# 3D DIGITALIZACIJA I ŠTAMPANJE SKULPTURE IZ NACIONALNOG SPOMENIKA „SMRIKE”

# 3D DIGITALIZATION AND PRINTING OF A SCULPTURE FROM SMRIKE NATIONAL MONUMENT

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*3D skeniranje i 3D štampanje sve više pronalazi primjenu u digitalizaciji, prezentaciji i izradi replika različitih umjetničkih dijela. U radu su mogućnosti ovih tehnologija predstavljene na primjeru odabrane skulpture iz nacionalnog spomenika „Smrike“.*
*Primjenom ručnog 3D skenera napravljen je poligonalni 3D model skulpture. Koristeći dobiveni 3D model, FDM tehnologijom 3D štampanja izrađeno je dvanaest umanjenih replika skulpture. Navedeni su i opisani različiti tehnički detalji i parametri, kao i obrada u različitim softverima.*

***Professional paper***

**SUMMARY**

*3D scanning and 3D printing finds more and more application in digitalization, presentation and replicas making of different artworks. In this paper the capabilities of these technologies are represented on the example of a selected sculpture from Smrike national monument.*
*Polygonal 3D model of the sculpture is made by using a manual 3D scanner. Using the obtained 3D model, twelve scaled-down replicas of the sculpture are made by FDM 3D print technology. Different technical details and parameters, as well as processing in different software are presented and described.*

## 1. UVOD

Tehnološki razvoj i digitalizacija doveli su do novih mogućnosti u diseminaciji umjetničkih djela, arheoloških artefakata i drugih objekata od interesa javnosti. Različite metode 3D skeniranja široko se primjenjuju za 3D digitalizaciju različitih skulptura, građevina, spomenika, artefakata i slično [1,2]. Ovaj pristup omogućuje drugačiji i novi način doživljaja i promatranja ovih djela i objekata, koji je u nekim aspektima čak i kvalitetniji od klasičnog direktnog promatranja [3].
Paralelni razvoj tehnologijâ 3D štampanja omogućio je i relativno jednostavnu i kvalitetnu izradu replikâ ovih 3D digitaliziranih objekata [4,5].

## 1. INTRODUCTION

Technological advancements and digitalisation lead to new possibilities in dissemination of artworks, areological artefacts and other objects of public interest. Different 3D scanning methods are widely used for 3D digitalization of various sculptures, buildings, monuments, artefacts, and the like [1,2]. This approach enables different and new way of experience and observation of these works and objects, even in some aspects of more quality than the classical direct observation [3].
Parallel development of 3D printing technologies enabled also relatively simple and good quality production of replicas of these 3D digitalised objects [4,5].

U ovom radu su ove mogućnosti prikazane na primjeru jedne od skulptura iz nacionalnog spomenika „Smrike“, koji se nalazi u okolici Novog Travnika, Bosna i Hercegovina. Nacionalni spomenik „Smrike“ u Novom Travniku je nekropola podignuta 1975. godine u spomen na 700 žrtava fašističkog terora iz 1941. godine. Spomenik je izveden prema projektu arhitekte Bogdana Bogdanovića, jednoga od najvećih regionalnih graditelja memorijalne arhitekture. U okviru spomenika je postavljeno dvanaest skulptura u nepravilno raspoređenim parovima. Skulpture predstavljaju dvanaest vojnika – stražara, koji zauvijek treba da ostanu na tom mjestu, širom otvorenih očiju. Oni su čuvari nedužnih, na straži sa zadatkom da spriječe stradanje. U septembru 2021. je završena je i restauracija ovog spomenika, koju ju provela Općina Novi Travnik.

These possibilities are presented in this paper on the example of one of the sculptures from Smrike national monument, located in the vicinity of Novi Travnik, Bosnia and Herzegovina. Smrike national monument in Novi Travnik is necropolis, built in 1975 to commemorate 700 victims of fascism terror in 1941. The monument is built according to the design of architect Bojan Bogdanovic, who was one of the greatest regional builders of memorial architecture. The monument consists of twelve sculptures placed in irregularly arranged pairs. The sculptures represent twelve soldiers – guards, who are supposed to stay for ever on that place, with eyes wide open. In September 2021, the restoration of this monument was finished, implemented by the Municipality of Novi Travnik.

