

Brza izrada prototipova i alata

Nastavnik:
Prof. Dr Mladomir Milutinović

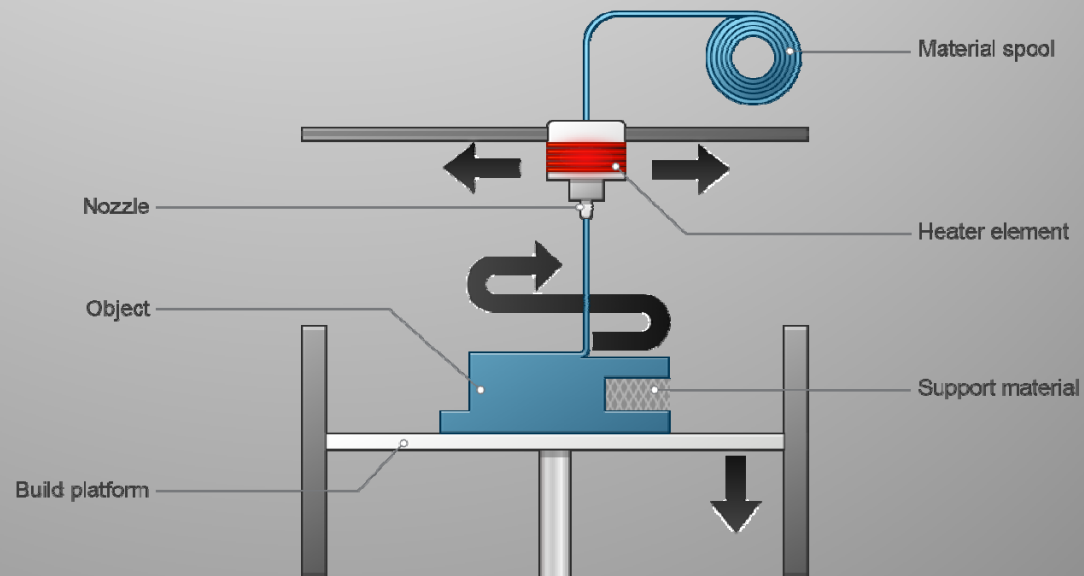
Asistent:
Dejan Movrin

Material Extrusion

(Ekstruzija Materijala)



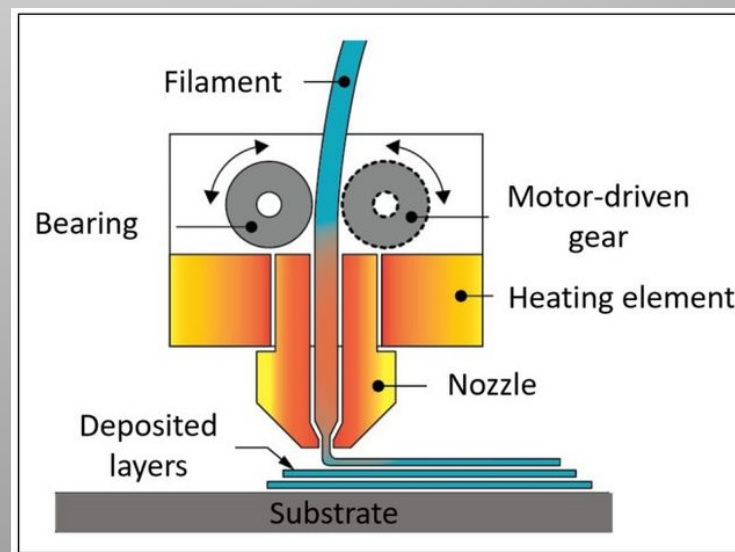
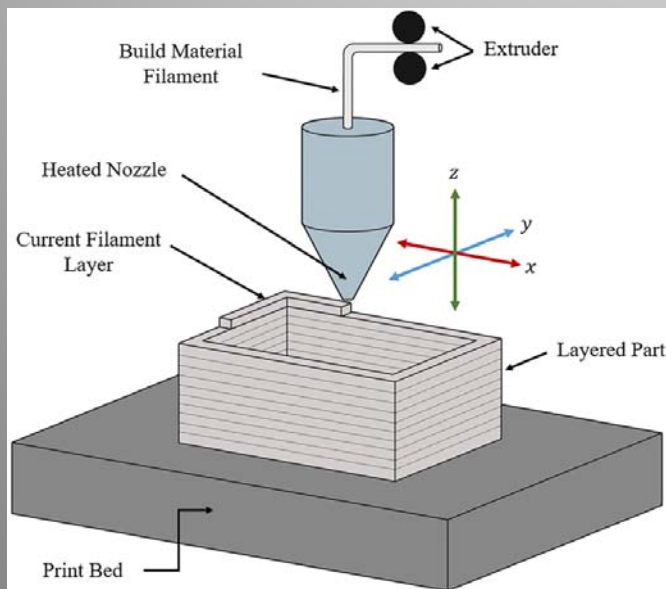
FDM (ili Fused Filament Fabrication) - Koristi se nit/žica od čvrstog termoplastičnog materijala, istisnuta kroz zagrejanu mlaznicu. Štampač precizno i kontinuirano polaže rastopljeni materijal na mesto gde se trenutno hladi i učvršćuje.



Postupci na bazi čvrstih materijala

Postupci bazirani na principu ekstruzije

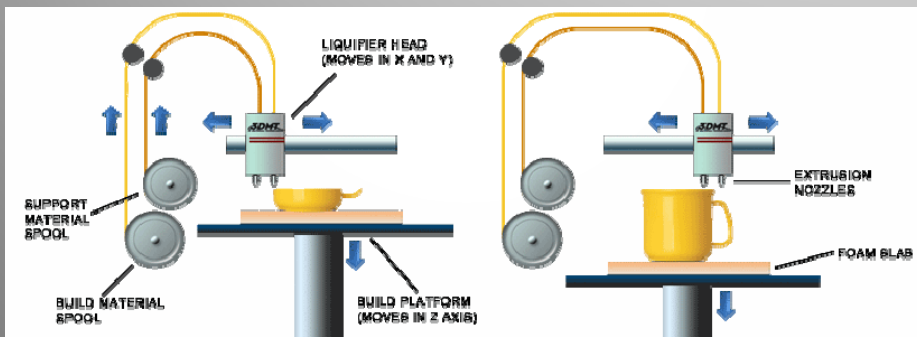
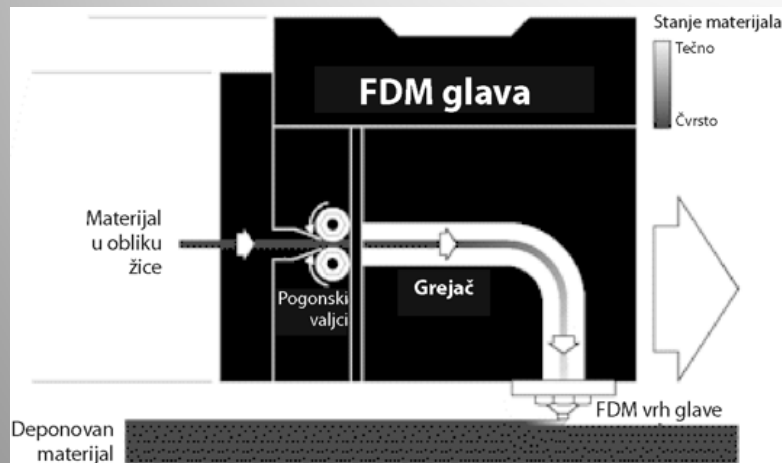
- Dopremanje materijala
- Topljenje materijala
- Postiskivanje materijala (pod dejstvom pritiska ili gravitacije)
- Ekstruzija
- Plotovanje u X-Y ravni
- Vezivanje i očvršćavanje materijala (hlađenjem ili hemijskim putem)
- Izrada potpornih struktura



