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NAČINI BRZE IZRADE PREDSERIJSKIH PROIZVODA
RAPID PROTOTYPING APPLICATION

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Sažetak: *Tehnologija 3D-ispisa predstavlja brz i relativno jednostavan način izrade prototipova. Osnovna je prednost uporabe tehnologije brze izrade (RP) u izravnom ispisu 3D-modela iz CAD/CAM podataka bez potrebe za dodatnim operacijama. Upravo je ta dostupnost brze izrade 3D-modela omogućila bržu komunikaciju i bržu evaluaciju različitih inženjerskih rješenja i koncepcija te lakšu komunikaciju s partnerima i prodavačima. Rezultati su vidljivi u kraćem ciklusu razvoja proizvoda te kraćem ciklusu projektiranja. U članku je dan prikaz nekolicine najzastupljenijih RP-tehnologija koje se danas koriste.*

Ključne riječi: – *rapid prototyping*
– CAD/CAM
– nekonvencionalni postupci

Abstract: *3D printing technology is a quick and relatively easy way of making prototypes. The main advantage of using the technology of Rapid Prototyping (RP) is the direct printing of 3D models from CAD / CAM data without the need for additional operations. The RP technology of manufacturing 3-D models allows faster communication and faster evaluation of various engineering solutions and concepts, and easier communication with partners and vendors. The results are visible in a shorter product development cycle and a shorter design cycle. The article presents several RP technologies that are in use today.*

Key words: – Rapid Prototyping
– CAD/CAM
– Unconventional methods of processing

1. UVOD

Tehnologija brze izrade prototipova (engl. *Rapid Prototyping* – RP) jedna je od trenutačno najbrže rastućih tehnologija. Zahvaljujući snažnom tehnološkom razvoju, rješenja za izradu 3D-modela postala su dostupna širem krugu proizvodnih subjekata. U nekim slučajevima vremena izrade prototipova znatno su smanjena [1, 2]. Na taj je način omogućena brža interakcija među svim sudionicima u lancu razvoja određenog proizvoda. U slučajevima kompleksne geometrije, koju nije moguće postići klasičnim načinima obrade, jedini način koji preostaje za izradu prototipa ili alata je RP-tehnologija. Za razliku od klasičnih obrada odvajanjem čestica, poput tokarenja, bušenja ili glodanja, tehnologija brze izrade prototipova pripada tzv. aditivnoj skupini. Prototip koji se izrađuje nastaje dodavanjem sloja [3] na prethodno kreiran sloj. Ovisno o vrsti korištene tehnologije na raspolaganju nam stoje različiti materijali koji se mogu kombinirati i na taj način povećati čvrstoću izratka, poboljšati tehnološka

1. INTRODUCTION

Rapid Prototyping Technology (U.S. Rapid Prototyping - RP) is one of the currently fastest growing technologies. According to such swift technological development, solutions for making 3D models have become available to a wider range of entrepreneurs. In addition, the application of this technology has significantly reduced the time for making a prototype [1, 2]. This allows for a faster interaction between all participants in the product development chain. In complex geometrical cases that cannot be achieved through conventional methods of processing, RP technology remains the only way to produce prototypes or tools. Unlike the conventional machining of a particle, such as turning, drilling or milling, the technology of rapid prototyping belongs to the additive technology group. The prototype is created as follows: to the previously created layer, a new layer [3] of material is added. Depending on the type of available RP technology, the different materials thus achieve a higher prototype hardness, better technological properties of a

svojstva dijela ili poboljšati ergonomski učinak.
Neke od trenutačno zastupljenijih tehnika [4, 5] brze izrade prototipa jesu:

- *Stereolitography* (SL) – stereolitografija,
- *Fused deposition modeling* (FDM) – modeliranje topljenim depozitima,
- *Laminated object manufacturing* (LOM) – laminirana objektna proizvodnja,
- *Selective laser sintering* (SLS) – selektivno lasersko sinteriranje,
- *3D-print* (3DP) – trodimenzionalni tisak,
- *Polyjet* i *Polyjet Matrix*.

Ovisno o namjeni pojedinog dijela bira se i vrsta brze izrade. Pored traženih svojstava koje prototip mora imati, cijena stroja važan je čimbenik. U tablici 1 dane su okvirne cijene ovisno o vrsti korištene tehnologije, prema [1-9]:

part or a better ergonomic efficiency.

Some of the RP techniques in use [4, 5] are:

- Stereolitography (SL),
- Fused deposition modeling (FDM),
- Laminated object manufacturing (LOM),
- Selective laser sintering (SLS),
- 3D print (3DP),
- Polyjet and Polyjet Matrix.

