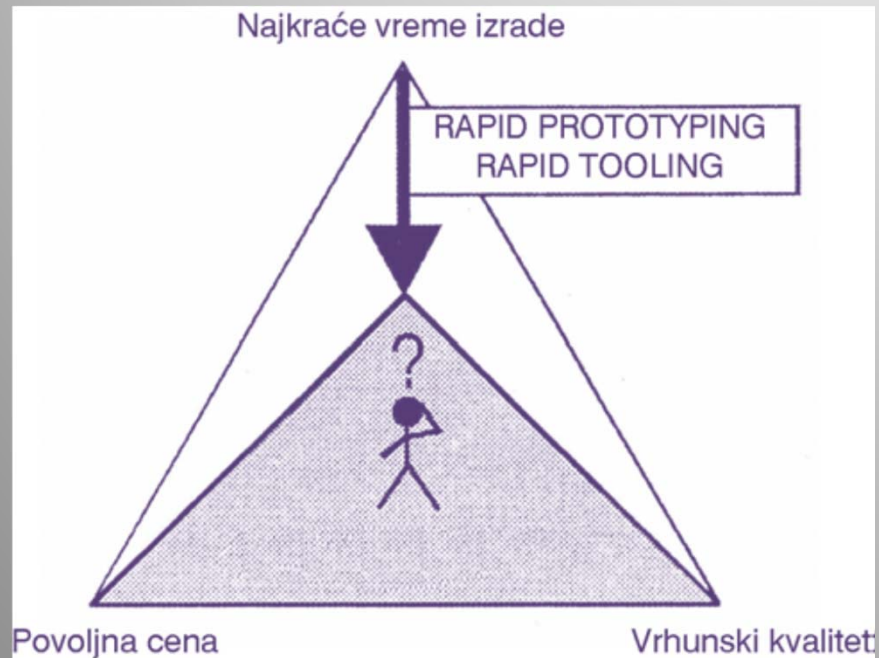


Brza izrada prototipova i alata

Nastavnik:
Prof. Dr Mladomir Milutinović

Asistent:
Dejan Movrin

Rapid Prototyping i Rapid Tooling

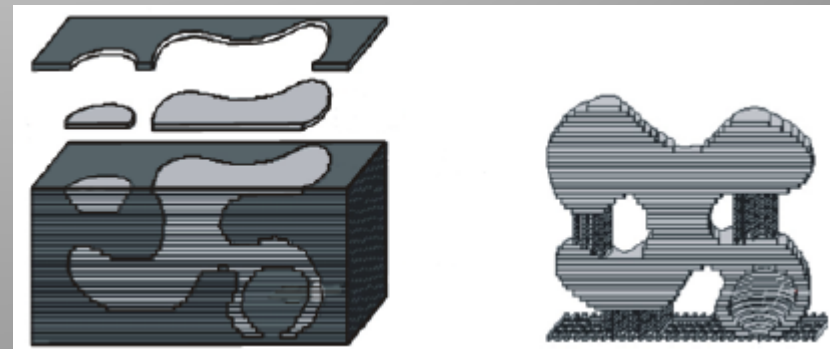
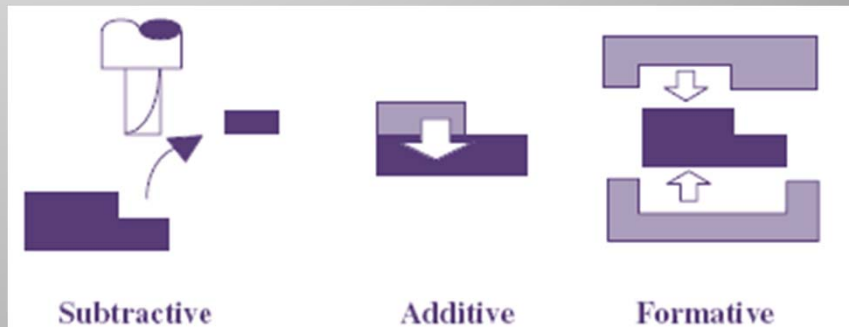


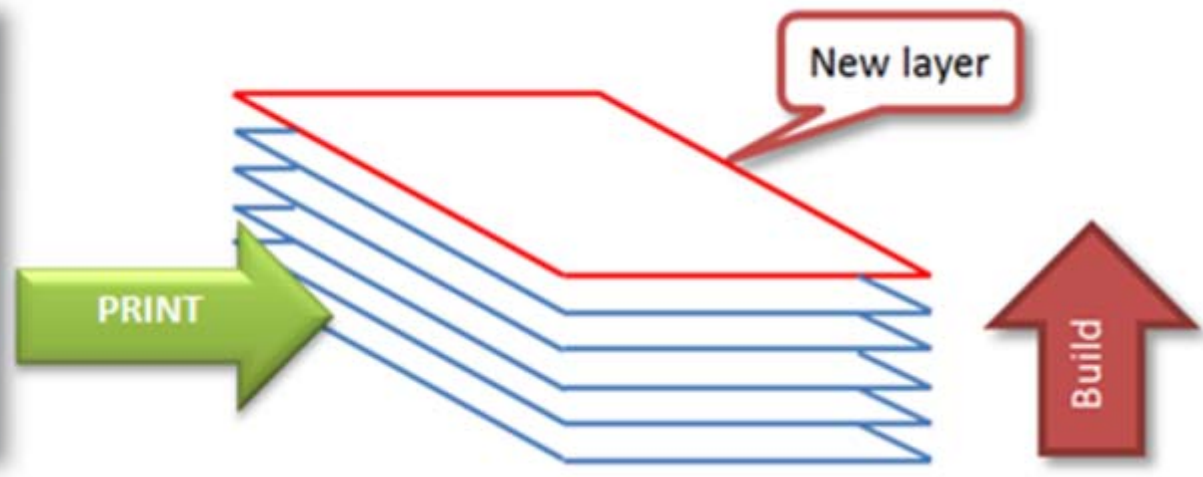
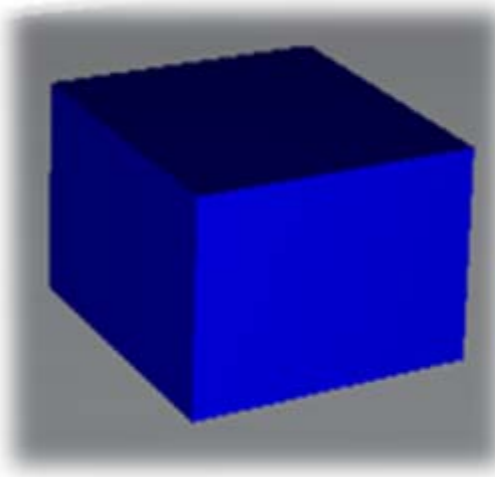
Definicija:

- *Rapid Prototyping* (RP) predstavlja grupu tehnologija pomoću kojih se fizički modeli izrađuju direktno iz 3D CAD, bez korišćenja alata i pribora. Pored varijante da se računarski model stvara u CAD-u, moguća je i varijanta da se već postojeće fizičko telo digitalizacijom i povratnim modeliranjem pretvori u CAD model (Reverse Engineering), a zatim uključi u RP i RT proces.
- *Rapid Tooling* (RT) obično opisuje proces koji koristi RP model kao šablon za brzu izradu kalupa, ili direktno koristi RP proces za izradu alata za predserije ili male serije (soft tools).

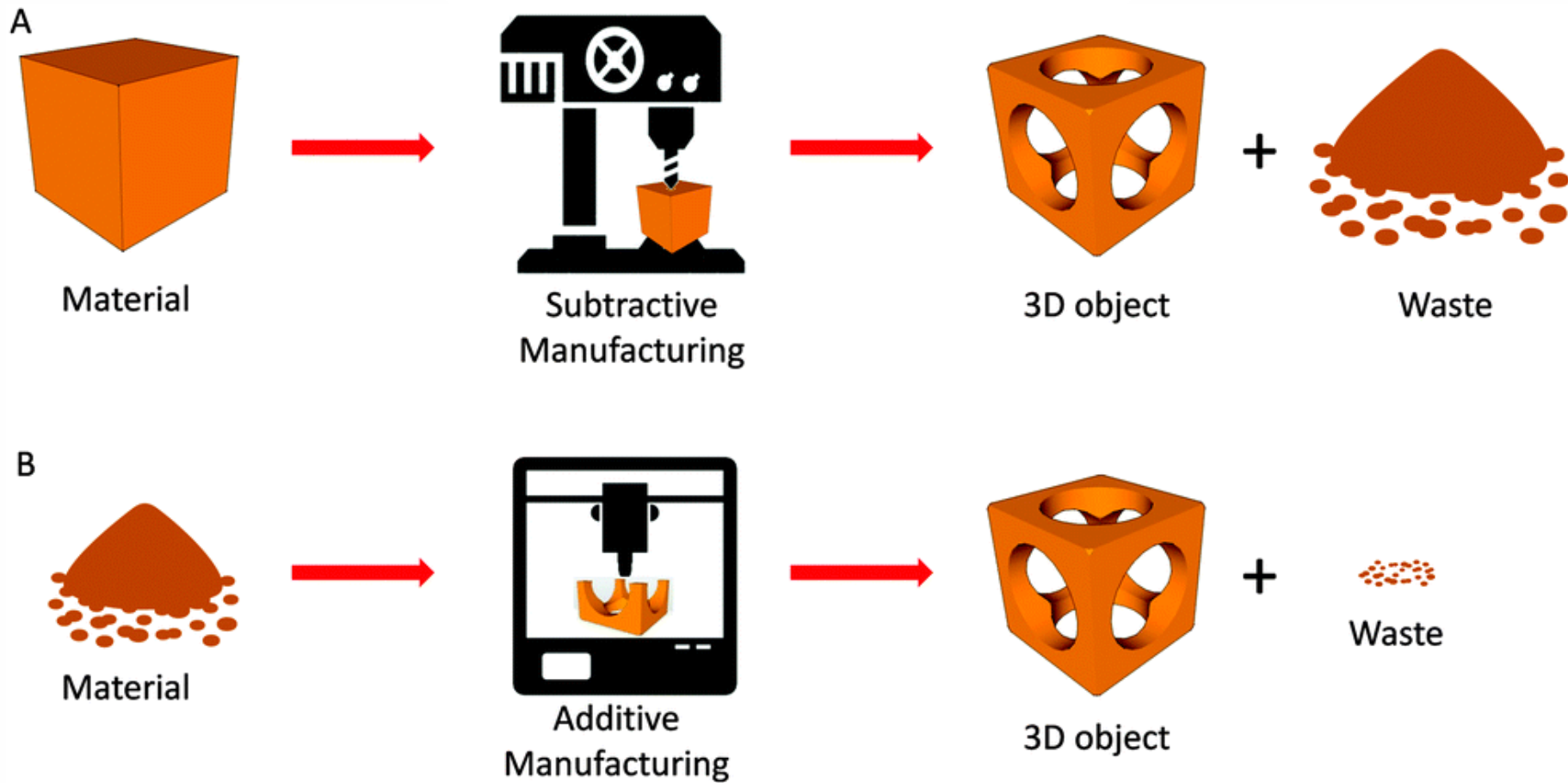
- Rapid manufacturing,
- Additive manufacturing,
- Additive fabrication,
- Additive digital manufacturing,
- Direct manufacturing
- 3D printing

Aditivni proces - dobijanje modela sukcesivnim generisanjem tankih slojeva na bazi prethodno kreiranog 3D CAD modela





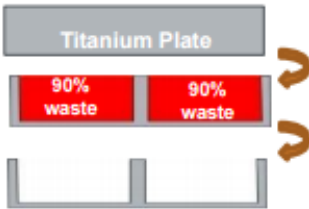
Additive vs. Subtractive manufacturing



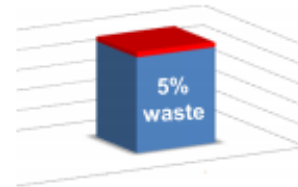
BENEFITS & CAPABILITIES

COST

Material Waste with traditional Manufacturing



Material Waste with AM



Material Price increasingly expensive



TIME



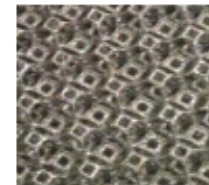
Additive Manufacturing guarantees high flexibility in design as modifying a part in retrospective only requires changing the virtual CAD data.