Fused Deposition Modeling (FDM)

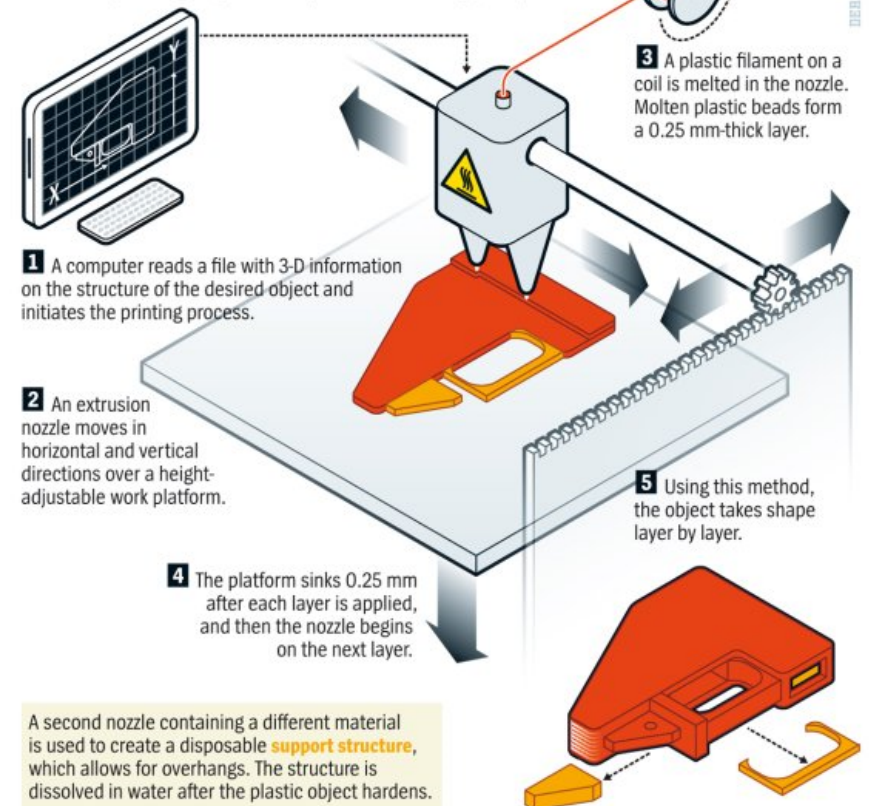
Modeliranje deponovanjem topljenog materijala

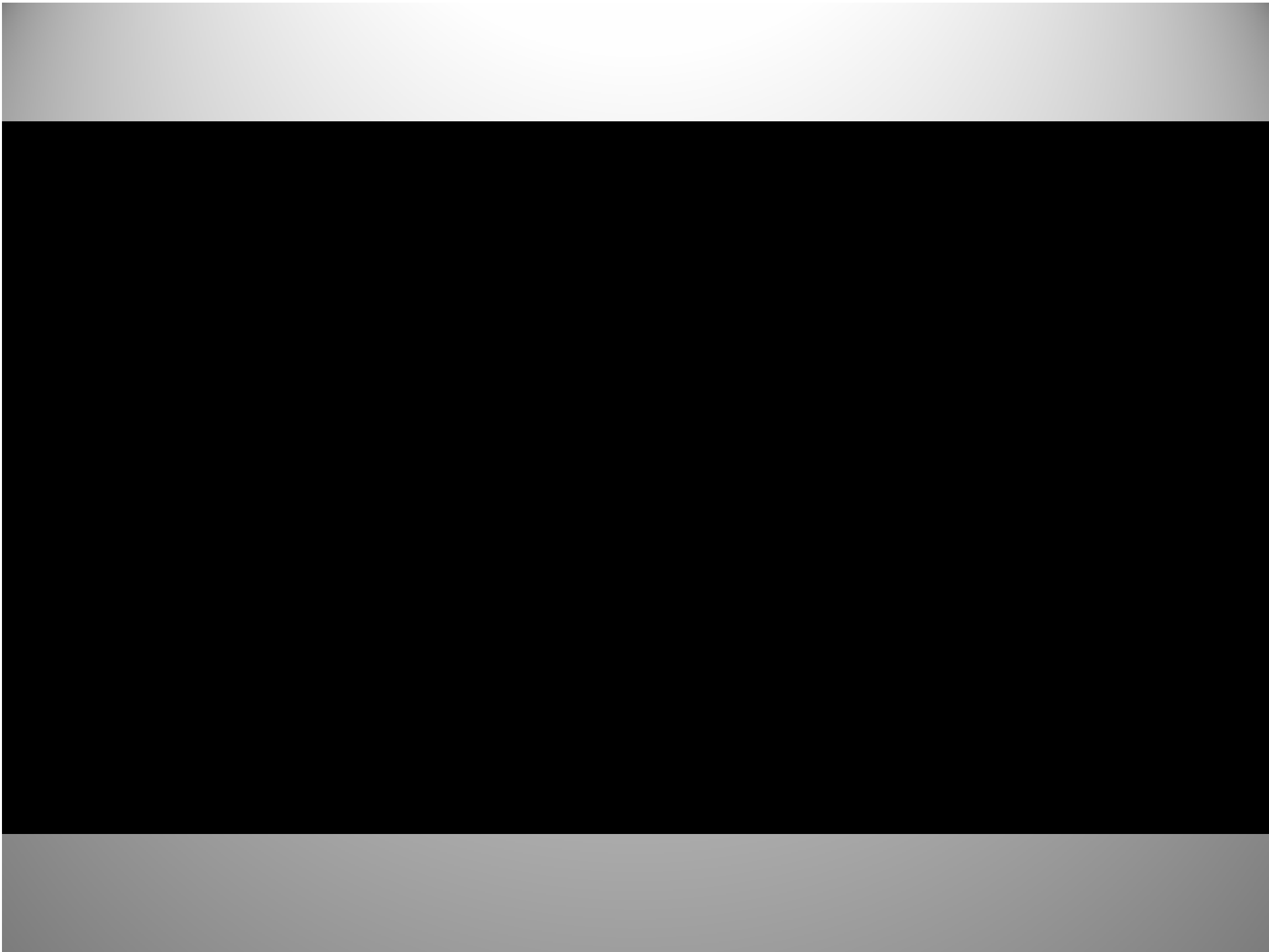
- Scott Crump, Stratasys Inc., Minesota, SAD
- Prvi komercijalni FDM sistem se pojavio 1992. godine - 3D modeler