Depending on the purpose of a chosen part, a rapid prototyping technique was chosen. In addition to the required properties of a part, the price of the machine is a significant factor as well. Approximate prices are given (Table 1) depending on the type of RP technologies used by [1 - 9]:

Tablica 1. Rezolucija, debljina sloja i okvirni cjenovni podaci
Table 1. Resolution, layer thickness and price range

Vrsta RP tehnologije *RP type*	*Rezolucija* *Resolution*	*Debljina sloja* *Layer thickness*	*Okvirna cijena koštanja* *Approximate cost*
SL – stereolitografija *SL – stereolitography*	±100 μm	50 μm	150 000 – 390 000 EUR
FDM – modeliranje topljenim depozitima *FDM – fused deposition modeling*	±127 μm	50 – 762 μm	12 000 – 800 000 EUR
LOM – laminirana objektna proizvodnja *LOM – laminated object manufacturing*	±127 μm	76 – 150 μm	6 000 – 100 000 EUR
SLS – selektivno lasersko sinteriranje *SLS – selected laser sintering*	±51 μm	100 – 150 μm	150 000 – 800 000 EUR
3DP – 3D tisak *3DP – 3D print*	±127μm	250 μm	12 000 – 65 000 EUR
Polyjet (Matrix)	600 – 1600 dpi	16 – 32 μm	25 000 – 250 000 EUR
Envisiontec DLP	1280 x 1024 dpi	15 – 100 μm	25 000 – 250 000 EUR

Navedene cijene RP-strojeva okvirne su i služe isključivo u orijentacijske svrhe. Svaki od navedenih načina proizvodnje ima svoje prednosti i nedostatke. U nastavku slijedi kratki opis za svaku od RP-tehnologija navedenih u tablici 1.

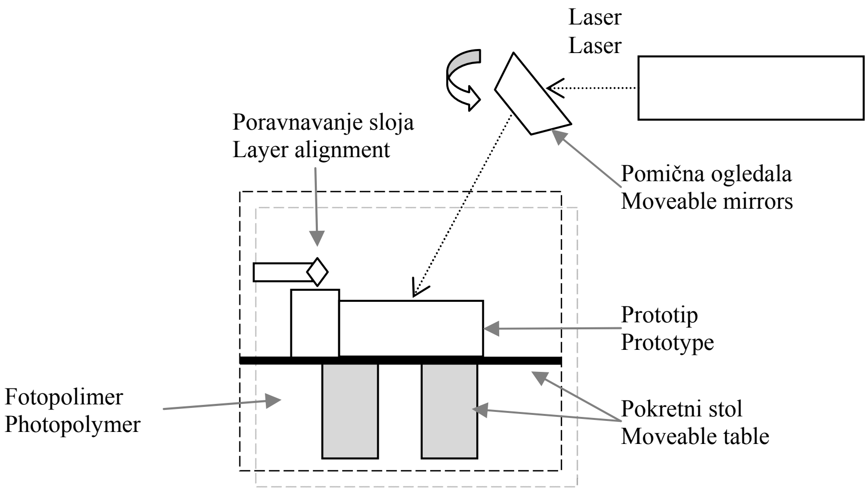
2. PRINCIP STEREOLITOGRAFSKE IZRADE (SL)

Osnovni koncept toga postupka zasniva se na uporabi lasera i fotopolimerne tekućine. Pri prolazu laserske zrake tekućina prelazi iz tekućega u čvrsto agregatno stanje formirajući na taj način konturu modela. Na slici 1 dan je shematski prikaz jednog uređaja za stereolitografiju.

The above prices of RP machines are approximate and are only for orientation purposes. Each of the listed RP technologies has its advantages and disadvantages. A brief description of each of the RP technologies is listed in Table 1, and they are as follows.

2. STEREOLITOGRAPHY (SL)

The basic concept of this procedure is based on the use of laser and photo liquid. When the laser beam passes through the liquid, it turns to a solid physical state, thus forming a contour model. In Figure 1, a schematic view of the stereolithography device is presented.



Slika 1. Shematski prikaz stereolitografije
Figure 1. Stereolitography – schematic view

Kako je prikazano na slici 1, laserska zraka navodi se pomoću sustava zakretnih zrcala u X–Y ravnini. Zraka pada na površinu fotopolimera i odvija se kemijska reakcija koja za posljedicu ima očvršćenje mjesta kojima je prošla. Ta se kemijska reakcija [10] naziva polimerizacija. Nakon što je završen jedan sloj, pokretni stol vrši posmak po Z-osi kako bi se započelo s kreiranjem drugog sloja. Prije kreiranja sljedećeg sloja slijedi poravnavanje pomoću oštrog noža. *Envisiontec* postupak je sličan stereolitografiji, samo što umjesto laserske zrake upotrebljava projiciranu UV-svjetlost iz DLP-izvora, koji se upotrebljava i u običnim projektorima za projekciju slika i filmova.
U slučaju kompliciranih geometrija kojima je težište pomaknuto izvan osi ili zbog drugih posebnih zahtjeva, potrebno je model poduprijeti kako bi se osigurala njegova stabilnost. Te se potporne strukture mogu kreirati ručno ili zajedno s glavnim modelom u nekom od CAD/CAM programa. Tablica 2 prikazuje usporedne podatke nekolicine SL-strojeva [7].

As shown in Figure 1, the laser beam is guided by using the mirrors in the X-Y plane. It falls on the surface of photopolymers and starts a chemical reaction that results in the hardening of that area. This chemical reaction [10] is called polymerization. After one layer is completed, the table performs the feed rate on the Z-axis in order to start creating the next layer. Before the creation of the next layer, a sharp knife aligns the surface. The Envisiontec process is similar to stereolithography, except that instead of using a laser beam, a projected UV light source from the DLP is used; it is used in regular projectors to project images and movies.

