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3D MODELLING OF ARUTELA ROMAN CASTRUM USING CLOSE-RANGE PHOTOGRAMMETRY

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Abstract

The state of the art of close-range photogrammetry reveals new methods for the creation of 3D models for heritage and archaeological objects and sites. Effective and competent methodologies have been developed for surveying and modeling archaeological sites and thus provide high quality and accurate realistic textured models for better research, preservation, education and monitoring projects. A specific methodology was applied to produce a scale 3D model of "Arutela (Căciulata) Roman Castrum" in a digital environment. A complex product is created, with complemental geometry and texture. The accurate geometry and appearance details (size, shape, position and texture) can be used for a proper documentation, preservation and restauration applications.

Keywords: Close-range photogrammetry; Digital photographs; 3D modeling; Archaeological site; Heritage conservation.

Introduction

Close-range photogrammetry offers solutions for 3D modelling of archaeological sites as technology is continuously developing. A digital 3D model depicting an archaeological object or site, with complex geometry and texture details, can be further used for diverse applications.

Nowadays, a representation in a digital environment for a proper documentation and preservation purposes is imposed, as 3D models reflect the realistic condition of an object/surface, at a certain moment in time. Following a certain methodology for Cultural Heritage 3D modeling, accurate results can be used for many applications: historical documentation, digital preservation and conservation, monitoring of shape and colors, aging and deterioration simulation, measurements, digital analysis, multimedia museum exhibition, 3D archives, restauration simulations etc. Accurate results of a 3D model are defined by geometry and radiometry details. Considering methods, laser scanning and close-range photogrammetry are well known for 3D modelling. Laser scanning has been intensively used for 3D applications of cultural heritage and it demonstrated its full capabilities for digital preservation [1, 2]. However, close-range photogrammetry offers the opportunity of achieving high resolution digital 3D models with a low budget, either using photographs acquired from ground level, either from cameras mounted on a UAV [3–6]. This paper has the objective of exploiting the potential of close-range photogrammetry for 3D modelling using only ground level photographs. The interpretation of restauration works which were conducted at this archaeological site is not discussed in this paper.

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In order to demonstrate the full capabilities of 3D modelling of an archaeological site, a case study for “Arutela Roman Castrum” was conducted. Arutela Roman Castrum was part of Limes Alutanus, meaning The Fortified Boundary along the Olt River of a Roman Province (Alutus means Olt River) [7]. Limes Alutanus was composed of 20 fortresses. A short description of Arutela Roman Castrum is imposed because it is necessary to understand the details that are going to be digitally modeled. A major archaeological excavation was undertaken by the Military Museum between 1967 and 1978 [8, 9]. In the first stage of the excavation, 975sqm were uncovered, along with small parts of the compound walls: 15m of the northern wall and 13.2m of the southern one. The thickness of the walls was alternating between 1.5 and 1.6m and the height of the revealed walls varied from 1.2m for the northern segment and 0.4-0.9m for the southern segment. There were also discovered some rowels, 1.68m in length. In the final phase of the excavation, the ruins were completely uncovered. In total, three sides were discovered, considering the fourth one was destroyed in the IIIth century during a river flood. The northern part is 46.4m long, the eastern one, 60.8m, while the southern one is 41.4m long. The height varies between 0.5 and 1.7m. The only part which was not affected by the flood is the eastern one. In its central part there is Porta Praetoria, measuring 30m in width and 8m in height, with two rowels on each side (Fig. 1). The two remaining corners of the Roman Camp, the north-eastern one and south-eastern one, are semicircular shaped and are considered to be the remains of two towers. Similar towers are considered to have existed in the other two corners of the compound walls, which were destroyed during the flood.