QUALITY

Weight Savings

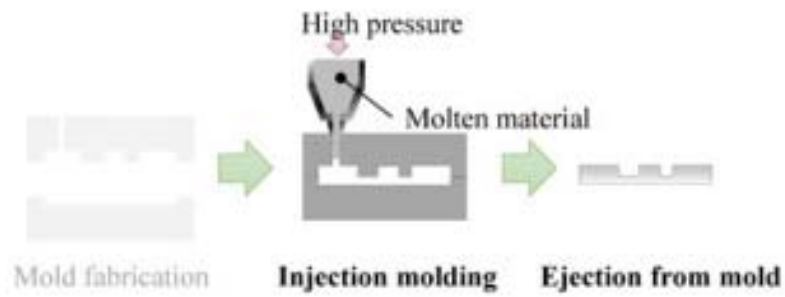


Unique Geometric Capability

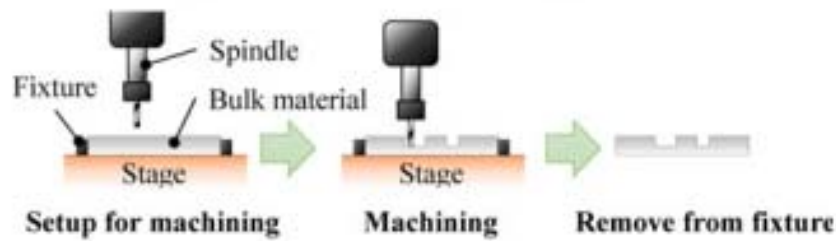


New Materials





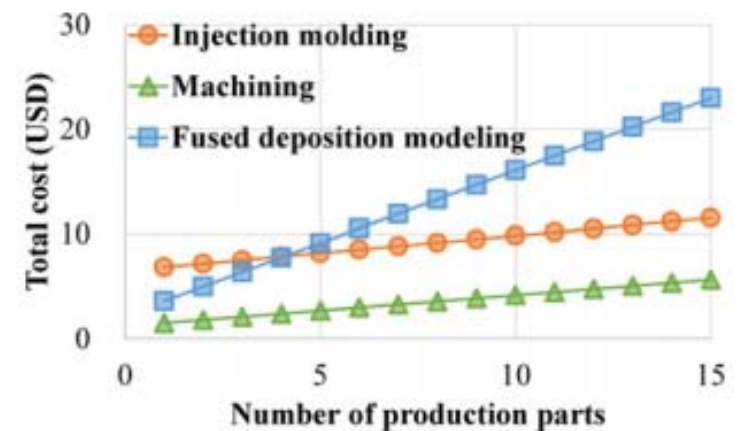
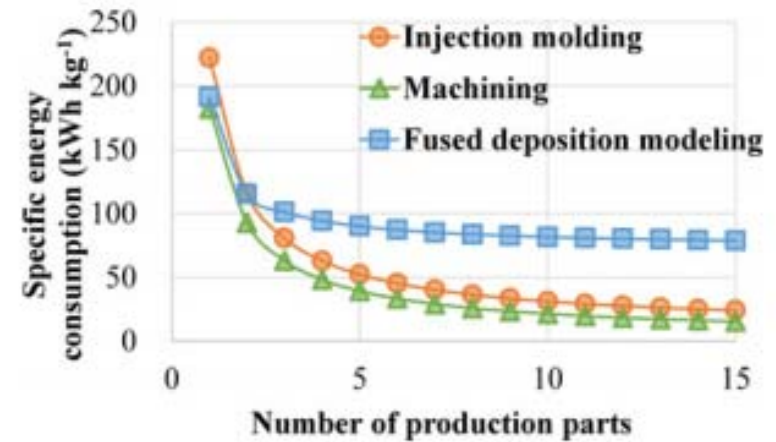
(a) Conventional bulk forming process



(b) Subtractive process



(c) Additive process



Rapid Prototyping i Additive Manufacturing???!!!

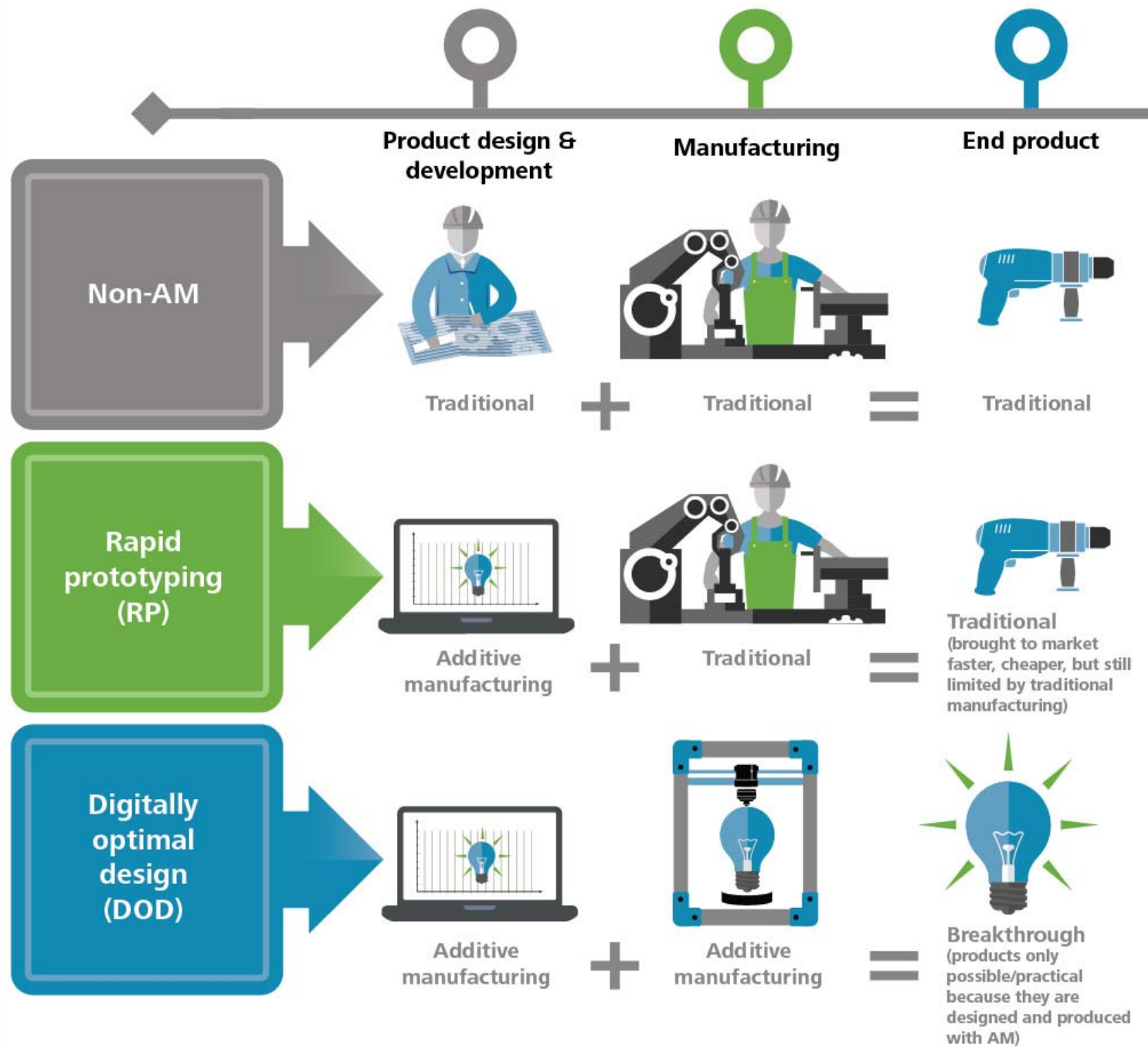
Razlika je nameni, ne u samoj tehnologiji:

Rapid Prototyping: koristi se za generisanje ne-strukturnih i ne-funkcionalnih demo delova ili pojedinačnih komada u svrhu potvrde koncepta.

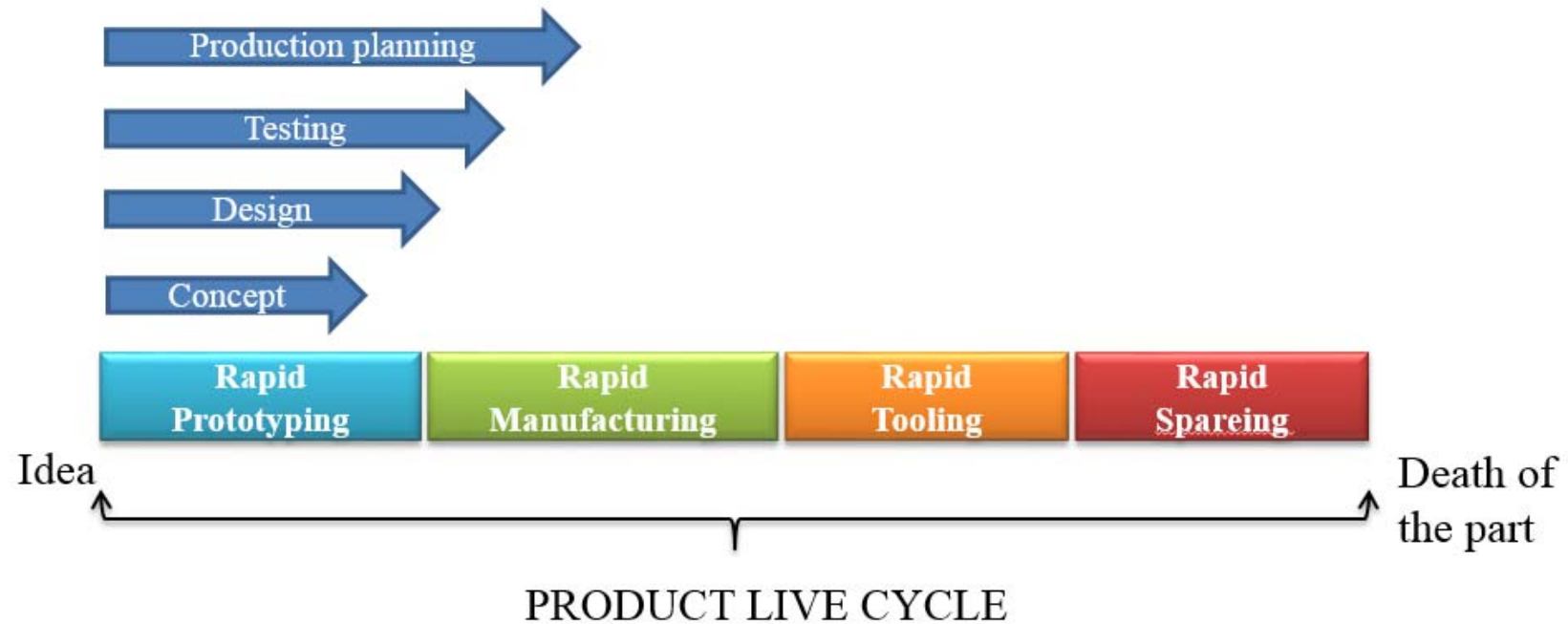
Additive Manufacturing: koristi se u smislu pravog proizvodnog procesa, za generisanje potpuno funkcionalnih komponenti od visoko kvalitetnih materijala u malo-serijskoj proizvodnji.



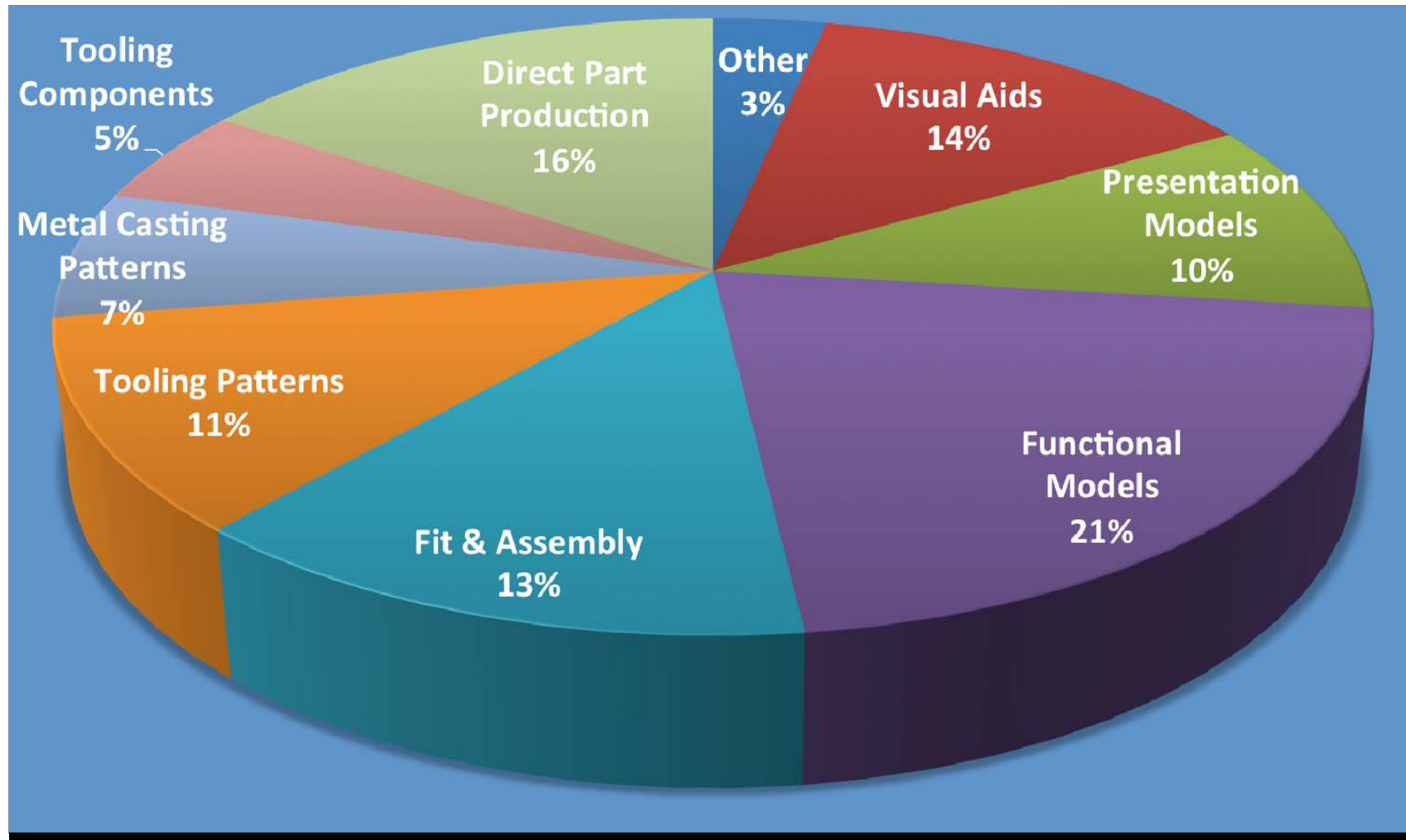
Morongo Casino, Palm Springs



Over the last years AM technology became valid for the hole lifecycle of a product

