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New approaches to modeling the volume of earthen archaeological features: A case-study from the Hopewell culture mounds

Matthew Magnani [a,*], Whittaker Schroder [b]

[a] Harvard University, Department of Anthropology, 11 Divinity Avenue, Cambridge, MA 02138, United States
[b] Department of Anthropology, University of Pennsylvania, 3260 South Street, Philadelphia, PA 19104-6398, United States

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ABSTRACT

Raised archaeological features form an abundant part of the prehistoric record, and come in many forms, from earthen mounds to shell middens. To calculate the volume of these features, archaeologists have relied on multiple strategies from simple geometric formulae to the use of aerial photogrammetry, typically to create energetic estimates of construction. No matter the technique, an undeveloped application of such volume estimates has the potential to inform our understanding of erosional processes and feature degradation. The largest of these earthen structures are typically best mapped and studied, leaving a paucity of data on the smaller, ubiquitous and often peripheral earthworks presently understudied at major archaeological sites. Using case studies from the Mound City and Newark mounds of the United States, we compare traditional methods of calculating mound volume for the purposes of ascertaining erosional processes with new photogrammetric protocols. Prior to this, the methodology is checked using artificially constructed earthworks of known volume, which are modified in controlled ways. The results presented here have implications not only for understanding prehistoric energetics more accurately in commonly overlooked portions of archaeological sites, but can also be used in the protection and potential reconstruction of archaeological mound features. While these sites are often afforded better protection than in the past, they are still exposed to natural and man-made erosional processes which warrants their detailed recording.

1. Introduction

Architectural and monumental ruins are some of the most ubiquitous and observable parts of the archaeological record throughout the world. Indeed, the most intricately designed of structures, given time, will ultimately collapse, and the natural forces of gravity and deposition will cause such remains to take the form of mounds. Such features may also form during occupation of certain areas, as repeated accretion and disposal of materials leads to several sequences of construction above earlier phases, commonly documented in the "Tel" remains of the Near East and the shell mounds of coastal regions. Other earthen monuments, however, are intentional constructions, built through cooperative and ceremonial mobilizations of labor for the creation of prominent markers across the landscape. In these examples, archaeologists generally examine phases of occupation and the energetics involved in construction of these monuments. Too often, the largest and most grand of these earthworks are mapped and recorded, leaving many of the smaller earthworks on the geographic and scholarly periphery of archaeological sites.

Detailed studies of mound features have additional bearing on issues of preservation, as the gradual erosion of these earthen archaeological sites is a reality, be it by plowing from farmers, archaeological excavations, or other natural processes. Many North American mound sites which previously stood meters tall now leave barely a trace in fields due to plowing, while others remain, though in a significantly altered form (Seeman and Soday, 1980; Olson et al., 2002). In the early to middle twentieth century some of these sites were reconstructed to varying degrees (Lacquement, 2010), based on early archaeological investigations (Squier and Davis, 1848). As more sites are opened to tourism, protected sites today face the significant daily threat of erosion from foot traffic, while sites in farmland remain susceptible to destruction from plowing. Recreational parks, paths, and roads still often overlap with mounds, slowly leading to their erosion. While numerous archaeological sites are better protected than they were in the past,

* Corresponding author.
E-mail address: matthewmagnani@g.harvard.edu (M. Magnani).

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conservationists must be aware of the changes that presently occur to monitor and protect them for future generations. One of the most effective ways to accomplish this goal is through recording and modeling the volume of such features.

Volumetric measurements have the potential to be calculated in a variety of ways, with methods equally variable in cost and time commitment. Measurements of volume can be calculated to varying degrees of accuracy (from least to most expensive methods): by hand using rough geometry; through the use of detailed contour maps; by using a total station, through photogrammetry; and most recently through employing LiDAR. Work on shell middens with ground-based LiDAR demonstrates the feasibility of utilizing the technology to calculate dimension and volume of features, and airborne LiDAR to place these features in lower-resolution topographical context (Larsen et al., 2015). LiDAR is also frequently used in non-archaeological construction contexts to assess changes in volume of large areas of earth or progress in construction (Du and Teng, 2007; El-Omari and Moselhi, 2008). Due to funding and time constraints, as well as access to appropriate equipment or trained personnel, a reasonable assumption is that this type of work will rarely be undertaken, even at sites with the highest perceived cultural value. In fact, documentation of monumental sites will often be detrimental to the study of smaller features, which may be outside the scope of such analyses. With the exception of ground-based LiDAR, the above mentioned methods cannot be done at a finer scale to inform researchers of intricate long or short-term erosional processes.

