A framework for using handheld 3D surface scanners in quantifying the volumetric tufa growth

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A framework for using handheld 3D surface scanners in quantifying the volumetric tufa growth

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Abstract— **The emergence of handheld 3D surface scanners can play an important role in improving the understanding of tufa formation dynamics. For the first time volumetric tufa growth was calculated using *Artec Eva* handheld 3D scanner. Volumetric tufa growth was measured on two limestone plates (PLs) which were installed near the Roški waterfall (National park Krka, Croatia). Tufa volumetric growth was calculated from a 3D models in *Artec Studio 14 Professional*. The applicability of *Artec Eva* in the measurement of small objects (25 cm²) was tested by comparing the volume of PL with a reference "true" value measured with *Artec Space Spider*. The mean volumetric tufa growth for Roški waterfall site was 1490,02 mm³ in six months period. Although initially *Artec Eva* is not intended for measurement of small objects, it can be used if the dimensions of the PLs on which the volumetric growth are slightly bigger. *Artec Eva* overestimated the PL volume by only 904.66 mm³, or 6.38%. This new approach uses handheld 3D surface scanners and high quality 3D models providing the alternative and user-friendly method for studying tufa formation dynamics.**

I. INTRODUCTION

Tufa is localized [13], terrestrial, highly porous, mainly monomineral rock typical for karst areas [1] which is formed in freshwaters [5] of ambient to near ambient temperature [2]. Tufa formation dynamic studies seek to quantify the mechanism of precipitation and growth or erosion rates [18]. Rates can be expressed as the mass accumulated or lost per unit area (eg. mg $cm^2 a^{-1}$) or height ($mm\ a^{-1}$) and volume ($mm^3 a^{-1}$) formed or eroded at some period. There are very few studies that quantified volumetric ($mm^3 a^{-1}$) tufa growth over longer time period [3]. Accurate calculation of tufa formation dynamics is important for several reasons. It addesses the fundamental geomorphological question of individual element landscape evolution. Second, recent rates of volumetric tufa growth can be compared to older ones and the determined difference may indicate on the important changes in the tufa environment (eg. achieving sustainable tufa formation condition or otherwise tufa degradation process) [8,9]. Despite the fact that recent advances in geospatial technologies (GST) have revolutionized the ability to quantifying the Earth's surface [16] at different scales [17], until now tufa volumetric growth (mm^3) has not been measured using the handheld 3D surface scanners. Of all modern geospatial sensors, only [10] presented the possibility of using SfM photogrammetry in quantifying the linear tufa growth ($mm\ a^{-1}$).

In this research a framework for using the 3D surface scanner *Artec Eva* in the quantification of tufa volumetric growth is presented. *Artec Eva* has been used for volume measurements in various scientific fields, from medicine [4, 6-7, 14] to geomorphometry [19]. Case study was Roški waterfall at National park “Krka” (NPK) in Croatia. Three main objectives of research were: propose a framework process for 3D scanning of small tufa samples, examine the applicability of *Artec Eva* in small object scanning and determine the average tufa volumetric growth for specific location in Roški waterfall.

Roški waterfall is located at National park “Krka” (NPK) in Šibenik-Knin County (Croatia) (Figure 1). It is one of the most famous landmarks of the NPK. According to Köppen's climate classification, this area belongs to Csa type.

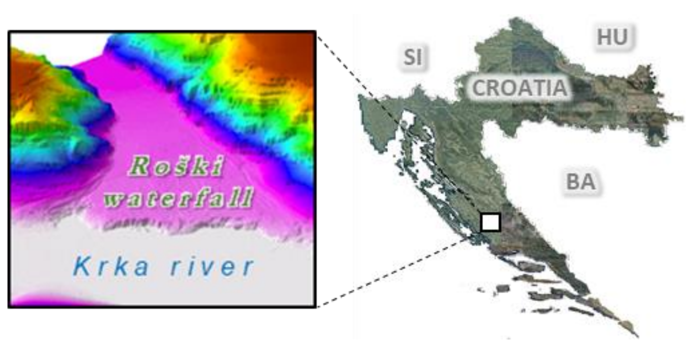

Figure 1. Location of Roški waterfall in Croatia.

