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SILVES BRIDGE GEOMETRIC MODEL VIA STRUCTURE-FROM-MOTION: TOOL FOR HERITAGE DIGITAL CATALOGS

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ABSTRACT

The old bridge in Silves, Portugal, has five perfectly formed arches extending over the Arade river with about 76 meters long built of local materials. In the 14th century this structure was rebuilt on the location of a previous structure built when Silves was the Moorish capital between the 8th and 13th centuries occupation of the Algarve. Though a Roman road might have crossed this area, there is no medieval descriptions mentioning a bridge in Silves, still it is also known as the Roman bridge. After interventions in the 14th, 17th, 18th and 20th centuries, the bridge was classified as monument of public interest and became pedestrian-only and frequently evaluated for its risk of collapse.

Stereo-photogrammetry is a recognized surface reconstruction tool applied for almost one century, where from several overlapping images of the surface a 3D model can be obtained. Contrasting with classical stereo-photogrammetry, Structure-from-Motion (SfM) is a nearly automated compilation of digital imagery processing strategies that solve for camera position and surface geometry using matching features identified in several images from diverse perspectives and preferably with high degree of overlap. Together with ongoing increase in computer power, SfM allowed digital stereo-photogrammetry to be operative for close-range, high-resolution and non-metric overlapping digital images, and cost-effective. Applying these nearly automated strategies to digital images of the old bridge in Silves taken from the surrounding grounds, a dense point-cloud was computed providing its complete digital model allowing accurate measurements and materials visual identification, key elements for heritage digital catalogs and historical building information models.

KEYWORDS: Silves bridge; structure-from-motion; geometric point-cloud; digital model.

1. INTRODUCTION

In recent years, ongoing increase in computer power has allowed to work with massive data sets. That is the character of point-clouds capable to geometrically describe structures as bridges. Point-clouds are acquired either by terrestrial laser-scanning or digital stereo-photogrammetry and are the straightforward way to import geometrical information to be converted to object-based building information models of existing structures, as those of archeological or heritage interest.

The old bridge in Silves, over the Arade river, was rebuilt after a 1439 royal order, which implies that there was a previous structure in place. In the 17th century the bridge lost two arches that were restored and then again it was restored in the early 18th century, both without changes in its stylistic structure. Though, in the 20th century, the arch reaching the north bank was removed to make way for a roadside walkway. The bridge of archaeological importance and classified as public interest monument, is being frequently evaluated for its risk of collapse, where its complete geometric description is useful.

The old bridge in Silves is aligned nearly north-south with the river running from east to west. However, due to the riverbed's small height above sea-level of about 2 m and not too far from the shoreline of about 15 km, the water level of the Arade river is influenced by tides, allowing small boats to navigate upstream to Silves, an important feature to Silves during its period as the Moorish capital, between the 8th and 13th centuries occupation of the Algarve.



Figure 1: Location of Silves, southwest of Iberic Peninsula (source: Google-Earth).

Unlike laser-scanning, digital stereo-photogrammetry has some limitations, mainly the object scale and features contrast on the photographic images are crucial. Conversely, digital stereo-photogrammetry is in general more cost-effective than laser-scanning. Additionally, digital stereo-photogrammetry can be made with the aid of unmanned aerial vehicles (UAVs).

An additional advantage of digital stereo-photogrammetry is the photographic data which allow for the visual identification of materials and their degradation status linked to the time of acquisition. In fact, most laser-scanners can acquire photographic data as well, therefore both allowing for a final product by rendering the surface mesh based on the point-cloud with the corresponding visual texture.

Structure-from-Motion and Multi-view Stereo were applied to digital images of the old bridge taken from the surrounding grounds, to compute for a dense point-cloud providing its complete geometric description, allowing accurate measurements and its materials visual identification.

2. FIELD DATA

Photographic data in the form of digital imagery of the old bridge was acquired with 3 objectives and corresponding characteristics: its faces; its arches; and its crossing road. The main characteristic is the high overlap of the digital images taken from different locations, covering the complete bridge structure.

The bridge faces were covered with the lens optical axis perpendicular to the faces also maintaining the distance to it (figure 2). The camera was distanced to the floor about 1.5 meters.



Figure 2: Digital images with the lens optical axis perpendicular to the bridge faces.

The arches were covered with left to right, frontal and right to left directed lens optical axis relative to the arch and slightly upwards towards the arch inner face (figure 3). Images were acquired from both sides of the arch. The camera was distanced to the floor about 0.5 meters.



Figure 3: Digital images with the lens optical axis slightly upwards towards the arch inner face.

