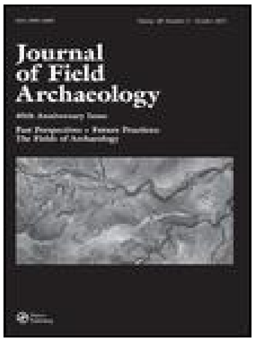

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Excavation is ~~Destruction~~ Digitization: Advances in Archaeological Practice

Christopher H. Roosevelt[1], Peter Cobb[2], Emanuel Moss[3], Brandon R. Olson[1], Sinan Ünlüsoy[4]

[1]Boston University, Boston, Massachusetts, [2]University of Pennsylvania, Philadelphia, Pennsylvania, [3]CUNY Graduate Center, New York City, New York, [4]Yaşar University, Izmir, Turkey

This article modifies an old archaeological adage—"excavation is destruction"—to demonstrate how advances in archaeological practice suggest a new iteration: "excavation is digitization." Digitization, in a fully digital paradigm, refers to practices that leverage advances in onsite, image-based modeling and volumetric recording, integrated databases, and data sharing. Such practices were implemented in 2014 during the inaugural season of the Kaymakçı Archaeological Project (KAP) in western Turkey. The KAP recording system, developed from inception before excavation as a digital workflow, increases accuracy and efficiency as well as simplicity and consistency. The system also encourages both practical and conceptual advances in archaeological practice. These involve benefits associated with thinking volumetrically, rather than in two dimensions, and a connectivity that allows for group decision-making regardless of group location. Additionally, it is hoped that the system's use of almost entirely "off-the-shelf" solutions will encourage its adoption or at least its imitation by other projects.

Keywords: digital culture, volumetric (3D) recording, image-based modeling, integrated spatial database management, Kaymakçı Archaeological Project (Turkey)

Introduction

"Excavation is destruction"—that emphatic exhortation for careful archaeological recording—is perhaps the most repeated adage among archaeologists (Lucas 2001: 35), from student to professor, novice to professional. If not a destructive activity, excavation is glossed also as an "unrepeatable experiment" (Barker 1982: 12), stressing the objective and scientific nature some hope it to embody. Others highlight the creative aspects of excavation, seeing it not as a "destroyer" of material but as a "creator" of data (Frankel 1993; Carver 2006), and emphasizing the creativities involved in the practice (Yarrow 2003). Similarly, excavation is seen as displacement, a material intervention, and a form of archiving (Lucas 2001) that incorporates an excavator's approaches, interpretations, and biases into the archive itself, with the implicit understanding that the archaeological record becomes subjective as soon as archaeologists engage with it.

Yet, in encouraging careful recording with the primary deterrent that excavation is destruction, some worry that it "has become a mantra we repeat to ourselves over and over and over again in an attempt to convince ourselves that it's true, in part to avoid close examination of the second problem, that of data quality" (Carver 2012: 19). And with advances in recording technologies like those highlighted in this article, some appear to have returned to a preservationist ethos that conflates increasing quality of data with the objectivity with which it can be recovered (Bradley 2006: 6; Wilkins 2012; Selden *et al.* 2014). Given the injection of excavators' biases into the process of excavation, however, the importance of archaeological recording dwells not so much in preserving exacting replicas of stratigraphic perplexities as it does in preserving exacting understandings of how excavators interacted with them. The modification of the adage proposed here—"excavation is digitization"—attempts not to suggest the preservation of a pristine, objective archaeological record, but only the high-quality recording of an excavator's interactions with it. Representation of these interactions via digitization is made possible by advances in archaeological practice that include the development of a recording system that encourages thinking digitally as well as spatially and, specifically, volumetrically, as discussed below.

The fully digital recording system presented here was developed for the Kaymakçı Archaeological Project (KAP), which had its first excavation season in the summer of 2014. Conceived and designed before excavation commenced, the system

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Correspondence to: Christopher H. Roosevelt, Department of Archaeology, Boston University, 675 Commonwealth Ave., Boston, MA, 02215. Email: chr@bu.edu

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was "born digital" (Austin 2014: 14), operating with integrated databases and aiming for the production of high-quality data with manifold improvements in accuracy and efficiency. The approach is also inherently three dimensional (3D), in which recording protocols are intended to capture the real world, volumetric nature of excavated contexts. By conducting daily work digitally and in a 3D environment, we connect recording procedures and interpretation with original volumetric spaces, making the interrelated processes of excavation and interpretation more intuitive by removing layers of abstraction that hinder direct consideration of the archaeological record.

Users of the recording system conceive of their work in purely digital terms, thus directly situating the archaeological process within a digital framework and enabling the flexibility that comes with it. This digital infrastructure shifts the way archaeology is practiced by leveraging an ever-expanding set of recording, analytical, and communication tools. Additionally, the system reorients the way in which 3D space is conceptualized such that excavators engage more in reconstructing the total archaeological record than is typically enabled by traditional recording methods. Furthermore, the structure of the recording system helps archaeologists produce already standardized data, making eventual open-access publication of complete datasets more feasible and timely, enabling archaeologists to become better "stewards of the archaeological record" (Kansa 2010:12). With the focus on increasing accuracy and efficiency, we mitigate the association of such qualities with an "industrialized archaeology" devoid of interpretive creativity (Shanks and McGuire 1996; Yarrow 2003) by taking it as implicit that interpretation is embedded in the process of stratigraphic excavation (Hodder 1997), as have many before us (Carver 2012; Thorpe 2012). The system described below, thus aims to offer practical and cognitive advances in archaeological practice and ethical professionalism (Kansa 2010: 12), just as it aims to improve interactions with archaeological material and the quality of resulting data.

Below, we review recent developments in digital recording in the field, integrated databases, and 3D recording, and how these things have been incorporated in our recent work. Then we present a newly developed recording system, illustrated further with a case study. Subsequently, we ponder the implications of the system, including what must be considered a paradigm shift in archaeological recording, both in terms of its digital nature and its conceptual emphasis on the volumetric, physical realities of archaeological materials. Finally, a brief section on some of the benefits of the system compared with traditional recording methods leads to discussion of current challenges and future opportunities.

Recent Work

Onsite digital recording and integrated archaeological databases

In parallel with the commercial digital electronics market, the practice of archaeology has been on a steady, decades-long march towards incorporation of computer-based technologies in every step of the archaeological process. Among the many steps inherent in this process, two recent examples stand out for their importance. The first is the direct digital recording of observations at the time and location of actual excavation; the second is the real-time integration of observations into a database that provides always up-to-date, interconnected views of the overall excavation. Direct, onsite digital recording first came to archaeological sites in the context of specific applications of digital photography and spatial measurement, using digital cameras, total stations, and Global Navigation Satellite Systems (GNSS) devices. Following this, many experiments attempted to employ digital methods for text entry and drawing. Laptops provided a familiar entry experience using a mouse, a keyboard, and sometimes also a stylus (pen) and touch input (Searcy and Ure 2008). Other portable devices, such as personal digital assistants (PDAs), have also been field-tested.