When the geometry is complex, or in a case where the brunt is not placed in the center, or for some other special requirements, it is necessary to support a model with an additional structure in order to ensure its stability. These supporting structures can be created manually or with the main model in CAD/CAM software. Table 2 shows the comparative data of several SL machines [7].

Tablica 2. Usporedni podaci SL strojeva
Table 2. Comparison of SL machines

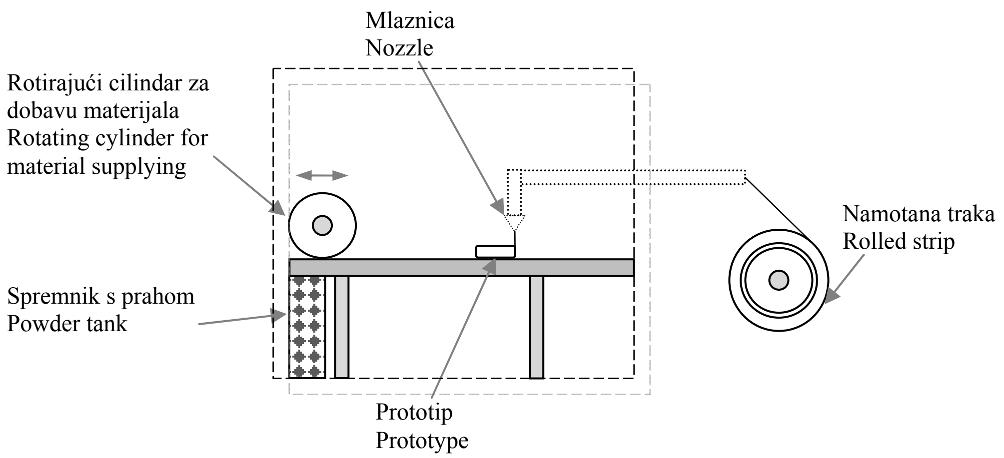
Model **Model**	**SLA 5000**	**SLA 7000**	**Viper si**
Namjena **Purpose**	Dijelovi velikih dimenzija/ Large parts production	Dijelovi velikih dimenzija/ Large parts production	Izrada preciznih dijelova/Precision parts manufacturing
Radna površina **Working area [mm]**	508x508x584	508x508x600	250x250x250
Tip lasera **Laser type**	Nd: YVO_4	Nd: YVO_4	Nd: YVO_4
Valna duljina lasera **Laser wavelength [nm]**	354,7	354,7	354,7
Izlazna snaga lasera **Laser power [mW]**	216	800	100
Očekivano trajanje lasera **Expected laser lifetime [h]**	5000	5000	7500

3. MODELIRANJE TOPLJENIM DEPOZITIMA (FDM)

Tehnologija modeliranja topljenim depozitima razvijena je i patentirana početkom 1990-ih godina [1]. Tijekom dva desetljeća znatno se povećavao tržišni udio te se prema nekim izvorima [1, 2, 12] procjenjuje da na ukupnom RP-tržištu FDM zauzima više od 50 %. Ta se tehnologija zasniva na izradi pomoću čvrstih materijala na principu ekstruzije kroz mlaznicu. U osnovi, plastično vlakno konstantno se dobavlja kroz mlaznicu maloga promjera, kao što je prikazano na slici 2. Mlaznica je zagrijana te se dobavljeni materijal topi i nanosi u slojevima. Tijekom nanošenja materijala mlaznica se giba u X-Y ravnini ravnomjerno istiskujući materijal. Nakon završetka nanošenja jednog sloja, radni stol vrši posmak po Z-osi te započinje nanošenje idućeg sloja. Prema [7] širina nanesenog sloja u horizontalnoj ravnini varira i kreće se oko 0,25mm.

3. FUSED DEPOSITION MODELING (FDM)

Fused deposition modeling technology was developed and patented in the early 90s [1]. During a period of over two decades, the use of RP technology has significantly increased. An estimated market share according to some sources [1, 2, 12] is more than 50 %. This technology is based on the principle of material extrusion through the nozzle. Basically, plastic fiber is constantly supplied through a small diameter nozzle, as shown in Figure 2. The nozzle is heated and supplied material melts during application in layers. During the material application, the nozzle moves in the X – Y plane, applying the material equally. After completion of the current layer, the table performs the feed rate on the Z-axis in order to start creating the next layer. According to [7], the width of the applied layer in the horizontal plane varies by approx. 0.25 mm.



Slika 2. Shematski prikaz modeliranja topljenim depozitom (FDM)
Figure 2. Fused deposition modeling (FDM) – schematic view

FDM omogućava izradu funkcionalnih dijelova materijalima istog ili približno istog sastava u svrhu daljnjeg ispitivanja. Posebno se ističe uporaba ABS-plastike kojom je moguće postići gotovo identičnu čvrstoću [2, 3] u odnosu na gotov proizvod. U tablici 3 dane su karakteristike nekolicine FDM strojeva.