**Slika 1.** Nacionalni spomenik „Smrike“
***Figure 1*** *Smrike national monument*

## 2. 3D SKENIRANJE SKULPTURE

Za 3D skeniranje je odabrana jedna od 12 skulptura iz spomenika, na osnovu najpovoljnijeg položaja i samog stanja i izgleda. Skeniranje odabrane skulpture je obavljeno pomoću ručnog 3D skenera *Artec Eva* (slika 1.) [6], spojenog na laptop sa softverom proizvođača, *Artec Studio 16 Professional* [7]. Skener *Artec Eva* radi na principu struktuiranog svjetla i namijenjen je za skeniranje objekata srednje i velike veličine. Radno rastojanje 3D skenera od objekta je od 0,4 do 1 m, s vidnim poljima od 214x148 mm (minimalno rastojanje) do 536x372 mm (maksimalno rastojanje). Proizvođač deklarira tačnost od 0,1 mm i rezoluciju od 0,2 mm. Model 3D skenera koji je korišten nije imao bateriju za napajanje, te je za rad skenera korišten benzinski agregat.

## 2. 3D SCANNING OF A SCULPTURE

One of the twelve sculptures from the monument is selected for 3D scanning, based on its optimal position and its condition and appearance. The scanning of the selected sculpture is conducted by using manual 3D scanner Artec Eva (Figure 1) [6], connected to a notebook with manufacturer’s software Artec Studio 16 Professional [7]. Artec Eva scanner operates on structured light principle, and it is intended for scanning middle and large size objects. Working distance of 3D scanner from the object is from 0,4 up to 1m, with fields of view from 214x148 mm (minimal distance) up to 536x27 2mm (maximal distance). The manufacture declares accuracy of 0,1 mm and resolution of 0,2 mm. Used model of 3D scanner did not have power feeding battery, so for the scanner’s operation a petrol generator was used.

Kako bi se pokrila cijela površina objekta napravljeno je 27 skenova skulpture u 4 odvojena Artec Studio dokumenta, ukupne veličine 11,1 GB. Skenovi su oblaci registriranih tačaka na objektu koje je potrebno naknadno obraditi. Skenovi su pravljeni tako da im se površine međusobno preklapaju, kako bi u naknadnoj obradi imali dovoljno zajedničkih površina (tačaka) za poravnavanje. Tokom skeniranja objekta bilo je moguće skenirati samo površine koje nisu izložene direktnom sunčevom svjetlu (slika 2.). Također, niti okular skenera nije mogao biti izložen direktnom sunčevom svjetlu. Cijelo skeniranje je obavljenu u jednom danu, tako da su tokom dana skenirane površine u hladovini (korištena je i tenda za zaklanjanje od sunčeve svjetlosti), a ostatak površina, koje nije bilo moguće skenirati tokom dana, skeniran je po zalasku sunca, u predvečerje.


**Slika 2.** Skener Artec Eva 3D
***Figure 2*** *Artec Eva 3D scanner*

## 3. OBRADA 3D SKENOVA I KREIRANJE 3D MODELA

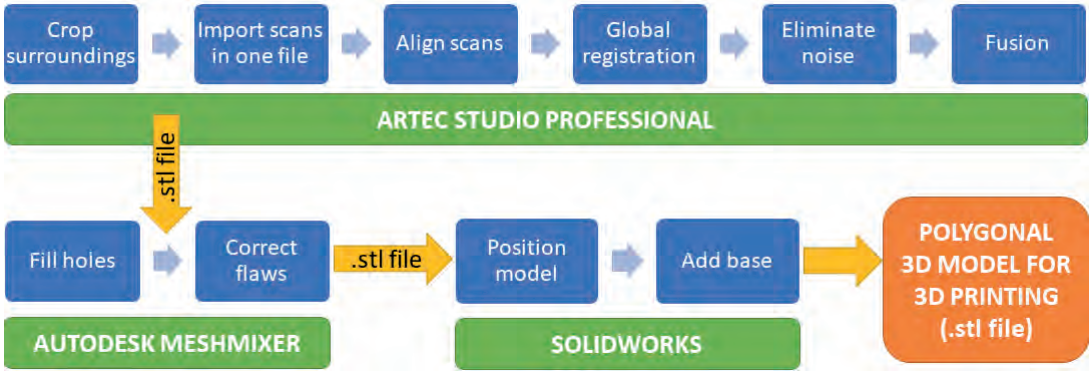
Proces obrade skenova i kreiranje poligonalnog 3D modela (dokument u formatu STL), koji je korišten za 3D štampanje, shematski je prikazan na slici 4. U ovom su procesu primijenjena tri komercijalna softvera. Prva faza obrade je obavljena u softveru proizvođača 3D skenera, *Artec Studio Professional*. Prvo je sa svih skenova uklonjena pozadina koja je snimljena zajedno sa skulpturom. Zatim su svi skenovi „uvezeni“ (objedinjeni) u jedan dokument (slika 5.a).