The current decade has seen significant growth in the use of mobile computing devices such as smartphones and tablets. Crucial to the widespread adoption of these devices in archaeology has been the rise in archaeologists' familiarity with their use from off-season personal communications and social networking. These devices have appeared at excavations naturally where their use now extends to recording multiple data types with or without the migration of paper forms to digital formats for textual input (Ellis and Wallrodt 2011; Pettegrew 2012; Fee *et al.* 2013). Recent generations of mobile computing devices are designed around interconnectivity via Wi-Fi or mobile networks, enabling the second important digital transformation of archaeology mentioned above: the real-time integration of data. Other data collection devices, too, such as high-quality cameras and GNSS receivers, increasingly have network connectivity. Accordingly, as data of any type are entered anywhere within a project's digital network, they can immediately enter an integrated datastore, simplifying data curation and allowing simultaneous analysis on up-to-date data (Levy *et al.* 2012; Sharp and Litschi 2014).

Back to the third dimension in archaeological recording

Archaeology has always been inherently real world and 3D, yet until recently it has had to rely on 2D abstractions of 3D realities. Over the last three years, 3D modeling software and recording instruments have rapidly become cheaper and more user friendly as their use in archaeological research has grown exponentially. This trend is discernible in the recent publication of a number of peer-reviewed journal issues dedicated entirely to digital approaches in archaeology: the *Journal of Field Archaeology* (39.2 [2014]), *Near Eastern Archaeology* (77.3 [2014]), the *Journal of Eastern Mediterranean Archaeology and Heritage Studies* (2.1 and 2.2 [2014]), *World Archaeology* (46.1 [2014]), and *Advances in Archaeological Practice* (2.3 [2014]). The *Journal of Archaeological Science*, too, has experienced a surge in published works focusing on 3D applications in archaeology, amounting to a 300% increase over the last decade (Olson *et al.* 2014: 162–163). What factors underlie such a trend? Attempts to update field-recording strategies with 3D solutions date back to the initial uses of terrestrial laser scanners in archaeology (Barcelo *et al.* 2003; Barcelo and Vicente 2004; Doneus and Neubauer 2005; Pollefeys *et al.* 2003). Digital heritage management has been a driving factor for 3D tools in archaeological documentation over the course of the last decade (Bruno *et al.* 2010; Guidi *et al.* 2004; Pavlidis *et al.* 2007; Yastikli 2007). The use of shading and stippling in artifact illustration, as well as the creation of artifact squeezes and casts, has sought to add a level of three-dimensionality to artifact recording throughout the last century (Heath 2015; Rick and White 1974), while 3D scanning has provided a digital workflow (Andrea *et al.* 2012; Chow and Chan 2009; Fowles *et al.* 2003; Grün *et al.* 2004; Zapassky *et al.* 2006). It is clear that 3D solutions in archaeology are not new, yet the preoccupation with them over the last three years marks a paradigmatic shift where the archaeological community has consciously adopted and adapted 3D tools to address a host of issues. A number of technological factors have been driving this change, especially the development of portable laser scanners, image-based modeling, and other inexpensive tools that record 3D data with relative ease and efficiency.

At the object scale recent emphasis moves beyond relatively simple 3D recording towards morphometric analysis: the quantification of objects' shape attributes for direct comparisons and group identification through automated clustering. Additionally, morphometric analysis provides data for the study of production technologies. Such methods are increasingly common, especially in studies of lithics (Bretzke and Conard 2012; Clarkson 2013; Grosman *et al.* 2008; Lin *et al.* 2010; Lycett and von Cramon-Taubadel 2013; Lycett *et al.* 2010; Sholts *et al.* 2012). Morphometric analyses of ceramics, too, have become common, in comparing shapes using either 2D profile drawings that presuppose wheelmade rotational symmetry (Gilboa *et al.* 2004; Karasik and Smilansky 2008, 2011; Grosman *et al.* 2014) or simplified representations of 3D objects (Selden *et al.* 2014). Our project uses Karasik and Smilansky's (2008) software to create 2D profile drawings from 3D models of ceramic sherds.

The use of image-based modeling in archaeology, also known as photomodeling (Opitz 2015), structure-from-motion modeling (Green *et al.* 2014; Howland *et al.* 2014; Smith and Levy 2014), digital photogrammetry (Quartermaine *et al.* 2013), and computational photography (Rabinowitz 2015), began in earnest in 2012. Several software programs offer image-based approaches (Olson *et al.* 2013: 248), including an open-source option (Green *et al.* 2014), but because of its affordability, ease of use, and quality outputs, Agisoft PhotoScan Pro is the leading commercial choice. Regardless of the software package adopted, image-based approaches are relatively simple. With the aid of Structure from Motion (SfM) and other comparable photogrammetric algorithms, accurate and photorealistic 3D models of any target of interest are created using data from overlapping digital photographs.

After a trial period in which a number of studies tested the accuracy and utility of image-based modeling (Lambers *et al.* 2007; Ortiz Sanz *et al.* 2010; Verhoeven 2011; Verhoeven *et al.* 2012; Hrynick 2012; Kjellman 2012; Olson *et al.* 2013; Remondino 2013; de Reu *et al.* 2013; Green *et al.* 2014; McCarthy 2014), archaeologists began using it to supplement or replace analog approaches to photography and drafting. Traditional archaeological field drafting, in particular, has been supplanted on some projects by less time consuming and considerably more accurate digitization from georeferenced orthophotos, spatially accurate overhead photographs deriving from image-based modeling (Howland *et al.* 2014; Prins *et al.* 2014; Quartermaine *et al.* 2014). Attempts to incorporate more image-based modeling techniques into excavation recording strategies have had varying levels of success (Olson *et al.* 2013; de Reu *et al.* 2014; Killebrew and Olson 2014; Forte 2014; Stal *et al.* 2014; Smith and Levy 2012, 2014; Demesticha *et al.* 2014; Hill *et al.* 2014). With the exception of Forte (2014) and Smith and Levy (2014), most experiments with 3D excavation recording strategies leverage only the 2D by-products of image-based approaches (i.e., digital elevation models [DEMs] and georeferenced orthophotos) as the primary analytical products of onsite documentation. Furthermore, many such projects design 3D recording workflows around time intervals (e.g., certain times of day) (Howland *et al.* 2014: 190), rather than intervals dictated by the excavation of individual spatial contexts. What remains missing is a wholly digital and 3D approach that favors volumetric recording at every stage of excavation recording as opposed to 2D abstraction. It is towards this integrated approach that KAP has recently made advances.

