Multi-Sensor 3D Modeling of Natural Heritage: Example of the Lake Zmajevo Oko

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Keywords: Zmajevo Oko, Geospatial Technologies, UAV, WASSP S3, MBES, Virtual Walk.

Abstract: In recent decades geospatial technologies (GST) have been affected by a process of rapid development. One of their applications involves the documentation of the protected areas reference state and the development of high-quality models for their preservation and management. The research area of this paper is Lake Zmajevo oko (Lake Dragon eye), near Rogoznica (Croatia). The research goals were to create a multisensor model of the lake and present the application of these technologies for promotional purposes. The secondary objective was to obtain morphometric data about the lake. The research methodology included performing the process of UAV photogrammetry and bathymetry. In UAV photogrammetry, a *Phantom 4 Pro* was used. In the bathymetric survey, an integrated system composed of *WASSP S3* multibeam depth sounder (MBES) and the *Hemisphere V320* GNSS smart antenna was used. The data collected by both methods were combined and an multisensor high-quality model of the lake was created. Ten underwater tunnels on the steep sides of the lake were detected. From the derived models, the volume and surface area of the lake, as well as the length of the lake shoreline were calculated. Furthermore, a virtual walk around the lake was made to promote this area. A physical model of the lake, which can serve as a souvenir, was printed with the 3D printer *Prusa i3 MK3*. The collected high-quality data can serve as the basis for future research, while derived models and a virtual walk can be used for its promotion.

1 INTRODUCTION

The rapid development of geospatial technologies (GST) in the last twenty years (Bodzin and Cirucci, 2009; Bishop et al., 2012; Šiljeg et al., 2018), enabled the modeling of complex processes and objects in different levels of detail (LoD), depending on the purpose of the research (Kyriakaki et al., 2014). To improve its quality, multisensor models are developed. These models are made from data collected by different methods and techniques (Fabris et al., 2010; Abdalla, 2016, Erenoglu et al., 2017) using different sensors (Hackett and Shah, 1990). In the process of generating multisensor models, data obtained by UAV photogrammetry and bathymetry are often being combined (Fabris et al. 2010; Šiljeg et al 2022). Great advances and the increasing availability of modern technology have enabled 3D-4D-5D documentation, conservation and, digital promotion of protected areas and facilities (Remondino and Rizzi, 2010; Ficarra, 2011, Kyriakaki et al., 2014). 3D documentation involves collecting, processing, reproduction, and presentation of geospatial data by determining the position, shape, and dimensions of an object or area in three-dimensional space to preserve the current state (Marić et al., 2019) of cultural (Manić et al., 2013) or natural heritage (Leonov et al., 2011; Bishop et al., 2012). UNESCO (1972) uses the term “natural heritage” for physical, biological, and geological features, formations, and sites of exceptional value from an aesthetic or scientific point of view (Boehler et al., 2001). The study of natural heritage largely depends on conservation because global climate change, natural disasters, mass tourism, terrorism, and human negligence greatly affect changes in the landscape, and thus on the protected areas (Marić et al., 2019). Furthermore, the rapid development of virtual reality

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technology (VR) offers the possibility of using GSTs for tourism purposes (Bruno et al., 2010; Leonov et al., 2011; Tussyadiah et al., 2018). Also, the use of 3D printers enables the production of attractive souvenirs. Therefore, the promotion of protected natural areas, using modern GSTs is necessary if decision-makers and administration want to keep up with the modern requirements of tourism. The object of this research was Lake Zmajevo oko near Rogoznica (Figure 1). It was recorded using UAV photogrammetry and multibeam echosounder (MBES). The research goals were to create an m model of the lake and present the application of these technologies for promotional purposes. Also, the secondary objective was to obtain morphometric data about the lake (surface area, volume, depth, and shoreline length).

