Quantifying the effects of erosion on archaeological sites with low-altitude aerial photography, structure from motion, and GIS: A case study from southern Jordan

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Abstract
Cutting-edge photogrammetric techniques combined with traditional methods are a boon for archaeologists interested in performing spatial analyses. Low-altitude aerial photography (LAAP) combined with photogrammetric Image Based Modeling (IBM) comprise a workflow that allows for precise and accurate recording of both photographic and elevation data of archaeological sites with a great deal of speed and efficiency. Through these techniques, the researcher can create spatially-referenced ortho-photos and digital elevation models (DEMs), which can serve as the basis for investigations into site formation processes. Due to the rapidity of the creation of these datasets, analysis of site formation processes can be completed over the course of hours or days. The results of such site formation studies can inform and guide further archaeological investigations of sites. This paper presents the application of a combined LAAP-IBM method to acquire GIS data, which serves as the basis for a case study of a new model of the effects of erosion on archaeological sites—a key factor in understanding site formation processes. These methods are applied to Khirbat Nuqayb al-Asaymir, a Middle Islamic site in southern Jordan, as a case study.

1. Introduction

The process of archaeology relies on interpreting how things were in the past (the systemic context) from how things are in the present (the archaeological context) (Schiffer, 1972). This, in turn, depends on the correction of distortions caused by cultural and environmental formation processes (c- and n-transforms, respectively), affecting the archaeological record after the original deposition of artifacts. Fortunately, formation processes have predictable and discoverable effects on the archaeological record, an area of theory that has been developed by Michael B. Schiffer (1972: 678), meaning that these transformations can be understood and accounted for. The documentation of biases caused by formation processes facilitates the reconstruction of the relationship between systemic and archaeological contexts. However, archaeological research relies on the existence of empirical evidence in order to demonstrate that certain n-transforms occurred. This is an a posteriori approach to making inferences about natural transformation processes’ effects on the archaeological record (See Cruz et al., 2014 for an excellent example of one such study). We suggest here that certain ubiquitous environmental transformation processes do not need to be proven to have occurred before they are considered in archaeological research, given the likelihood of their occurrence. As such, a priori presupposition of these factors may provide insight into the predictable patterns of evidence one would expect to find as the results of these processes when conducting intensive archaeological investigation. In the same way that one would be unlikely to plan excavation or survey without due consideration of the ways in which cultural formation processes (i.e. artifact deposition) affect the archaeological record, we propose that the biasing effects of environmental formation processes such as erosion are also important to factor into planned investigation of archaeological sites. Erosion in particular has rarely been the main focus of comprehensive archaeological study, with some exceptions (James et al., 1994; Stiros et al., 1999; Turnbaugh, 1978; chapters in...
substantial benefits in terms of understanding the spatial distribution of artifacts at sites prone to erosion.

Fortunately, recent developments in field recording methods and technology provide an excellent basis for an a priori study of water-caused erosion at archaeological sites. We have developed a workflow using techniques including low-altitude aerial photography, computer vision, soil science, ethnoarchaeology, and GIS to study the effects of this formation process. Our aims in conducting this work are threefold: first, we intend to demonstrate the viability of conducting various spatial analyses usually applied at a regional level at an intra-site scale. Second, we develop a model workflow for detailed site survey and a priori consideration of erosion as a site formation process affecting the development of archaeological context. Finally, we apply these studies to the site of Khirbat Nuqayb al-Asaymir (henceforth KNA) (Fig. 1), a copper production site in southern Jordan’s Faynan region dating to the Middle Islamic Ic-IIa (ca. 2nd half of 12th to 1st half of 13th century CE) periods (Jones et al., 2012, 2014, 2017), for use in understanding the spatial distribution of artifacts and the relationship between systemic and archaeological context at the site.