Gygaia Projects: The Central Lydia Archaeological Survey and the Kaymakçı Archaeological Project

The Kaymakçı Archaeological Project is the second cultural-heritage initiative of Gygaia Projects, an umbrella-like organization of activities concerned with culture, nature, and community—ancient and modern—especially in the Marmara Lake basin in the middle Gediz River valley of western Turkey (http://www.gygaia.org) (FIG. 1). Between 2005 and 2014, the Central Lydia Archaeological Survey (CLAS)—Gygaia Projects' first venture—aimed to document the remains of all past human activities in the Marmara Lake basin, and the presentation of its results is ongoing (Luke and Roosevelt 2009; Roosevelt *et al.* 2014). From GNSS and Geographic Information Systems (GIS) to relational databases, CLAS leveraged digital solutions and developing technologies from its inception in discovering and recording remains dating between the Palaeolithic and the present. As an eager and early adopter, it relied on both open-source and off-the-shelf solutions (with GRASS GIS and ArcGIS, MySQL and PostgreSQL database platforms, and OpenOffice.org and Microsoft Office software), attempted to maintain cross-platform operability (including Linux), and made prodigious use of a variety of technologies to improve understanding of the past, from compositional analyses (Instrumental Neutron Activation Analysis, petrography, X-Ray Florescence) (Luke *et al.* in press), to palaeoenvironmental coring and satellite remote sensing (Besonen and Roosevelt n.d.), to microtopographic mapping and geophysical prospection with ground-based and aerial solutions (Roosevelt 2014). It adopted the in-the-field digital recording, integrated database management, and 3D recording described above with Android tablets used in pedestrian field survey, a centrally served PostgreSQL database, and 3D laser-scanning and object-scale image-based modeling (Roosevelt *et al.* in press). Furthermore, it committed to the concept of open-access online publication of data, a goal towards which work continues.

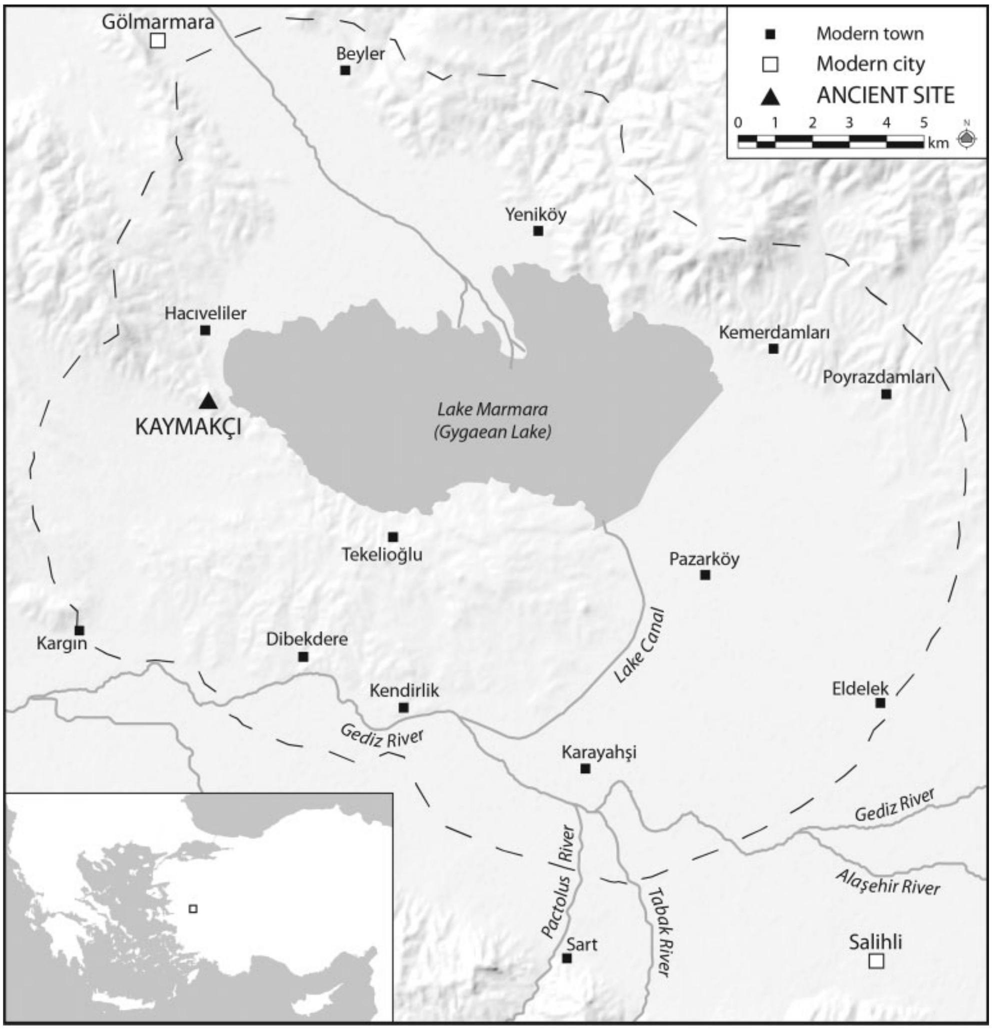

Figure 1 Map showing the location of Kaymakçı and the study area of the Central Lydia Archaeological Survey (dashed circular line) in the Marmara Lake basin, western Turkey.

Kaymakçı—the focus of the current project, KAP—is one of many discoveries resulting from CLAS research. The site is most notable for its ridge-top fortifications enclosing an 8.6 ha citadel and also at least one cemetery and low-density remains representing a vast built environment. All areas of the site remain in remarkably good condition, having been abandoned in or at the end of the Late Bronze Age, ca. 1200 B.C. Its pristine nature and good preservation, in fact, were prime factors in the decision to conduct excavations. The topographic and functional diversity of the site, however, ranging from the stony ridge-top citadel to the valley-bottom cemetery and settlement, necessitated a recording system versatile enough to handle a variety of excavation strategies.

The KAP Recording System

Starting a new excavation project, KAP directors had the opportunity to develop and refine systems of recording archaeological excavation that could help push forward the discipline of field archaeology. Rather than adopting one of many previously existing recording systems (Pavel 2010) and adapting it to our needs, the project developed a new system that leverages developing technologies and strives to be easily intelligible, spatially and terminologically accurate, and methodologically efficient to ensure standardized data management and relatively quick data dissemination. Key characteristics of the system in both field and lab work include real-time interaction with a fully relational database, real-time and cloud-shared documentation of all activities in texts and images, and the ability to capture volumetric (3D) contextual information using accurate and efficient digital methods. A final key characteristic is connectivity—between field and lab, area supervisors and directors, specialists and excavators, conservation and excavation teams, etc.—that facilitates smooth collaboration between scholars and practical and efficient fieldwork management (cf., May and Crosby 2010). Inherent in each characteristic is the 100% digital nature of the system. The KAP recording system, thus, aims to produce, manage, and rapidly publish digital data from an information system with standards that can conform easily to other digital heritage and information ecosystems (Limp *et al.* 2011; Kansa and Kansa 2014), regardless of the specific software and hardware solutions adopted.

While not a primary goal of the system, its adoption by others is encouraged by its reliance almost entirely on off-the-shelf solutions. Custom-designed and, especially, open-source recording systems are laudable (Fee *et al.* 2013; Gidding *et al.* 2014; Smith and Levy 2014; Vincent *et al.* 2014), yet their portability to other projects has been limited. Efforts involved in developing custom-made software hardly seem worthwhile when widely adopted and familiar solutions offered by back-end database structures like PostgreSQL, aspatial database managers such as Microsoft Access, and spatial database managers like ArcGIS are available. Cost is, of course, an important issue. Yet because most archaeological projects are sponsored by academic institutions with site licenses for these or similar software packages, costs can be mitigated. Further encouraging replicability are intuitive terminology and numbering systems designed to aid implementation and interpretation.