2 STUDY AREA

The bathymetric survey covered the area of Lake Zmajevo oko (Figure 1), while the UAV photogrammetric survey covered the wider coastal area. The area is characterized by a large terrain roughness. It is located on the Gradina peninsula, which is connected to the mainland by a thin isthmus and surrounded by the bays of Soline and Koprišće. The lake is connected to the sea by underground tunnels. This is indicated by the salinity of the water, the presence of the mediolateral staircase, and the change of tides (Bakran-Petricioli et al., 1998). Physicochemical properties are specific. The lake is characterized by sudden changes in temperature, salinity, and density caused by poor water mixing, geomorphological features, and meteorological conditions. The lake is naturally sheltered from the wind since it is located in a valley. This is one of the main reasons for the constant chemical stratification (Ciglenečki et al., 1996; Bakran-Petricioli et al., 1998; Bura-Nakić et al., 2012). The bottom layer is characterized by a thick layer of hydrogen sulfide which makes the water cloudy and white. Anoxia is also present (Bakran-Petricioli et al., 1998; Bura-Nakić et al., 2007; Bura-Nakić et al., 2012).

3 MATERIALS AND METHODS

UAV photogrammetry was used for the recording of the water body and the wider coastal area in order to obtain data about the surface area and the shoreline length as well as to develop high-resolution models for visualization. An MBES survey was performed to obtain data on the depth and volume of the lake as well as to detect and map underwater tunnels.

Figure 1: Geographical position of the Lake Zmajevo oko.

3.1 UAV Photogrammetric Survey

A UAV photogrammetric survey of Lake Zmajevo oko was performed on July 19, 2019. The *Phantom 4 Pro* (Figure 2A) was used for imagery acquisition while RTK-GPS *Stonex S10* (Figure 2B) was used to measure ground control (GCP) and check points (CP). The detailed specifications of the used UAV are available (URL1) and GNSS receiver at (URL2). The *Stonex S10* was also used to monitor the water level during data acquisition.

Figure 2: *Phantom 4 Pro* and *Stonex S10.*

A UAV photogrammetric data acquisition and processing were performed in several steps. The first was to mark and collect GCPs and CPs. A total of 9 points (6 GCPs and 3 CPs) were marked and collected (Figure 3). On the east side of the lake, it was not possible to collect any points because the area was fenced (private property).

The second step was the development of an optimal survey plan. That included the selection of mission types concerning the morphology of the terrain and the distribution of points. Multiple double grid missions were performed at flight altitudes of 70 m with a camera angle of 90°. Also, one circular and one free flight mission was conducted to collect oblique images of the steep coastal parts of the lake.

The front and side overlap was set to 80%. Before data acquisition, the vision positioning system, inertial measurement unit (IMU), and compass were calibrated. An image processing was performed in

Figure 3: Spatial distribution of GCPs and CPs.

Agisoft Metashape Professional 1.5.1. The image workflow process consisted of several steps as in Marić et al. (2019). The camera calibration was done automatically whilst aligning photos in Metashape. The image alignment, the building of the dense cloud, and the mesh were set to medium quality. After positioning the GCPs and CPs, the accuracy of the derived models were calculated mean absolute error (MAE) and root mean square error (RMSE).

The values of MAE and RMSE in CPs are stated in (Table 1). The MAE for the X-axis was 1.48, for the Y-axis 3.26, and for the Z-axis 1.16 cm. The total MAE of the CPs was 3.99 cm. The MAE in the image coordinate system was 0.18 pixels. The RMSE for the X-axis was 1.72, for the Y-axis 3.48, and for the Z-axis 1.36 cm. The total RMSE of the CPs was 4.13 cm. The RMSE in the image coordinate system was 0.20 pixels. The MAE and RMSE correspond to the values achieved in similar studies and papers (Agüera-Vega et al., 2017; Marić et al., 2019; Rogers et al., 2020). We are aware that only three CPs are not enough to assess the accuracy of the model, but due to the large terrain roughness, very dense vegetation, and private property on the east side, there were not many available places where more points could be marked.

Table 1: The accuracy of CPs.

