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3D modelling in archaeology: The application of Structure from Motion methods to the study of the megalithic necropolis of Panoria (Granada, Spain)

J.A. Benavides López [a], G. Aranda Jiménez [b,*], M. Sánchez Romero [b], E. Alarcón García [b], S. Fernández Martín [b], A. Lozano Medina [b], J.A. Esquivel Guerrero [b]

[a] Department of Architectural Graphic Expression and Engineering, University of Granada, Campus Fuente Nueva s/n, 18071 Granada, Spain
[b] Department of Prehistory and Archaeology, University of Granada, Campus Cartuja s/n, 18071 Granada, Spain

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A B S T R A C T

Archaeology is benefiting from fresh technological developments that are introducing new recording systems based mainly on 3D modelling. Innovative digital recordings are improving key aspects of archaeological practice, including accuracy and efficiency. This is the case of a novel procedure that uses Unmanned Aerial Vehicles (UAVs) for data acquisition and software such as Structure from Motion (SfM) to produce volumetric models from photographs.

These photorealistic 3D models can be processed further using Building Information Modelling (BIM) to create plans, sections, digital elevation models, orthophotographs and other types of images useful for analysis and publication. The study of the architectural features of the megalithic necropolis of Panoría (Granada, Spain) has benefited from these innovative technologies.

1. Introduction

New recording technologies are bringing about dramatic changes in archaeological documentation protocols, providing increasingly accurate representational systems and higher quality data (Roosevelt et al., 2015). We are witnessing a true revolution in field archaeology, an area that has traditionally been characterised by unreflective procedures applied uncritically, as if they were a set of defined recipes (Carver, 2009, 2012; Lucas, 2012). If digging is aimed to produce historical knowledge through texts and images, innovation in this area should be considered of paramount importance in archaeology.

Ideally archaeologists should record archaeological features in such way that other researchers will be able to reproduce the site as it appeared when it was excavated (Howland et al., 2014). Innovating in recording techniques to produce higher quality data is a constant obligation for archaeologists, especially if we take into account that excavating is a destructive activity in which the material remains are removed from their context. Digging could be considered a unique experience with no going back. Excavation is far from a lab experiment that can be repeated whenever you want (Hodder, 1999) and omissions in recording cannot be rectified later. Archaeologists have the responsibility to engage with recording improvements and to bring forward all the theoretical and practical means available.

Archaeology is benefiting from fresh technological developments that are implementing new recording systems based mainly on 3D modelling. In recent years as new software and recording devices have become low-cost and user-friendly, their use has increased rapidly in archaeology. Although 3D technologies are not entirely new to archaeology (Barcelo et al., 2003), the use of image-based modelling, also known as digital photogrammetry and Structure from Motion, has only begun in recent years (Howland et al., 2014; Prins et al., 2014; Quartermaine et al., 2013; Roosevelt et al., 2015).

These innovative recording methods are bringing about improvements –mainly in accuracy and efficiency– to different aspects of archaeological practice. The fact that less time is needed for recording archaeological evidence is a key issue, because it reduces economic costs. In fact, time is a valuable commodity in archaeology, as there is normally a very limited period in which to carry out the fieldworks.[1] Nevertheless, accuracy and high quality representation are probably

* Corresponding author.
E-mail addresses: Jbenavidd@gmail.com (J.A.B. López), garanda@ugr.es (G.A. Jiménez), marsanch@ugr.es (M.S. Romero), eva@ugr.es (E.A. García), info@arquenatura.com (S.F. Martín), aguedalozanomed@gmail.com (A.L. Medina), esquivel@ugr.es (J.A.E. Guerrero).

[1] This is especially dramatic in Commercial Archaeology (Aranda Jiménez, 2011; Aranda Jiménez et al., 2015).

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the most significant innovations. Traditional protocols based on hand-drawn plans and sections no longer come up to the standards of precision achieved by the new methods in recording the real world more accurately. Representations and analytical descriptions thus gain in reliability (Austin, 2014). Furthermore, real-time recording on digital media facilitates collaboration among different archaeologists through cloud-shared documentation (Levy et al., 2012).

This paper is aimed to explore the advantages of innovative techniques based on 3D modelling, such as Structure for Motion (SfM) and Building Information Modelling (BIM), in terms of their efficiency, accuracy and quality of representation. For this purpose, the excavation undertaken in 2015 at the megalithic necropolis of Panoría (Spain) offered an excellent case study for the adoption of these new developments. During four months of intensive fieldwork, we excavated four dolmens and one small megalithic cist. In what follows, we will first set out the foundations of the 3D recording techniques and the methodological steps carried out in the data collection and processing; then the results of the spatial entities documented (architecture, features, etc.) will be analysed; and finally the advantages and disadvantages of the new methodological procedure will be discussed.