Terminology and numbering

The project's in-field excavation protocols most closely resemble those of the Single Context Excavation System developed by the Museum of London (Westman 1994) and extended by English Heritage (2010), among others; thus standardized fields and entry options in our system accord closely to theirs. The aim of the KAP system of terminology and numbering is to provide a logical and internally consistent system of recording and managing spatial and aspatial information deriving from excavations that is user-friendly, database-efficient, and query-flexible. Terms used most frequently include "areas", "contexts", and "samples". The KAP recording system aims to embed easily intelligible meaning in identifiers such that any record identification (record ID) can provide information on the spatially distinct context from which it derives.

To achieve these goals, KAP uses a tripartite, nested system of record identification that creates unique records for all types of excavation data (FIG. 2). The first component of the record ID identifies excavation areas; the second, specific spatial contexts; and the third, samples. Beyond excavation area IDs (see below), the spatial context and sample IDs can be thought of as two separate but related numbering systems. The context numbering system is associated with the process of excavation and the spatially discrete, three-dimensional deposits and features it defines; contexts can be thought of as "containers." The sample numbering system is associated with the process of sampling deposits and features and the various aspatially discrete and/or in situ artifact, ecofact, faunal, botanical, soil, and other samples and treatments it defines; samples can be thought of as "things that receive actions," wherein actions range from simple recording to more detailed analyses or even conservation treatments. A key characteristic of both contexts and samples is the ability to combine them into archaeologically meaningful groups for analytical purposes. Whereas contexts and samples can both be grouped, samples can sometimes be subdivided, as well.

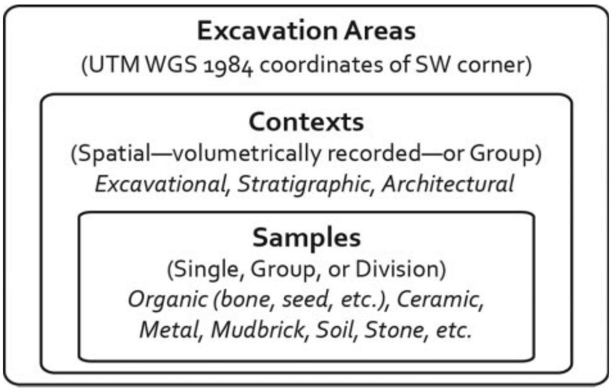

Figure 2 Schematic diagram illustrating the nested concepts of KAP recording system terminology.

We concede that this terminological and numbering system may seem daunting at first. It is rather more straightforward and certainly more standardized than other systems known to us, however, and it was quickly adopted by both field and laboratory staff during its inaugural season of use. We provide a detailed discussion here because it forms the basis of how the full digital recording system is structured, as described in the following sections.

EXCAVATION AREAS

Because the KAP recording system is intended to be flexible enough to handle multiple approaches to excavation (e.g., open-area, gridded, targeted), it adopts a spatially significant schema in naming excavation areas. At Kaymakçı, this is defined by a 10 × 10 m grid derived from the Universal Transverse Mercator (UTM) coordinate system and the World Geodetic System 1984 datum. In western Turkey, Kaymakçı falls within Zone 35N, but because the system employs a global coordinate system, it can be adopted anywhere on earth. A typical excavation area in our 2014 field season was identified by a coordinate pair representing the southwest corner (or 0,0 origin point) of each 10 × 10 m excavation area, trimmed at the decameter level to two or three digits. For example, excavation areas with southwest UTM coordinate pairs of 580810E 4275510N and 580990E 4275260N would be trimmed and abbreviated as E81.N551 and E99.N526, or, more simply, 81.551 and 99.526. Within each 10 × 10 m excavation area, a one-meter wide L-shaped baulk was left along the north and east sides to allow its contexts and samples to be recorded entirely within a single excavation area upon potential removal.

CONTEXTS: SPATIAL AND GROUP

Within excavation areas, spatial contexts are the spatially discrete, three-dimensional (volumetric or surficial) entities exposed, explored, and (usually) extracted through the process of excavation. Typically, spatial contexts include stratigraphically uniform deposits (pit fills, collapse, etc.) and features (pit cuts, robbing trenches, walls, etc.) identified by the term "context" in many excavation-recording systems. In the KAP recording system, however, the term spatial context refers also to the smallest spatially discrete unit of excavation (identified in other systems as loci, baskets, etc.) not necessarily coincident with a complete stratigraphic unit. Accordingly, some (if not many) spatial contexts may form component parts of larger and potentially stratigraphically uniform deposits or features. In this way, the terminology aligns with a general definition of "archaeological context" as the absolute and relative location of archaeological entities. The recording of physical and stratigraphic relationships among spatial contexts is essential, as spatial data are recorded for these types of contexts alone, even when "small finds" are concerned (see below).

It is of primary importance to understand that spatial contexts can be collected into group contexts, each composed of two or more spatial or group contexts. A group context is thus identified as soon as two or more contexts are established as belonging to the same stratigraphic unit, whether in the field or in the lab, and is always given a new context number. Just as contexts can be joined into group contexts, so too can group contexts be joined into larger group contexts for the purposes of conceptual comparisons at higher levels across the site, between pits, rooms, or houses, for example. Thus group contexts are essentially only containers of component spatial contexts and/or other group contexts. They inherit the spatial data of their contents and thereby provide cumulative spatial data for the group that avoids redundancy in measurement. In this way, group contexts can be used conceptually, also, as records of features or deposits missed or mistaken during excavation of particular spatial contexts.

Contexts are numbered in running sequences according to each individual excavation area, regardless of the year in which the context is excavated, and regardless of whether they are spatial or group contexts, from the first spatial context of an excavation area to the last, when excavation of said area is complete. When group contexts include spatial contexts from different excavation areas, as is possible, they are numbered according to the excavation area containing the dominant, majority, or first recorded component(s) of the group.

SAMPLES

The KAP recording system uses the term sample to refer to anything sampled in or from a spatial context, whether as a bulk collection of finds or environmental samples, for example, or as an individual find, sample, or in-situ feature recovered either during excavation or in subsequent material processing.

A key feature that distinguishes the sample from the context numbering system is that (as stated above), whereas both samples and contexts can be grouped, only samples can be subdivided. Each sample is associated with one and only one spatial context and never more than one context nor a group context, thereby preserving its original spatial information.

Special samples warranting individual, in situ recording—the "small finds" of other systems—are treated similarly. Rather than just point coordinates, however, each such sample is given its own spatial context containing only the sample itself, thereby documenting its precise volumetric information, including orientation. All spatial data in the recording system are thus handled consistently, simplifying comparative analyses and avoiding imprecise abstractions. As described above, the spatial contexts of such samples can be grouped at higher levels to enable larger-scale analyses.

Each and every sample has a unique identifier—a record ID or ID triad—composed of the excavation area ID, the spatial context ID, and a sample ID, irrespective of the particular type of sample (as above). When combined in this order (from excavation area to spatial context to sample), the ID triad provides a unique record ID for each sample associated with a particular context in a particular excavation area. Accordingly, with just a glance the ID triad provides basic information about both horizontal (area) and relative stratigraphic context (spatial context).