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II. Methods

The volumetric tufa growth was measured using a 3D surface scanner *Artec Eva*. It is a state-of-the-art 3D scanning technique that uses triangulation and structured light while collecting 3D data. It is compact and lightweight 3D scanner [11]. 3D resolution of *Eva* is up to 0.5 mm at a working distance of 40 cm to 1 m, while accuracy of 3D points is up to 0.1 mm [11] although [15] and [12] states an accuracy of 0.05 mm. Results have shown that *Eva* is very reliable instrument for measuring volume [14]. In this study, the applicability of *Eva* in the measurement of small objects was examined using the *Artec Space Spider* measurements (Figure 2). *Space Spider* is newer handheld 3D surface scanner designed for measuring small objects. It has 3D resolution up to 0,1 mm, 3D point accuracy up to 0,05 mm and working distance of 0.2 – 0.3 m.

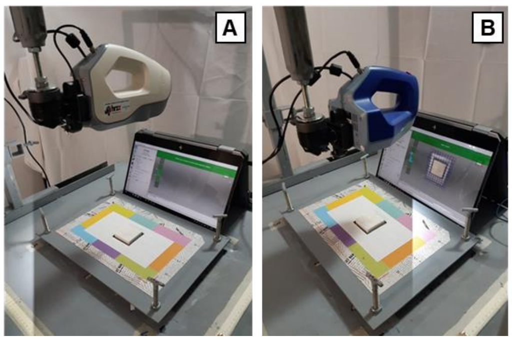

Figure 2. Measurements of the test limestone PL32 using the *Artec Eva* A) and *Artec Space Spider* B) for the testing the applicability of *Artec Eva* in the measurement of small objects

A. Installation of limestone plates (PLs)

Tufa volumetric growth was measured on the upper surface (25 cm^2) of two limestone plates (PLs). The PLs were positioned in the immediate surroundings of the Roški waterfall. Specific code was engraved beneath each PLs and unique ID and name were assigned to location (Figure 3). Each PL was measured using *Artec Eva* before being installed in tufa forming watercourse. On July 1st. 2019. PLs were fixed with two stainless steel screws. Before the second measurement, which was done after six months on January 10th, 2020, they were left drying at room temperature for 4 days.

Figure 3. Limestone PLs installed near Roški waterfall.

B. Data processing of scans

Scans of the initial and final PLs were processed in *Artec Studio 14 Professional*. It is an industry-recognized software package designed for advanced 3D scanning and data processing. No scan segmentation occurred during the scanning therefore processing workflow included five steps (Figure 4). First was *crop surroundings*. Using the *rectangular selection* tool, the larger scanned area around the PLs was erased. Next was *global registration*. The position of the scans has been optimized to prepare them for further processing. The algorithm converts all one-frame surfaces into a single coordinate system using information about the shared location of paired surface points. The third was *outliner removal*. This eliminates noise or larger errors on the scans. The fourth was *sharp fusion*. A unique model surface was created with respect to the initial input. The *simplify mesh* function was not used because we wanted to retain a large number of polygons. The final step was *apply texture*. The texture was acquired by integrated 1.3 MPx camera.