2. Structure for Motion and Building Information Modelling

Among the 3D recording methods, Structure from Motion (SfM), a technique that produces volumetric models from photographs (Green et al., 2014; Howland et al., 2014; Ortiz Sanz et al., 2010; Olson et al., 2013; Prins et al., 2014), has been shown to be especially efficient and precise in comparison with the more traditional laser scanning techniques. SfM is the computer view corresponding to the human ability to understand 3D structures (Green et al., 2014). Using a collection of photographs, SfM creates a 3D point cloud that represents the surfaces of the archaeological features depicted. It works by finding and matching common points located throughout a series of overlapping photos. To create the point clouds, commercial software such as Agisoft's Photoscan is one of the most popular (De Reu et al., 2014; Howland et al., 2014; Verhoeven, 2011; Verhoeven et al., 2012a, 2012b), although open source programs like Bundler and Patch-Based Multi-View Stereo (PMVS) are also beginning to be used (Green et al., 2014).

All these programs are based on algorithms for automatic location of points shared between images to create a sparse point cloud. The most widely used algorithm for this process is the Scale-Invariant Feature Transform (SIFT) (Lowe, 1999) operating on radiometric pixel values. Once these points are identified, software such as Photoscan is able to pinpoint the relative position of all photographs by inverse triangulation. The next step consists of building a dense point cloud using DMVS (Dense Multi View Stereo) algorithms (Scharstein and Szeliski, 2002). The matched pixels and their estimated 3D positions become a cloud of millions of points that allow a mesh model to be built. Finally, to give a photorealistic texture to the model, images are used to project pixels onto the 3D representation. Rather than standing in a static position for capturing 3D data, SfM algorithms use a variation in camera position for each image to find the distance between them and, at the same time, triangulate the 3D positions of pixels matched in overlapping photographs (Smith et al., 2014).

The resulting SfM-based point cloud can then be processed further to create 3D models, digital elevation maps and scaled plans and sections. Building Information Modelling (BIM) is a very appropriate tool for managing point clouds and obtaining 3D plans, sections, digital elevation models, orthophotographs etc. BIM is a process involving the creation and management of digital representations of the physical and functional characteristics of objects. Currently BIM software is ushering in a new generation in the design and modelling of the real world for planning, designing and building new infrastructures. The elements represented are not simple wire-frame geometries, but more complex graphic entities that contain inherent information about the object itself (geometry, composition, hierarchical relationships with other objects, etc.). BIM technology also defines objects parametrically, i.e. objects are considered as parameters in relation to other elements, so that if a linked object is modified, those dependent on it will also change automatically. BIM therefore covers more than just geometry (Eastman et al., 2011).

Although BIM software is a successful tool for planning and designing new constructions, even extending their efficacy throughout the building life cycle, they can also be very useful for archaeological studies and heritage management. The full potential of BIM is currently being explored in different archaeological projects. For instance, the advantages of integrating archaeological data into Building Information Models is being analysed by the Museum of London Archaeology (MOLA) in large infrastructure developments.[2] For heritage purposes, some experimental BIM applications have also been developed for Roman archaeological remains (Scianna et al., 2014). Although Building Information Modelling has great potential for designing and managing the archaeological environment more efficiently, we will focus on how this software can be used to process the SfM-based point cloud to generate graphic documents.

BIM working with data captured by laser scanning and photogrammetry needs to be manually remodelled due to the complexity of the forms to be reproduced. Different automated systems are developed to transform point clouds into mathematical surfaces, such as modelling by polygons and Non-Uniform Rational B-Splines (NURBS) (Remondino and Rizzi, 2010; Echter and Bischoff, 2010; Castro García et al., 2011). In our case study, the geometric and morphological complexity of the architectural features has been modelled manually based on multiple sections from the dense point cloud.

3. Data collection and processing

The use of SfM recording methods in archaeology offers different analytical possibilities. Through a case study, this paper focuses on 3D modelling, digital elevation models, plans and sections using BIM software. The data collection and processing has followed the succeeding steps:

3.1. Fieldwork

Initially the site was included in a global reference system (UTM-ETRS89) using real-time DGPS equipment. Fixed reference equipment sends the coordinates of the points to a mobile receiver with an accuracy of between 1 and 2 cm, depending on the number and geometry of the satellites. These coordinates were based on the National Geodetic Network. The equipment used was a Leica DGPS Smart Rover 1200, enabling the reception of signals from the NAVSTAR-GPS and the GLONASS constellation.

In a second stage, a number control points with known coordinates were located on the ground in order to georeference the model. Although SfM-based modelling can produce a 3D model almost automatically based on the analysis of images, it is necessary to provide parameters that are critical for ensuring precision. Using control points, the 3D models were provided with a scale and orientation according to the site's system of coordinates. Furthermore, they were used to remove the inherent biases of camera lenses, thus improving accuracy. Although artificial intelligence algorithms can identify and correlate tens of thousands of similar points in different images, photographic distortion needs to be rectified to create a uniform scale that correctly represents the actual situation.

Control points were made using adhesive markers placed in the ground and visible in the sequence of images captured by the Unmanned Aerial Vehicle (UAV). Control point coordinates were taken using a Leica TCR 805 total station with infrared measurement over a mini-prism. Ten points were measured, including 7 adhesive

[2] http://www.mola.org.uk/blog/bim-and-archaeology-unlikely-match-made-heaven (Accessed 11/01/2016).