EXAMPLES IN PRACTICE

As an introductory example, consider the following scenario: in excavation area 81.551 the second spatial context excavated after topsoil is the uniform fill of a pit. The context is thus programmatically identified as 81.551.2. As the pit fill is excavated, recovered materials (including sediments) are collected into bags, boxes, or buckets, separated by and appropriate to material type, each of which is labeled only by the spatial context ID (81.551.2) before processing in the lab. While still in the field, dry sieving of sediments from the pit might result in a collection of small sherds, which would be assigned the first sample number (ID triad) of the context (81.551.2.1), while a block-sediment sample for micromorphological analysis would also be assigned a sample number in the field (81.551.2.2).

When collected materials are subsequently processed in the lab, each sample from the spatial context is numbered programmatically and sequentially, drawing a non-duplicate sample number directly from the database. Sample numbers might be given to collections of pottery sorted by particular wares (81.551.2.3, 4, and 5); a particularly diagnostic sherd might be given its own sample number (81.551.2.6); a terracotta spindle whorl would be given its own sample number (81.551.2.7); and collections of sheep/goat and pig bones might be given their own sample numbers (81.551.2.8 and 9). Subsequent flotation of sediments from a sediment bag might result in a collection of carbonized seeds (81.551.2.10), while sediments set aside for soil-chemistry analysis would get their own sample number, too (81.551.2.11). For every sample, then, the recording of its recovery type (excavation, sieving, flotation, etc.) is essential.

If we extend the scenario, imagine that a nearly whole ceramic vessel (or another special sample) is identified during the excavation of fill from a second pit (81.551.3), and it is deemed worthy of recording as a separate sample, requiring its own spatial recording. As it represents an entity for which spatial recording is deemed worthy, the excavation of the vessel gets its own unique, spatially discrete, spatial context number (81.551.4), within the pit, and the vessel itself would be recorded as sample one of that spatial context (81.551.4.1).

Additionally, imagine that the subsequent study of pottery from the first pit fill (81.551.2) resulted in the discovery that several sherds of a particular ware joined. If deemed worthy of individual recording, the original sample (81.551.2.3) would be subdivided so that joined sherds could get a new sample number (81.551.2.12), separate from the original ware-specific sample (which was 81.551.2.3). If additional joining sherds are discovered in the pottery sample from another excavation area (e.g., 99.526.3), they would be pulled out of their original sample and given their own sample number (e.g., 99.526.3.2); that subdivided sample would then be grouped with the earlier subdivided sample (81.551.2.12), which would now be given its own new sample ID representing the entirety of the group of joining sherds (e.g., 81.551.2.13). Original spatial context information for particular sherds would be preserved in the database and through sherd labeling. Just as for spatial contexts, samples can be collected into group samples, as appropriate, and numbered according to the excavation area and spatial context containing the dominant, majority, or first recorded component(s) of the group.

In grouping or subdividing samples, one always does so according to the most meaningful scale or resolution of recording, which translates also to the most meaningful scale of analysis and practical need of storage. The scenarios described above pertain especially to pottery samples, but protocols for different sample types (e.g., botanical, faunal, soil-chemistry) can be modified flexibly. The basic principles of establishing new sample numbers for both subdivisions and groups need to be adhered to, however, even while type-specific guidelines should be followed to allow for the particularities of each material's standard recording protocols.

Physical network infrastructure

To create a system of real-time centralized data recording and project-wide communications, we first had to provide infrastructure to support it. The two main infrastructural components are a centralized server for all project data and a network for direct communications among all project digital devices, including the server (FIG. 3). Because all team members work directly with server data, breaks in connectivity interrupt work. Network reliability, then, and to a lesser extent internet-uplink reliability, was crucial to the success of the system. The challenge to building this local network stemmed from specific local topographic conditions. Kaymakçı lies in a rural area of western Turkey, 10 km from the nearest urban center and a few kilometers from the nearest source of electricity. Project laboratories are located in two separate building complexes in the agricultural village of Tekelioğlu, some 6.5 km from the site as the crow flies (FIG. 4). Accordingly, to support the recording system, network architecture needed to accommodate this geographical situation, including the establishment of all physical infrastructure onsite from scratch.

Onsite infrastructure included a portable photovoltaic (PV) system consisting of four 150 W solar panels and three 140 A batteries (FIG. 5). The PV solution avoided onsite power outages, problems encountered frequently on the municipal grid in Tekelioğlu and mediated only by use of numerous universal power supplies (UPS). Additionally, the portability of the PV system minimizes site damage and enables movement to other excavation areas in future seasons. The onsite network supplied Wi-Fi connectivity to three areas separated by up to 500 m by means of a set of fiber-optic and electric cables radiating out from the centrally located PV hub, at the ends of which consumer-grade Wi-Fi routers in protective cases provided 50 m-radius wireless signals to nearby excavation areas.

In Tekelioğlu a more standard network included multiple consumer-grade Wi-Fi routers connected via ethernet cables to a central server, a high-performance desktop computer running the Windows Server 2012 operating system. A low-cost but unreliable Wi-Fi bridge connected the separate