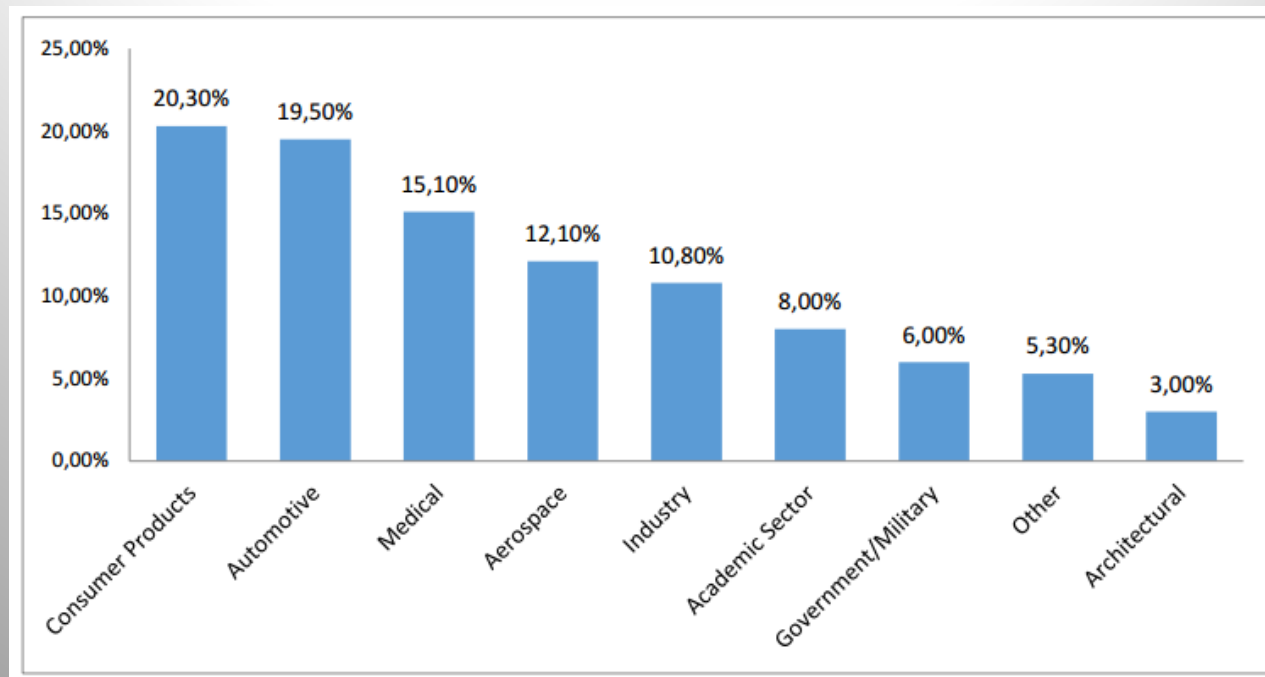


Rapid Prototyping vs Additive Manufacturing



Razvoj AM sektora

- ▶ Three of the **fastest-growing areas** for AM include the **medical, dental, automotive** and **aerospace** sectors¹
- ▶ In 10 years, **the use of AM for the production of final products** has gone from almost **nothing to 28.3%** of the **total product and services revenue** from AM worldwide.

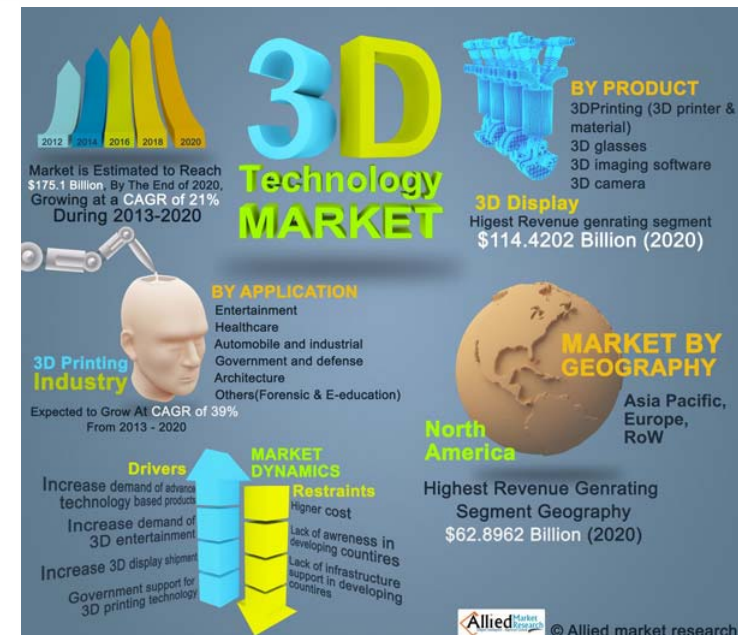
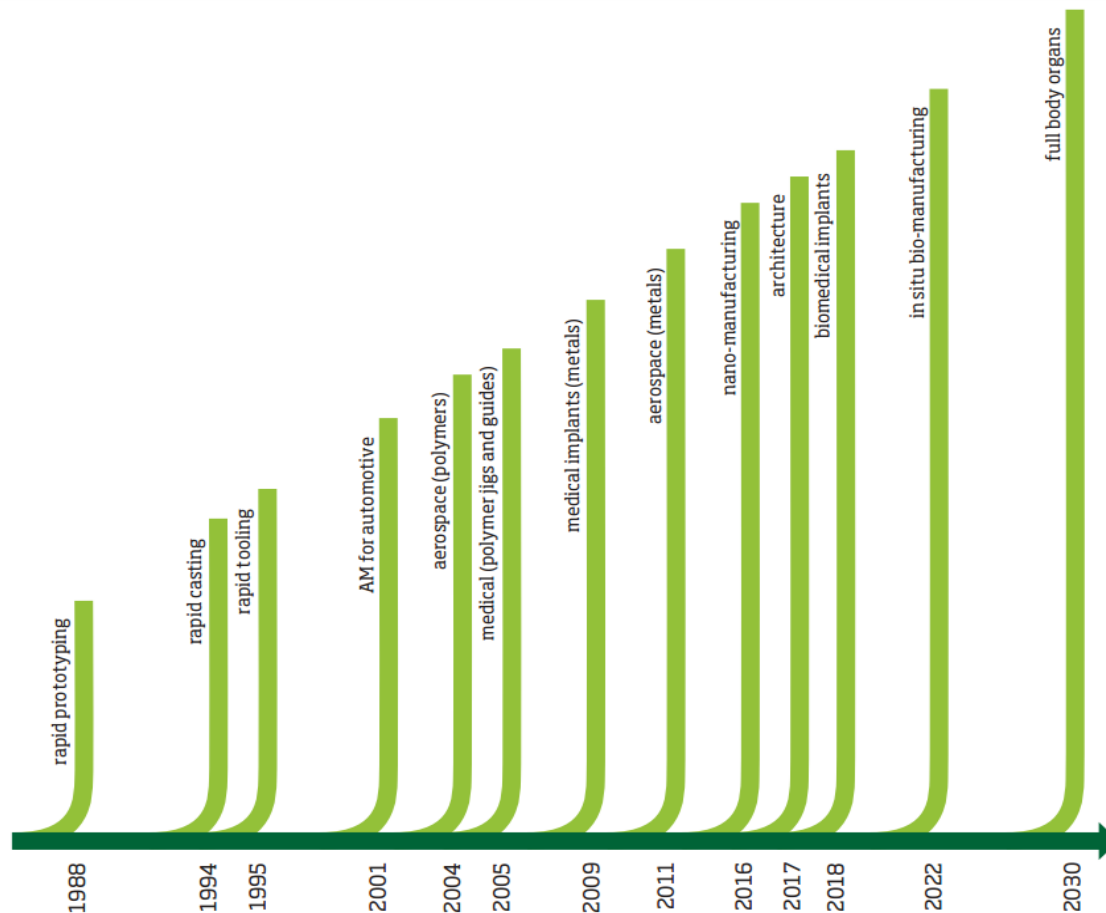


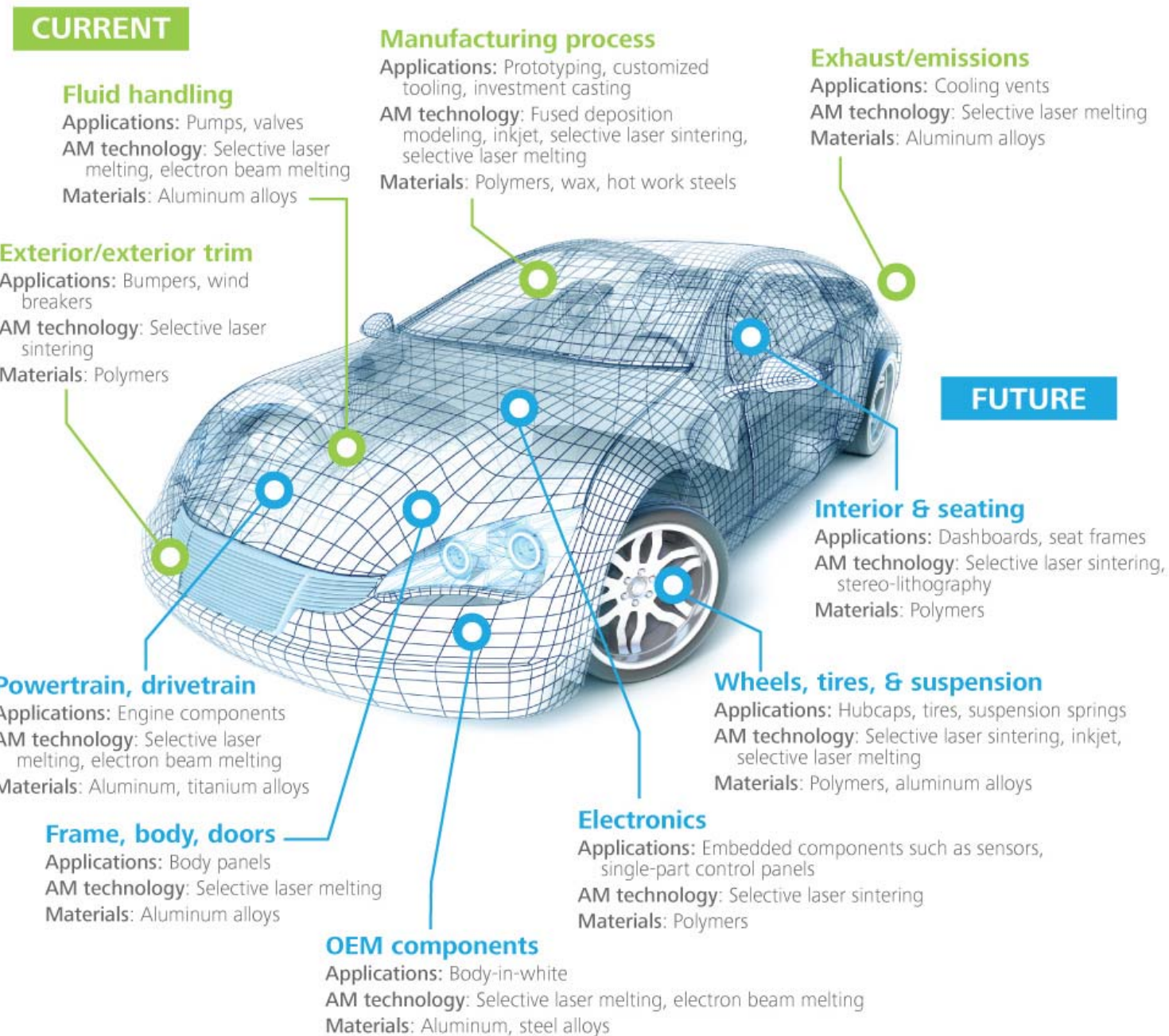
“3D PRINTING’S POTENTIAL TO REVOLUTIONIZE MANUFACTURING IS QUICKLY BECOMING A REALITY.”

Global 3D printing market

Estimates and forecast of market value to 2018, in USD

Category	2013 estimates	2014 forecast	2018 forecast
Total	\$2.5b	\$3.8b	\$16.2b





Source: Deloitte analysis.

Graphic: Deloitte University Press | DUPress.com

Urbee, the first AM-produced car

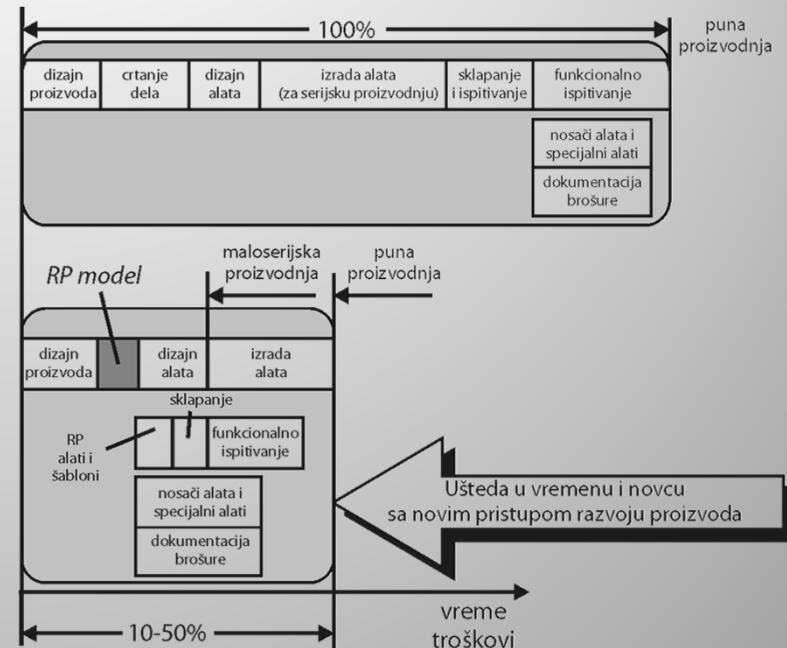


- Built external frame comprised of 20 separate panels built through rapid prototyping using fused deposition modeling (FDM)
- Partnered with a major rapid prototyping service bureau in production of the frame
- Used design and simulation software

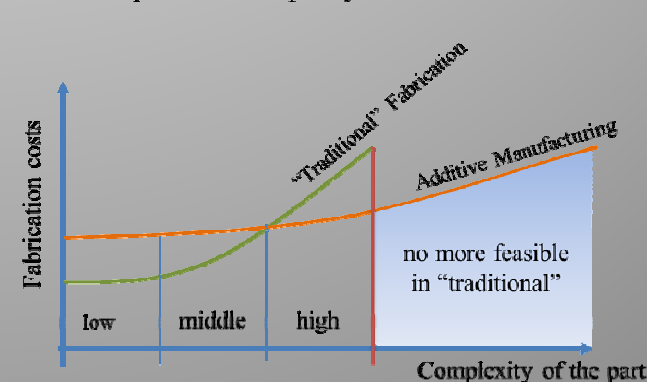
- CAD modeling begun in 2013
- 3D print interiors in addition to the external body
- More parts—40–50 major body and interior parts will be 3D printed
- Greater complexity of parts which cannot be produced through traditional manufacturing methods