FDM allows for the creation of functional parts with the same or nearly the same material composition for the purpose of further testing. Especially, the use of ABS plastic is of interest, because of its ability to achieve nearly identical strength [2, 3] with regard to the finished product. In Table 3, the characteristics of several FDM machines are given.

Tablica 3. Usporedni podaci FDM strojeva
Table 3. Comparison of FDM machines

Model / **Model**	**Dimension SST**	**Fortus 400mc**	**Fortus 900mc**
Radna površina / **Working area [mm]**	203x203x305	355x254x254	882x588x882
Debljina sloja / **Layer thickness [mm]**	od 0,178 do 0,33 / from 0.178 to 0.33	od 0,127 do 0,330 / from 0.127 to 0.254	od 0,171 do 0,318 / from 0.178 to 0.356
Materijal / **Material**	ABS	ABS, PC-ABS, PC, PPSF / PPSU, ULTEM 9085	ABS, PC-ABS, PC, PPSF / PPSU, ULTEM 9085

S obzirom na to da se dobava materijala vrši kroz mlaznicu i izravno se nanosi na prethodno očvršćeni sloj, mala je količina neiskorištenog materijala. S obzirom na relativno visoke cijene materijala to izravno doprinosi uštedi.

Osnovni materijali koji se koriste u ovome procesu su razne vrste polimera ili voska. Pored navedenih polimernih i voštanih materijala koji se nalaze u standardnoj ponudi za većinu strojeva koji rade s topljenim depozitom, neprekidno se vrše istraživanja [5, 6] kako bi se uveli i novi materijali poput keramike, polikarbonata ili metala.

Due to the direct supply of material through the nozzle, the application of material is made directly on the previous layer and there is a small amount of waste material. Regarding these facts, this can represent a significant reduction in the relatively high cost of the applied material.

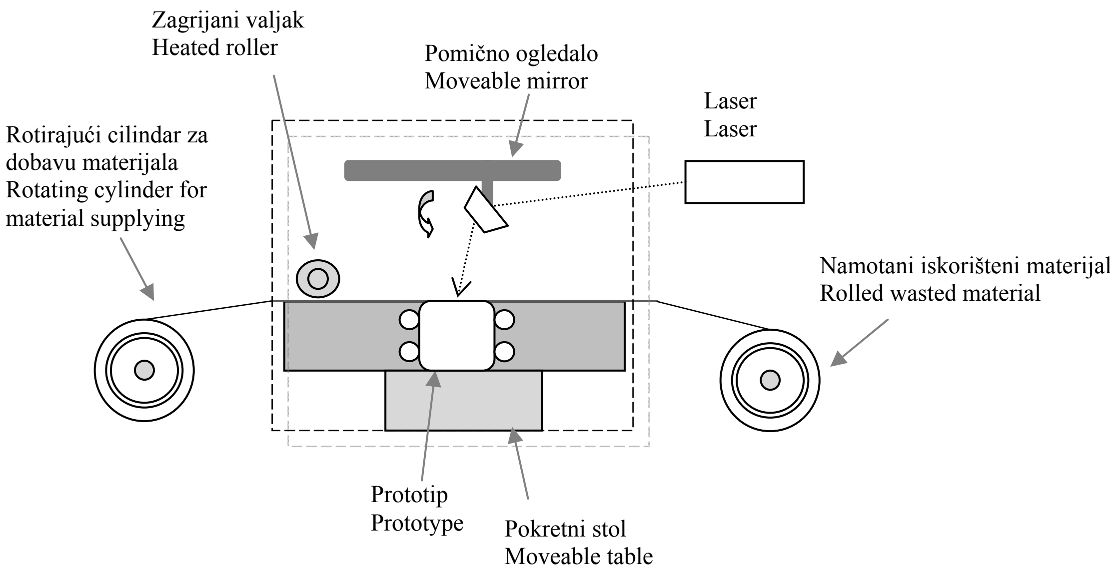
The base materials used in this process are various types of polymers or wax. In addition to the above polymer and the wax material contained in the standard offer for most of the machines that work with molten deposit, constant research is being carried out [5, 6] in order to introduce new materials such as ceramic, polycarbonate or metal.

4. LAMINIRANA OBJEKTNA PROIZVODNJA (LOM)

Laminirana objektna proizvodnja koristi se kod izrade komada većih dimenzija. Od korištenih materijala izdvaja se papirnata, polimerna i kompozitna folija koja je namotana na valjak. Na slici 3 dan je shematski prikaz laminirane objektne proizvodnje.

4. LAMINATED OBJECT MANUFACTURING (LOM)

Laminated object manufacturing is using for making larger pieces. Some of the used materials are paper, polymer and composite foil wound around the roller. In Figure 3, a schematic view of laminated object manufacturing machine is presented.