In order to cover all of the object surface, 27 scans of the sculpture are made in 4 separate Artec Studio files, with total size of 11,1 GB. The scans are clouds of points registered of the object that require postprocessing. The scans are made in a way that surfaces overlap, so there would be enough common surfaces for alignment in postprocessing. During the scanning it was possible only to scan the surfaces not directly expose to the sunlight (Figure 2). Also, the scanner lenses could not be exposed to the direct sunlight. A whole scanning process was done in a day, in a way that during the day surfaces in a shade were scanned (an awning was used as a sun shelter), and the remaining surfaces, that could not be scanned during the day, were scanned after sundown, in the early evening.

**Slika 3.** 3D skeniranje površine skulpture u hladovini skenerom *Artec Eva*
***Figure 3*** *3D scanning of sculpture surface in the shade with Artec Eva scanner*

## 3. EDITING OF 3D SCANS AND CREATING 3D MODEL

The process of scans editing and creating polygonal 3D model (an STL file format) , used for 3D printing, is schematically presented in Figure 4. In the process, three commercial software were implemented. The first stage was accomplished in the 3D scanner manufacturer’s software, Artec Studio Professional. First, the background, recorded together with the sculpture, was removed from the scans. Then, all the scans were imported in one file (Figure 5a).




**Slika 4.** Proces obrade skenova i kreiranja 3D modela za štampanje
***Figure 4*** *Process of scans editing and creating the 3D model for printing*


**Slika 5.** Artec Studio - obrada, neporavnati (a) i poravnati (b) 3D skenovi
***Figure 5*** *Artec Studio - editing, unaligned (a) and aligned (b) 3D scans*

Poravnavanje svih skenova je napravljeno pomoću algoritma za automatsko poravnavanje u softveru. Poravnavanje nije napravljeno za sve skenove zajedno, nego su se pojedinačno dodavali i poravnavali skenovi, pri čemu je na početku jedan odabran kao bazni. Prilikom ovog procesa, kod svakog sljedećeg poravnavanja i dodavanja novog skena pazilo se da novi sken, koji se poravnava, ima dovoljno preklapajućih površina s već poravnatim skenovima. Prije dalje obrade skenova, svi su umanjeni na odabranu veličinu za 3D štampanje. Nakon što su svi skenovi poravnati (slika 5.b), napravljena je globalna registracija, proces koji optimira relativne pozicije skenova u zajedničkom koordinatnom sistemu. U algoritmu za globalnu registraciju su korišteni preporučeni parametri u softveru.

Alignment of all scans was made by using the option for the automatic alignment in the software. The alignment was not done for all the scans at once, but the scans were added and aligned separately, where one scan was selected as the base one at the beginning. During this process, for every next adding and aligning of a scan, it was taken care of the new scan to be aligned to have enough overlapping surfaces with the already aligned scans. Before any additional processing of the scans, all of them were scaled-down to the selected size for 3D printing. After all the scans were aligned, global registration was made, a process which optimise relative positions of all scans in a common coordinate system. Software default values were applied in the global registration algorithm.

Objedinjavanje skenova i izrada površinskog poligonalnog modela u formatu STL urađena pomoću *fusion* algoritma. Ovaj algoritam stapa i fiksira sve skenove. Primijenjena je opcija *sharp fusion*, pri kojoj se zadržavaju sitni detalji i kreiraju oštrije ivice, bez zaglađivanja, kako bi se dobio model koji što više odgovara originalnoj skulpturi. Nije upotrijebljena funkcija popunjavanja otvora, te u ovoj fazi nije kreiran potpuno zatvoren model koji bi se mogao koristit za 3D štampanje. Popunjavanje otvora i još neke dodatne korekcije su napravljene u sljedećim fazama, pomoću softvera *Autodesk Meshmixer* [8] i *Solidworks* [9]. Za popunjavanje otvora na površini modela je primijenjen automatski algoritam softvera *Autodesk Meshmixer,* koji na osnovu oblika okolnih površina i ivica zatvara otvore. Ovdje su upotrijebljene i alatke za uređivanje površine modela, kojim su otklonjene uočene nepravilnosti na površini modela (slika 6.). Konačna priprema modela za 3D štampanje je napravljena u softveru *Solidworks*. Uvezeni model bilo je prvo potrebno poravnati s osnovnim koordinatnim sistemom, a potom je na dnu modela dodatno izvučeno postolje na kojem stoji skulptura (slika 7.).