Koristi od upotrebe RP tehnologija

- eksperimentisanje sa fizičkim objektima proizvoljne kompleksnosti uz relativno mali utrošak vremena
- zavisno od obima serijske proizvodnje, uštede u vremenu i ceni mogu biti od 50% do 90% ukoliko se koriste RP sistemi
- dizajneri mogu stvarati kompleksnije delove bez značajnih utrošaka vremena i novca
- smanjuje se i fizički rad u proizvodnji i pojednostavljuje se nabavka
- znatno se umanjuje vreme do plasiranja proizvoda na tržište



Schema – Impact of the complexity on the cost

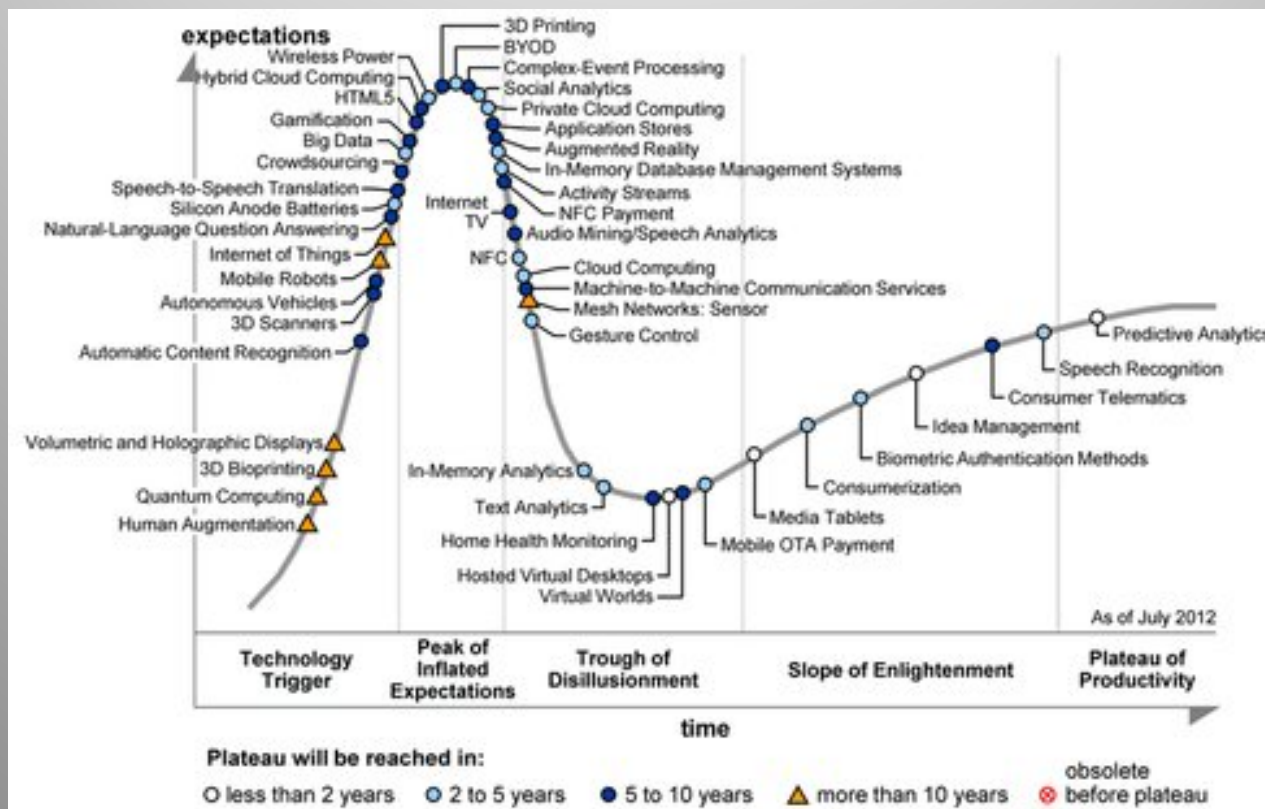


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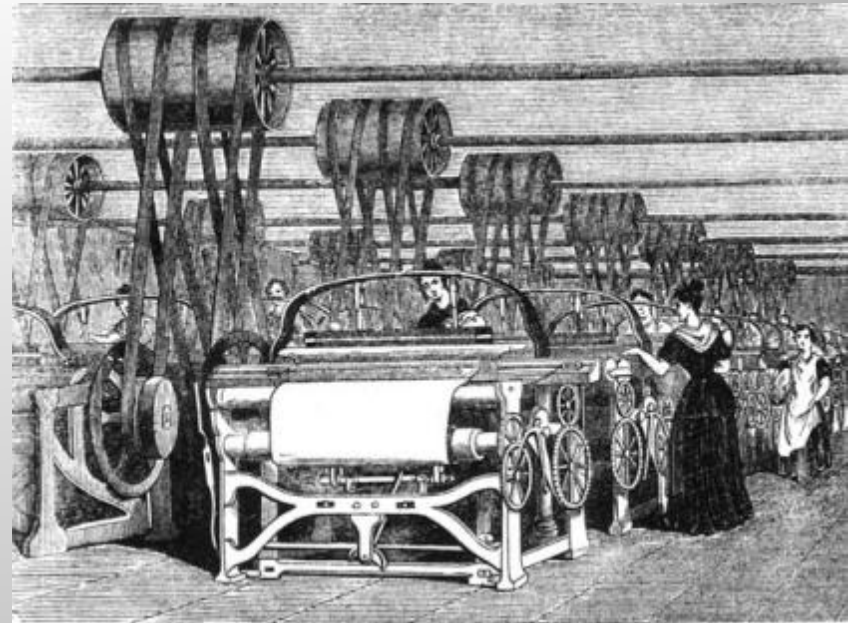
Razvoj RP tehnologija

Year of Inception	Technology
1770	Mechanization [4]
1946	First Computer
1952	First Numerical Control (NC) Machine Tool
1960	First commercial Laser [5]
1961	First commercial Robot
1963	First Interactive Graphics System (early version of Computer-Aided Design) [6]
1988	First commercial Rapid Prototyping System



Geometric Modeling	Prototyping
❶ First Phase: 2D Wireframe <ul style="list-style-type: none"> Started in mid-1960s Few straight lines on display may be: <ul style="list-style-type: none"> circuit path on a PCB plan view of a mechanical component "Natural" drafting technique 	❶ First Phase: Manual Prototyping <ul style="list-style-type: none"> Traditional practice for many centuries Prototyping as a skilled crafts is: <ul style="list-style-type: none"> traditional and manual based on material of prototype "Natural" prototyping technique
❷ Second Phase: 3D Curve and Surface Modeling <ul style="list-style-type: none"> Mid-1970s Increasing complexity Representing more information about precise shape, size and surface contour of parts 	❷ Second Phase: Soft or Virtual Prototyping <ul style="list-style-type: none"> Mid-1970s Increasing complexity Virtual prototype can be stressed, simulated and tested, with exact mechanical and other properties
❸ Third Phase: Solid Modeling <ul style="list-style-type: none"> Early 1980s Edges, surfaces and holes are knitted together to form a cohesive whole Computer can determine the inside of an object from the outside. Perhaps, more importantly, it can trace across the object and readily find all intersecting surfaces and edges No longer ambiguous but exact 	❸ Third Phase: Rapid Prototyping <ul style="list-style-type: none"> Mid-1980s Benefit of a hard prototype made in a very short turnaround time is its main strong point (relies on CAD modeling) Hard prototype can also be used for limited testing Prototype can also assist in the manufacturing of the products

The first industrial revolution “began in Britain in the late 18th century, with the mechanisation of the textile industry.



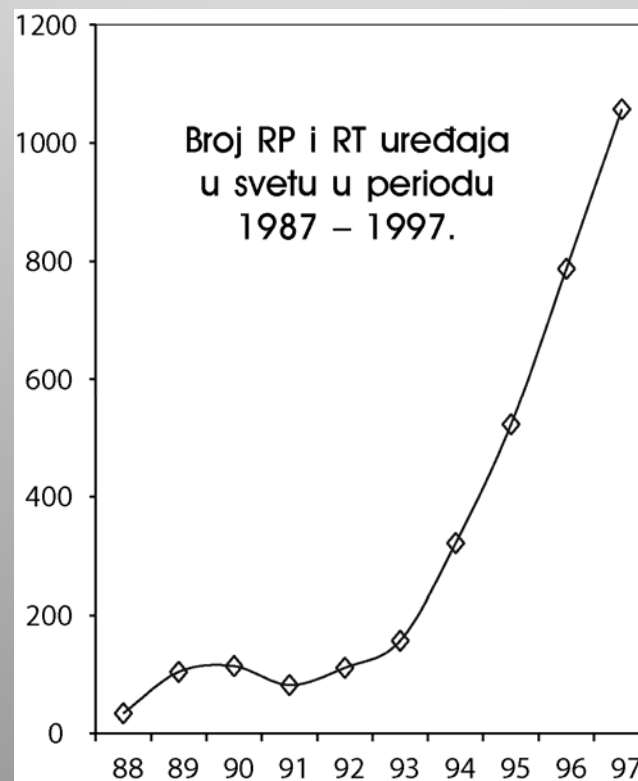
The “second industrial revolution came in the early 20th century, when Henry Ford mastered the moving assembly line and ushered in the age of mass production.”

The third revolution “is under way” and that consists of manufacturing “going digital.”

Next Industrial Revolution



- Prvi rezultati primene RP (SL) objavljeni su 1982. a prva industrijska primena počela je 1989. godine (firma 3-D Systems, SAD koja je i sad lider na tržištu sistema za RP).
- U početku proces je bio skup i komplikovan.
- Danas je to jedan efikasan postupak koji je odlučujući u lancu brzog i savremenog razvoja novog proizvoda.



History



1984 - 86

Charles Hull invents 3D printing and coins the term "Stereo Lithography"



1992

First 3D printer built by 3D Systems



1999

First application of 3D printing in the medical field
- creating the human bladder



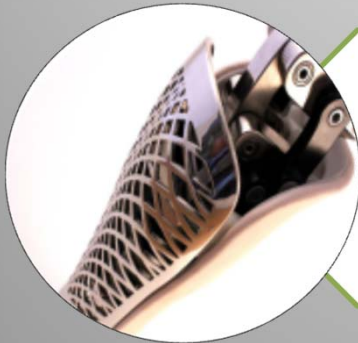
2000

Miniature human kidney created through 3D printing



2006

The Selective Laser Sintering machine – printing multiple materials & fields



2009

First usable prosthetic leg – this opens the door for customized products using 3D printing