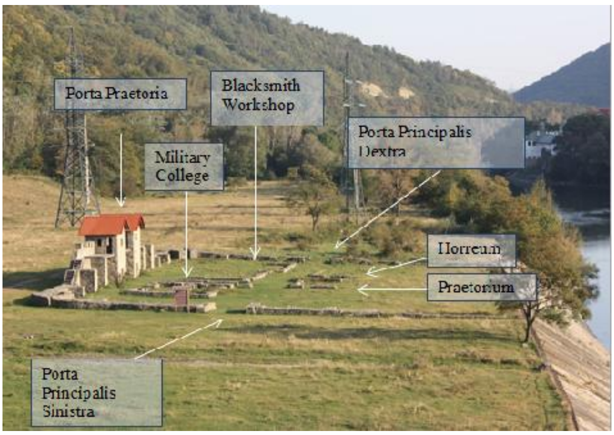

Fig. 1. Elements of Arutela Roman Castrum to be digitally modeled

Besides the geometry of the camp, its appearance is also important for considering when texturing the model. Colors and construction materials have to be taken into consideration when conducting a photogrammetric survey, given that the 3D model is a realistic digital representation of an object. The compound walls were built from large blocks of rectangular stones, tied in-between with mortar. The stone alignments are parallel.

Methodology

Considering all the characteristics of Arutela Roman Castrum, a specific methodology was applied in order to successfully model the remaining vestiges. The methodological phases refer to both manual and automatic processes (Fig. 2). For automatic tasks, Agisoft Photoscan was used (after conducting several tests on smaller surfaces for validation) and for manual tasks, Netfabb, which delivered the best solution for mesh editing. The software applications were chosen in order to meet the requirements of such a large project.

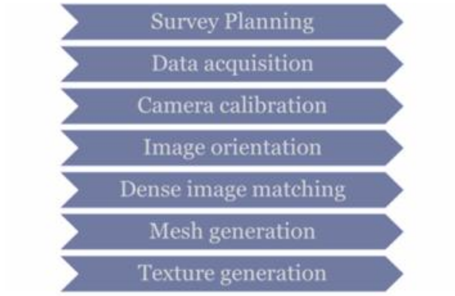

Fig. 2. Workflow for the construction of a 3D model

Survey Planning

Establishing project requirements is the first step in the close-range photogrammetric workflow. A series of important parameters were set: area to be covered, access to areas surrounding the object, object's dimensions, weather and accuracy of final product. [10]. Accuracy, image scale and project size are directly related, thus the better the expected accuracy, the greater the project amplitude will be. For this case study, a total length of 270m of walls has been digitally modeled. The expected accuracy is 1 cm GSD, thus the image scale was set to 1:2000. Using 35mm focal length and having the pixel size of 0.0052mm, the distance from the camera to the object, in order to obtain the required results, was calculated to be maximum 7 meters. Several computations were made using the principles of close-range photogrammetry. Moreover, in order to create 3D coordinates from 2D coordinates of the same pixel, seen from different perspectives on photographs, an overlap of minimum 60% between images had to be achieved; a baseline of approximately 1m was computed between each image center (Table 1).

Table 1. Project's parameters and general camera calibration values

Parameter	Value
Required accuracy	10 mm
Pixel size	0.0052 mm
Focal length	35 mm
Image scale	1:2000
Max. distance from object	7 m
Baseline	1 m

Data acquisition

A digital SLR CANON 450 D was used to take photographs according to photogrammetric principles, relying on the parameters in the survey planning phase. About 2400 images were acquired at the archaeological site, from which 2200 photographs were used in the 3D modelling process. Some photographs were eliminated from processing because of different illumination conditions which can affect the results. Also, 15 GCPs were measured in order to georeference the model in the national coordinate system, Stereo 70. Moreover, several measurements were made so that the results can be validated based on the real dimensions.

Camera calibration

Nowadays, software applications are powerful enough to automatically calibrate the camera, reducing processing time and achieving high quality results. The process of identifying the parameters of recorded images is therefore automatic: focal length, format size, principal point, lens distortion.

Image orientation

The 3D geometric reconstruction is a complex mathematical problem, which is resolved in two steps: a) Interior orientation (reconstruction of the bundle perspective geometry in the camera system of each photograph) and b) External orientation: the position of each bundle in relation to a coordinate system is determined, and also its relationship with the reference bundle [11]. Therefore, position and orientation of the perspective center of the camera are calculated and images are aligned (Figure 3). The image alignment is done by automatically identifying a number of common points between images, counting the image orientation properties. Software for 3D reconstruction uses SfM and MVS for image alignment and geometric reconstruction [6], based on the principle that a scene can be reconstructed in 3D from overlapping 2D photographs taken from different locations and orientation.