Slika 3. Shematski prikaz laminirane objektne proizvodnje (LOM)
Figure 3. Laminated object manufacturing (LOM) – schematic view

Preko sustava upravljivih pomičnih ogledala (slika 3) laserska zraka izrezuje konturu objekta od posebne vrste folije koja je namotana na valjak. Umjesto lasera mogu se koristiti i oštri noževi za rezanje – primjerice *Solido*. Folija s donje strane ima disperzirano vezivno sredstvo [1, 2, 5] koje osigurava čvrsto povezivanje slojeva. Kako bi se osiguralo dobro povezivanje, nakon svakoga izrezanog sloja zagrijani valjak prolazi po površini modela. Na taj se način aktivira vezivno sredstvo i povezuje izrezani sloj s ostatkom modela. Nakon završetka izrade aplicira se impregnacijsko sredstvo radi zaštite od vlage.

Through the controllable moving system of mirrors (Fig. 3) the laser cuts the outline of the model from the foil that has been wound around the roller. Instead of lasers, a sharp knife can be used for cutting - for example Solido. On the bottom side of the foil, a binder is dispersed [1, 2, 5]. That provides a strong connection between the layers. To ensure a good connection, after each cut layer the heated roller passes over the surface of the model. In this way, the binder activates and a strong connection between layers is achieved. After completion of all layers, impregnation must be applied to protect the model from moisture.

Tehnologijom laminirane objektne proizvodnje moguće je proizvesti modele mase 0,1 kg do 50 kg, dok debljina presjeka ovisi o vrsti korištene folije [1], odnosno ona uobičajeno iznosi od 1 do 100 mm. Hrapavost površine modela također ovisi o vrsti korištene folije. S obzirom na najčešće korištene materijale, hrapavost površine kreće se između 100 do 140µm. U tablici 4 dan je usporedni prikaz nekolicine strojeva za laminiranu objektnu proizvodnju [7-11].

With the use of laminated object manufacturing technology, it is possible to produce models of masses starting from 0.1 kg to 50kg. The thickness of the section ranges depends on the type of film used [1] and usually is in a range from 1 to 100mm. The surface roughness model also depends on the type of film used, and when working with the commonly used materials surface roughness ranges from 100 to 140µm. In Table 4, a comparative view for the laminated object manufacturing of several machines [7- 11] is given.

Tablica 4. Usporedni podaci LOM strojeva
Table 4. Comparison of LOM machines

Model **Model**	Solido SD300 Pro	LOM-1030	LOM SC800
Radna površina **Working area [mm]**	330 x 250 x 350	400 x 280 x 406	600 x 600 x 600
Debljina sloja **Layer thickness [mm]**	0,168 0. 168	od 0,106 do 0,2 from 0.106 to 0.2	od 0,178 do 0,356 from 0.178 to 0.356
Materijal **Material**	SolidVC®, a rigid PVC based plastic	Papir, folija Paper, foil	Papir, folija Paper, foil

Područje primjene kreće se od izrade kalupa za lijevanje, do uporabe u automobilskoj industriji. Zbog relativno niske cijene izrade u odnosu na ostale RP-tehnologije, ali i velike tolerancije na pogreške geometrije unutar .stl datoteke, LOM način izrade sve se češće koristi. No s druge strane, točnost u izradi geometrije u smjeru Z-osi niža je nego primjerice kod stereolitografije ili selektivnoga laserskog sinteriranja. Debljina sloja uvjetovana je debljinom sloja folije od koje se izrađuje model.

The scope ranges from making molds for casting to applications in the automotive industry. Because of its relatively low cost of development compared to other RP technologies and its high tolerance for errors in the geometry of the .Stl file, the LOM method of production is widely used. However, accuracy in the preparation of the geometry in the direction of the Z - axis is lower, for example, than in stereolithography or selective laser sintering. Thickness depends on the thickness of the film that made the model.

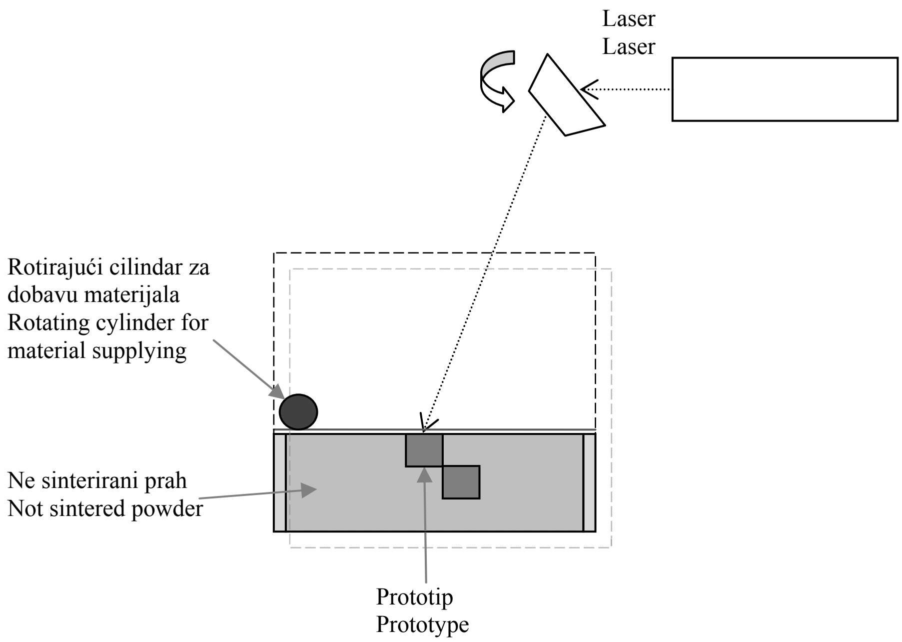
5. SELEKTIVNO LASERSKO SINTERIRANJE (SLS)