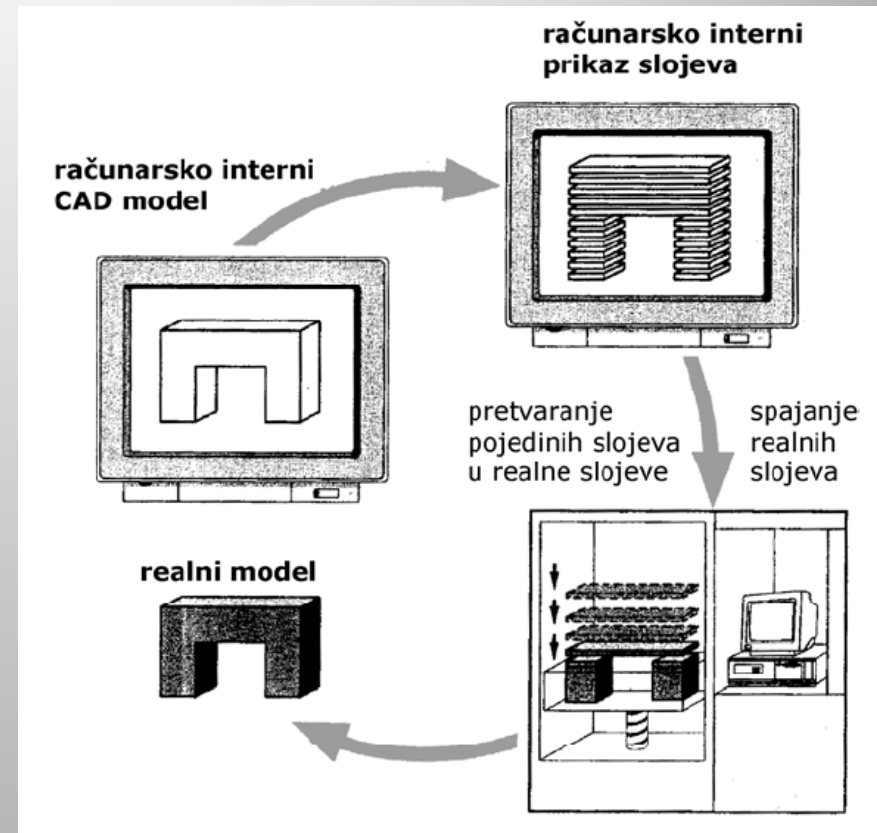
2011

3D printers start offering 14k gold as printable material

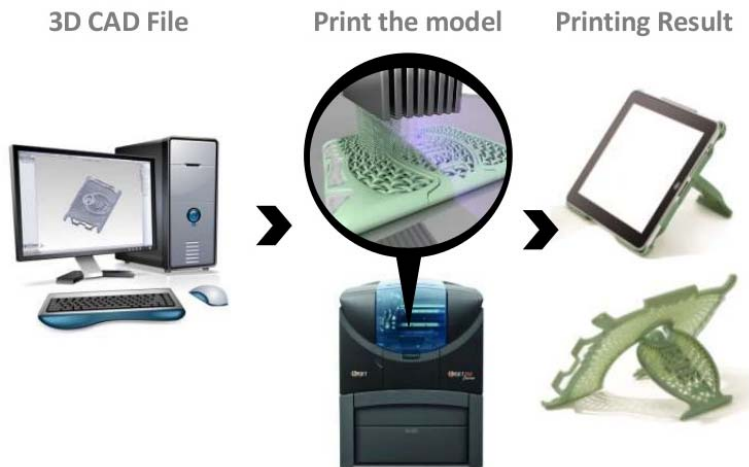
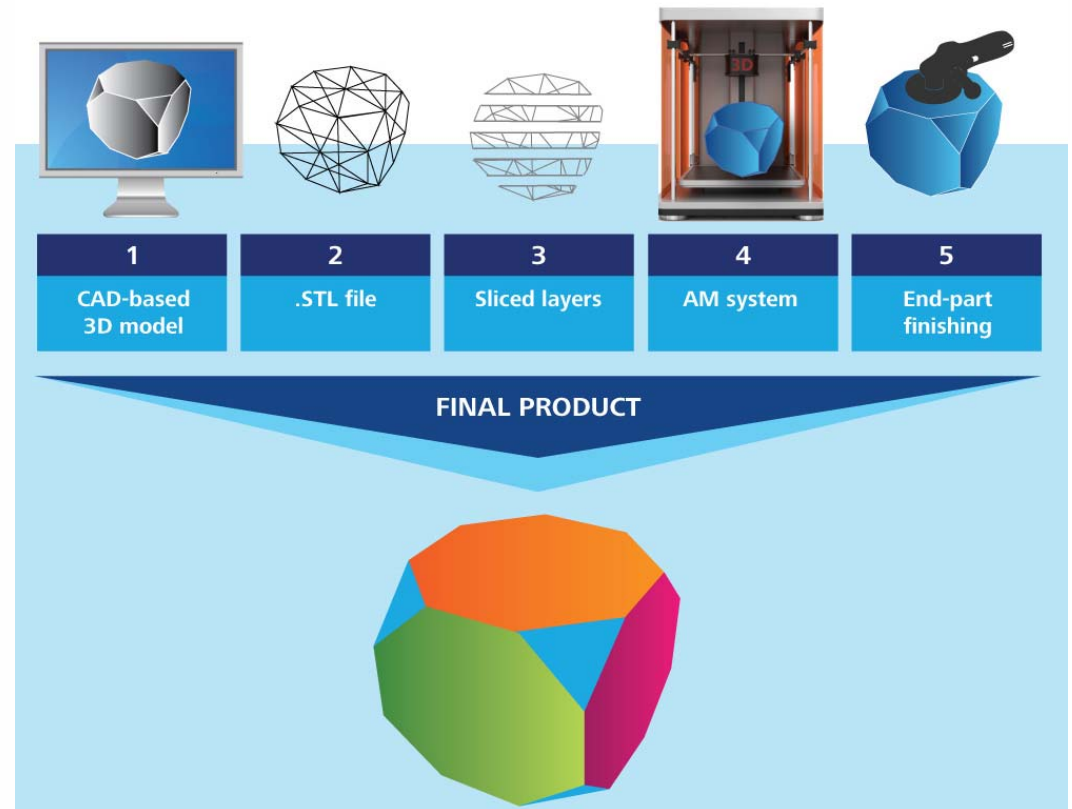
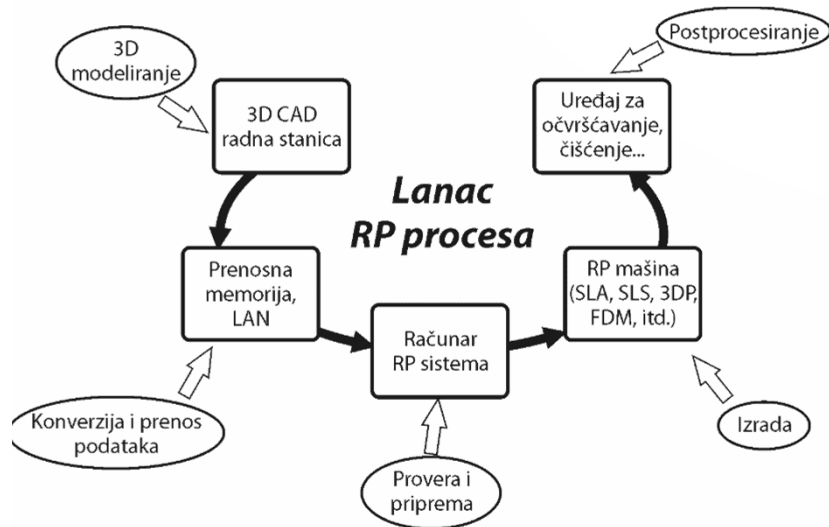
Osnove RP tehnologija

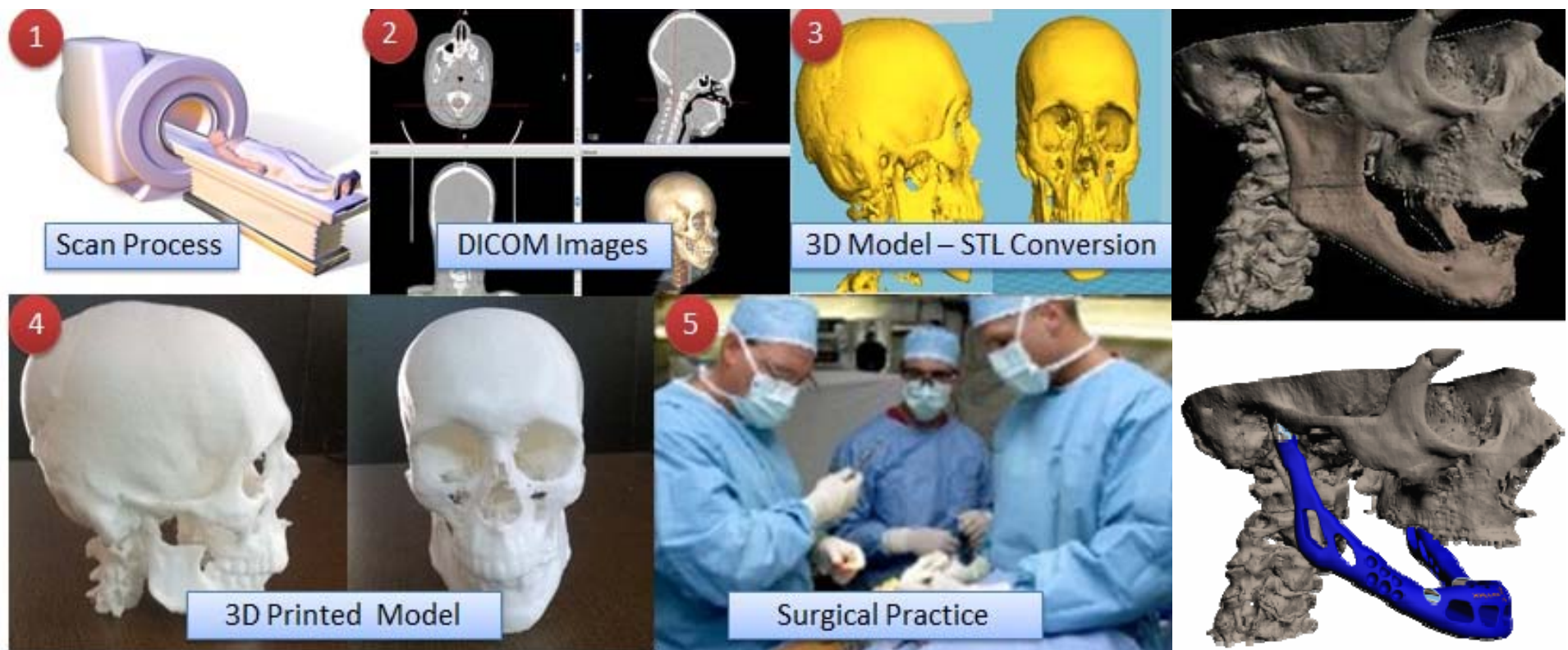
Osnovni pristup zajednički za sve RP tehnike je sledeći:

- Predmet ili neki njegov deo se modelira u 3D CAD softveru. Model mora biti predstavljen zatvorenim površinama.
- Dobijeni model se zatim konvertuje u STL (*S*Tereo*L*itography) fajl format. Fajl je ASCII ili binarnog tipa i predstavlja listu trougaonih površina koje opisuju kompjuterski generisani prostorni model. Pored STL- formata koriste se i CLI, VRML ili IGES formati.
- Poseban softver analizira poligonalni model i pretvara ga u niz poprečnih preseka. Podaci se procesiraju na taj način što se virtuelni model deli u slojeve debljine od 0.05 mm do 0.3 mm.
- Mašina dalje ovakav model koristi za formiranje modela sloj po sloj, pri čemu se svaki sloj vezuje sa onim pre i onim posle njega.



Lanac RP procesa





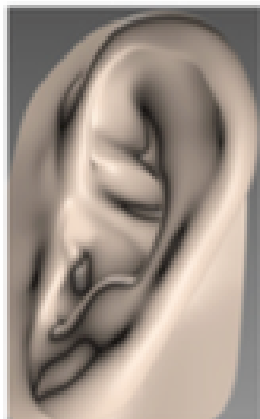
Medical imaging
(CT, MRI)

3D CAD model

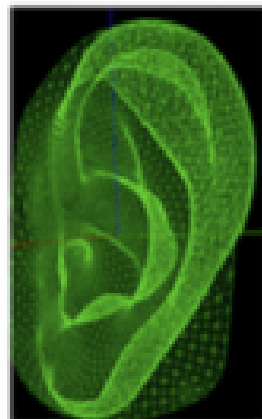
Visualized motion
program

3D printing process

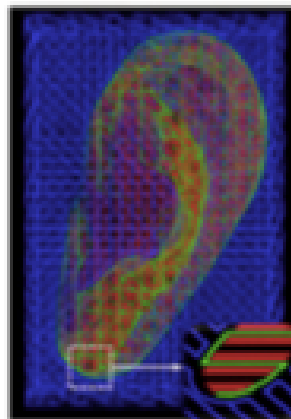
3D bioprinted
tissue product



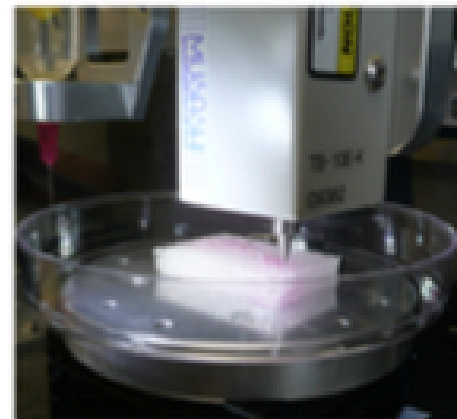
DICOM format



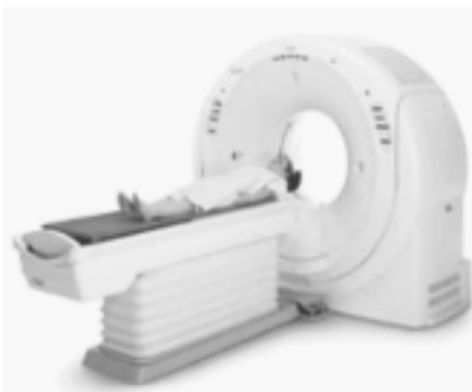
STL format



Text-based
command list



10 mm



CT SCANNING



**PHOTO FORMAT
PREPARATION**



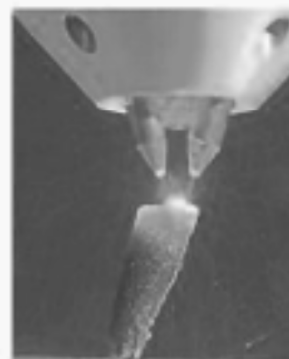
**3D RECONSTRUCTION-
CAD MODEL**



STL FILES



**LENS-PREPARATION OF
THE MACHINE**



**IMPLANT
MANUFACTURING**

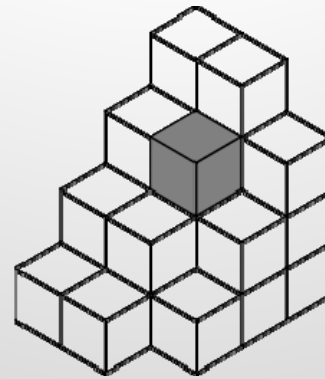


BUILT IMPMANT

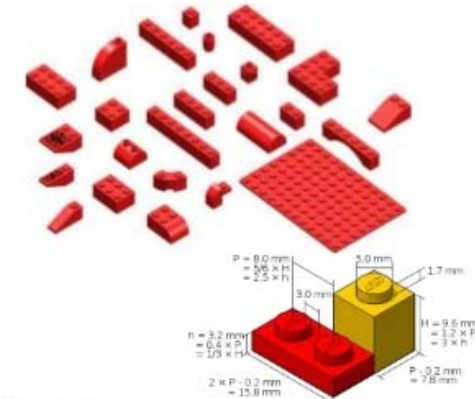
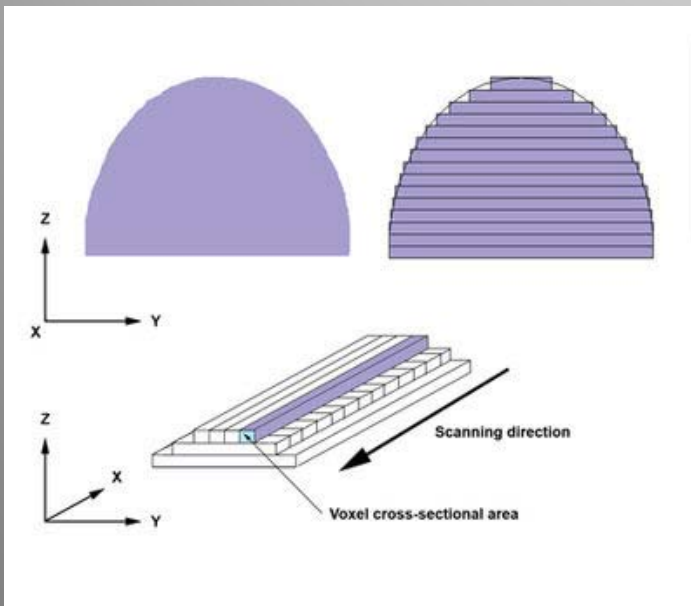
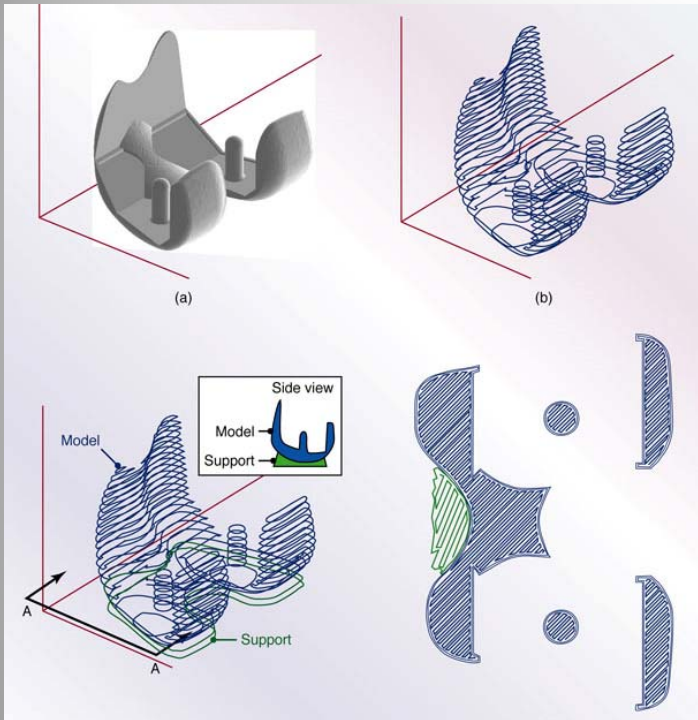