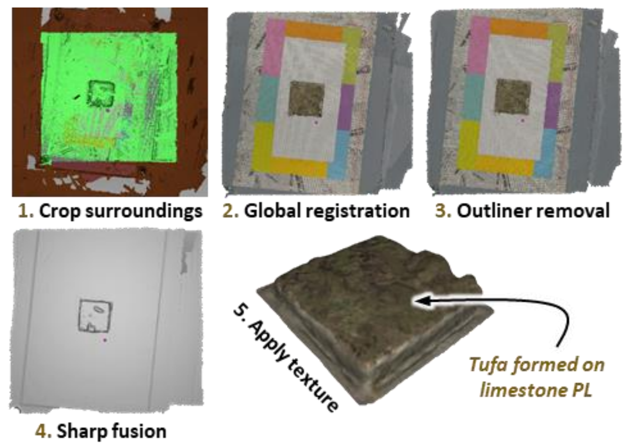

Figure 4. Data processing in *Artec Studio 14 Professional*

C. Calculation of volumetric (mm^3) tufa growth

The volume of PLs and tufa was calculated from derived 3D models using the *Measure - Section* tool. Volume was calculated above the specific plane of the local coordinate system (LCS). The initial and final 3D models were positioned in the same LCS using the *Positioning* tool. The volumetric (mm^3) tufa growth was calculated as the difference between the B) volume of the final model and the A) volume of the initial PL model (Figure 5).

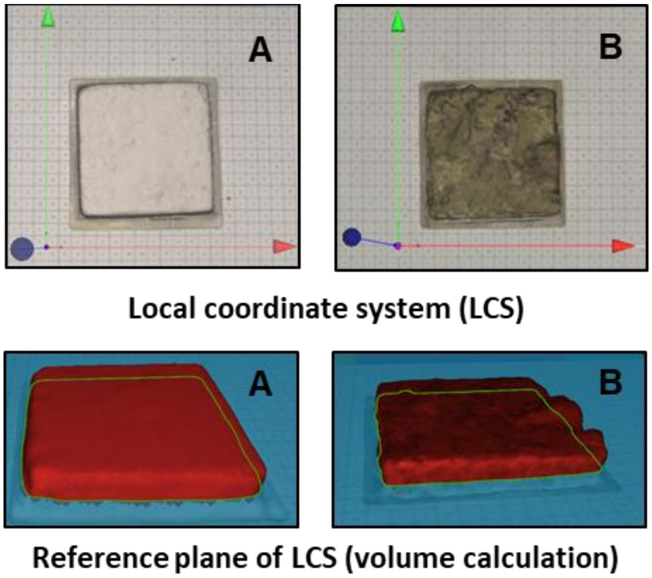

Figure 5. Calculation of tufa volumetric (mm^3) growth

D. Comparison of Artec Eva and Space Spider

The applicability of *Eva* in small objects measurement was tested by the comparison of the volume (mm^3) of a specific PL with surface area of 25 cm^2. The volume generated using *Space Spider* was used as the benchmark or reference “true” data. *Eva* and *Space Spider* scans of the specific PL were processed using the above mentioned processing workflow. Two 3D models of the same PL were imported into one *Artec Studio* project (Figure 6).

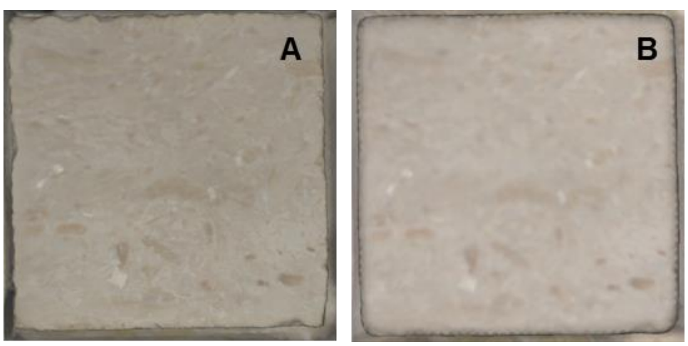

Figure 6. 3D model of PL32 generated with A) *Space Spider* and B) *Eva*

Volume of PLs was calculated from 3D models in *.obj format.* The accuracy of the *Eva* is then expressed the with absolute (AE) and percentage error (PE). AE was calculated as the difference between the “true” (volume generated by *Space Spider*) and the measured value (volume generated by *Eva*). PE is expressed as the percentage difference between the measured and the “true” value by formula:

$$Pe = \frac{|A_E|}{\text{"}true\text{" } value} X\,100 \qquad (1)$$

where A_E is absolute error and “true” value is volume of PL generated using *Space Spider.*

The accuracy of *Artec Eva* is then analysed through the *surface-distance map* from which the RMS (root mean square-the square root of the arithmetic mean of the squared distances) and MAD (mean absolute deviation) were derived. *Surface-distance map* enables comparison of two 3D models and assess the deviation of their forms. Also, it can be used in quality control of the original "true" model with the scanned one.