Label	X error (cm)	Y error (cm)	Z error (cm)	Total error (cm)	Image (pix)
CP1	2.45	-2.63	-1.73	3.99	0.30
CP2	1.67	-2.18	-0.15	2.75	0.16
CP3	-0.32	-4.96	1.59	5.22	0.08
MAE	1.48	3.26	1.16	3.99	0.18
RMSE	1.72	3.48	1.36	4.13	0.20

3.2 MBES Survey

The first step of the MBES survey was to obtain secondary data that were necessary for optimal bathymetric survey planning. The reference mean water level was determined using geodetic measurement (GNSS-RTK receiver Stonex S10). The reference mean water level was recognized as the point marked by wet conditions, a difference in color, and algae formed on the steep side of the lake. The MBES survey was performed with an integrated measurement system (Figure 4) which included eight main components: (a) *WASSP S3 Multibeam Wideband Sounder c/w DRX* (Figure 4B); (b) *WASSP Sensor Box* (Figure 4D) with integrated Spatial IMU (Figure 4E); (c) *Hemisphere V320 GNSS Smart Antenna* (Figure 4A); (d) *WMB-160* probe (Figure 4C); (e) battery and power cord; (f) configuration computer and cable; (g) configuration software; (h) Data Management and Exporting Software (CDX).

Figure 4: Integrated measuring system components.

All components were connected and configured according to the manufacturer's instructions and international standards concerning the characteristics of the boat. In addition to the above system configuration, it was important to calibrate the probe during the measurement and to calculate the optimal speed of sound in water based on the output results of the temperature and salinity of the water. The visual effect of incorrect speed of sound is manifested by the concave or convex curvature of the flat seabed (Dong et al., 2007; Dong et al., 2011) (Figure 5A). Therefore, the device was calibrated on the flattened part of the lake to minimize measurement errors (Figure 5B). Considering the characteristics of temperature and salinity on the day of measurement, the speed of sound was 1531.58 m/s.

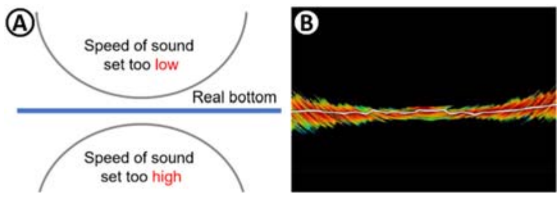

Figure 5: A) An example of the inaccuracy of the lake bottom display due to an incorrect speed of sound; B) An

set speed of sound during the bathymetric survey of the lake.

The MBES survey (Figure 6) was performed four times (Table 2) to collect as many points as possible so that a more accurate bathymetric model can be made after the point filtering process. The percentage of overlap was 50% because the relatively small research area allowed it. The operating frequency was set to 160 kHz, while the operating beam width was 20°. The ping rate varied from 10 to 14 /sec. The device collected and displayed real-time data of boat position, speed, azimuth, plane deviation, and depth based on predefined user-defined system settings. The GPS antenna was connected to the CROPOS (*Croatian Positioning System*) system via the GSM network. That enabled a very high accuracy of the collected data. The system collected data in the WGS84_UTM_N33 projection.

Figure 6: The MBES survey of the Lake Zmajevo oko.

Table 2: Characteristics of collected unfiltered points.

Survey	Min Z	Max Z	Z Range	Number of points
1	-0.91	-18.54	-17.63	1 397 243
2	-0.73	-19.82	-19.09	1 267 833
3	-1.07	-20.37	-19.30	1 487 819
4	-1.25	-16.91	-15.66	521 969
Total				4 674 864

The measured data were transferred to the desktop computer for further processing and interpretation via software packages for guidance (CDX) and data management (*Data Manager*). Numerous authors stated that one of the most demanding tasks in the MBES process is data filtering (An et al., 2019; Šiljeg et al. 2022). Following the Šiljeg et al. (2022) three methods were used in the data filtering process: (a) manual removal which is an extremely time-consuming and demanding process; (b) automatic method *Label Connected Components* in *CloudCompare* software, and (c) SOR filter (*Statistical Outlier Removal*).