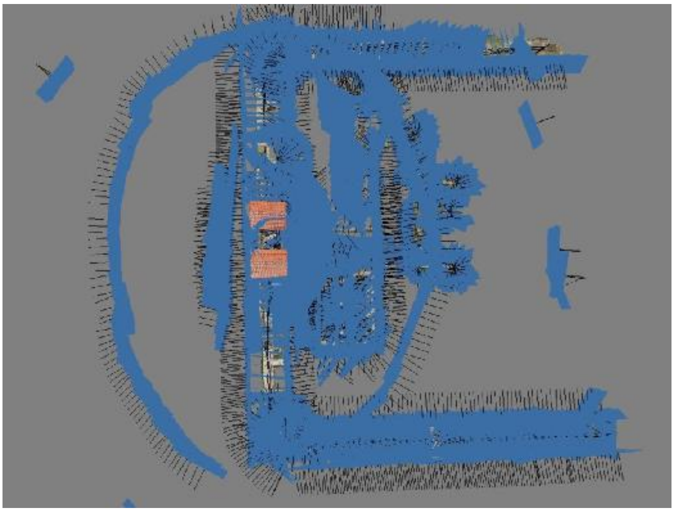

Fig. 3. Image alignment obtained from interior/exterior orientation of images

Dense point cloud generation

After the image alignment, a dense point cloud is generated. This dense point cloud represents projected pixels of each aligned image in the 3D space and each point is represented with X,Y and Z coordinates. Calculating the position, orientation and focal length of each image frame, a depth map is calculated, that is the intersection of the perspective pixel rays with pixel rays from other images. A dense point cloud is computed from combining different depth maps into a single scene [6]. This dense point model reveals the artificial aspect of Arutela Roman Castrum.

A number of 25041031 of points were automatically generated for the entire archaeological site. The resulted model was further edited in order to eliminate all unnecessary points.

Mesh generation

Based on the previously constructed and edited dense point cloud, a mesh was generated in order to represent a continuous surface by connecting all the points in a Triangulated Irregular Network (TIN). A complex (un-textured) model was created [12]. The dense point cloud was triangulated for constructing a 3D mesh.

A total number of 48547439 faces were generated (Fig. 4), illustrating all the irregularities on the object's exterior aspect. The object's geometry is very important in conducting different types of analysis.

Mesh editing

In the process of automatic mesh computation, a high number of network faces were generated. Moreover, in the areas with a reduced number of points, small gaps were generated. Problems in mesh generation arose also in areas less accessible from ground level, where a limited number of photographs could be acquired. These issues were corrected by manually edit the 3D mesh. After an initial mesh decimation to easily manipulate the data, the triangles were reduced from 8000000 to 1000000. The geometry was not altered after decimation. As all the details were still captured (surface's irregularities, windows, gate), the workflow continued with mesh editing. In order to correctly connect the points and to represent the real aspect of the walls, the mesh was edited by deleting, adding and modifying triangles (Fig. 5).

