Use of photogrammetric techniques for virtual modeling of historical heritage. Application: Santa Bárbara Bridge (Almería, Spain).

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ABSTRACT

Photogrammetry using images from unmanned aerial vehicles (UAV) has revolutionized the conservation and dissemination of heritage, being increasingly used to document and preserve buildings of historical and cultural value, allowing a moment in time to be preserved for posterity. The aim of this study is the virtual reconstruction of the Santa Bárbara Bridge (Huércal Overa, Almería). For this purpose, two techniques was combined: on the one hand, photogrammetric techniques to carry out a survey of the current state, and on the other hand, architectural modeling software to reproduce the original state of the bridge. Complementarily, it has been essential to collect historical information that allows us to adjust to the reality built in its day.

1. INTRODUCTION

The use of photogrammetry for 3D reconstruction of cultural heritage elements has become an everyday tool in the world of archaeology and heritage conservation. The rapid and accurate acquisition of 3D models by photogrammetry with images from unmanned aerial vehicles (UAV) promotes heritage protection, constituting an effective tool for archaeological and architectural interest of data's collection.

In archaeology and architectural history, four different uses of 3D technologies have been identified: producing digital reconstructions, virtually analyzing reality-based data, calculating advanced spatial analyses, and disseminating research results (de Kleijn et al.2016). Through these technologies and the implemented methodology, any singular work of local history can be preserved for future generations, with reduced cost, in a timely manner and without causing additional damage to the current state of the work (Perez et al.2011). The main objective of the study is the virtual reconstruction of the Santa Barbara Bridge combining two techniques, on the one hand, the 3D modeling of the current state through UAV photogrammetry, and on the other hand, software

for architectural modeling to reproduce the original state of the bridge. For this, it has been essential to collect historical information that allows us to adjust to the reality built in its day.

2. METHOD

2.1. Description of the building

The bridge of Santa Bárbara was built after the General Road Plan of 1864 in which it was presented the need to build 526 kms in the province of Almeria belonging to the General Road Network of the State.

The Santa Bárbara Bridge built on a flat spur on the Almanzora River, and cut by the route of the old road CN-340, controls the boxing of the Almanzora River to penetrate the first foothills of the Sierra de Almagro, (Quintero et al. 2018).

The iron bridge of Santa Barbara (Fig 1), was destroyed around October 1973 by a huge flood that Almeria suffered from it, But its iron construction and its almost indestructibility are evident in photos that attest of its imposing design.

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Figure 1. Santa Barbara Bridge before and after its destruction

2.2. Photogrammetric Survey

For the photogrammetric survey, a DJI Phantom 3 Professional drone was used with a camera model FC300X (3.61 mm), with a resolution of 4000 x 3000. The flight was carried out at a height of 33.1 m above ground level, taking a total of 841 photographs used to carry out the photogrammetric process between zenithal of the whole set and oblique photographs of detail in the areas of the abutments.

To obtain the support points for the topographic survey, a Trimble GPS with R6 receivers was used with the base located at the coordinates (591470.096, 4133789.004, 174.259) in the ETRS89 UTM30N system. A total of 25 support points were measured; however, only 15 points were used to adjust the photogrammetric project, keeping the rest for quality control. The photogrammetric process was carried out using Agisoft Metashape software version 1.6.1.10009, formerly called Agisoft Photoscan. This software performs photogrammetric processing of digital images and generates 3D spatial data for use in GIS applications, cultural heritage documentation and visual effects production, as well as for indirect measurement of objects of various scales. In the process of aligning images, the software is able to calibrate the camera, and this process allows to detect the points and obtain the orientation and position of the cameras (Fig 2). Thus a dense point cloud is obtained, a model or mesh is generated and then texture is applied (Marteau et al.2016). Finally, an orthophoto is generated where we can see the ground control points (GCPs) we have worked with. This orthophoto serves as a basis for measurements.
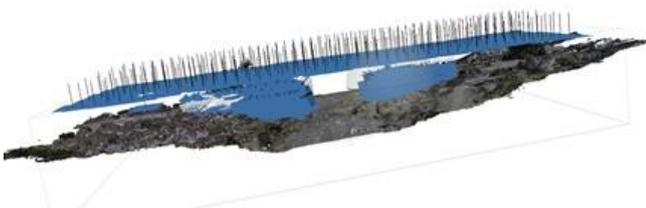
Figure 2. Image Processing in Agisoft Metashape