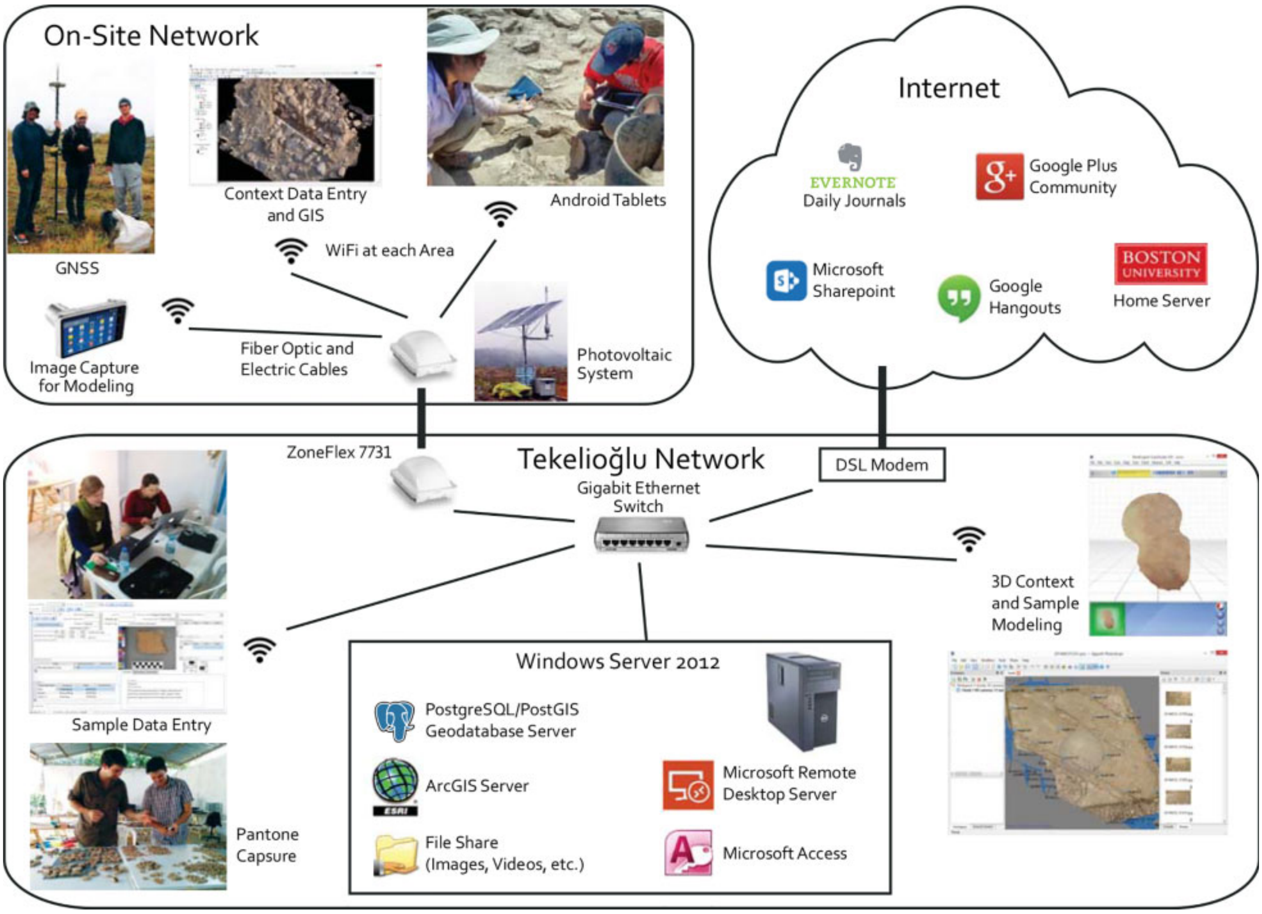

Figure 3 Schematic diagram illustrating the physical network infrastructure of the KAP recording system as well as data entry and management systems.

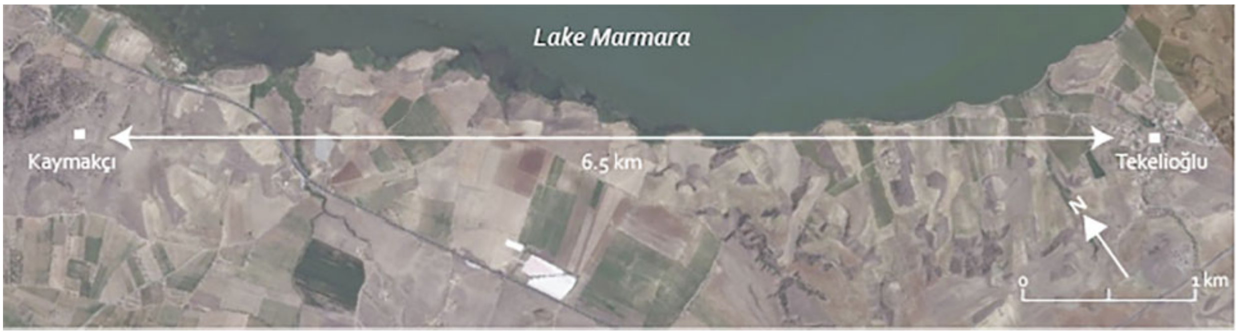

Figure 4 Map showing the locations of Kaymakçı and Tekelioğlu, connected over a 6.5 km line-of-sight by means of the ZoneFlex antennae.

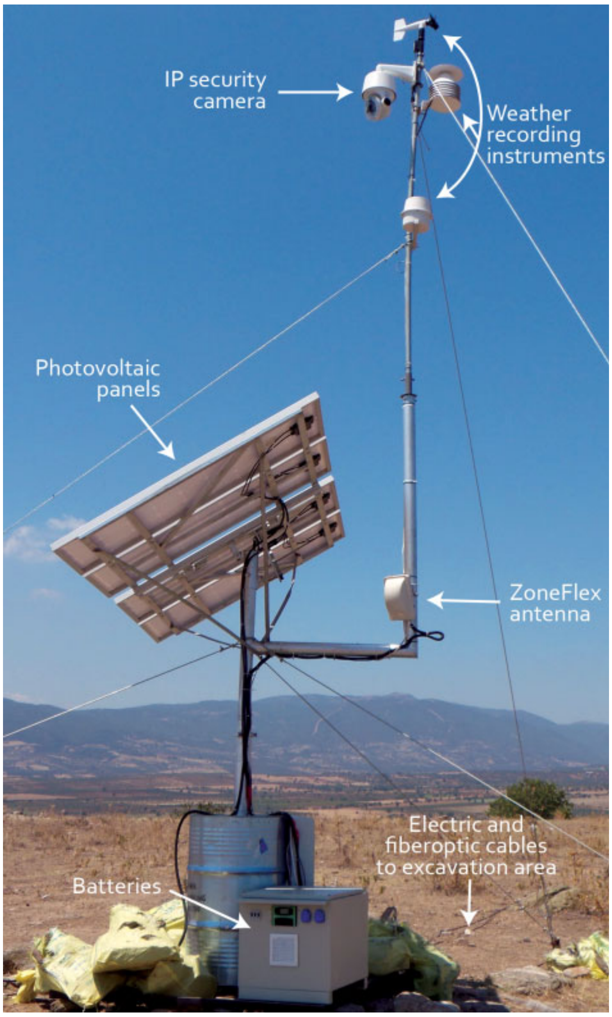

Figure 5 Photograph of the portable PV system on site, the onsite communications hub, with arrows indicating the locations of key features.

building complexes. The linchpin of the entire onsite system was the network link between server and site, spanning the 6.5 km between Kaymakçı and Tekelioğlu. A pair of Ruckus Wireless ZoneFlex 7731 antennae provided this link, taking advantage of the intervisibility between the site and the laboratories (FIGS 4–5). Finally, a consumer-grade Digital Subscriber Line (DSL) modem in the village served as both the Dynamic Host Configuration Protocol (DHCP) server for assigning Internet Protocol (IP) addresses to all devices on the network and as a bridge to the wider internet.

To our satisfaction (and mild surprise), this physical and network infrastructure proved quite reliable. Only a handful of outages over the course of two and a half months interrupted work as a result of problems with either the network or village electricity. A reboot of one of the components of the system immediately solved network problems, and a power outage only once outlasted project UPS devices, even then for less than an hour. During these rare episodes, onsite work continued apace, requiring only temporary recourse to off-line note taking, which always remains an option in case of catastrophic system failure. Regular backups to an external hard drive and periodic uploads to an off-site server ensured data preservation.

Structured data

Each part of the KAP recording system leverages the physical network infrastructure to record and analyze diverse yet structured data from a variety of digital interfaces. Central to the system is a PostgreSQL relational database that links all project data together (FIG. 3). The area, context, and sample numbering system discussed above defines the primary keys that relate data tables. Data integrity and structure are carefully controlled using best practices of database management, including access controls and validation checks, thereby facilitating the production of publication-quality data in real time. We use PostgreSQL for its power, reliability, and price (free), but also because it has been developed to accommodate spatially significant data through the PostGIS extension. Thus our central database serves also as a geodatabase storing all spatially georeferenced data such as vector geometries.