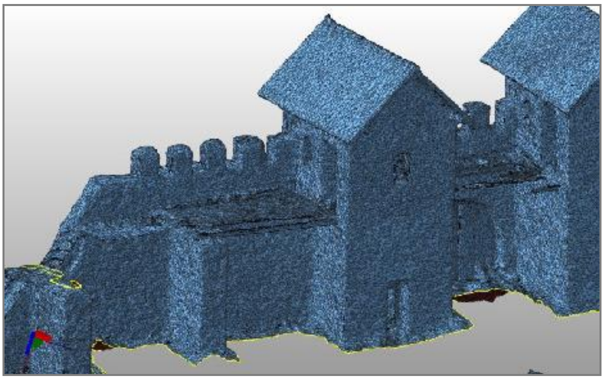

Fig. 4. TIN for "Arutela Roman Castrum", detail for Porta Praetoria

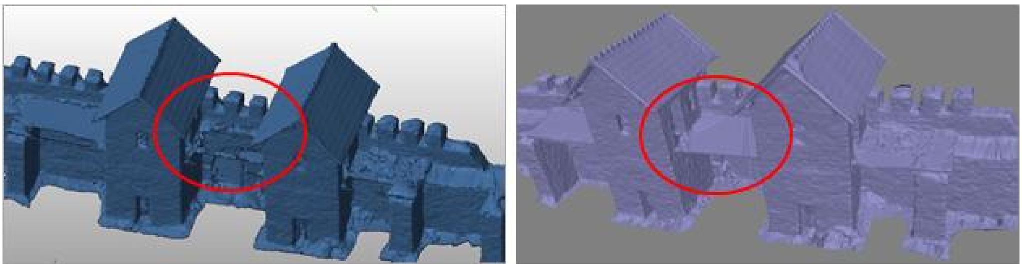

Fig. 5. Poor geometry due to limited accessibility and low number of images acquired. Detail with repaired geometry before/after mesh editing

Texture generation

The texture mapping was automatically generated based on the pixel information from the images. In this final step, the texture map is calculated by projecting original images on the geometric structure of the model. UV-mapping is performed by assigning a color value in 2D to a 3D geometry, where 3D coordinates (x,y,z) of geometry are linked with 2D coordinates (u,v) of the texture map [6].

The sharper the images, the greater quality of the texture to be determined in the textured model as the colors have to be realistic in the digital environment. Texture mapping offers a better visual quality for the final model.

Results

The "Arutela Roman Castrum" 3D model represents a scale model, meaning that it can be further used to determine the size of the real-world area in a digital environment [13]. The colors are realistic and the details are well represented: rooftiles, stairs, stones in the walls and planks in the boardwalks (Fig. 6). All the parameters set during survey planning were respected for the final result. The resulted GSD is 1cm.

Fig. 6. a) External façade of Porta Praetoria; b) Internal façade of Porta Praetoria; c) Inner walls of "Arutela Roman Castrum" and internal façade of Porta Praetoria

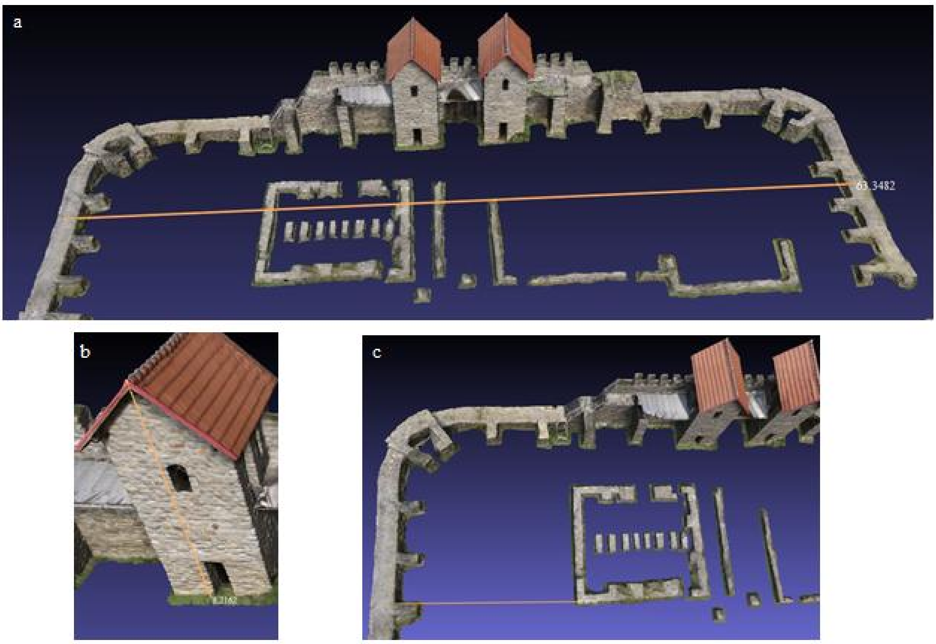

Fig. 7. a) Distance measurement from northern wall to the southern one (63.3 m); b) Height measurement of Porta Praetoria (8.2 m); c) Distance measurement from northern wall to inner wall (13.7 m)

Further analysis can be conducted in a virtual environment as the geometry and the texture are combined in a realistic 3D model which offers a complex visual support for many applications. Basic measurements can be done on this 3D model (such as distances, height, width measurements) (Fig. 7), but also more complex ones (various digital simulations and restauration techniques, digital exhibitions, various research projects). The objective of this study was achieved, as the methodology was successfully applied for the construction of a 3D model.