Inside a 3-D Printer

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

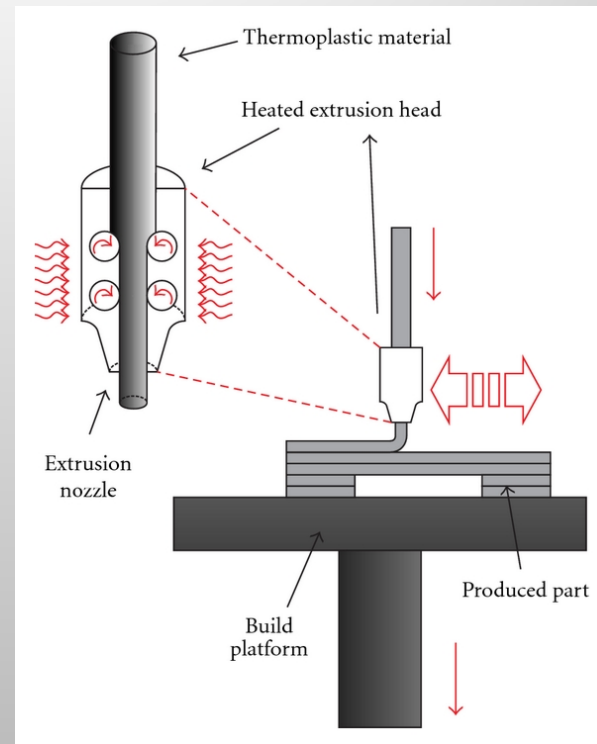




Fused Deposition Modeling (FDM)

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)

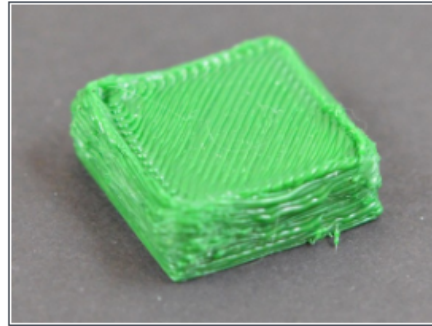
Temperatura: 0,5 veća T_{top} (70 °C za vosak i 270 °C za ABS termoplast)

Vreme očvršćavanja: 0,1s

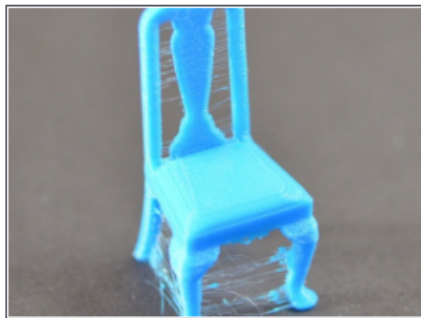
FDM - greške



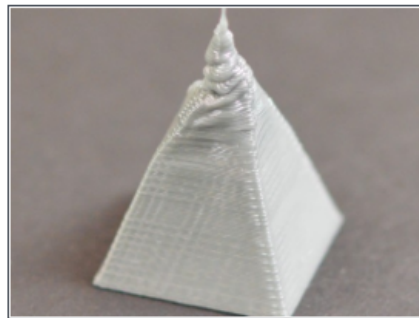
Under-Extrusion



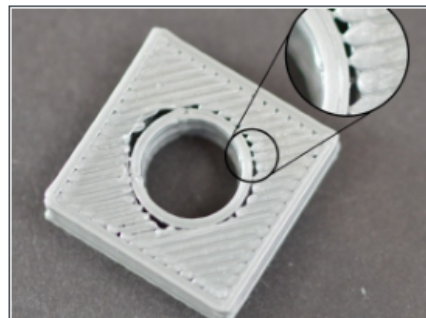
Over-Extrusion



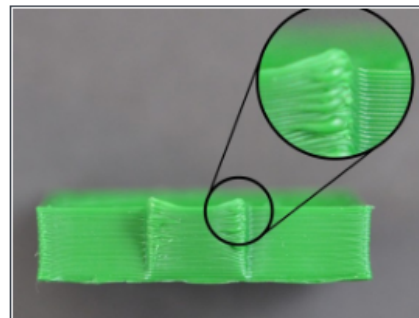
Stringing or Oozing



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

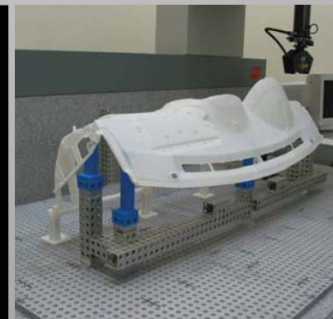
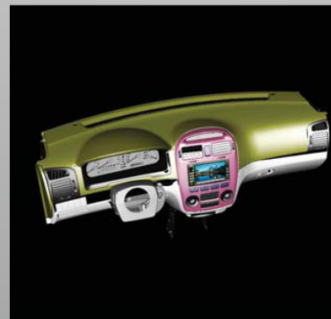
Nedostaci procesa

- 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?