2. Materials and methods

2.1. Low-altitude aerial photography and structure from motion

During the 2012 and 2014 UC San Diego Edom Lowlands Regional Archaeological Project (ELRAP) expeditions to the Faynan region of southern Jordan, the team developed an integrated workflow for detailed aerial archaeological survey (Fig. 2).

ELRAP deployed a low-altitude aerial photography (LAAP) photography platform for the purposes of photogrammetric Image-based modeling-oriented data collection and three-dimensional spatial survey of investigated sites in the region. Image-based modeling (IBM) is a broad term for the use of 2D images to generate 3D representations of physical objects (Remondino and El-Hakim, 2006: 271). One increasingly popular digital approach to IBM, Structure from Motion (SFM), applies photogrammetric principles to digital photographs in order to generate a 3D point cloud. SFM processes identify “feature points” (matching pixels) across multiple photographic images through comparison of their intensity and the characteristics of their geometric neighborhood. These points, along with Exif data (metadata describing the camera settings and other information about each image), allow for the algorithm to calculate the relative locations from which each photo used in processing was taken and to form a sparse point cloud (Ullman, 1979). Many software packages released in recent years (including Agisoft Photoscan, http://www.agisoft.com/, one particularly popular application) combine SFM-based point cloud generation with mesh model and texture generation functions, for an integrated IBM workflow. Archaeologists have noted the cost-effectiveness of these digital photogrammetric techniques, their precision and accuracy (in some cases rivaling laser scanning), and its temporal efficiency in field recording (Verhoeven, 2011; Doneus et al., 2011: 84; Lambers et al., 2007; De Reu et al., 2014; Quartermaine et al., 2014; Forte, 2014: 13; Roosevelt, 2014; Meylemans et al., 2014; Jorayev et al., 2016; Reshetuyk and Mårtensson, 2016; Sapirstein, 2016; Thomas.,). Others have highlighted the capacity of photogrammetric IBM techniques for documentation at many scales, ranging from the artifact-to the site-level (Olson et al., 2013). IBM-oriented photographic data collection can allow for the production of high-quality spatial datasets suitable for interpretation and analysis within a Geographic Information System (GIS) framework at levels of resolution and accuracy unparalleled by other techniques (Howland, 2014: 106). The GIS-compatible datasets produced through IBM-based approaches consist of digital elevation models (DEMs) and orthophotographs, vertical photographs corrected for lens and elevation distortions (Howland, 2014; Verhoeven et al., 2012). The technique can also be married to methods of low-altitude aerial photography to expand the scale of data collection to a site-wide or greater extent (Verhoeven, 2011; Olson et al., 2013; Remondino et al., 2011; Howland, 2014; Smith et al., 2014; Roosevelt, 2014; Sapirstein, 2016; Jorayev et al., 2016). Given the possibility of rapid collection of accurate, precise, and useful 3D and spatial data through combined LAAP and IBM approaches, these methods form an excellent basis for preliminary survey of archaeological sites.

To perform this type of aerial 3D survey, ELRAP deployed a 1-ply Kingfisher Aerostat K14U-SC balloon (Dimensions: ca. 3.6 m x 3.0 m, volume: ca. 21.0 m³, and lift: ca. 13.6 kg when fully inflated, tethered with 800lb SPECTRA line) tethered to and manipulated by a ground-based operator. This balloon was outfitted with a custom triangular frame capable of holding one or two high-resolution (15.1 megapixel) Canon EOS 50D Digital Single-Lens Reflex (DSLR) cameras equipped with 18 mm lenses. The balloon was selected over other LAAP options (such as UAVs or kites) due to the stability of the platform, its greater net lift, and the reduced chance of a catastrophic crash. The balloon also had performed well in prior field expeditions for similar purposes (Smith et al.2015; Howland, 2014). This platform allowed for an intensive campaign of photographic and 3D recording during the ELRAP field season.

The team intensively photographed five relatively large sites (Neolithic Wadi Fidan 61 [ca. 6ha] Levy et al., 2001), the Iron Age
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