A digital bathymetry model (DBM) with continuous surfaces was produced from a filtered dense point cloud using the interpolation method *Natural Neighbour*. Spatial resolution was calculated using the *Grid calculator* and the *Point pattern analysis* method was chosen (Hengl, 2006). The optimal spatial resolution of 5 cm was selected for the multisensor model (DBM+DSM). It represents a compromise between the sampling density of points collected by UAV and MBES points and the research area. The resolution was reduced to 10 cm for visualization. The validation method of the generated DBM included only the visual inspection of the created model with the findings of an experienced diver who knows the bottom of the lake in order to make sure that the most conspicuous outliers were removed. In the final phase of the processing, the surface area, volume, and shoreline length were calculated. The volume was calculated from a regular grid obtained by interpolation. Three Newton-Cotes formulas integrated within the *Surfer* software were used: (a) *Trapezoidal Rule*; (b) *Simpson's Rule*; and (c) *Simpson's 3/8 Rule*. The total surface area of the lake and the shoreline length were calculated in the *ArcMap* software.

3.3 Virtual Walk

Using the trial version of *Lumion*, a short promotion video and six 360° panoramas were created. First, the created 3D models in *.obj* format were imported. The high polygon count within the photogrammetry process caused a slowdown. Therefore, the number of it was reduced. The next step included a selection of the six locations which represented the best model (Figure 7). The final step was to set the parameters in the *render all 360° panoramas* option. The output quality was set to 4/5, the stereoscopic view was turned on and the distance between the two eyes was set to 64.0 mm to give the appearance of space depth. The images were generated for computer or mobile platforms. Panoramas were exported in resolution 4096x4096. To create a promotional video, 50 selected viewpoints were rendered. Video quality was set to 5/5, and the number of frames per second to 30. The video resolution was set to *Full HD* (1920x1080).

Figure 7: Spatial distribution of the six 360° panoramas.

3.4 3D Print

A 3D printing of the Lake Zmajevo oko was performed using a 3D printer *Prusa i3 MK3*. Creating a 3D physical model consisted of several steps (Figure 8). First, the data was converted to *.stl* format. This mesh must be dense enough to achieve the satisfactory quality of the physical model. However, it should not be too complex to avoid overloading and slowing down of the computer (Marić et al., 2019). Then, the 3D printing parameters were set. The orientation of the model and the type of filament were adjusted. PLA (polylactide) plastic has proven to be the best choice because of its compactness, strength, and further processing.

The height of the filament layer was set at 0.15 mm. Then the model was exported in the *G-code* format that is standard for most 3D printers and industrial machines. In the final phase, the model was transferred to a previously calibrated 3D printer with a USB memory and 3D printing of the lake was performed.

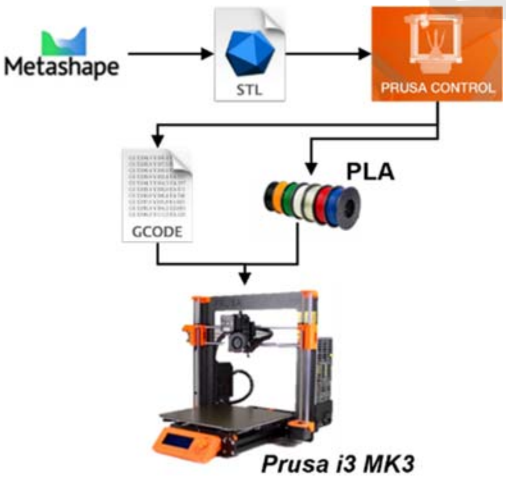

Figure 8: 3D printing process of the Lake Zmajevo oko.