Selektivno lasersko sinteriranje (SLS) u osnovi je proces trodimenzionalnoga printanja na bazi tehnologije sinteriranja, a komercijalizirala ga je tvrtka *DTM*, koju je kasnije preuzela tvrtka *3D Systems*. Danas je najveći proizvođač SLS-sustava tvrtka *EOS*. Princip rada je sljedeći: laserska zraka CO2 usmjerava se na materijal (u obliku finog praška) koji uslijed visoke temperature kojoj je izložen sinterira. Na taj se način pod visokom temperaturom između čestica praha povećava adhezija, tako da se prah grupira u veću krutinu točno određenog oblika [3, 4]. Fizikalne karakteristike modela stvorenih sinteriranjem mogu se lako mijenjati promjenom gustoće, stvaranjem legura ili daljnjim pečenjem u nekoj od kasnijih faza, a finalni proizvod može biti i mnogo čvršći [6] od onoga napravljenog konvencionalnim metodama. SLS-tehnologija u 3D-pisačima također se izvodi u slojevima (koji mogu biti tanki i do nekoliko tisućinki milimetra), a prah materijala doprema se pomoću rotirajućeg cilindra u komoru za modeliranje, kako je prikazano na slici 4. Sav višak praha koji izlazi izvan

5. SELECTIVE LASER SINTERING (SLS)

Selective laser sintering (SLS) is basically a three-dimensional printing process based on sintering technology that was commercialized by the DTM company, which was later acquired by the 3D System company. Today, the largest manufacturer of SLS systems is the EOS company. The working principle is as follows: the CO2 laser beam is focused on the material (in the form of a fine powder) that sinters due to the high temperature to which it is exposed. In this way, the high temperature increases the adhesion between the powder particles, and the powder particles start grouping into larger solids in the desired form [3, 4]. The physical characteristics of the model created by sintering can be easily changed by changing the density of material, using alloys, or by further heating at some of the later phases so that the final product can be much stronger [6] than those produced through conventional methods. SLS technology, by means of a 3D printer, can also be applied in layers that can be as thin as a few thousandths of a millimeter. A powder material using a rotating cylinder is gabarita modela ujedno služi i kao potporna konstrukcija, pa nema potrebe za dodatnim potpornim materijalima i strukturama kao kod primjerice FDM-tehnologija. Svi plinovi koji se tijekom procesa oslobađaju prolaze kroz sustav dimnih filtara, te stoga ta tehnologija nije opasna za okoliš.

transported into the chamber for modeling, as shown in Figure 4. Any excess powder that comes outside of the sized model also serves as a supporting structure, so there is no need for additional support materials and structures, unlike with FDM technology. All gases that are released during the process pass through a system of filters, so that this technology does not pose a threat to the environment.



Slika 4. Shematski prikaz modeliranja selektivnim laserskim sinteriranjem (SLS)
Figure 4. Selective laser sintering (SLS) – schematic view

SLS-tehnologija može se ovisno o izboru materijala smatrati *rapid tooling* odnosno *brzom izradom alata* (RT) ili *rapid manufacturing* odnosno *brzom proizvodnjom* (RM), budući da je njome moguće napraviti ne samo prototipove, već i posve funkcionalne finalne proizvode koji posjeduju iznimno veliku stabilnost, čvrstoću, trajnost i otpornost na trošenje. Od 2009. godine ukida se naziv RM (brza proizvodnja) i primjenjuje se termin AM – aditivna proizvodnja, za sve brze postupke (RP, RM) osim za RT – brzu izradu alata koja je zanimljiva samo kao *Bridge tooling*. U tablici 5 dani su usporedni podaci [1, 5, 7] za nekoliko SLS-strojeva.

SLS technology, based on the choice of materials, can be considered to be fast tooling production (rapid tooling - RT) or fast manufacturing (rapid manufacturing - RM), since it is possible to make not only prototypes, but also fully functional final products. These products can have extremely high stability, wear resistance, strength and durability. Since 2009, the name RM – Rapid Manufacturing was repealed, and AM is applied – Additive Manufacturing, for all the fast processes (RP, RM), except for RT – Rapid Tooling, which is interesting only as Bridge tooling. In Table 5, comparative data [1, 5, 7] for SLS machines is given.