While not designed for direct data entry by users of varying levels of computer comfort, PostgreSQL can interact as a powerful back-end with many database client programs. The project adopted Microsoft

Access (henceforth Access) for the development of data entry forms that serve as the front-end Graphical User Interface (GUI) of the database. Access forms are quick to build, easy to use, and able to present the same data in multiple ways. Access also provides relatively user-friendly tools for building Structured Query Language (SQL) queries across related tables, enabling users of varying levels of experience to ask complex questions of data. Accordingly, separate entry forms were established for contexts, ceramic and lithic analyses, and conservation treatments, for example, so that such data could be entered in field or lab environments on desktop, laptop, or mobile devices. Access and some other software programs we use, however, lack cross-platform support as they run only on Windows. To mitigate this significant limitation, users of Android and other non-Windows devices access Windows programs on the server by establishing a remote desktop connection (RDC) from mobile or desktop platforms, usually via the free Microsoft Remote Desktop app. Even with an average of 10 simultaneous users working on the central server via RDC, no lag or latency was experienced within the local network.

The starting point for structured data entry is the excavation of spatial contexts. Data include a context's ID and attributes, such as sediment color and type of context. Primary devices used to enter field data in 2014 were Android tablets, including Panasonic's Toughpad FZ-A1 and Samsung's Note 10.1, chosen for their battery life, camera, and, especially, their screens with active digitizers, enabling the use of accurate, stylus-based input for taking notes, sketching, and digitizing features. The Panasonic's rugged design and sunlight-readable screens were well suited to fieldwork, yet its camera quality proved less than desirable. The Samsung seemed less durable yet survived the season fine and benefited from a faster processor and better camera. Although Access forms do not enable finger inputs from tablet screens, they function perfectly well with styli via RDC, obviating the need to invest precious resources in tablet-specific user interfaces for field data entry, especially given the fast pace of software and hardware improvements.

Photography and videography

We captured a variety of visual record types in the field. "Progress" photos of spatial contexts taken with tablet cameras periodically track changes during excavation. "Record" shots for more formal documentation record spatial contexts with higher quality cameras at key moments in excavation. In all database interfaces, especially Access forms, images are linked dynamically with the contexts they depict. Given the enormous quantity of image files this photography produces and to avoid overtaxing PostgreSQL, we used the server's file system for physical storage. In this one instance, suitable off-the-shelf automated image-file management software was unavailable. Accordingly, we contracted a freelancer to build a simple Android app that uploads photographs to particular directories on the server based on context data selected from the database (available at https://github.com/anatolian/field-photographs). To employ this app for higher quality imagery, we used Wi-Fi-enabled Samsung Galaxy Camera 2 units running the Android operating system.

In addition to these routine photographic documentation protocols, we experimented with daily video logs using tablets to convey daily progress, questions, and/or concerns to all project members in a convenient and efficient manner, usually requiring no more than five minutes to make. Videography worked well also because of its concise, visual nature, enabling others to understand spatial relationships easily.

3D spatial recording

Our system requires a precise, georeferenced, and volumetric digital model for each identified spatial context, whether a deposit, feature, or artifact. Our primary approach to producing such models included image-based modeling and Real-Time Kinematic (RTK) GNSS survey. Although other projects have experimented with image-based modeling in excavation, they tend to record 3D data on daily or half-daily schedules regardless of excavation progress. We established an intricate yet straightforward system of field recording and simultaneous lab processing for frequent 3D modeling implemented upon the complete excavation of each spatial context. Consequently, the system encourages best practices of material collection and stratigraphic separation because it prevents contexts that physically overlap whatsoever from simultaneous excavation: a spatial context—a unit of either stratigraphic or excavation significance—must be removed entirely before underlying spatial contexts are opened (for illustration, see case study, below).

Following the complete excavation of each spatial context, area supervisors took a series of digital photographs of the resulting surface, representing the bottom of the excavated spatial context and the top of underlying contexts, and a set of Coded Targets (CTs), the UTM coordinates of which were recorded with the GNSS system (FIG. 6). Digital photographs and CT coordinate data were then uploaded over the local network to the server in Tekelioğlu, where a team member used Agisoft Photoscan Pro to produce multiple outputs. Applying Photoscan Pro's automated CT detection routine then georeferenced resultant models as efficiently as possible.

Owing to PhotoScan Pro's limited ability to manipulate 3D models and our dedication to volumetric

Figure 6 Photograph of the capturing of digital images of a full excavation area with Coded Targets (CTs) in place.

recording, we worked first with 2D and 2.5D derivatives to meet our needs. Orthorectified and georeferenced photographic mosaics—2D orthophotos—were prepared for area supervisors who used ArcGIS via RDC and tablet styli to trace polygon outlines of the tops of subsequent spatial contexts. Thus the bottom surfaces of the previous spatial contexts served as the top surface of immediately underlying spatial contexts. These surfaces, represented as 2.5D digital elevation models (DEMs), were then used to derive context spatial characteristics, such as elevation, thickness, and slope. Furthermore, as detailed in the case study below, they were trimmed and modeled to produce volumetric entities that, when fitted together, represent the pre-excavation state of excavated contexts in "watertight", interlocking models.

Daily journals

For routine documentation of project activities, we used Evernote, a commercial, cloud-based recording system that enables sharing of text and images between project members and runs natively on most operating systems. Each excavation area supervisor recorded daily Evernote journal entries in which they listed standard information, such as onsite personnel, work conditions, daily goals, contexts excavated, and samples recovered, and documented fully the process and progress of excavations, describing strategies, decision-making processes, initial interpretations, etc. Such documentation was not only textual, but visual, too, via the annotation of embedded images. Using stylus-enabled tablets, excavators could quickly draw directly over photographs or make interpretive sketches using Skitch, an Evernote extension. Thus many images embedded in Evernote journals are quick plans annotated by handwritten text. An advantage of relying on off-the-shelf products is their ability to introduce innovations quickly. Evernote will likely continue to improve our ability to manage daily journals efficiently, with possible advancements in handwriting or voice recognition. A clear disadvantage of Evernote includes the current lack of links between contexts and samples referenced in journal entries and database records.

Sample processing

The integrated nature of the KAP recording system means that by the time samples are processed, all contextual information is available in the database. Integrated data-structure controls mean also that those processing different types of samples—e.g., botanical, faunal, ceramic—can work simultaneously without conflicting sample numbers, as such identifiers are provided programmatically on demand.

The high-quality and dense nature of field-data collection was applied to laboratory data collection as well. Over 50,000 lithics, ceramic sherds, bones, and other materials were photographed, counted, weighed, and analyzed in 2014 from samples containing one or more objects. Where appropriate to material type, samples were sorted and described using standardized forms, including such characteristics as Munsell color. For the latter, we accomplished efficiency and standardization by employing a Pantone Capsure, a digital camera-enabled device with self-controlled lighting conditions, to match colors to the Munsell scale automatically.

As with spatial contexts, objects, too, were documented most accurately in their real-world, 3D physicality.

We created as many 3D models as possible of metal, stone, and ceramic samples, using both a NextEngine Portable 3D laser scanner and image modeling via Agisoft's Photoscan Pro (FIG. 7). For an average small-sized object, such as a pottery sherd, a five-division laser scan at the highest quality takes about 15 minutes on the scanner. Using current protocols, we were able to process around 40 sherds per day with continuous scanning, a rate comparable to that achieved by the Israel Antiquities Authority, although under different circumstances (Karasik *et al.* 2014: 210). Dark objects, especially bronze and obsidian, however, are better suited to image modeling, which is less efficient vis-à-vis person-hours. With the help of Karasik and Smilansky's (2008) software, resultant 3D scans were used to produce publication-quality illustrations (Gilboa *et al.* 2012), with the ultimate goal of automated morphometric analysis (see above).