**Slika 6.** 3D model nakon obrade u softveru Meshmixer
***Figure 6*** *3D model after editing in Meshmixer software*

Unification of scans and creation of polygonal surface STL file was made with fusion algorithm. The algorithm melts and fixes all scans. The *sharp fusion* option was implemented, in which small details were preserved and sharp edges created, without smoothing, to obtain the model that resembles to the original sculpture as much as possible. Fill holes function was not used, so in this stage fully close model, that could be used for 3D printing, was not created. Holes filling and some additional corrections were made in the next stages, with Autodesk Meshmixer and Solidworks software. Automatic algorithm from Autodesk Meshmixer was implemented for holes filing, to close holes based on shape of adjacent surfaces and holes edges (Figure 6). There were also used surface editing tools to remove the observed flaws on the model surface. Final preparation of the model for 3D printing was done in Solidworks. First, it was necessary to align the imported model with the base coordinate system, and then a base on which model stands was extruded at the model bottom (Figure 7).

**Slika 7.** Konačni 3D model u softveru *Solidworks*
***Figure 7*** *Final 3D model in Solidworks software*

## 4. 3D ŠTAMPANJE

Za 3D štampanje replikâ skulpture korištena je tehnologija FDM (*Fused Deposition Modelling* - modeliranje topljenim depozitom)> najekonomičnija, najpristupačnija i najviše primijenjena tehnologija u posljednjim godinama. U radu su korištena dva štampača *Ultimaker 3D*: *Ultimaker S5* [10] i *Ultimaker S3* [11]. Ova dva modela imaju vrlo slične tehničke mogućnosti i karakteristike, te su pružili i vrlo sličan kvalitet izrade. Skulptura je originalne visine 2,2 m, dok je model za 3D štampanje pripremljen u visini od 12,5 cm.

Kada se radi priprema za 3D štampanje, prvo je potrebno pripremljeni 3D model uvesti u softver za štampanje. Korišten je besplatni softver proizvođača štampačâ *Ultimaker Cura* [12]. Osnovni zadatak prilikom pripreme 3D modela za 3D štampanje je njegova podjela na slojeve (slika 8.) na osnovu koje se pravi G-kod dokument (program), koji sadrži putanju kretanja mašine i druge parametre za štampanje. Kod pripreme se definiraju i različiti parametri i konfiguracija 3D štampanja, gdje se za većinu mogu primijeniti vrijednosti koje su unaprijed definirane ili se automatski proračunaju u softveru.

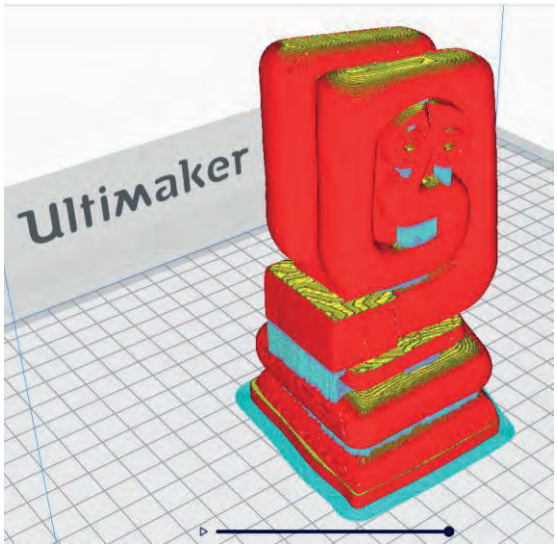
Za štampanje replikâ skuplture odabrana je debljina slojeva od 0,15 mm, s popunom unutrašnjosti modela od 10%. Ugao površine od 80° korišten je kao granična vrijednost od koje je potrebno primijeniti potpore. Ova granica za potpore je veća od preporučene, ali ipak je ostvaren zadovoljavajući kvalitet 3D štampe, a naknadna završna obrada je značajno olakšana, jer je smanjen broj potpora. Također, povećana je brzina štampanja u odnosu na preporučenu, osobito kod početnih slojeva. Ovim je smanjeno vrijeme štampanja s 12 sati (s preporučenim vrijednostima brzine) na 10 sati, uz i dalje dobar kvalitet izrade. Nakon štampanja (slika 9.) bila je potrebna ručna završna obrada modela radi otklanjana potpora. Ovo je obavljeno uz pomoć skalpela i reznih kliješta (slika 10.). Površine na kojima su bile postavljene potpore bilo je potrebno dodatno obraditi ručnim brušenjem pomoću brusnog papira. Na slici 11. prikazan je konačni izgled replike skulpture izrađene 3D štampanjem.