Tablica 5. Usporedni podaci SLS strojeva
Table 5. Comparison of SLS machines

Model **Model**	**EOS Eosint P395**	**Sinterstation Pro 230**	**Sinterstation HiQ**
Radna površina **Working area [mm]**	340 x 340 x 620	550 x 550 x 750	381 x 330 x 457
Debljina sloja **Layer thickness [mm]**	od 0,06 do 0,18 from. 0.06 to 0.18	oko 0,1 approx. 0.1	oko 0,076 approx. 0.076
Materijal **Material**	Polimeri, metali Polymers, metals	Poliamid, SandForm^{TM}Zr, SandForm^{TM}Si	Poliamid, SandForm^{TM}Zr, SandForm^{TM}Si

Većina proizvedenih modela odmah je spremna za uporabu, već nakon minimalne obrade i čišćenja, bez potrebe za dodatnom termičkom obradom. Izrada koja uključuje SLS-tehnologiju ima velik raspon dostupnih materijala, budući da se mnoštvo metala može sinterirati. To osobito vrijedi za čiste metale proizvedene u izoliranim i sterilnim uvjetima. S druge strane, za sinteriranje su također pogodni i mnogi nemetali, poput stakla ili različitih organskih polimera.

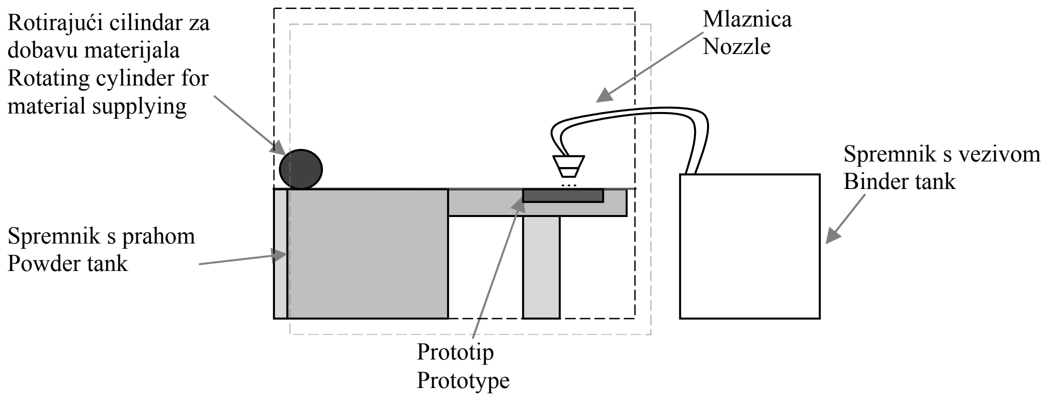
6. 3D TISAK

Tehnologija 3D-tiskanja predstavlja brz i dostupan način izrade fizičkih prototipa. Kao i kod drugih opisanih metoda, prednost je u izradi probnih 3D-modela neposredno iz računalnih podataka [3, 4], programa ili nacrta. Dostupnost brze izrade 3D-modela omogućava bržu komunikaciju i ocjenjivanje različitih dizajnerskih rješenja i koncepcija te lakšu komunikaciju s partnerima i prodavačima. Rezultati su vidljivi u kraćem ciklusu dizajna i projektiranja te skraćenim vremenima unutar proizvodnog procesa. 3D-pisači su mini CNC-sustavi s upravljanjem u XYZ-osima. Upravljački program najprije konvertira 3D CAD-nacrt u poprečne presjeke odnosno tanke slojeve, debljine od 0,076 do 0,254 mm. Debljina sloja bira se ovisno o željenoj točnosti. Nakon toga se predmet, tj. model, izrađuje tako da se u radnom prostoru u programiranim tankim slojevima nanosi specijalni prah i učvršćuje sredstvom za vezivanje, koje se nanosi na prah, tj. "printa" pomoću uobičajenih komponenti. Nanošenje veziva počinje s donjim slojem i može biti monokromatsko ili u boji.

Most of the produced models are immediately ready for use after only slight adjustment and cleaning, without the need for additional heat treatment. Model production with the SLS technology allows for the use of a wide range of available materials, since many metals can be sintered. This is particularly true for pure metals created in isolated and sterile conditions. Even many non-metals are also suitable for sintering, such as glass or various organic polymers.

6. 3D PRINT

3D printing technology is a fast and affordable way of making prototypes. As with other methods described above, the advantage lies in making test 3D models directly from computer data [3, 4], programs or plans. The availability of the rapid 3D model prototyping enables faster communication and evaluation of different designs and concepts, and easier communication with partners and vendors. The results are evident in a shorter design cycle and the product is sooner ready for the production process. 3D printers are mini CNC systems with control of the XYZ-axes. The controller first converts 3D CAD design into cross sections, thin layers of thickness from 0.076 to 0.254 mm. The thickness is chosen depending on the desired accuracy. Thereafter, the object, i.e., the model is made in such a way that the thin layer of special powder is placed on the workspace, and then the binding medium that reinforces the powder is injected into the accurately programmed spots, i.e., material is "printed" onto the workspace using common components. Application of the binder starts with the bottom layer and can be monochromatic or in color.