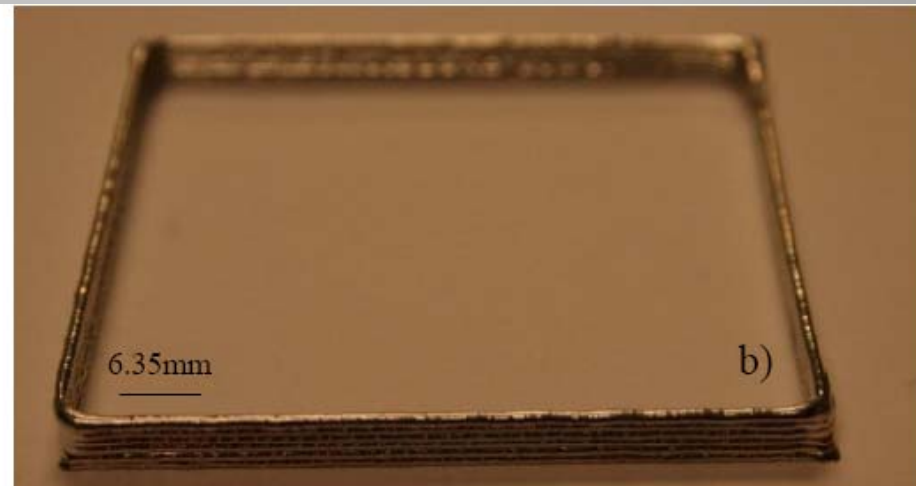
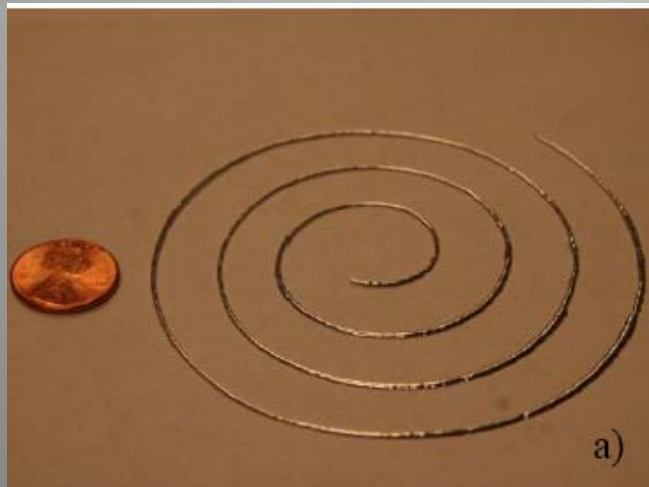
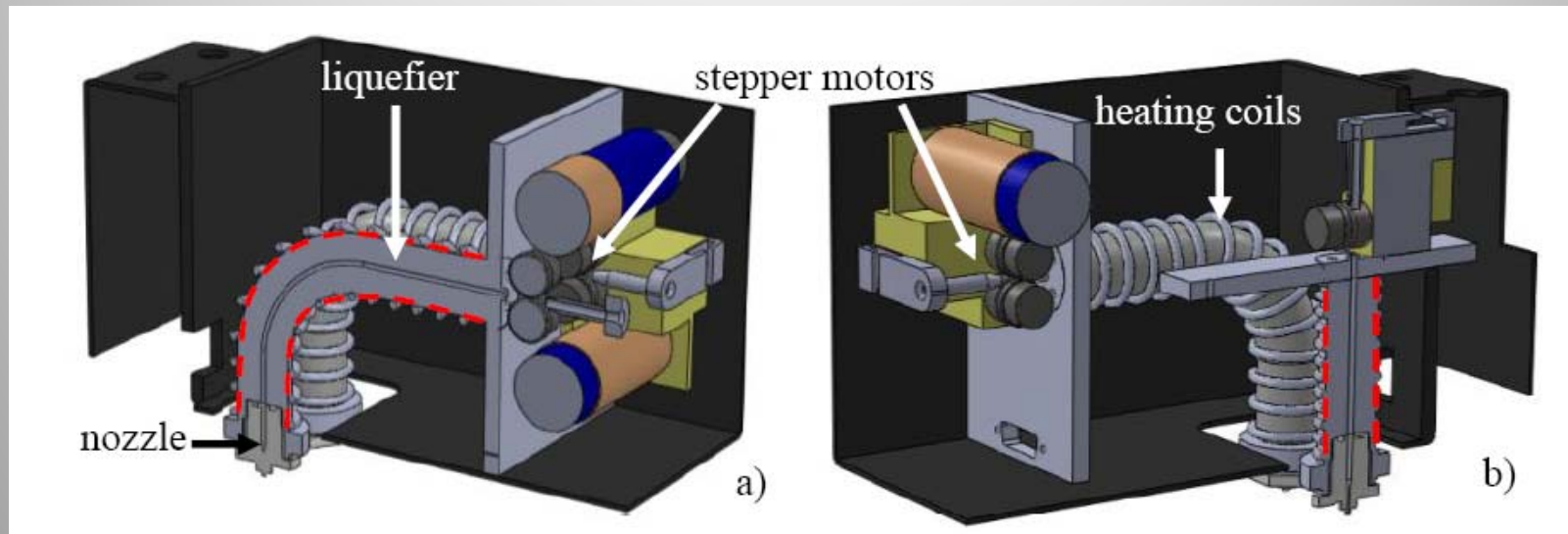
Method	Cost	Lead Time
Traditional process	\$40,000	120 days
FDM Technology	\$3,090	20 days
Savings	\$36,910 (92%)	12 days (80%)

Karakteristike FDM sistema firme Stratasys

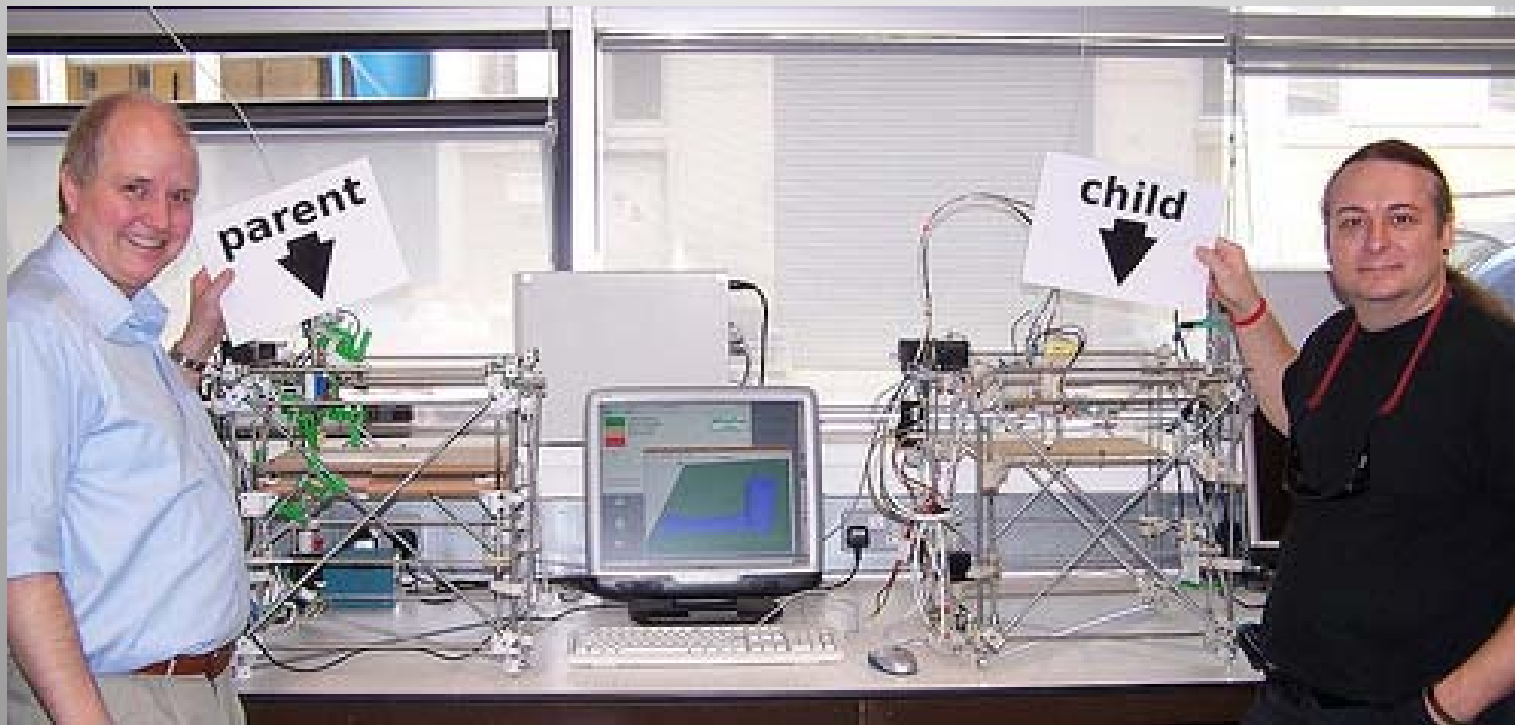
Model	Prodigy Plus	FDM Vantage SE	FDM Titan	FDM Maxum
Maksimalna veličina dela	203x203x305 mm	406x355x406 mm	406x355x406 mm	600x500x600 mm
Tačnost	±0,127 mm	do 127 mm: ±0,127 mm preko 127 mm: ±0,038 mm/mm	do 127 mm: ±0,127 mm preko 127 mm: ±0,038 mm/mm	do 127 mm: ±0,127 mm preko 127 mm: ±0,038 mm/mm
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