III. Results and Conclusions

A. Volumetric tufa growth for Roški waterfall site

The PLs were removed from the site on January 10th, 2020, after around six months (193 days) (Figure 7) spent in a watercourse.

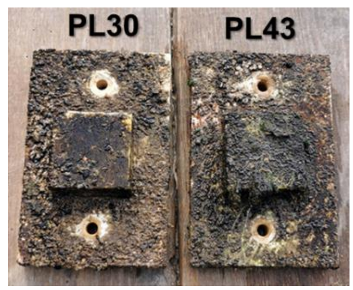

Figure 7. Surface of PLs 30 and 43 after 193 days spent in the flow

In total four 3D model of PLs were generated from which two represent initial PL shape and others two shape after six months spent in the flow. Despite the fact that the PL30 and 43 were placed in a flow at a distance smaller than 30 cm, volumetric tufa growth for PL43 was 791,70 mm^3 larger than on the PL30. This is due to the characteristics of the PLs micro locations. The PLs are set at a similar slope, but the PL43 is more exposed to water spray zone than the PL30. The mean volumetric tufa growth for location was 1490,02 mm^3 (Table 1). The data obtained show that the tufa grew 7,72 mm^3 per day.

Table 1. Volumetric (mm^3) tufa growth calculated in *Artec Studio*

PL CODE	Volume (mm^3)		Volumetric tufa growth (mm^3)
	Initial state	Final state	
PL30	14070,08	15164,25	**1094,17**
PL43	15258,66	17144,53	**1885,87**
MEAN			**1490,02**

B. Application of Artec Eve in small object measurement

Surface-distance map is a colored rendering on the particular regions of surfaces. Corresponding values of distances and their distribution can be read from the graduated scale with the histogram (Figure 8). Blue color corresponds to negative distance while red represents positive distance. RMS was 0.259 while MAD was 0.281 mm.

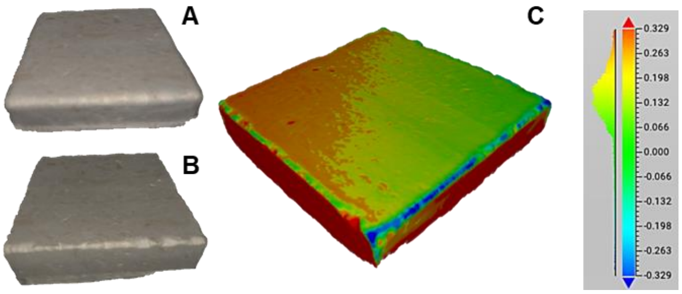

Figure 8. 3D model of PL32 generated with A) *Eva* and B) *Space Spider* with C) *Surface-distance map*

Volume of PL32 measured with *Artec Eva* and *Space Spider* was compared. The AE of measurement with *Artec Eva* was -904,66 mm^3. Respectively, *Artec Eva* overestimated the PL volume by only 904.66 mm^3, or 6.38% (PE) (Table 2).

Table 2. PL volume (mm^3) calculated in *Artec Studio* for *Artec Space Spider* and *Artec Eva*

PLCODE	**Volume (mm^3)**	
	Artec Eva	***Artec Space Spider***
PL32	**15077.14**	**14172.48**

In conclusion, we have demonstrated a framework for using handheld 3D surface scanners in quantifying the volumetric tufa growth. The mean volumetric tufa growth for Roški waterfall was 1490,02 mm^3 in six month period. The applicability of *Artec Eva* in measurement of small objects was tested. Although *Eva* is not intended for measuring small objects (eg. surface area of 25 cm^2), it can be used to measure volumetric tufa growth if the dimensions of the artificial substrates (PLs) are slightly bigger. In this case, *Artec Eva* overestimated the PL volume by only 904.66 mm^3, or 6.38% (PE).

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