Finally, the crossing road was covered with the lens optical axis in about 45 degrees with the road and from the left side slightly to the right and vice-versa (figure 4), in 4 lines combining the roadside, left or right, with walking north towards or south away from Silves town. The camera was distanced to the floor about 2.0 meters. Particularly the crossing road could have been covered with the help of an UAV.



Figure 4: Digital images with the lens optical axis in about 45 degrees with the crossing road.

Approximately 240 photographic images with 12 mega-pixels resolution were acquired to cover the old bridge in Silves.

3. METHODS AND RESULTS

Structure-from-Motion (SfM) is a nearly automated compilation of digital imagery processing strategies that solve for camera position and surface geometry at once using matching features identified in several images from diverse perspectives and preferably with high degree of overlap [1]. The complete SfM solution, that can include lens calibration coefficients, arises from the highly redundant data of a large number of automatically detected matching features proportional to the image resolution and the surface texture, and the well-known geometry of the photography's central projection [2]. Massive geometric data of a dense point cloud for complete surface reconstruction can then be assimilated by Multi-view Stereo (MvS) processing that decomposes the overlapping images into handy subsets to independently detect and compute additional matching features [3]. The Agisoft Photoscan was applied to process the digital imagery of the old bridge in Silves.

The SfM-MvS strategies involve the identification of features in individual images, the measurement of its coordinates in the camera reference system and the estimation of camera and features positions in a non-scaled and arbitrary coordinate system. Only with ground control points or known positions of the camera centers in an appropriate earth reference system the three-dimensional surface reconstruction is attained, generating a dense point cloud. Therefore, the complete imagery processing can be made with manual interaction almost limited to the ground control points' identification (figure 5). Consequently, the required ground control points positions were measured with a Global Navigation Satellite Systems (GNSS) receiver and a Topographic Total Station (TTS). A total of 9 ground control points was used.

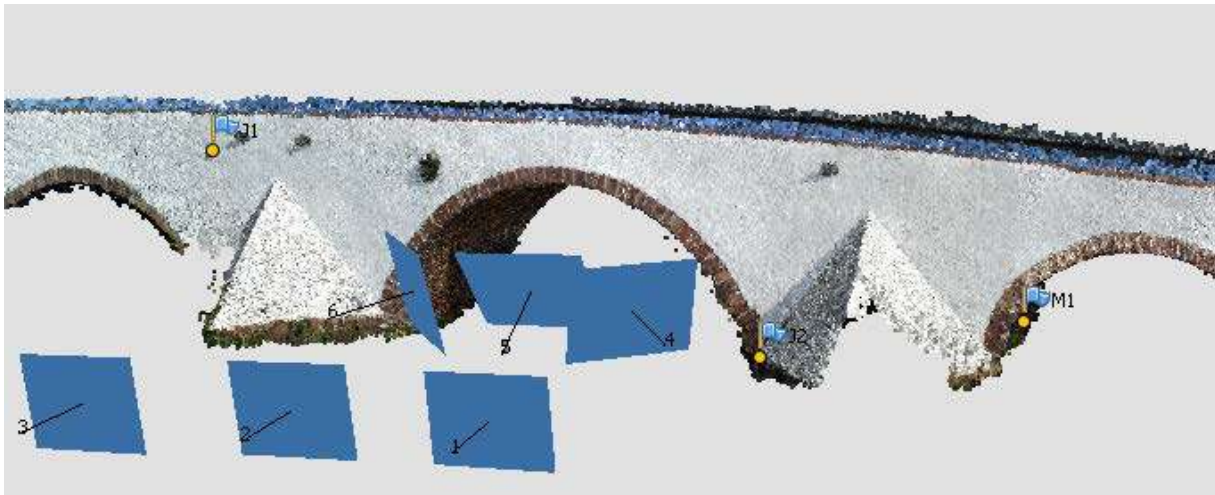


Figure 5: 3 ground control points positioned over the processed point-cloud and computed position and orientation of 6 digital images for faces (1, 2 and 3) and arches (4, 5 and 6).

The point-clouds processed in 3 independent sets, the crossing road, the 3 southmost arches in dryland and the 2 northmost arches over the riverbed, were then joined together with Autocad RECAP since all point-clouds were processed in the same coordinate reference system provided by the GNSS (figure 6).

From RECAP the point-cloud may then be exported to any BIM, as Autocad REVIT, to be object based modeled and eventually passed out to a structural resistance software to be tested by simulation. There is, however, the difficulty of having proper objects in today's BIM libraries [5,6], requiring that these needed objects must also be created both in geometry and materials.

Both, Autodesk RECAP and REVIT allow precise measurement of the structure through its point-cloud model, which correct dimension is related to the ground control points precision, that in this work was estimated under 5 cm with a 99% confidence level. Some small areas of the bridge were not covered for the reason that they were obstructed by vegetation, without compromising the geometry measurement.