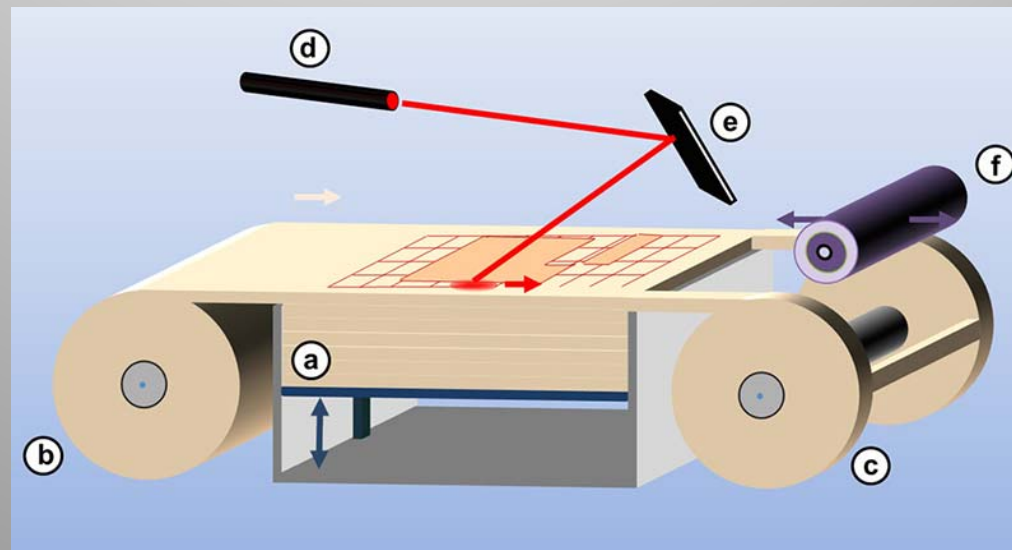
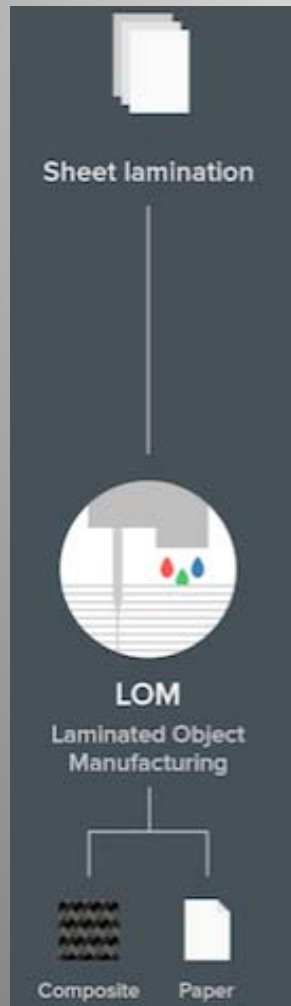
The Future ? Self-replication !



Sheet Lamination

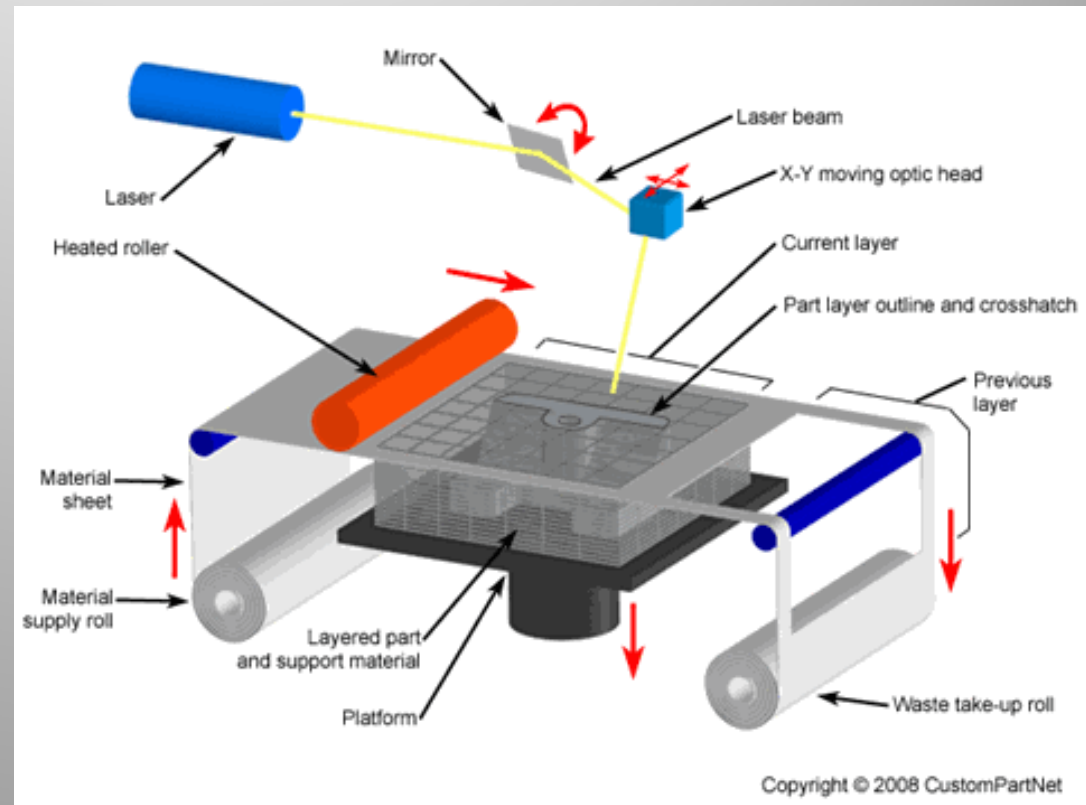
(Laminacija folija)

(LOM) – Koristi se folije/lamele papira, plastike ili metala (lima) koje se međusobno lepe i seku po odgovarajućoj konturi primenom laserkog zraka ili mehaničkih noževa. Gotovi delovi se mogu dalje modifikovati mašinskom obradom ili bušenjem.