Conclusion

A specific methodology was applied to successfully create a realistic 3D model of Arutela Roman Castrum, establishing that photogrammetric principles can be applied to obtain an accurate, fast, reliable and low cost 3D model [14]. For this study, 2200 photographs acquired at ground level were processed in a SfM-MVS workflow and the 3D model was constructed. Final GSD is 1cm. Moreover, the colors are realistic and construction details are well represented. The scale 3D model of Arutela Roman Castrum was analyzed with basic measurements of several parameters: heights, distances in-between external walls, wall thickness etc. This 3D model can be the starting point of more specific studies conducted by other scientists (archaeologists, historians). This result can be used for different application purposes: heritage documentation and conservation, reconstruction simulation, measurements without damaging the ancient vestiges.

References

[1] M. Calin, G. Damian, T. Popescu, R. Manea, B. Erghelegiu, T. Salagean, *3D Modeling for Digital Preservation of Romanian Heritage Monuments*, **Agriculture and Agricultural Science Procedia**, **6**, 2015, pp. 421–428.

[2] J. a. Beraldin, M. Picard, S. F. El-hakim, G. Godin, V. Valzano, A. Bandiera, *Combining 3D technologies for cultural heritage interpretation and entertainment*, **Proceedings of the society of photo-optical instrumentation engineers (SPIE)**, **5665**, no. January, 2005, pp. 108–118.

[3] H. Hanan, D. Suwardhi, T. Nurhasanah, E. S. Bukit, *Batak Toba Cultural Heritage and Close-range Photogrammetry*, **Procedia – Social and Behavioral Sciences**, **184**, no. August 2014, 2015, pp. 187–195.

[4] A. S. Hernán-Pérez, M. G. Domínguez, C. R. González, A. P. Martín, *Using iphone camera in photomodeler for the 3D survey of a sculpture as practice for architecture's students*, **Procedia Computational Science**, **25**, 2013, pp. 345–347.

[5] W. Wahbeh, C. Nardinocchi, *Toward the Interactive 3D Modelling Applied to Ponte Rotto in Rome*, **Nexus Network Journal**, **17**(1), 2015, pp. 55–71.

[6] C. STAL, B. Lonneville, T. Nuttens, P. De Maeyer, A. De Wulf, *Highly Detailed 3D Modeling if Myan Cultural Heritage Using an UVA*, **FIG Congress**, no. June, 2014, pp. 1–14.

[7] C. Vladescu, *Tehnica de constructie a castrelor care constituiau apararea Masivului Cozia*, **Studii Valcene - Arheologie**, **VII**, 1985, pp. 33–41.

[8] C. Vladescu, *Centrele militare romane din sectorul de nord al Limesului Alutan*, **Buridava, Studii si Materiale**, no. 4, 1982, pp. 55–65.

[9] C. Vladescu, Gh. Poenaru Bordea, *Sapaturile de salvare de la Castrul Arutela din 1979*, **Materiale si Cercetari Arheologice**, Muzeul Tarii Crisurilor, Oradea, 1979, pp. 235–236.

[10] N. Matthews, *Aerial and Close-Range Photogrammetric Technology: Providing Resource Documentation, Interpretation, and Preservation*, Bureau of Land Management, National Operations Center, U.S. Department of the Interior, 2008, p. 42.

[11] J. Lluisi i Ginovart, J. M. Toldrà, A. Costa, S. Coll, *Close range photogrammetry and constructive characterization of masonry gothic vaults*, **Revista de la Construccion, 13**(1), 2014, pp. 47–55.

[12] H. Rüther, J. Smit, D. Kamamba, *A Comparison of Close-Range Photogrammetry to Terrestrial Laser Scanning for Heritage Documentation*, **South African Journal of Geomatics**, **1**(2), 2012, pp. 149–162.
[13] ***, Cultural Heritage Imaging Organization, San Francisco, CA [Online]. Available: http://culturalheritageimaging.org/Technologies/Photogrammetry/.
[14] M. Yakar, *Using close range photogrammetry to measure the position of inaccessible geological features*, **Experimental Techniques**, **35**(1), 2011, pp. 54–59.

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