2.2.1. 3D modeling of the original state

The geometric complexity of the architectural features has been modeled manually from multiple sections of the dense point cloud through the 2D design and 3D modeling software "Autocad". CAD systems allow, through photogrammetric and topographic support, to establish the real position in space of the building, and to build the virtual model according to the inserted results (Cámara and Latorre 2003), Autocad allows to perform three-dimensional reconstructions of

the buildings by generating polygons from a dense point cloud and rectify them to create the respective textures (Bacigalupo and Cessari 2003). The objective, in our case, is to extract the 2D geometry of the bridge from the 3D point cloud model data. The passage from Agisoft Metasahpe software to AutoCAD requires exporting the photogrammetric model in (*.rcs) format using the Recap software. From the upper section plane at different levels, the front and rear section planes, the geometry of the bridge is obtained (Fig. 3). The front section plane allows the height of the architectural elements to be obtained. Like the complete bridge, the extracted 2D drawings will be exported in (*.dwg) format to the Sketchup software, which is a face-based 3D modeling and graphic design program. The software allows importing the ground location through Google Earth, so the implementation of the model and terrain is according to the coordinates in reality (Meini et al. 2018).

Figure 3. Back section with AutoCAD

In the absence of the original plans, photographs have been the main source for an objective modeling of the bridge. The modeling of the abutments is based on the import of the 2D plan, as well as the vertical section. As for the modeling of the bridge, bowstring type, it has a deck that is distributed in 13 equal spans, each span has a main support that has the same interior width as the arch, with two suspenders and a gusset connection point. It has been necessary to pre-dimension the arch due to lack of documentation. The ideal deflection (f) will be that which results in the smallest volume to the volume of the material according to Rebello (Fernandes et al. 2018).

F=Height, L=Arch span, H=Arch thickness, B=Arch width, 53.10/10= 5.310m ≤ F ≥ 53.10/5= 10.62m.

1.062/10= 0.1062m ≤ B ≥ 1.062/5= 0.212m

H = 0.02x53.10 = 1.062m

The 3D model was georeferenced and placed on the digital map imported from Google Earth, once the model was finished (Fig 4). The next phase was managed in the Lumion environment. Lumion is a powerful architectural visualization tool, allowing to build a 3D environment and add textures and materials, to get a real view of the model. Both software Sketchup and Lumion are compatible, therefore, the 3D model can be opened in Lumion in (*.skp) format (Meini et al. 2018).

Figure 4. Bridge modeling in Sketchup

3. RESULTS

The accuracy of the photogrammetric model is calculated from all the points not used for model fitting (CheckPoints) (Table 1). The holes appeared in the point cloud, have been solved with the help of MeshLab3, choosing the best closure algorithm for each of the holes, taking into account the dimensions and the position with respect to the model (Pierdicca 2018). The model obtained from Agisoft Metashape both in mesh level and texture has the level of accuracy sought, having a multitude of photographs in the most hidden areas, and the ability to move the UAV tool throughout the environment of the bridge.

Table 1. Accuracy obtained in each CheckPoint.

Label	XY error (m)	Z error (m)	Error (m)	Error (pix)
P10	0.0943959	-0.0056393	0.094564	0.252
P11	0.0477962	-0.130596	0.139068	0.464
P12	0.100177	-0.187536	0.212615	0.543
P13	0.0757485	-0.0689666	0.102441	0.667
P15	0.103087	0.217072	0.240306	0.486
P2	0.394938	-0.0392625	0.396885	0.528
P22	0.0505994	0.365492	0.368978	8.082
P23	0.0414179	0.0183191	0.045288	2.042
P24	0.026645	0.223695	0.225276	1.183
P3	0.18833	0.00776761	0.18849	2.777
P4	0.070044	-0.222663	0.23342	0.583
P5	0.122694	-0.100879	0.158841	0.031
P6	0.13204	-0.192194	0.23318	8.994
P7	0.0949744	-0.205719	0.226584	0.466
P8	0.210996	0.390464	0.443826	0.439