Slika 5. Shematski prikaz 3D tiska (3DP)
Figure5. 3D print (3DP) – schematic view

Kako je shematski prikazano na slici 5, 3D CAD datoteku šaljemo na pisač koji je uz pomoć različitih programskih rješenja obrađuje i dijeli na tanke slojeve (engl. *layers*). Pisač zatim u ponavljanom procesu kroz svaki sloj tiska model do krajnje izrade. Tiskanje sloja odvija se ovim redoslijedom: kroz mlaznicu se najprije nanosi vezivno sredstvo na prah, zatim boja pa slijedi posmak po Z-osi i

As shown schematically in Figure 5, a 3D CAD file is sent to the printer, the printer then uses one of the software packages for model processing and divides the model into thin layers. The printer then iterates the printing process through each layer of the model to the final design. The printing of one layer occurs in the following order: first, the binder is applied to the powder nanošenje veziva za idući sloj. Prije nanošenja novoga sloja veziva, iz spremnika s prahom nanosi se novi sloj praha pomoću posebnog valjka. Pisače te tehnološke skupine odlikuju iznimna točnost i kvaliteta izrade. U tablici 6 prikazani su usporedni podaci nekolicine 3D-pisača [8 - 11].

through the nozzle, then the paint, and then the printer moves the Z-axis by the defined layer thickness and then applies the binder for the next layer. Before the placement of a new layer, the powder from the container is applied using a special roller. Printers for these technologically advanced applications are characterized by exceptional accuracy and printing quality. Table 6 shows the comparative figures of several 3D printers [8 - 11].

Tablica 6. Usporedni podaci za 3D pisače
Table 6. Comparison of 3D printers

Model Model	**Z-Print 310**	**Voxeljet VX500**	**Ex One R-1**
Radna površina Working area [mm]	203x254x203	500x400x300	50,8x38,1x50,8
Debljina sloja Layer thickness [mm]	od 0,089 do 0,203 from 0.089 to 0.203	od 0,1 do 0,15 from 0.1 do 0.15	od 0,05 do 0,2 from 0.05 to 0.2
Materijal Material	silikatni sadrasti prah silicate plaster powder	praškasti plastični materijali, plastic powder materials	nehrđajući čelik, bronca, zlato stainless steel, bronze, gold

Brzina ispisa ovisi o traženoj kvaliteti, odnosno debljini sloja, koju biramo. Većina pisača može nanijeti nekoliko slojeva u minuti [5]. Međutim brži odabir ispisa rezultira lošijom kvalitetom. Stoga je prije početka ispisa potrebno odabrati traženu kvalitetu. Odabirom vrste praha i punjenjem modela različitim suportima, korisnici mogu kreirati predmete različitih svojstava. Tako se, ovisno o tehničkim zahtjevima koje model treba zadovoljiti, postižu njegova čvrstoća, elastičnost ili temperaturna izdržljivost. Sličan princip ima i tehnologija *Polyjet* pri kojoj se tekući fotopolimer nanosi kroz glavu, sloj po sloj, gradeći tako traženi model. Trenutno tehnologija *Polyjet* pruža najbržu i najtočniju izradu, omogućujući odabir materijalnih svojstava izrađenih prototipova.

Printing speed depends on the requested quality, i.e., the on chosen layer thickness. Most printers can lay several layers within a period of one minute [5]. However, selection of higher speed results in inferior print quality. Therefore, prior to printing one must choose the desired quality. By selection of the type of powder and application of different supports for the model, users can create objects of different characteristics. In that way, depending on the technical requirements that the model should satisfy, it is possible to achieve the desired strength, elasticity and temperature resistance of the object. A similar principle has PolyJet technology in which the liquid photopolymer is applied through the head, layer by layer building a model. Currently, PolyJet technology enables the fastest and most accurate production, allowing for the selection of material properties.

7. ZAKLJUČAK

U članku je dan kratki prikaz nekoliko RP načina izrade modela. U osnovi, tehnologija brze izrade pripada tzv. aditivnim tehnologijama. Prilikom izrade modela nanosi se sloj po sloj sve dok nije izrađena cjelokupna geometrija. Upravo stoga količina otpadnog materijala smanjena je na najmanju moguću mjeru. Za svaku od tehnologija dan je shematski prikaz s osnovnim tehničkim podacima. Izložene su osnovne smjernice njihova korištenja te prednosti i nedostaci prilikom uporabe. Pored osnovnoga prikaza funkcioniranja, za svaki od opisanih načina izrade prikazani su i usporedni podaci između nekoliko strojeva.

Jedna je od većih prednosti svih RP sustava u tome što se podaci CAD/CAM modela šalju izravno na ispis bez potrebe za dodatnim postupcima. Većina CAD/CAM

7. CONCLUSION

The paper gives a brief overview of some RP methods for model making. Rapid prototyping technology is an additive technology. When creating models, layer by layer of material is placed on the desired positions, until the total geometry is made. Therefore, the amount of waste material is reduced to a minimum. Each technology is presented by schematics with basic technical information, some general guidelines for use and advantages and disadvantages during use. In addition to the basic presentation of operation for each of the described methods for model making, detailed comparative data between several machines is given. One of the major advantages of RP systems is that CAD / CAM models data is sent directly to print without the need for additional processing. Most CAD / CAM programskih rješenja poput *SolidWorksa* ili *CATIE* u sebi sadrži integriran barem jedan modul povezan s tehnologijom brze izrade.

software such as SolidWorks or CATIA contains at least one integrated module associated with the rapid prototyping technology.

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