓ | — | ✗ | ✗ | ✗ |
| Cost- High Volume | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | — |
| Lead Time | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ |
| Material Selection | — | — | — | — | ✗ | ✓ | ✓ | ✓ | ✓ |
| Surface Finish | — | — | — | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ |
| Tolerance | ✓ | — | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ |
| Integrated Assembly | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Complexity | ✓ | ✓ | ✓ | ✓ | ✓ | — | — | ✗ | ✗ |
| Customizability | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ |

✓ is good, — is fair, ✗ is poor



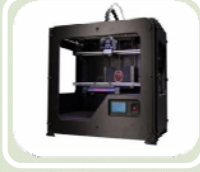
Rep Rap
Model:
RepRapPro Huxley
Price:
\$599



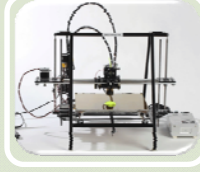
Eventorbot
Model:
Delta Micro
Up Afinia
H-Series
Price:
\$1,500



Printrbot
Model:
Printrbot
GO
Price:
\$1,500



Makerbot
Model:
Replicator
2x
Price:
\$2,800



The Future
is 3D
Model:
Glacier
Steel
Price:
3000



3D
Systems
Model:
CubeX
Price:
\$3000



Formlabs
Model:
Form 1
Price:
\$3,300



Stratasys
Model: U
print SE
Plus
Price:
\$15,000