Laminated Object Manufacturing (LOM)

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

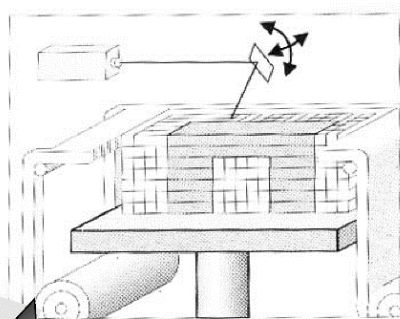


Laminated Object Manufacturing (LOM)

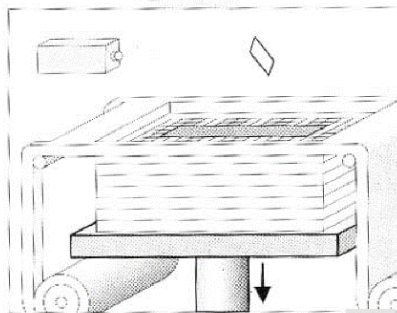
Faze procesa

Procesiranje

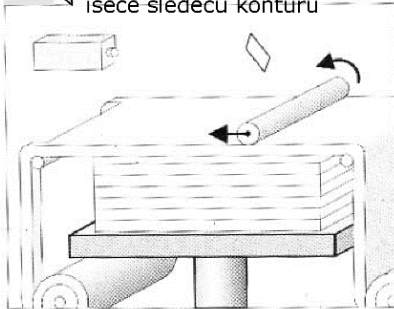
1. Isecanje konture laserskim zrakom



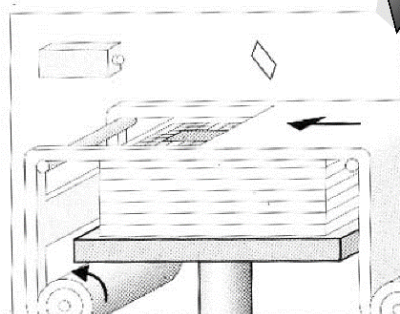
2. Spuštanje platforme za debljinu sloja



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

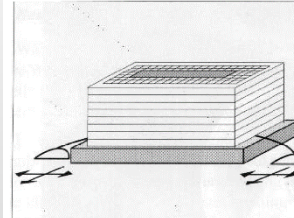


3. Dotur novog materijala



Post-Procesiranje

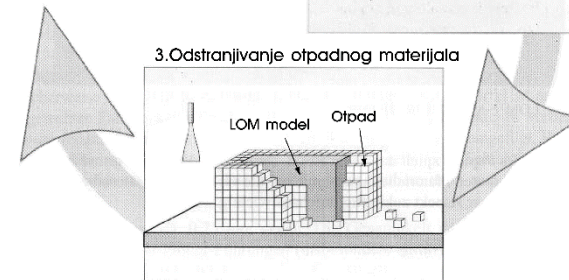
1. Skidanje sa platforme



2. Vađenje iz okvira



3. Odstranjivanje otpadnog materijala



(a)



(b)



Laminated Object Manufacturing (LOM)



Laminated Object Manufacturing (LOM)

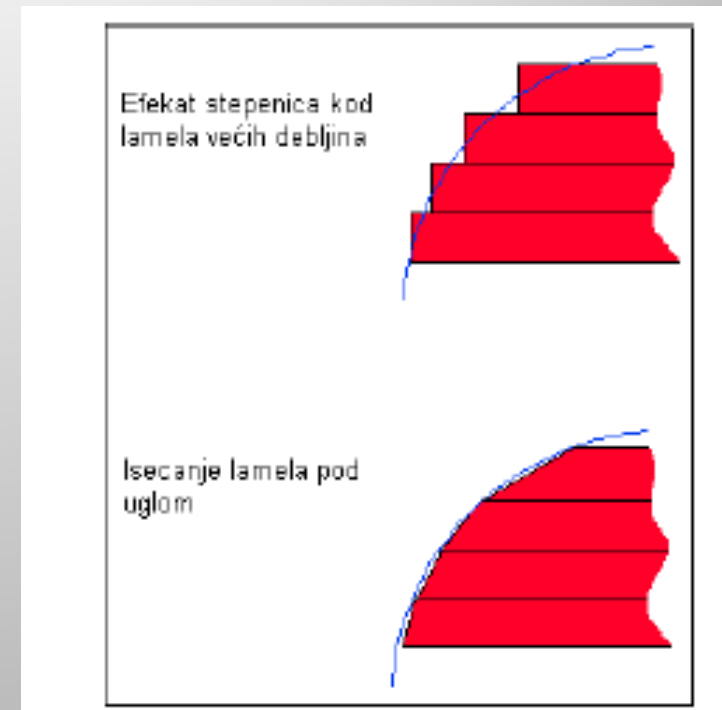
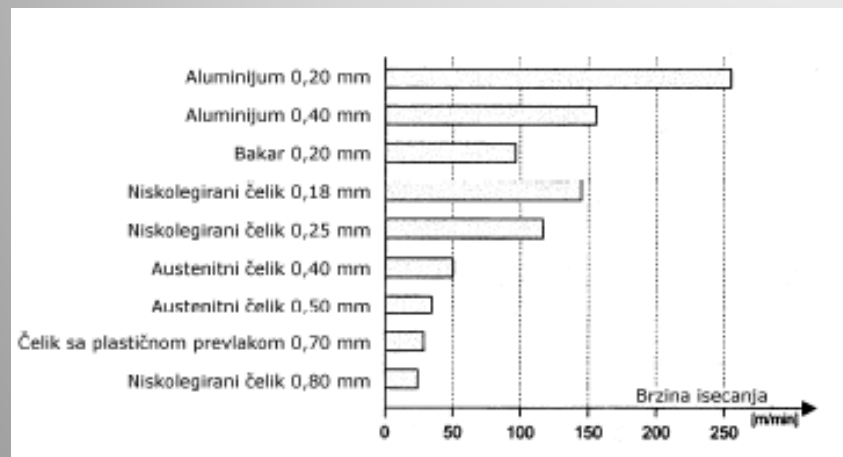
Glavne prednosti