Furthermore, the erosional processes which occur at earthwork sites are variable and contextually unique. Depending on the soil composition, mound slope, and local environment, transformations occur over time, modifying the height and volume of the mounds from their original form of construction. In order to ascertain long-term change at individual sites, the creation of a baseline estimate of volume and visualization of topography is necessary. Alterations in surface morphology, as well as volumetric changes can inform archaeologists' conservation plans for specific site locales. Finally, archaeologists can directly utilize accurate models to reconstruct excavated earthen mounds, for the purposes of preserving site integrity for visitors.

Fortunately, inexpensive means of documenting volume and surface characteristics of earthworks are now widely available to archaeologists. In particular, photogrammetry is particularly promising as a rapid-documentation technique, and applications addressing the ascertainment of mound volumes started as far back as the 1980s when the technique was far less accessible (Shenkel, 1984). Today the process is largely automated, and relies on computer algorithms to align two-dimensional photos. Points shared between photographs are matched and a field of depth is created. Other scholars have argued that after a relatively quick learning process, photogrammetry can be used by researchers to address broad questions in cultural resource management and academic contexts alike (Douglass et al., 2015) Commonly- employed software utilizing "Structure through Motion" (SfM) algorithms can identify the place from which a photo was taken without knowing the placement of any markers in space. Verhoeven has published applications, including specifics of the process, and touches on specific algorithms and best-use practices of Agisoft PhotoScan (especially in the case of aerial photogrammetry) (Verhoeven, 2011).

Photogrammetry has been applied in a number of circumstances, from the documentation of small artifacts, to the logging of larger archaeological features (Magnani, 2014; De Reu et al., 2013). The creation of photogrammetric models is also commonly used for the purposes of cultural heritage management and preservation (Yastikli, 2007; Yilmaz et al., 2007). The methodology has been demonstrated to have high accuracy at the level of archaeological sites, with errors on the order of less than one centimeter, when compared to known ground control points (GCPs) (De Reu et al., 2013; Olson et al., 2013). Photogrammetry has been used to a limited extent to observe erosion of structural features at archaeological sites, but its use has not become widespread (Fujii et al., 2009). Analyses undertaken using photogrammetric protocols can yield accurate spatial measurements, which can be used to estimate erosion or energetics, as well as a recording of valuable topographical information and appearance. This protocol is ideal for recording smaller mound sites, which typically lack the detailed contour maps or sustained interest of researchers.

1.1. Mound volume applications

Within the Eastern Woodlands culture area of North America, archaeologists associate an early florescence of mound building with the Middle Woodland period (AD 1–500), and a particular manifestation of geometric earthworks centered on modern Chillicothe, Ohio is associated with the Hopewell tradition. Based on the distribution of certain non-utilitarian and mortuary artifacts, the "Hopewell Interaction Sphere" (Caldwell, 1964; Dancey, 2005) extends throughout the American Midwest, with outlying influence as far as Ontario, Canada to the north and the Florida panhandle to the south (Bernardini, 2004:334).

In addition to conical mounds, Hopewell earthworks are classified into various geometric walls and embankments, most commonly circles, octagons, and squares, typically enclosing similar areas of land that measure as much as 12 ha (Romain, 1996). The embankments are often accompanied by a ditch, within or outside of the wall, and large areas of soil procurement have been documented at some sites (Riordan, 2006). The lack of domestic artifacts and the distance between earthworks suggests that geometric earthworks served a communal purpose, in which populations from across the region gathered to participate in ceremonial building events (Byers, 2006; Cowan, 2006; Dancey and Pacheco, 1997; Greber, 1979; Madsen, 1997; Pacheco, 1996; Seeman, 1979).

Thus, archaeologists have relied on energetics, the translation of architectural volume into person-hours necessary for labor (Abrams, 1994), to understand labor organization through the effort expended in construction of monuments, with implications for determining population sizes and assessing political dynamics as centralized or communal in nature (Abrams and Bolland, 1999; Bernardini, 2004; Blitz and Livingood, 2004; Rosenswig and Burger, 2012). Such estimates, however, invariably require some level of assumption in either the number of laborers or the length and number of work days.

Other more specific issues confront energetics applications in the Hopewell example. The creation of a Hopewell earthwork required many more steps than merely the accumulation of dirt in an established area. The process would have begun with the clearing of an area large enough to contain massive earthworks. This step could have been completed largely through the use of anthropogenic fire; however, some amount of labor would have been necessary to clear burned debris. Furthermore, the collection of soil would have to be planned, as many earthworks contain levels of different colors and textures of earth, some of which can even be subterranean (Mills, 1922). When ditches do not accompany embankments, soil would have been transported greater distances, and additionally the manufacture and repair of baskets used to transport soil would have created a large demand for labor, as findings at the Hopewell Site suggest that earth loads could weigh as much as fourteen kilograms (Shetrone, 1926:72). A final and important challenge to an energetics study that attempts to translate mound volume directly into person-hours, is the unfortunate reality that the volume of earthen constructions