4 RESULTS AND DISCUSSION

4.1 UAV Photogrammetric Survey

From the UAV photogrammetric survey conducted on July 19, 2019, the following models of the Lake Zmajevo oko were derived: (a) a high-resolution DOP (Figure 9); (b) a high-resolution DSM (Figure 10); and (c) a 3D model of the lake (Figure 11). A high-resolution DOP of the Lake Zmajevo oko had a spatial resolution of 1.56 cm (Figure 9).

Figure 9: A high-resolution DOP of the lake.

A DSM (GSD = 3.12 cm) (Figure 10) of the wider coastal area of the Lake Zmajevo oko was generated from a dense point cloud. The high value of resolution is because the *Quality* parameter in *Agisoft Metashape* was set to *High*.

Figure 10: A high-resolution DSM of the lake.

Finally, a 3D model of the wider coastal area of Lake Zmajevo oko was generated (Figure 11). The derived model can be used for promotional purposes by creating a virtual walk. It is necessary to render selected points around the lake to do that. However, it is also possible to make a virtual walk in which the user cannot manage and make decisions, but the whole walk is pre-programmed. Panoramic 360° shots and a short promotional video were made based on this model.

Figure 11: A 3D model of the lake.

4.2 MBES Survey

A total of 4 674 864 points were collected. The operating frequency of 160 kHz allowed mapping the actual bottom of the lake despite the presence of a thick layer of hydrogen sulfide in the bottom layer. The minimum collected value of depth was -0.73 m, and the maximum depth was -20.37 m (Table 1). These maximum and minimum values are the results of outliers present in the unfiltered point cloud. They were removed following the point-cloud processing approach presented in Šiljeg et al. (2022). Thanks to the wide operating angle, the possibility of side-scanning, and the selected operating frequency, ten horizontal underwater tunnels (cracks) were detected and marked (Figure 12).

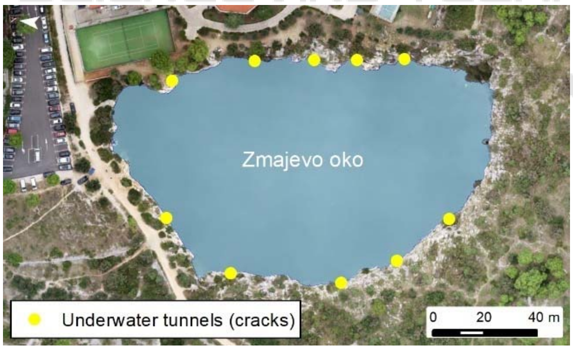

Figure 12: Locations of underwater tunnels (cracks).

A DBM with a maximum depth of -13.45 m was generated. The first multisensor model of the Lake Zmajevo oko was created by merging a DBM with a DSM created by UAV photogrammetry (Figure 13).

The volume of the Lake Zmajevo oko on the day of the MBES survey was 90691.74 m^3, the length of the coastline was 513.15 m, and the surface area was 0.99 ha.

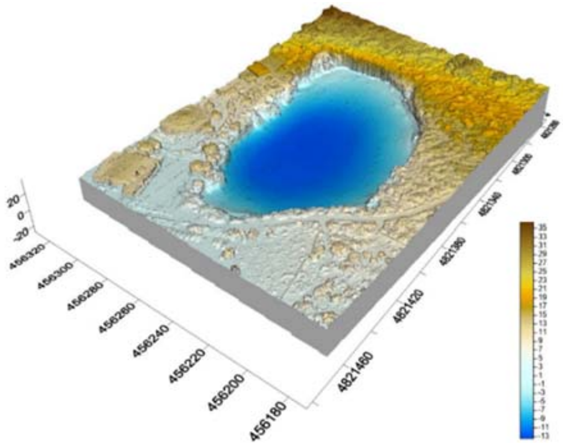

Figure 13: An multisensor model of the lake Zmajevo oko.

4.3 Virtual Walk

A promotional video called *Zmajevo oko Virtual Walk (Rogoznica, Croatia)* was created (Figure 14). It was published on the official website of the *Geospatial Analysis Laboratory* (GAL).