IMPLEMENTATION

VOXEL



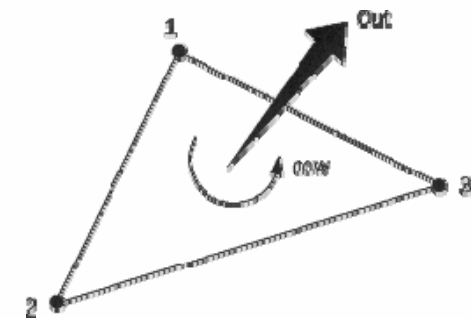
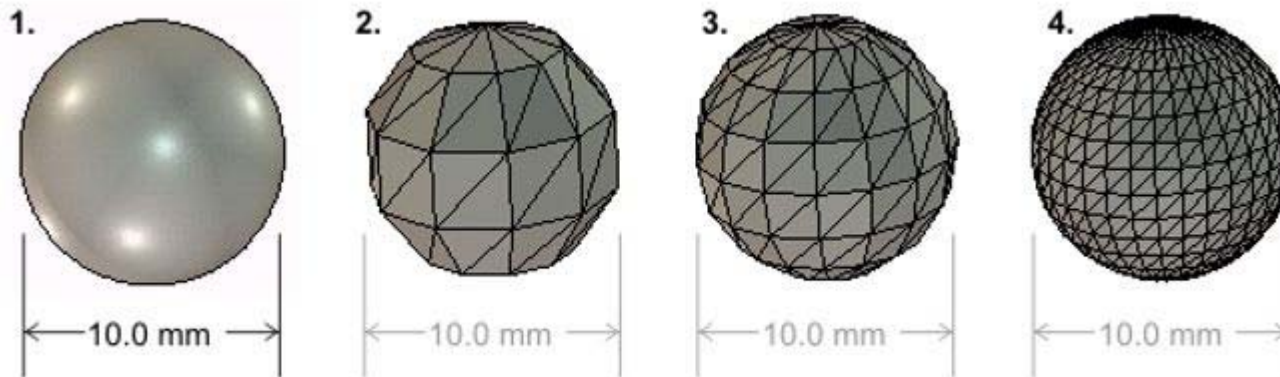
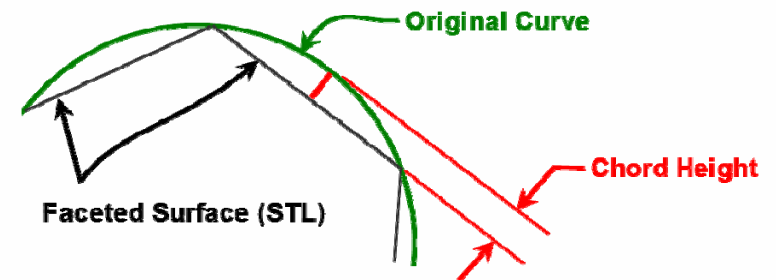
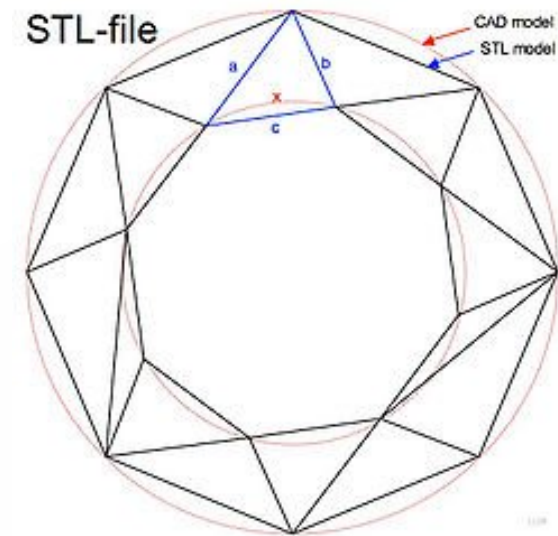
VOXEL (volumetric pixel ili tačnije Volumetric Picture Element) je zapreminski element koji predstavlja osnovni parametar mreže u trodimenzionalnom prostoru. On je analogan pixel-u, koji se koristi kao parametar 2D slika (bitmap).

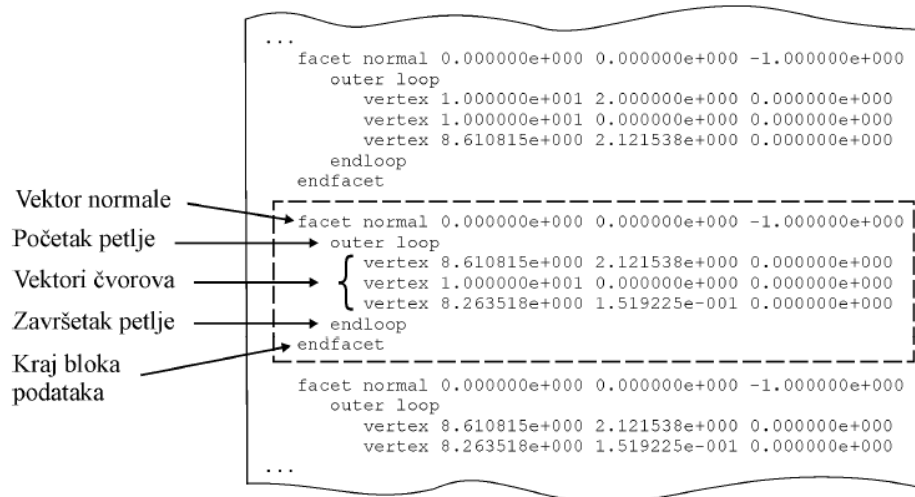
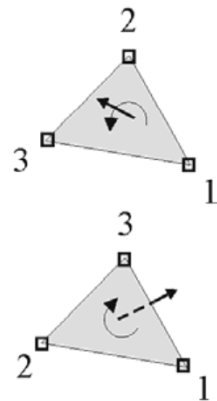
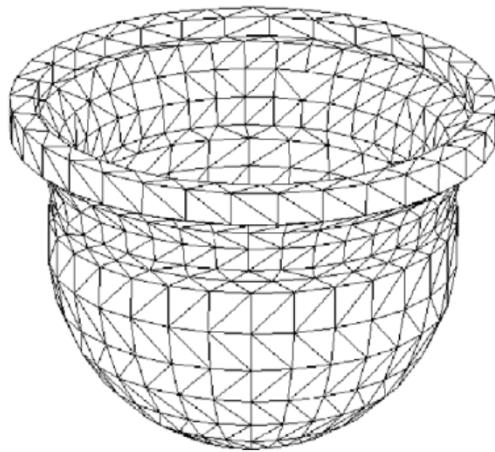
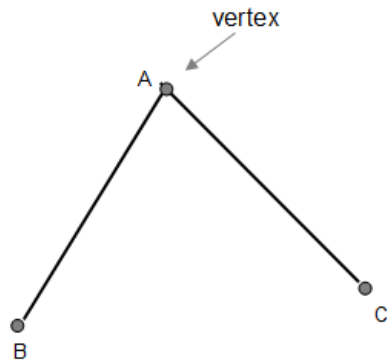


- 1 cubic millimeter – ~20,000 Objet voxels
- The smallest Lego brick – ~4,000,000 Objet voxels
- Full tray – 10^{12} Objet voxels

STL

*The STL (stereo lithography) file format is supported by most CAD packages, and is widely used in most rapid prototyping / additive manufacturing technologies. STL files describe only the surface geometry of a three dimensional object without any representation of color, texture or other common CAD model attributes. The STL file describes a discretized triangulated surface by the unit normal and vertices coordinates for each triangle (ordered by the right-hand rule).

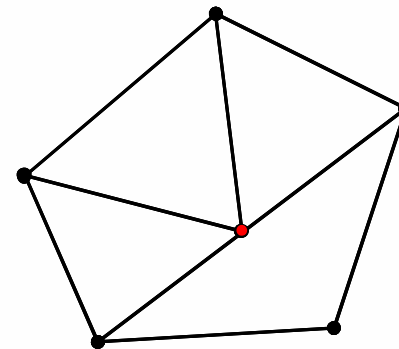




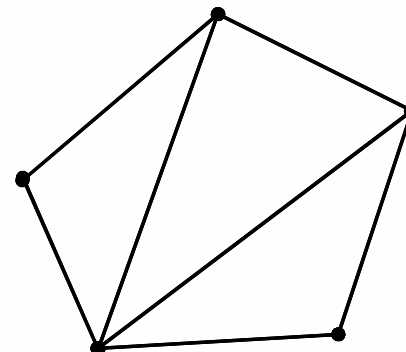
STL Pravila:

1. Površina proizvoljnog (konačnog) oblika → objekat može imati otvore
2. Višestruke površi su dozvoljene (sklopovi)
3. Površina mora biti zatvorena
4. Vertex-to-vertex rule

Svaki trougao mora da deli dva temena sa svakim od susednih trouglova. Drugim rečima, temena jednog trougla ne mogu ležati na strani drugog.