## 4. 3D PRINTING

FDM (*Fused Deposition Modelling*) 3D printing technology was used for 3D printing of sculpture replicas: the most cost effective, available, and used technology in the last years. Two Ultimaker 3D printers were used: Ultimaker S5 [10] and Ultimaker S3 [11]. These two models have similar technical capabilities and features, hence they provide a very similar printing quality. The original sculpture height was 2,2 m, while the model prepared for 3D printing was high 12,5 cm.

When preparing for 3D printing, it is first necessary to import the prepared 3D model in the software for printing. The free software of the printer manufacturer named Ultimaker Cura [12] was used. The main task in 3D model preparation for 3D printing is slicing it into layers (Figure 8) and, based on it, a G-code file (program) will be made, containing machine trajectory and other printing parameters. Different parameters and configuration of 3D printing are defined in preparation, where for the most of them default or values automatically calculated in software can be applied.

Layers height of 0,15 mm and model inside infill of 10% was selected for the sculpture replicas printing. A surface angle of 80° was used as a limit value from which support application is necessary. This limit was greater than the recommended one, yet the appropriate quality of 3D print was achieved, and afterwards finishing process was considerably facilitated because number of supports was reduced. Also, the printing speed was increased comparing to the recommended one, especially for initial layers. Hence, the printing time was reduced from 12 hours (with recommended values for speed) to 10 hours, still with a good quality of a print. After printing (Figure 9), manual finishing was necessary to remove the supports. This was done using a precision knife and a cutting pliers (Figure 10). The surfaces on which supports were located needed additional manual grinding with grinding paper. Figure 11 shows final appearance of a sculpture replica made by 3D printing.




**Slika 8.** Model podijeljen na slojeve s pomoćnim strukturama u štampaču *Ultimaker Cura*
***Figure 8*** *The sliced model with support structures in Ultimaker Cura*

**Slika 9.** 3D štampanje replike skulpture
***Figure 9*** *3D printing of a sculpture replica*


**Slika 10.** Uklanjanje potpora s replike skulpture
***Figure 10*** *Supports removal from a sculpture replica*

**Slika 11.** Replika skulpture izrađena 3D štampanjem
***Figure 11*** *A sculpture replica made by 3D printing*

## 5. ZAKLJUČAK

3D skeniranje i 3D štampanje su savremene tehnologije koje nalaze sve širu primjenu u različitim granama ljudske djelatnosti. One nude velike moćnosti u digitalizaciji, prezentaciji i izradi replika različitih umjetničkih djela. U ovom radu je dio tih mogućnosti predstavljen na primjeru odabrane skulpture iz nacionalnog spomenika „Smrike“ u Novom Travniku.
Pomoću ručnog 3D skenera *Artec Eva* obavljeno je 3D skeniranje skulpture, čime je dobijeno više oblaka tačaka za različite prolaze pri skeniranju. Naknadnom obradom svi skenovi su spojeni i od njih je napravljen poligonalni 3D model (dokument u formatu STL). Ovaj 3D model je iskorišten za 3D štampanje 12 umanjenih replikâ skulpture od PLA materijala FDM tehnologijom (slika 12.). U radu je opisana provedena procedura 3D skeniranja i 3D štampanja, predstavljeni su tehnički detalji i parametri koji su primijenjeni, kao i različiti softveri koji su implementirani.

## 5. CONCLUSION

3D scanning and 3D printing are modern technologies that find more and more application in different fields of human activity. They offer great possibilities in digitalization, presentation and replicas making of various artworks. In this paper, a part of these possibilities is presented on an example of selected sculpture from Smrike national monument in Novi Travnik.
3D scanning of the sculpture is done by manual 3D scanner Artec Eva by which several points of clouds from different scanning runs are obtained. All scans are joined in postprocessing and polygonal 3D model (STL file) is made from them. The 3D model is used for 3D printing of 12 scaled-down replicas of sculpture from PLA material by FDM technology (Figure 12). In the paper, the conducted procedure of 3D scanning and 3D printing is described, applied technical details and parameters are presented, as well as different implemented pieces of software.


**Slika 12.** Dvanaest replikâ skulpture
***Figure 12*** *Twelve sculpture replicas*

***ZAHVALA***

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