Six viewpoints with panoramic 360º images were also rendered (Figures 7 and 15). They cover the researched area and give the potential visitor a quality visual impression about this protected area. Videos and panoramic images can be used to promote the lake online.

Figure 14: A clip from a promotional video *Zmajevo oko Virtual Walk (Rogoznica, Croatia).*

Panoramic 360º images of the lake can be found on the *360Cities* open-source platform. The recordings can be viewed at the following links:

P1: https://cutt.ly/KInIJbQ;
P2: https://cutt.ly/GInI2ye;
P3: https://cutt.ly/gInI7Gy;
P4: https://cutt.ly/NInOtJP;
P5: https://cutt.ly/lInOp89;
P6: https://cutt.ly/KInOh64.

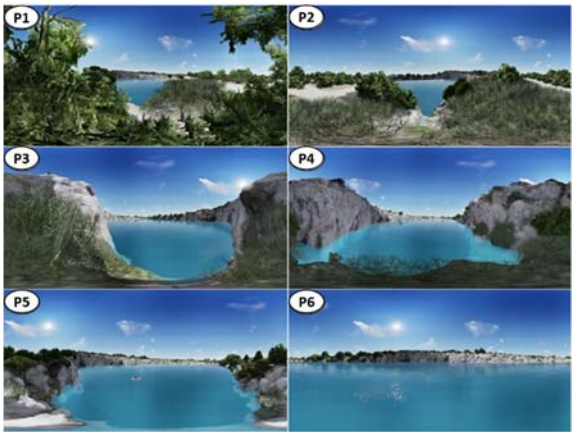

Figure 15: Panoramic 360° images of the lake Zmajevo oko from six viewpoints.

4.4 3D Print

The physical model (12 x 9 cm) of the Lake Zmajevo oko (Figure 16) was generated. This model can be used as a souvenir, and if desired, it can be personalized. The filament is made of completely workable material and can be painted as desired. Anastasiadou and Vettese, (2019) examined visitor preferences and managers' views on 3D printed souvenirs and concluded that there is a tourist interest in this type of souvenir and that this is the future of tourism.

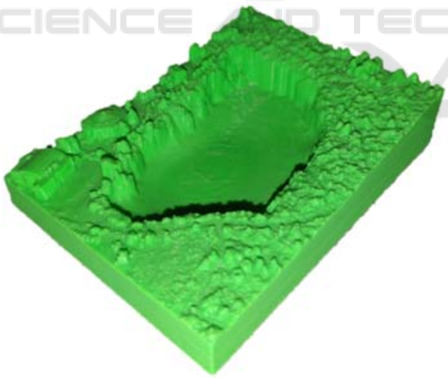

Figure 16: A physical model of the Lake Zmajevo oko.

5 CONCLUSIONS

In this research, we presented an application of modern GSTs and their use for promotional purposes. High-quality DSM and DBM have been created. A multisensor model of this natural phenomenon was made. The accuracy of the UAV images calculated by the MAE is 3.99 cm and for the RMSE 4.13 cm in CPs. The biggest challenge was the choice of the operating frequency of the MBES considering the physio-chemical characteristics of the lake. The operating frequency of 160 kHz allowed mapping the actual bottom of the lake despite the presence of a thick layer of hydrogen sulfide in the bottom layer. All four measurements were made with the same frequency and dense cloud points were successfully collected.

The integrated measuring system enabled the detection of underwater tunnels. The distribution and characteristics of the detected underwater tunnels will be discussed in future research. Based on the DOP and DSM, exact volume, surface area and shoreline length data were derived. Based on 3D model of the lake the virtual walk was generated. Finally, using a modern 3D printer, a physical model of the lake with a wider coastal area was made. That model can be used as a souvenir to promote the Lake Zmajevo oko. The documentation of this natural heritage can enable further monitoring of changes and it is the starting point for future research in this area.