The position of the control points influences the accuracy of the model, so it is important to distribute the points throughout the study area (Caroti et al. 2015). The dense point cloud obtained by UAV photogrammetry using Agisoft Metashape, had a total of 44,966,257 points. The mesh obtained had a total of 5,165,417 faces and 2,589,219 vertices (Fig 5).

Figure 5. Dense point cloud Agisoft Metashape

The final model is georeferenced according to the real coordinates in sketchup, the same can be obtained directly from Autocad, in fact in this software, it is possible to draw complete 3D models of buildings, from photogrammetric models, detect several points where intervention is necessary, as well as the whole in a single coordinate system, located in its real position. Both software, Autocad and Sketchup, allow this in different ways but with the same objective (Cámara and Latorre 2003). The 3D model, and the sections obtained, can be considered as a basis for further detailing the project, because in the end, the most important thing is to have detailed technical information, not only based on the aesthetics of the model, but also on the geometry of its materials, its structure... (López et al. 2013).

The bridge has an arch span of about 53.10 m, and a maximum height of 9.55 m from the bottom of the arch to the deck. Both arches are braced together by 6 steel beams with an external section similar to the section of the arch in the last two, and increasing the section, in the center of the bridge. The deck has a width of 9.75m, it's composed of 6 longitudinal beams and 12 transverse beams of HEB type (800 x 300), the transverse beams are distributed at 4.085m each, where are also located the pendants (vertical suspenders), 24 in total, also carrying diagonal bracing. From these main supports, the diagonal suspenders, two for each, 44 in total, with St. Andrew's cross bracing. A rope-like profile connects the vertical and diagonal suspenders, this is the bowstring system. Figure 6 shows the final model of the Santa Barbara Bridge with Lumion, with the objective of achieving a photorealistic finish, which allows the construction of an information system of the engineering work, to which all documentation and georeferenced elaborations are incorporated.
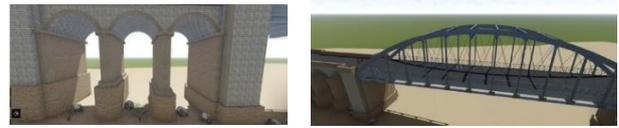
Figure 6. Renders obtained with Lumion software

4. DISCUSSION

The findings of the study show that UAV-assisted photogrammetric technique can be a complementary method to achieve a 3D model. The most important advantages of UAV-based photogrammetry are cost-effectiveness and flexibility, which allows obtaining 3D models with photorealistic textures with metric, topographic, texture, material properties and characteristics of the model, which invites to improve the capabilities of this technique for a better result, (Arias et al. 2005).

The objective of our study was to extract the maximum information with the help of the UAV technique to obtain a virtual reality of the bridge, and to obtain a rigorous documentation of the real estate, given that the structure of the bridge no longer exists, creating a model of the Santa Barbara bridge through photographs is probably the only way to return the building to its previous state, and therefore, this virtual model acquires a new perspective, to preserve the heritage, as well as the use of the UAV tool, the use of laser scanner, has proved to be a very useful tool that presents almost the same accuracy in areas that are located orthogonally to the shooting axis, on the contrary in areas with a vertical axis, the result is of lower quality with the UAV tool, but the latter presents superior results in areas of reduced accessibility (Martínez-Espejo et al. 2017).

In this study, several fields have been exploited in order to model the Santa Barbara Bridge in its original state, for this purpose photogrammetric data from the photogrammetric survey, topographic data from Google Earth, architectural data with the combination of the sections in Autocad and technical documentation projected in Sketchup were integrated. The old photographs have been the only source for the reproduction of the bridge, all this to obtain a three-dimensional reconstruction in order to obtain a model with optimal visualization quality.

