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Original article

Towards the definition of best 3D practices in archaeology: Assessing 3D documentation techniques for intra-site data recording

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ABSTRACT

Archaeology is becoming increasingly 'digital'. In the last 10 years, the use of 3D technologies for the documentation of tangible cultural heritage has changed the way to approach archaeological intra-site survey. These technologies allow for the reproduction of 3D replicas of sites and monuments and have proven to be a powerful tool for the documentation and preservation of the archaeological record. However, the full integration of 3D technologies in archaeological field methods requires the definition of best documentation practices and methods of accurate assessment of the acquired data. In fact, although the use of 3D laser scanners, computer vision and photogrammetric methods is now well established, there are no convincing quantitative comparisons between laser scanning and image-based modelling techniques for the acquisition of archaeological stratigraphy in extreme environmental and lighting conditions. In this sense the 3D documentation of the archaeological site of Las Cuevas, Belize, represented an important opportunity to test and compare phase shift variation laser scanning and image-based modelling techniques in an environment characterized by very high humidity and variability in lighting. This study compared both the accuracy and density reliability of 3D models showing how the different 3D documentation techniques can be integrated for the recording of the excavation process. The research presented in this paper provides an accurate data assessment representing a concrete starting point for the definition of a sharable and overall methodology that will help to define best 3D practices for the documentation of archaeological sites.

1. Research aims

This study aims to compare image-based modelling and phase shift variation laser scanner technologies for the 3D documentation of archaeological stratigraphy in extreme environmental conditions. Specifically, the Las Cuevas site (Belize) has been selected to challenge these two technologies in order to understand their performance in environments characterized by extreme humidity, difficulty of access and challenging light conditions.

Three areas of the site, characterized by different light conditions and architectural contexts, were acquired using the two techniques, and three different comparisons were made on each area. The first comparison was of data acquisition and processing time to understand the performance of the two techniques in this kind of environment. The second comparison assessed the geometric accuracy of the meshes generated by the two techniques. The final evaluation compared high-resolution laser scanner geometries and meshes from image-based modelling processed at different resolutions. These comparisons aimed to understand if and how 3D survey technologies can be integrated into day-to-day archaeological excavation practices without affecting time and logistics. This on-site, comparative analysis is fundamental to the goal of having a comprehensive understanding of the technical abilities and research-related potential of phase shift variation laser scanning and image-based modelling techniques, as well as the ability to verify their use and integrate these technologies effectively in the 3D documentation process.

2. Introduction

The use of 3D documentation technologies has greatly accelerated over the past decade and has become more common in archaeological practice. Scholars and practitioners in the discipline have started to introduce these new tools for the documentation of archaeological sites (see e.g. [1–6]), but the effective integration of 3D technologies within day-to-day fieldwork practice requires greater understanding of the real potential of the different technologies. This is only measurable through the definition of best 3D documentation practices and accurate data assessment of the acquired 3D models. To respond to this need, the research presented here compared two of the most commonly used techniques

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in archaeology today: phase shift variation laser scanning (PST), Faro Focus 3D, and image-based modelling (IBM), Photoscan [7]. Recent advances in processing power have led to the development of new tools that allow 3D information to be obtained from unorganized image sets (IBM; see [8–10]). Software based on IBM is well established in archaeology and is currently used largely for the 3D documentation of archaeological stratigraphy [2,3,11,12], artifacts [13,14] and architecture [10,15]. Whether the cheaper and more portable IBM gives similar results, in terms of measurement precision and accuracy, to the more expensive laser scanner technologies is still a matter of debate in archaeology and heritage studies today [2,3,11,12,16].

The potential to record a monument or site in 3D simply by taking pictures would mark a revolutionary change in the discipline: the unprecedented dissemination of 3D representations of tangible heritage. While some scholars have made comparisons between different techniques for the 3D documentation of artifacts [13,14] and buildings [15,17,18], there has been a lack of research dealing with accurate quantitative comparisons between laser scanning technology and IBM for the 3D documentation of archaeological stratigraphy, especially in extreme environmental conditions characterized by high humidity and significant variability in lighting. According to Dellepiane et al. [2: 203], 'although someone claims that dense stereo reconstruction is a mature alternative to 3D scanning, no convincing comparison has been presented until now. Recently, some initial effort has been made in this direction, but an overall methodological definition and accurate data assessment are still missing.' This study compared both the accuracy and density reliability of 3D models coming from the two techniques, PST and IBM, at the Las Cuevas site. This site is a perfect case in which to test different 3D documentation techniques, since it presents difficulty of access, a wide range of environmental conditions, and variability in lighting (i.e. dark recesses of caves, areas in shaded sunlight under the jungle canopy, and areas of more direct sunlight in locations that have been cleared of brush or exposed by treefall). These characteristics provided an opportunity to investigate the potential of the two techniques under different lighting conditions.