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REFERENCES

Abdalla, R. (2016). Introduction to geospatial information and communication technology (GeoICT). *Springer International Publishing*.

Agüera-Vega, F., Carvajal-Ramírez, F., & Martínez-Carricondo, P. (2017). Assessment of photogrammetric mapping accuracy based on variation ground control points number using unmanned aerial vehicle. *Measurement*, *98*, 221-227.

An, L., Rignot, E., Millan, R., Tinto, K., & Willis, J. (2019). Bathymetry of northwest Greenland using "Ocean Melting Greenland"(OMG) high-resolution airborne gravity and other data. *Remote Sensing, 11*(2), 131.

Anastasiadou, C., Vettese, S. (2019). "From souvenirs to 3D printed souvenirs". Exploring the capabilities of additive manufacturing technologies in (re)-framing tourist souvenirs. *Tourism Management*, *71*, 428-442.

Bakran-Petricioli, T., Petricioli, D., Požar-Domac, A. (1998). Influence of isolation and peculiar ecological properties on biodiversity–an example of marine lake Zmajevo Oko near Rogoznica (Adriatic Sea). *Rapports et proces verbaux des réunions–Commission internationale pour l'exploration scientifique de la mer Méditerranée*, *35*(2), 518-519.

Bishop, M. P., James, L. A., Shroder Jr, J. F., Walsh, S. J. (2012). Geospatial technologies and digital geomorphological mapping: Concepts, issues and research. *Geomorphology*, *137*(1), 5-26.

Bodzin, A. M., Cirucci, L. (2009). Integrating geospatial technologies to examine urban land use change: A design partnership. *Journal of Geography*, *108*(4-5), 186-197.

Boehler, W., Heinz, G., Siebold, M. (2001). Topographic information in cultural and natural heritage visualization and animation. *International Archives of Photogrammetry and Remote Sensing*, *34*(5/W1), 56-61.

Bruno, F., Bruno, S., De Sensi, G., Luchi, M. L., Mancuso, S., Muzzupappa, M. (2010). From 3D reconstruction to virtual reality: A complete methodology for digital archaeological exhibition. *Journal of Cultural Heritage*, *11*(1), 42-49.

Bura-Nakić E., Ciglenečki I., Bošković N., Burić Z., Ćosović B. (2007): Sezonska i okomita raspodjela organske tvari i reduciranih sumpornih vrsta u vodenom stupcu Rogozničkog jezera, *Hrvatske vode i Europska Unija - izazovi i mogućnosti: zbornik radova,* Zagreb: Hrvatske vode, 85-90.

Bura-Nakić, E., Marguš, M., Orlić, S., Ciglenečki, I. (2012). Zmajevo oko–a unique example of anchialine system on the Adriatic coast (Croatia) during spring-summer stratification and autumn mixing period. *Natura Croatica: Periodicum Musei Historiae Naturalis Croatici*, *21*(suppl. 1), 17-20.

Ciglenečki, I., Kodba, Z., Ćosović, B. (1996). Sulfur species in Rogoznica lake. *Marine chemistry*, *53*(1-2), 101-110.

Dong, Q. L., Cui, M. X., Zhou, J. H., Wang, J. G., Xu, Y. (2011). Analysis and Processing of Transform Geography of Convex and Cave in Multibeam Sounding System [J]. *Hydrographic Surveying and Charting*, *1*.

Dong, Q. L., Han, H. Q., Fang, Z. B., Pan, L., Chen, Y. Y., Lu, G. F. (2007). The Influence of Sound Speed Profiles Correction on Multi-beam Survey. *Hydrographic Surveying and Charting*, *2*, 56-58.

Doulamis, A., Grammalidis, N., Ioannides, M., Potsiou, C., Doulamis, N. D., Stathopoulou, E. K., ... & Dimitropoulos, K. (2015). 5D modelling: an efficient approach for creating spatiotemporal predictive 3D maps of large-scale cultural resources. In *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume II-5/W3, 25th International CIPA Symposium 2015, 31 August – 04 September 2015, Taipei, Taiwan

Erenoglu, R. C., Akcay, O., & Erenoglu, O. (2017). An UAS-assisted multi-sensor approach for 3D modeling and reconstruction of cultural heritage site. *Journal of cultural heritage*, 26, 79-90.