5. CONCLUSION

Too many cultural heritage buildings around the world are in danger of being destroyed by natural processes or deliberate acts. UAVs and 3D technologies have provided ways to document history, preserving in the present time, what has been destroyed. With the destruction of the bridge, its original state has been permanently lost and preserving history is about remembering and learning from the past, bringing what is gone to birth again in the present. This project does just that, preserving the past, and giving life to the bridge, in addition with this methodology it is possible to detect pathologies in the constructive elements, as well as demonstrating that with this methodology, it is possible to obtain a restructured project that has been very convenient, that can be obtained in a reduced time and presents a photorealistic finish, as well as a technical documentation for conservation and archiving purposes.

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REFERENCES

Arias J, Herraez H, Lorenzo & C. Ordoñez (2005). Control of structural problems in cultural heritage monuments using close-range photogrammetry and computer methods. Computers and Structures, 83, 1754-1766.

A Bacigalupo C & Cessari L (2003). Survey techniques and virtual reality for the recovery plan. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 40-42.

Cámara L, Latorre P, (2003). El Modelo Analítico Tridimensional obtenido por fotogrametría. Descomposición, manipulación y aplicaciones en el campo de la restauración arquitectónica. Arqueología de la arquitectura, 2, 87-96

Caroti G I, Martínez-Espejo Zaragoza I, & Piemonte A (2015). Accuracy assessment in structure from motion 3d reconstruction from uav-born images: the influence of the data processing methods. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(1), 103.

De Kleijn M, de Hond R & Martinez-Rubi (2016). A 3D spatial data infrastructure for Mapping the Via Appia. Digital Applications in Archaeology and Cultural Heritage. 3, 23-32.

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.

Fernandes B P, Novello S M & Zacarias Pravia C M (2018). Um ábaco para pré-dimensionamento de seções de coberturas em arco treliçadas de perfis formados a frio. Revista de Estrutura do Aço 7(2).

Lancaster J (2018). Pre-and post-arson three-dimensional reconstructions of the Lichtenwalter schoolhouse, Green, Ohio. Digital applications in archaeology and cultural heritage, 8, 1-9.

López JAB, Barrera JA & Civanto JMM (2013) Documentación gráfica del patrimonio: Un paso adelante. XI Congreso internacional de expresión gráfica aplicada a la edificación, 590-594.

Marteau B, Vericat V, Gibbins C, & Batalla JR (2016). Application of Structure-from-Motion photogrammetry to river restoration: Application of SfM Photogrammetry to River Restoration. Earth Surface Processes and Landforms 42(3).

Martínez-Espejo Zaragoza I, Caroti G, Piemonte A, Riedel B, Tengen D & Wolfgang Niemeie W (2017). Structure from motion (SfM) processing of UAV images and combination with terrestrial laser scanning, applied for a 3D-documentation in a hazardous situation. Geomatics, Natural Hazards and Risk, 8(2), 1492-1504.

Meini M, Felice G Di & Petrella M (2018). Geotourism Perspectives for Transhumance Routes. Analysis, Requalification and Virtual Tools for the Geoconservation Management of the Drove Roads in Southern Italy, Goesciences, 8(19), 1–32.

Pérez JL, Mozas A, Cardenal Escarcena FJ, & López Arenas A (2011). Fotogrametría de bajo coste para la modelización de edificios históricos. Virtual Archaeology Review 2(3), 121.

Pierdicca R (2018). Mapping Chimu's settlements for conservation purposes using UAV and close range photogrammetry. The virtual reconstruction of Palacio Tschudi, Chan Chan, Peru, 8, 27-34.

Ramazan Cuneyt Erenoglua & Ozgun Akcay (2017). An UAS-assisted multi-sensor approach for 3D modeling and reconstruction of cultural heritage site. Journal of Cultural Heritage, 26, 79-90.

Quintero G, Mederos Martin A, Díaz C A & Bashore Acero C (2018). El poblado fortificado metalúrgico del Calcolítico Medio y final de Puente de Santa Bárbara (Huércal-Overa, Almería). Zephyrus, 81-71.