WRONG

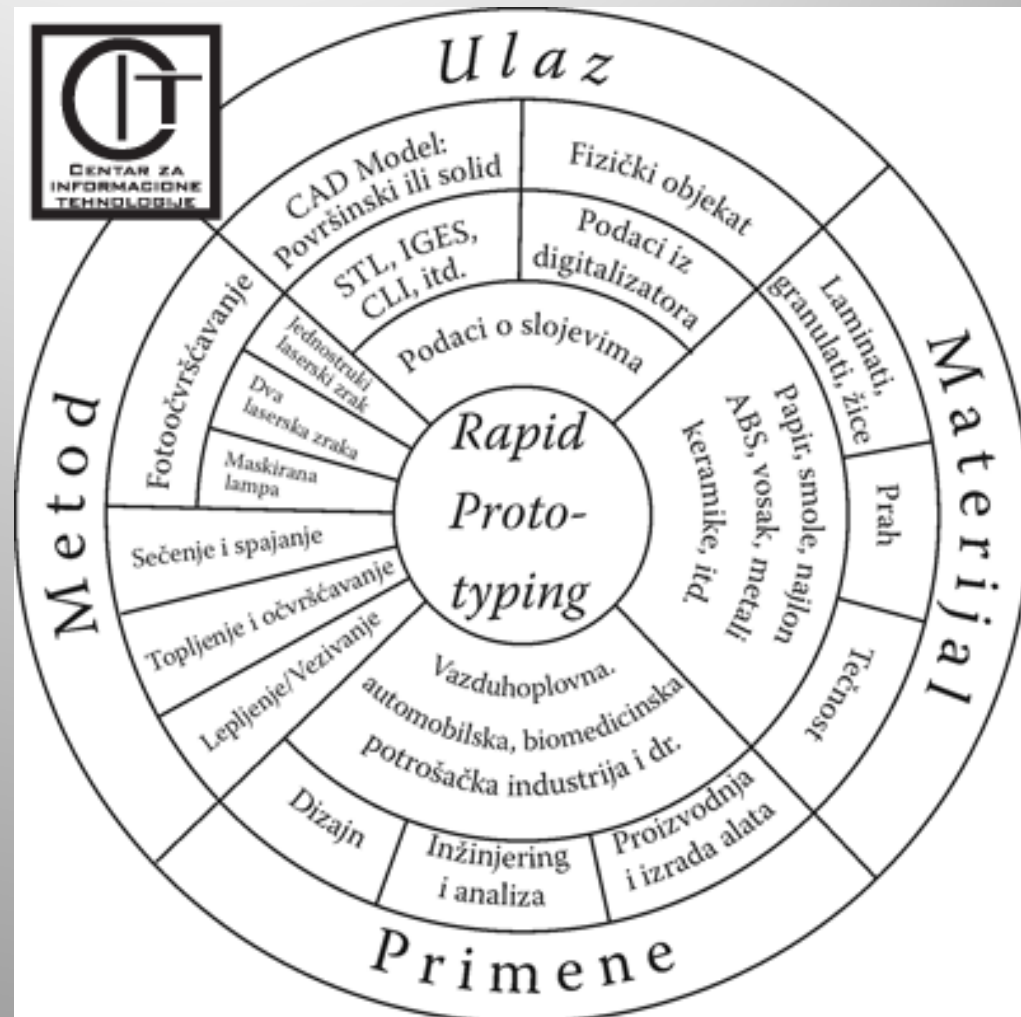


CORRECT

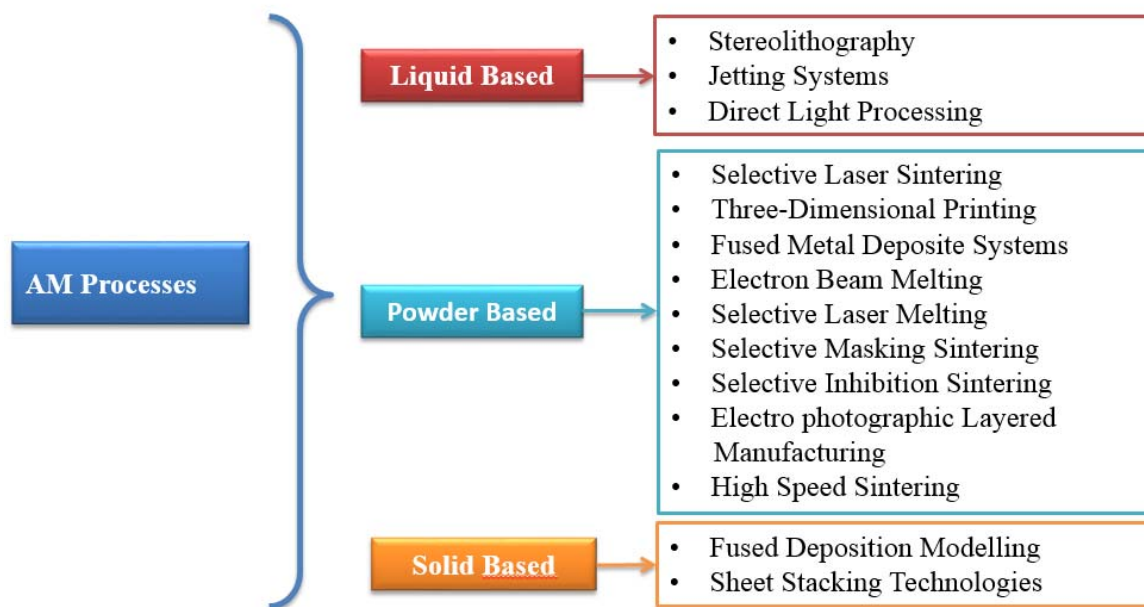
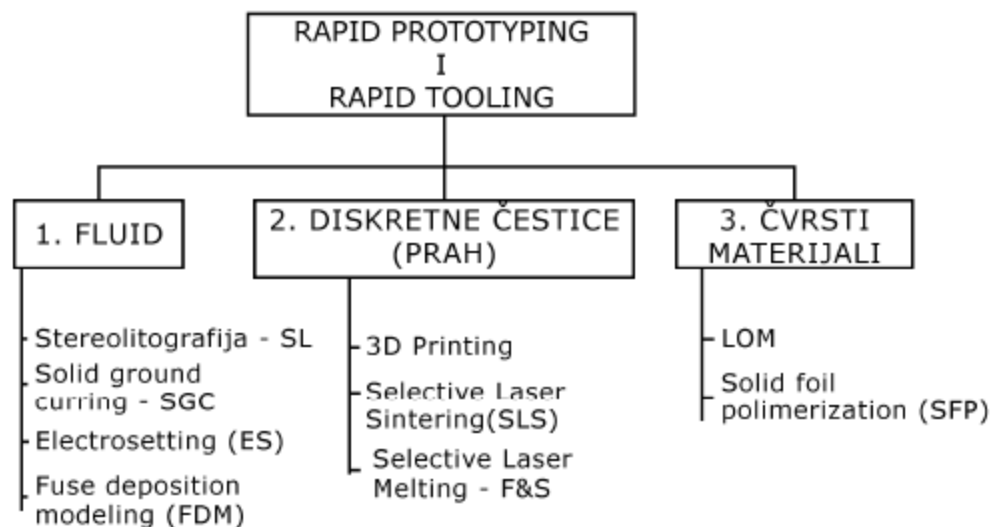
	Opis	Komentar
Prednosti	Jednostavna konverzija 3D u STL	Konverzija 3D modela u STL format odvija se primenom standardnih, jednostavnih algoritama, uz mogućnost kontrolisanja tačnosti aproksimacije
	Univerzalnost	Svi tipovi 3D geometrije mogu se aproksimirati mrežom ravanskih trouglova
	Jednostavno generisanje ravanskih preseka	Algoritmi za generisanje ravanskih preseka na STL modelu najčešće su jednostavni
	Mogućnost segmentiranja STL datoteke	Za potrebe prilagođavanja radnom prostoru RP mašine, veći modeli mogu se podeliti na nekoliko STL datoteka
Nedostaci	Problemi svojstveni STL formatu	Opširnost i ponavljanje podataka Veličina datoteke Pojava greške zaokruživanja
	Greške u procesu konverzije	
	Nedostaci u pogledu projektovanja tehnološkog postupka	Skupo i vremenski zahtevno korigovanje STL datoteke Nedostatak topoloških informacija Nedostatak tehnoloških parametara

Četiri glavna aspekta RP tehnologija

- Ulazni podaci
- Metod izrade
- Materijal izrade
- Primena

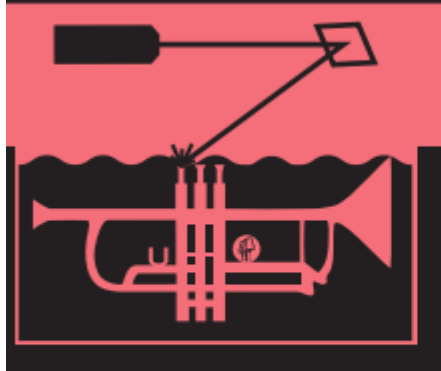


Vrste i podela RP i RT procesa



7 Families of Additive Manufacturing

According to ASTM F2792 Standards



**VAT
PHOTOPOLYMERIZATION**

Alternative Names:

SLA™ - Stereolithography Apparatus
DLP™ - Digital Light Processing
SLPP™ - Scan, Spin, and Selectively Photocure
CLIP™ - Continuous Liquid Interface Production

Description:

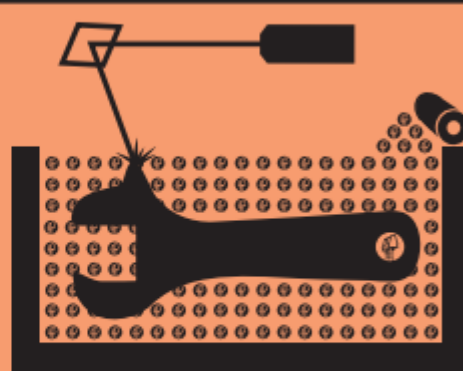
A vat of liquid photopolymer resin is cured through selective exposure to light (via a laser projector) which then initiates polymerization and converts the exposed areas to a solid part.

Strengths:

- High level of accuracy and complexity
- Smooth surface finish
- Accommodates large build areas

Typical Materials

UV-curable Photopolymer Resins (with various fillers)



**POWDER BED
FUSION (PBF)**

Alternative Names:

SLS™ - Selective Laser Sintering; DMLS™ - Direct Metal Laser Sintering; SLM™ - Selective Laser Melting; EBM™ - Electron Beam Melting; SHS™ - Selective Heat Sintering; MJF™ - Multi-Jet Fusion

Description:

Powdered materials are selectively consolidated by melting it together using a heat source such as a laser or electron beam. The unfused powder surrounding the consolidated part acts as a support material for overhanging features.

Strengths:

- High level of complexity
- Powder acts as support material
- Wide range of materials

Typical Materials

Plastics, Metal and Ceramic Powders, and Sand



**BINDER
JETTING**

Alternative Names:

3DP™ - 3D Printing
ExOne
Voxeljet

Description:

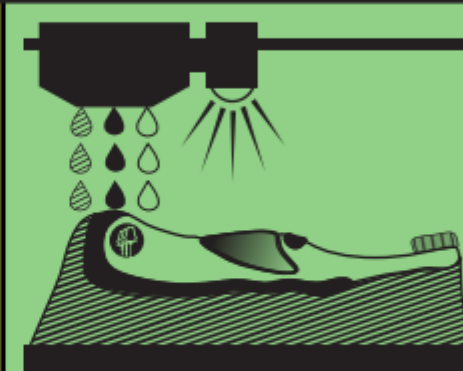
Liquid bonding agents are selectively applied onto thin layers of powdered material to build up parts layer by layer. The binders include organic and inorganic materials. Metal or ceramic powdered parts are typically fired in a furnace after they are printed.

Strengths:

- Allows for full color printing
- High productivity
- Uses a wide range of materials

Typical Materials

Powdered Plastic, Metal, Ceramics, Glass, and Sand.



**MATERIAL
JETTING**

Alternative Names:

Polyjet™
SCP™ - Smooth Curvatures Printing
MJM - Multi-Jet Modeling
Projet™

Description:

Droplets of material are deposited layer by layer to make parts. Common varieties include jetting a photocurable resin and curing it with UV light as well as jetting thermally molten materials that then solidify in ambient temperatures.

Strengths:

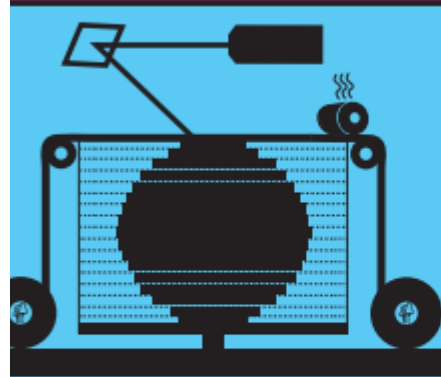
- High level of accuracy
- Allows for full color parts
- Enables multiple materials in a single print

Typical Materials

Photopolymers, Polymers, Waxes

7 Families of Additive Manufacturing

According to ASTM F2792 Standards



**SHEET
LAMINATION**

Alternative Names:

LOM - Laminated Object Manufacture
SL - Selective Deposition Lamination
UAM - Ultrasonic Additive Manufacturing

Description:

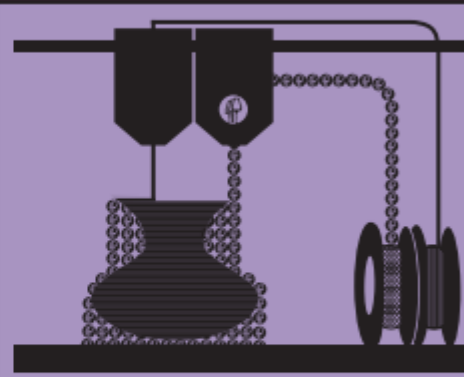
Sheets of material are stacked and laminated together to form an object. The lamination method can be adhesives or chemical (paper/plastics), ultrasonic welding, or brazing (metals). Unneeded regions are cut out layer by layer and removed after the object is built.

Strengths:

- High volumetric build rates
- Relatively low cost (non-metals)
- Allows for combinations of metal foils, including embedding components.

Typical Materials

Paper, Plastic Sheets, and Metal Foils/Tapes



**MATERIAL
EXTRUSION**

Alternative Names:

FFF - Fused Filament Fabrication
FDM™ - Fused Deposition Modeling

Description:

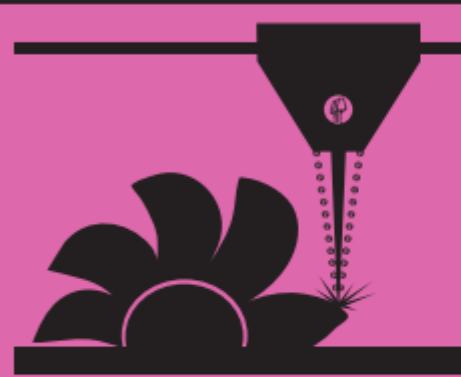
Material is extruded through a nozzle or orifice in tracks or beads, which are then combined into multi-layer models. Common varieties include heated thermoplastic extrusion (similar to a hot glue gun) and syringe dispensing.

Strengths:

- Inexpensive and economical
- Allows for multiple colors
- Can be used in an office environment
- Parts have good structural properties

Typical Materials

Thermoplastic Filaments and Pellets (FFF); Liquids, and Slurries (Syringe Types)



**DIRECTED ENERGY
DEPOSITION (DED)**

Alternative Names:

LMD - Laser Metal Deposition
LENS™ - Laser Engineered Net Shaping
DMD™ - Direct Metal Deposition

Description:

Powder or wire is fed into a melt pool which has been generated on the surface of the part where it adheres to the underlying part or layers by using an energy source such as a laser or electron beam. This is essentially a form of automated build-up welding.

Strengths:

- Not limited by direction or axis
- Effective for repairs and adding features
- Multiple materials in a single part
- Highest single-point deposition rates

Typical Materials

Metal Wire and Powder, with Ceramics



HYBRID

Alternative Names:

AMBIT™ - Created by Hybrid Manufacturing Technologies

Description:

Laser metal deposition (a form of DED) is combined with CNC machining, which allows additive manufacturing and 'subtractive' machining to be performed in a single machine so that parts can utilize the strengths of both processes.