Fabris, M., Baldi, P., Anzidei, M., Pesci, A., Bortoluzzi, G., Aliani, S. (2010). High resolution topographic model of Panarea Island by fusion of photogrammetric, lidar and bathymetric digital terrain models. *The photogrammetric record*, *25*(132), 382-401.

Ficarra, F. V. C. (2011, September). The expansion era of the communicability: first nations for the local and global promotion of cultural and natural heritage. In *International Workshop on Human-Computer Interaction, Tourism and Cultural Heritage* (pp. 25-37). Springer, Berlin, Heidelberg.

Hackett, J. K., Shah, M. (1990, May). Multi-sensor fusion: a perspective. In *Proceedings., IEEE International Conference on Robotics and Automation* (pp. 1324-1330). IEEE.

Hengl, T. (2006). Finding the right pixel size. *Computers & geosciences*, *32*(9), 1283-1298.

Kyriakaki, G., Doulamis, A., Doulamis, N., Ioannides, M., Makantasis, K., Protopapadakis, E., ... & Weinlinger, G. (2014). 4D reconstruction of tangible cultural heritage objects from web-retrieved images. *International Journal of Heritage in the Digital Era*, 3(2), 431-451.

Leonov, A., Aleynikov, A., Belosokhov, D., Bobkov, A., Eremchenko, E., Frolov, P., ... Klimenko, S. (2011). 3D Documentation of Natural Heritage for Virtual Environments and Web—Case Study: Valley of Geysers, Kamchatka. In *Proc. of the IADIS International Conference CGVCVIP* (pp. 255-259).

Manić, L., Aleksić, M., Tankosić, M. (2013). Possibilities of New Technologies in Promotion of the Cultural Heritage: Danube Virtual Museum. In *2nd International Conference on Sustainable Tourism and Cultural Heritage (STACH'13)"Advances in Environment, Ecosystems and sustainable Tourism", Brasov, Romania*.

Marić, I., Šiljeg, A., Domazetović, F. (2019). Geoprostorne tehnologije u 3D dokumentaciji i promociji kulturne baštine–primjer utvrde Fortica na otoku Pagu. *Geodetski glasnik*, *50*, 19-44.

Remondino, F., Rizzi, A. (2010). Reality-based 3D documentation of natural and cultural heritage sites—techniques, problems, and examples. *Applied Geomatics*, *2*(3), 85-100.

Rogers, S. R., Manning, I., Livingstone, W. (2020). Comparing the spatial accuracy of Digital Surface Models from four unoccupied aerial systems: Photogrammetry versus LiDAR. *Remote Sensing, 12*(17), 2806.

Šiljeg A, Marić I, Domazetović F, Cukrov N, Lovrić M, Panđa L. (2022). Bathymetric Survey of the St. Anthony Channel (Croatia) Using Multibeam Echosounders (MBES) - A New Methodological Semi-Automatic Approach of Point Cloud Post-Processing. *Journal of Marine Science and Engineering*,10(1):101.

Šiljeg, A., Barada, M., Marić, I. (2018). Digital Terrain Modelling. *Alfa d.d. and University of Zadar*, Zagreb.

Tussyadiah, I. P., Wang, D., Jung, T. H., tom Dieck, M. C. (2018). Virtual reality, presence, and attitude change:

Empirical evidence from tourism. *Tourism Management*, *66*, 140-154.
UNESCO (1972). *UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage*, United Nations Educational, Scientific and Cultural Organization, Paris (1972).
URL 1 https://www.dji.com/hr/phantom-4-pro/info, 28 February, 2022.
URL 2 https://www.stonex.it/project/s10-gnss-receiver/, 28 February, 2022.