- ✓ 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

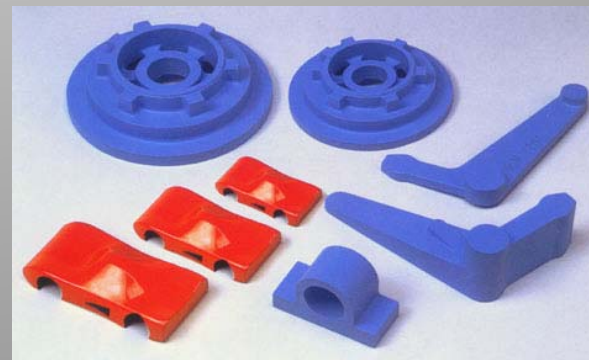
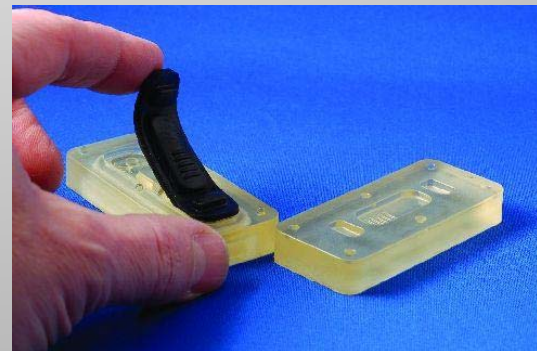
Laminated Object Manufacturing (LOM)



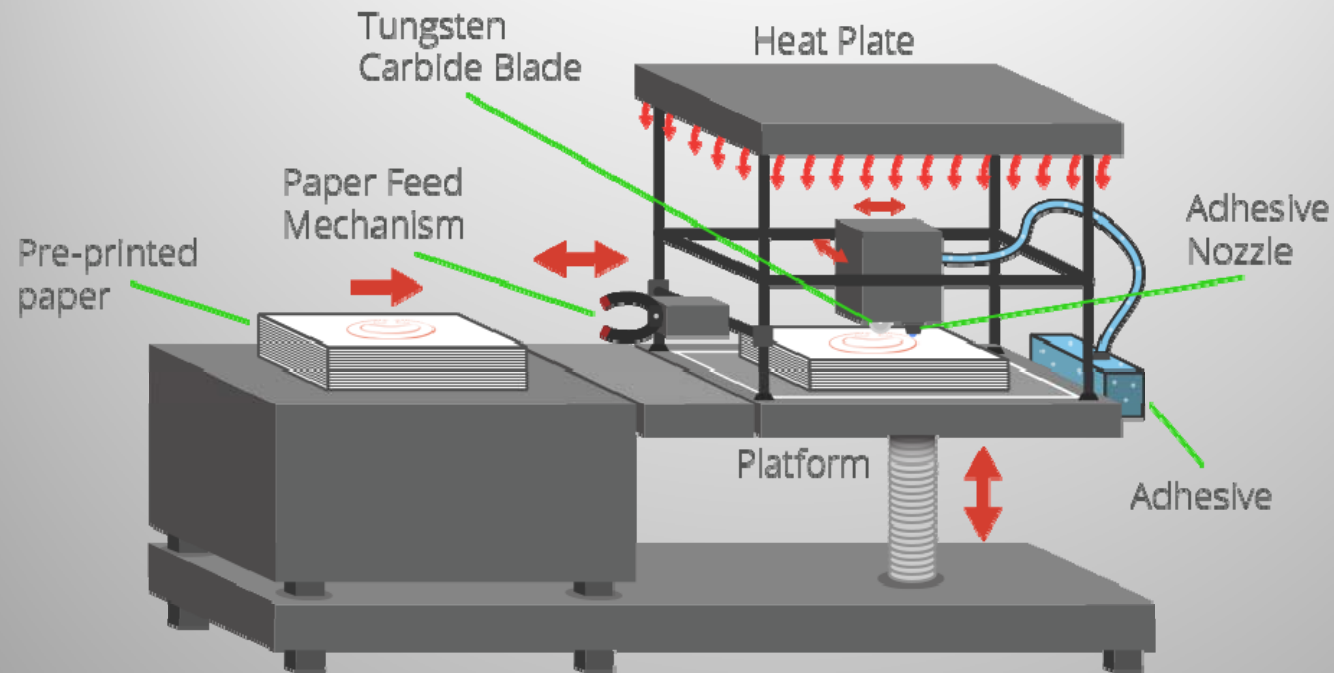
Laminated Object Manufacturing (LOM)


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.

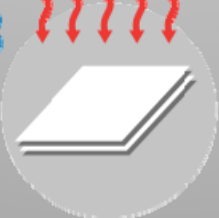



Selective Deposition Lamination (SDL)




- 

1 First sheet of paper is added to the platform
- 

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

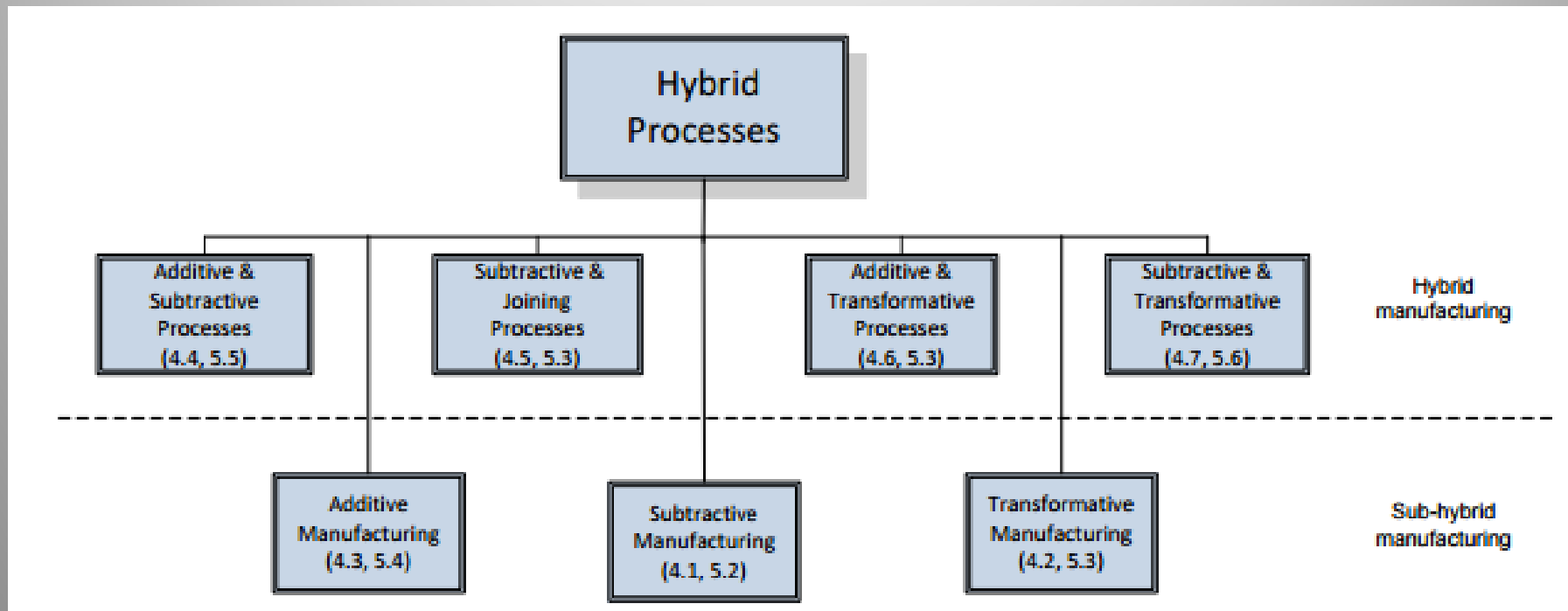
3 Heat & pressure is applied to help bond the paper
- 

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 logo features the word "SAUER" in a bold, white, sans-serif typeface. The letters are centered horizontally and have a subtle drop shadow, giving them a three-dimensional appearance as if they are floating above the background. The background is a solid, deep blue. This central blue area is framed by a light gray horizontal band at the top and a darker gray horizontal band at the bottom, creating a balanced, rectangular composition.