Strengths:

- Smooth surface finish AND High Productivity
- Geometrical and material freedoms of DED
- Automated in-process support removal, finishing, and inspection

Typical Materials

Metal Powder and Wire, with Ceramics

Liquided - Based

- (1) 3D Systems' Stereolithography Apparatus (SLA)
- (2) Cubital's Solid Ground Curing (SGC)
- (3) Sony's Solid Creation System (SCS)
- (4) CMET's Solid Object Ultraviolet-Laser Printer (SOUP)
- (5) Autostrade's E-Darts
- (6) Teijin Seiki's Soliform System
- (7) Meiko's Rapid Prototyping System for the Jewelry Industry
- (8) Denken's SLP
- (9) Mitsui's COLAMM
- (10) Fockele & Schwarze's LMS
- (11) Light Sculpting
- (12) Aaroflex
- (13) Rapid Freeze
- (14) Two Laser Beams
- (15) Microfabrication

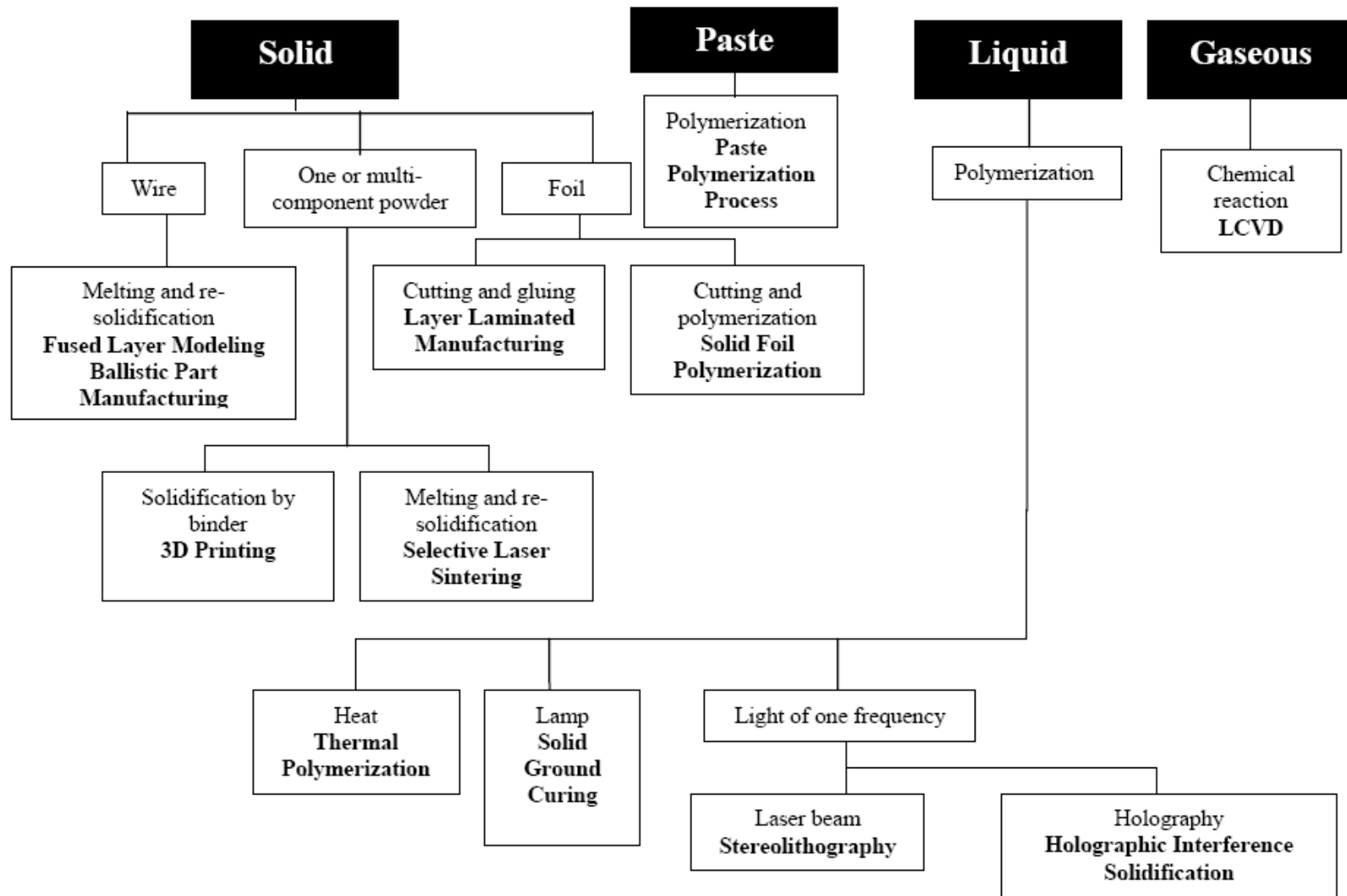
Solid-Based

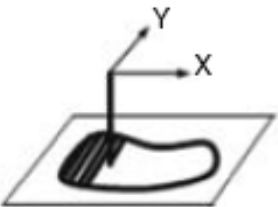
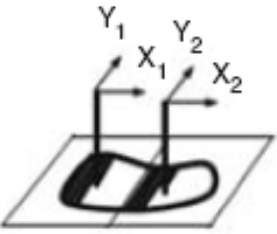
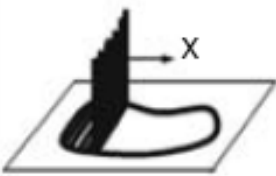
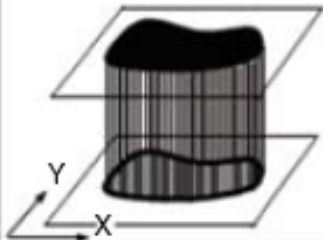
- (1) Cubic Technologies' Laminated Object Manufacturing (LOM)
- (2) Stratasys' Fused Deposition Modeling (FDM)
- (3) Kira Corporation's Paper Lamination Technology (PLT)
- (4) 3D Systems' Multi-Jet Modeling System (MJM)
- (5) Solidscape's ModelMaker and PatternMaster
- (6) Beijing Yinhua's Slicing Solid Manufacturing (SSM), Melted Extrusion Modeling (MEM) and Multi-Functional RPM Systems (M-RPM)
- (7) CAM-LEM's CL 100
- (8) Ennex Corporation's Offset Fabbers

Powder-Based

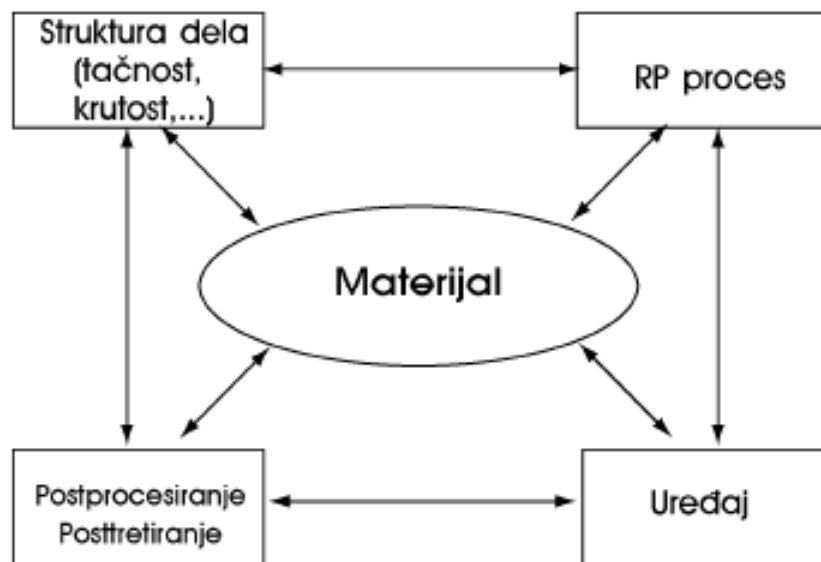
- (1) 3D Systems's Selective Laser Sintering (SLS)
- (2) EOS's EOSINT Systems
- (3) Z Corporation's Three-Dimensional Printing (3DP)
- (4) Optomec's Laser Engineered Net Shaping (LENS)
- (5) Soligen's Direct Shell Production Casting (DSPC)
- (6) Fraunhofer's Multiphase Jet Solidification (MJS)
- (7) Acram's Electron Beam Melting (EBM)
- (8) Aeromet Corporation's Lasform Technology
- (9) Precision Optical Manufacturing's Direct Metal Deposition (DMDTM)
- (10) Generis' RP Systems (GS)
- (11) Therics Inc.'s Theriform Technology
- (12) Extrude Hone's PrometalTM 3D Printing Process

Generative Manufacturing Processes



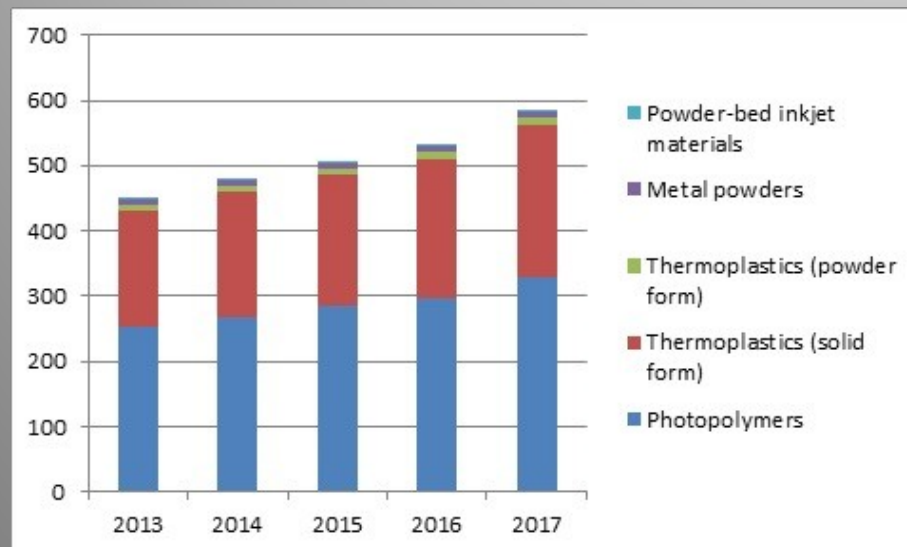
	1D Channel 	2x1D Channels 	Array of 1D Channels 	2D Channel 
Liquid Polymer	SLA (3D Sys)	Dual beam SLA (3D Sys)	Objet	Envisiontech MicroTEC
Discrete Particles	SLS (3D Sys), LST (EOS), LENS Phenix, SDM	LST (EOS)	3D Printing	DPS
Molten Mat.	FDM, Solidscape		ThermoJet	
Solid Sheets	Solido PLT (KIRA)			

Materijali



Karakteristike:

- mehaničke osobine
- aspekt zaštite čovekove sredine
- reološke osobine (fluid)
- regulisanje parametara za vreme procesa
- postprocesiranje





Platinum



Gold



Sterling Silver



Precious Plated Metal



Strong & Flexible Plastic



Frosted Detail Plastic



Acrylic Plastic



Metallic Plastic



Brass



Bronze



Steel



Full Color Sandstone



Porcelain



Castable Wax



Elasto Plastic



Aluminum

Mechanical Properties of Selected Materials for Rapid Prototyping

Process	Material	Tensile strength (MPa)	Elastic modulus (GPa)
Stereolithography	SL5180 ^a	55-65	2.4-2.6
	SL5195 ^a	46.5	2.1
	SL5510 ^b	73	2.8
	SL7940 ^b	37-39	1.3
Fused-deposition modeling	Polycarbonate	62	-
	ABS	35	2.5
Selective laser sintering	Nylon	36	1.4
	Polycarbonate	23.4	1.2
	Polyamide	44	1.6
	SOMOS 201	17.3	14
	ST-100 ^c	305	137
Three-dimensional printing	S3 stainless steel	406	148
	S4 stainless steel	682	147

^a After a 90-min UV cure; ^b after a 90-min UV cure at 80°C; ^c sintered and bronze-infiltrated steel powder

Materials

Technologies

Parts built through polymerization

Parts built through bonding agent

Parts built through melting

Ceramic



BJ



LM

Metal



EBM

Sand



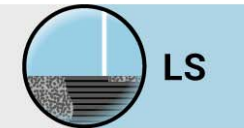
SL



PJ



FDM



LS

Wax



MJ *

Lower

Durability

Higher

Smoother

Surface finish

Rougher

Higher

Detail

Lower

Prototypes | Indirect processes

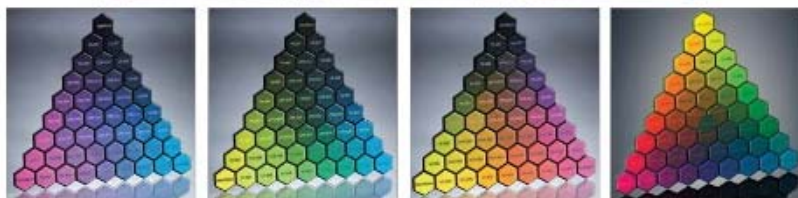
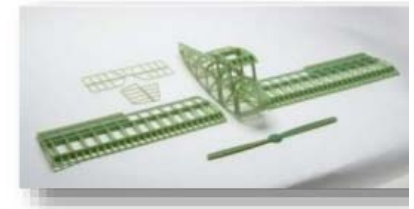
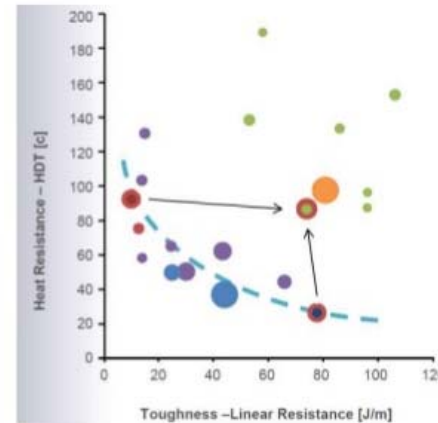
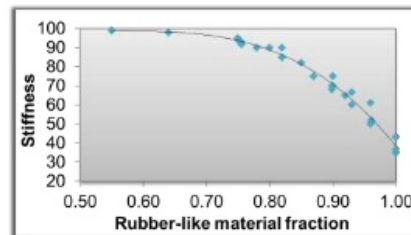
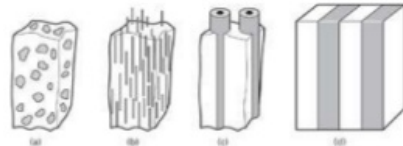
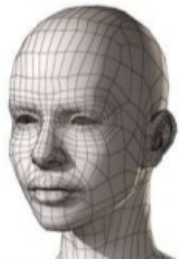
Application

Functional parts

Digitalni (kompozitni) materijali

Digital Materials are engineered materials manufactured from two or more different constituent materials, according to a digitally encoded three dimensional phase structure design (the DM code), and produced by an additive manufacturing process.

- Heterogeneous/Homogeneous
- Anisotropic/Isotropic
- Geometry Dependent



Sandwich X



Sandwich Y



Sandwich Z