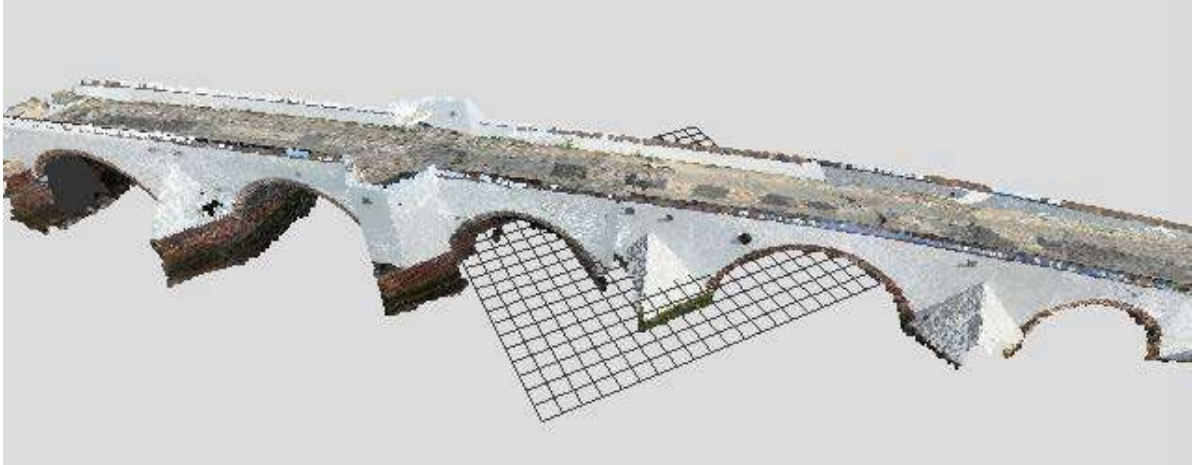


Figure 6: Complete point-cloud of the old bridge in Silves.

4. CONCLUSIONS

The opportunity to apply cost-effective technologies to digitalize entire structures and their dimensions through massive geometric information in the form of point-clouds, and then converted to object based models are the straightforward way to Heritage Building Information Models (HBIM). In this work case, a common Samsung WB600 digital camera and a total of 4 hours of field work, including ground control points data acquisition, were required.

However, objects in Heritage structures are more complex and their geometry and characteristics are the main limitation found in Building Information Modelling objects libraries [5,6]. The conversion to an object-based model was not completed, requiring the generation of compatible objects. Nonetheless, the complete geometry of the old bridge in Silves is now known and digitalized for future reference.

Because photographic images were made, also the materials identification and degradation status (figure 7) was registered, adding information and being the basis of the 4 dimensions model of the old bridge in Silves, assessing the bridge materials evolution.



Figure 7: Arch zoom-in for materials identification and degradation status.

The complete point-cloud of the old bridge in Silves was attained applying Structure-from-Motion and Multi-view Stereo to photographic images taken by a conventional digital camera, without the support of an Unmanned Aerial Vehicle or a Terrestrial Laser-Scanner. The geometric and material information is, furthermore, available to support any additional assessment of the bridge risk of collapse.

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6. BIBLIOGRAPHY

- [1] Westoby MJ, Brasington J, Glasser NF, Hambrey MJ, Reynolds JM. Structure-from-Motion photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology*. 2012; 179:300-314. <http://dx.doi.org/10.1016/j.geomorph.2012.08.021>.
- [2] Snavely N, Seitz SM, Szeliski R. Modeling the World from Internet Photo Collections. *International Journal of Computer Vision*. 2008; 80(2):189-210. <http://dx.doi.org/10.1007/s11263-007-0107-3>.
- [3] Furukawa Y, Ponce J. Accurate, Dense, and Robust Multi-View Stereopsis. In: 2007 IEEE Conference on Computer Vision and Pattern Recognition. 2007; 1-8. <http://dx.doi.org/10.1109/CVPR.2007.383246>.
- [4] Prizeman, OEC. HBIM and matching techniques: considerations for late nineteenth- and early twentieth-century buildings. *Journal of Architectural Conservation*. 2015; 21:3:145-159. <http://dx.doi.org/10.1080/13556207.2016.1139852>.
- [5] Rodríguez-Moreno C, Reinoso-Gordo JF, Rivas-López E, Gómez-Blanco A, Ariza-López FJ, Ariza-López I. From point cloud to BIM: an integrated workflow for documentation, research and modelling of architectural heritage. *Survey Review*. 2018; 50:360:212-231. <http://dx.doi.org/10.1080/00396265.2016.1259719>.