SAUER





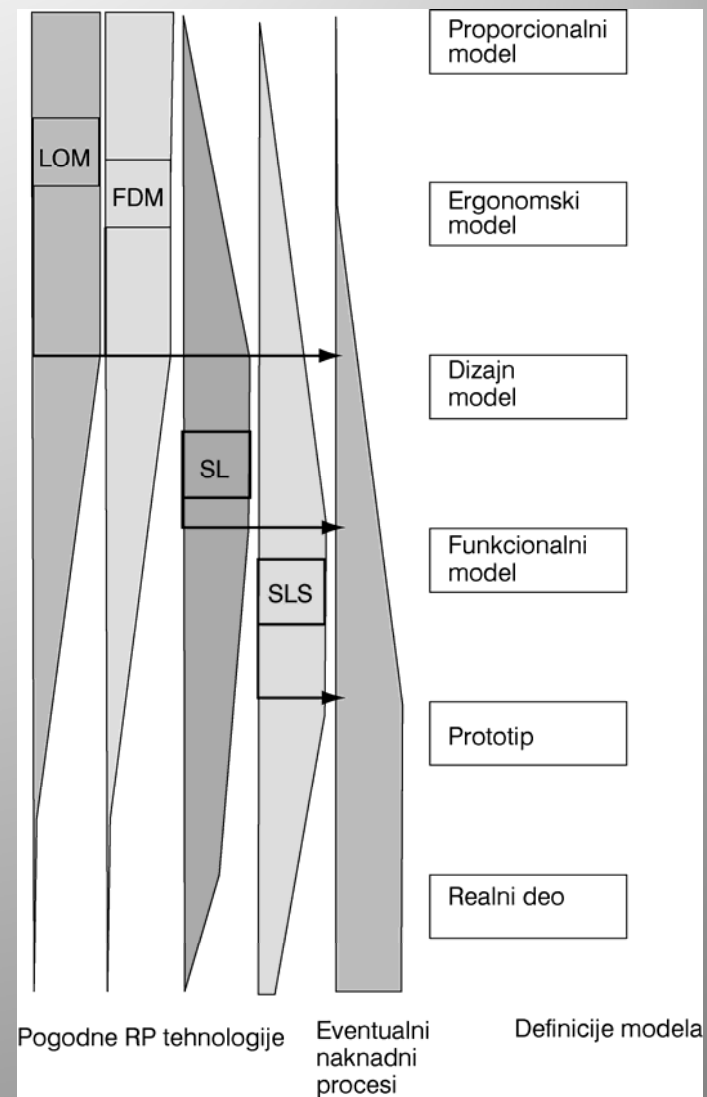
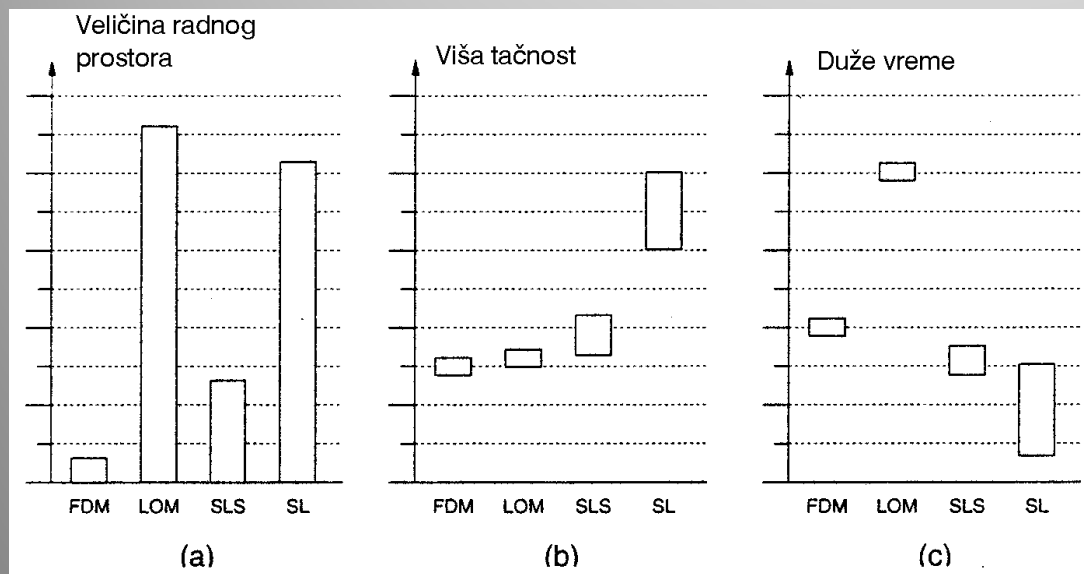
Automatic and semiautomatic
decomposition of parts into
features for additive/subtractive
operations definition



Komparacija RP tehnologija

Kriterijumi:

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



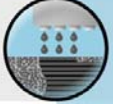
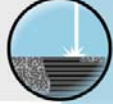
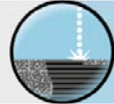





Komparacija RP tehnologija

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	Solidshape	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	\$7.5-110	\$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

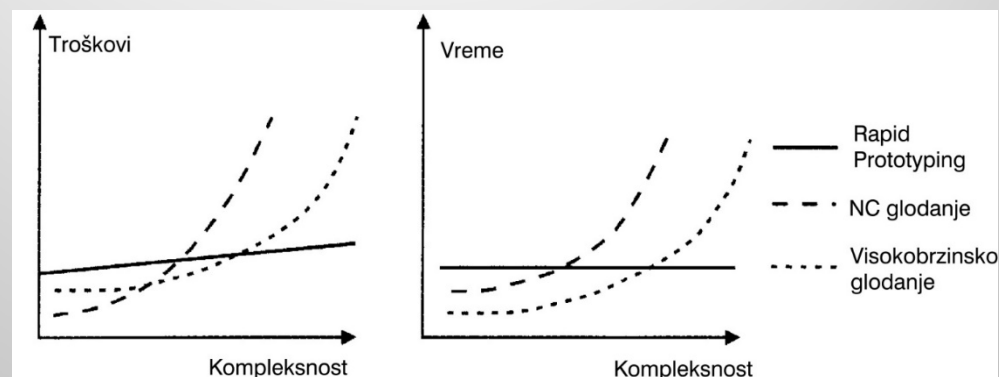
Materijal

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