The 2012 data acquisition campaign at Las Cuevas was a follow-up study to the 2011 data collection conducted at the same site [16]. During the 2011 fieldwork campaign, IBM was compared with triangulation laser scanning (TLS). This comparison showed that, despite the proven ability of TLS to acquire sub-centimetric information, this technique has some limitations in 3D documentation of archaeological stratigraphy in this kind of environment (e.g. extreme difficulty working in direct light conditions; limited optical 3D measurement range; the high level of humidity in the cave environment negatively affecting laser scanner performance). Thus, in the 2012 fieldwork campaign, the survey was conducted using IBM and PST, in order to understand if one of these technologies works better in the different environmental and lighting conditions of the Las Cuevas site.

Archaeologists and heritage specialists are debating the real potential of different documentation techniques, and one of the most important aspects in this discussion relates to the accuracy of the acquired data. What kind of accuracy is really needed for documenting the archaeological stratigraphic record? Is the centimetric accuracy that it is obtainable from IBM sufficient to the needs of archaeology? Or is the reproduction of millimetric 3D models necessary for the correct analysis and interpretation of the archaeological record?

3. Materials and methods

During the 2012 fieldwork campaign, PST (Faro Focus 3D) was compared to IBM (Photoscan, Agisoft) in three different areas of the site, characterized by diverse environmental conditions and light exposures:

- test 1 – cave's entrance chamber (unit 3 – no natural light; Fig. 1a);
- test 2 – structure 1/eastern pyramid, plaza A (unit 9 – areas in shaded sunlight under the jungle canopy/wet soil; Fig. 1c–d);
- test 3 – Ballcourt (unit 17 – direct sunlight in areas that had been cleared of brush or exposed by treefall; Fig. 1b).

A Nikon D90 at 12 MPixel with a 60 mm Nikkor lens was used for the IBM acquisition. All 3D models acquired were scaled to real measures and aligned through the total station's control points. Several targets located at the corners of the excavation areas were taken as reference points to align the total station data survey and the 3D models acquired using the two techniques. These procedures allowed for the geo-referencing of the 3D models and their alignment with the reference frames used for the survey of the site.

The first test was conducted in the cave's entrance chamber (unit 3). Unit 3 is an excavation (8 × 5 m) located in the passageway at the end of the entrance chamber of the Las Cuevas cave [19]. Two layers of the excavation were recorded through PST and IBM (unit 3, levels 1 and 2; Fig. 1a).

To record the excavation seven scanner positions were needed and each of them took about 6–7 minutes to complete (average instrument distance 3.75 m). Acquisition of color in unit 3 was crucial, and for this the built-in scanner camera was used. Six lamps (DeWALT DC020 fluorescent light; color temperature 2700 K) were used to provide adequate light for the scanner camera to be capture color information.

The first stage of point processing and editing of the excavation area was performed with the FARO Scene software supplied by the scanner manufacturer. The single scans were exported, filtered, aligned and meshed in Meshlab using the *Poisson surface reconstruction* approach [20]. By setting, a 2 mm scan resolution during the acquisition process, it was possible to obtain very accurate meshes, which allowed for the description of all the features contained in the levels (Fig. 2a). Since this reconstruction tool does not allow the projection of the point cloud's vertex color, this information was applied to the refined mesh from the point cloud using the *vertex attribute transfer* filter [20].

Despite the good quality of the acquired data and the use of a constant light source during the acquisition of the scans, it was impossible to get uniform colors in the final model (Fig. 2b). Unit 3 was also acquired through IBM. The total number of photos used for the generation of the 3D model of unit 3 was 105.

The second test involved unit 9, a 3 × 3 m excavation located close to the center of the top of structure 1 (eastern pyramid, plaza A; Fig. 1c–d [19]). Data comparisons were run on the 3D models of the two most significant levels of unit 9. These two levels correspond to two of the four floors found during the excavation: level 10/floor 3 and level 3/floor 1. The two levels were acquired using four scan positions (average instrument distance 3.56 m), while the total number of photos used for the IBM processing was 54 for level 10 and 52 for level 3.

The third test was conducted on an excavation area opened over the southeast corner of Structure 6 and characterized by an irregular trapezoid-shaped feature (unit 17, 7 × 4 m; Fig. 1b [19]). Unit 17 was acquired using five scan positions for PST (average instrument distance 3.87 m) and 135 photos for IBM.

The PST acquisition of units 9 (3 × 3 m) and 17 (7 × 4 m) was faster than unit 3 (8 × 5 m) since the use of artificial light was not necessary for the acquisition of the color information. Moreover, fewer scan positions were necessary to acquire the two areas (four for unit 9 and five for unit 17) compared to unit 3 (seven scan positions). The PST data processing procedure was exactly the same as that used for unit 3.