Project coordination and connectivity

Equally important to the success of intricate projects such as excavations is the coordination of work. Here too we were able to leverage digital tools, notably Microsoft Sharepoint (henceforth Sharepoint) and Google Hangouts. Sharepoint, available through an institutional site license, serves as the central hub for all project information and schedules. Such information ranges from pre-season procedures for acquiring Turkish research visas, to excavation and laboratory protocols and cheat-sheets for Turkish vocabulary. Team members thus always have access to up-to-date project-related information. Similarly, team scheduling is managed through Sharepoint, with shared calendars coordinating everything from research-related field and lab staff rotations to more mundane but necessary scheduling of laundry-machine access. Sharepoint integrates directly with Microsoft Office, too, thus enabling the collaborative editing of documents and spreadsheets, complete with version control and change tracking, functions used by the co-authors to write this article.

In addition to coordination, real-time communication is crucial for large and fast-moving projects. While single person-to-person mobile service remains

Figure 7 **Illustration of the stages of recording ceramic fragments, from laser scanning and photography of individual samples (left) to 3D model and 2D profile (right).**

useful, we engaged a more flexible solution for maintaining conversations with multiple people at multiple physical locations: Google Hangouts, a free text, voice, and video conferencing system available to anyone with a gmail account. The Hangouts app runs on all popular mobile, laptop, and desktop platforms and allows for free video conferencing of up to 10 simultaneous connections. Throughout the season, we maintained multiple chat conversations engaging with the relevant parties of particular topics. For example, a conversation thread connected excavation area supervisors to the conservation team, with a simultaneous conversation connecting area supervisors and the 3D photogrammetry lab. More informally, a private Google Plus Community enabled sharing and cross-commenting on candid photographs of everyday life within and outside field and lab work. As these solutions are cloud-based, they rely neither on our server nor on our physical location in western Turkey. Thus, they are seamlessly extended beyond the field season and have become crucial tools for coordinating activities across multiple continents in both pre-season preparations and post-season collaboration.

Case Study: The Recording of a Semi-Subterranean Granary

Description and discussion of the excavation and documentation of a single feature and its contents here demonstrates how the KAP recording system is implemented in practice. This case study focuses on the contents of a circular stone-lined pit (99.526.80) discovered adjacent to and outside a house wall in the northern portion of excavation area 99.526. Its identification is still preliminary; for the sake of simplicity, we refer to it hereafter as a "granary," a storage facility for grain (FIGS. 8, 9). Its contents were excavated in a total of four spatial contexts: 99.526.31, 99.526.39, 99.526.43, and 99.526.47.

The granary was first revealed upon the complete removal of a uniform deposit of fill (99.526.6) extending from the house wall to the edges of the excavation area. To document the closing of this context, 15 CTs were placed at even intervals across it. (For smaller contexts, CTs can be placed immediately outside their margins.) Following a modified version of a previously published image-capturing strategy (Olson *et al.* 2013: 252), the context was then photographed in 47 overlapping images using a Samsung Galaxy Camera 2. While the images were uploaded directly from the camera to the server using its Wi-Fi network connection and the free ES File Explorer app, the point coordinates of the CTs were recorded using the GNSS. The coordinates recorded at each CT location were labeled using the unique three-digit ID of each CT, and then the set of points for the spatial context were exported as a comma-delimited text file to a flash drive using the USB port on the GNSS and uploaded to the server using an onsite laptop. The result of this documentation process, using the Samsung camera and the GNSS, was referred to as a "photobatch." Each photobatch thus corresponds to a set of data associated with a surface revealed by excavating a spatial context: a set of photographs, coordinate data for CTs, and the intermediate outputs produced in Agisoft PhotoScan Pro. These intermediate outputs include the orthophotos used in ArcGIS by the excavators, as well as several other outputs discussed below.

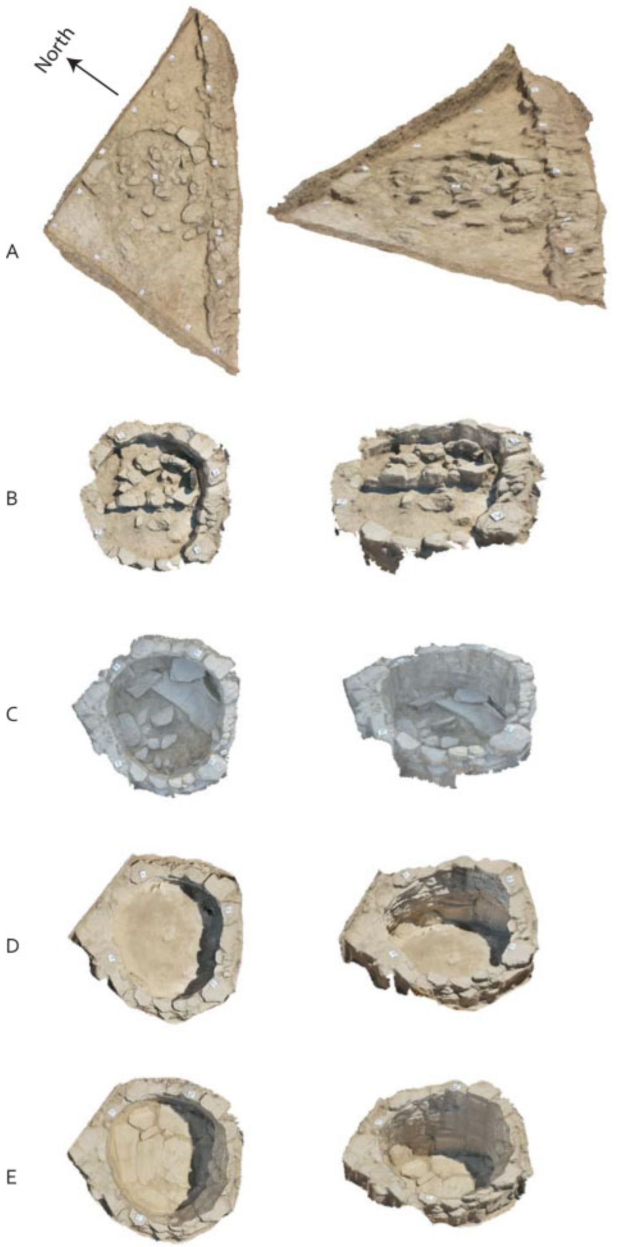

Figure 8 Illustration of the recording stages of the semi-subterranean granary, showing orthophotos (left) and photorealistic surfaces (right). A) Uppermost surface associated with the feature, immediately beneath fill 99.526.6; B) Bottom surface of fill deposit 99.526.31; C) Bottom surface of fill deposit 99.526.39; D) Bottom surface of fill deposit 99.526.43; E) Bottom surface of fill deposit 99.526.47 and hence the bottom of the granary (see online supplementary links at http://www.maneyonline.com/doi/full/10.1179/2042458215Y.0000000004).

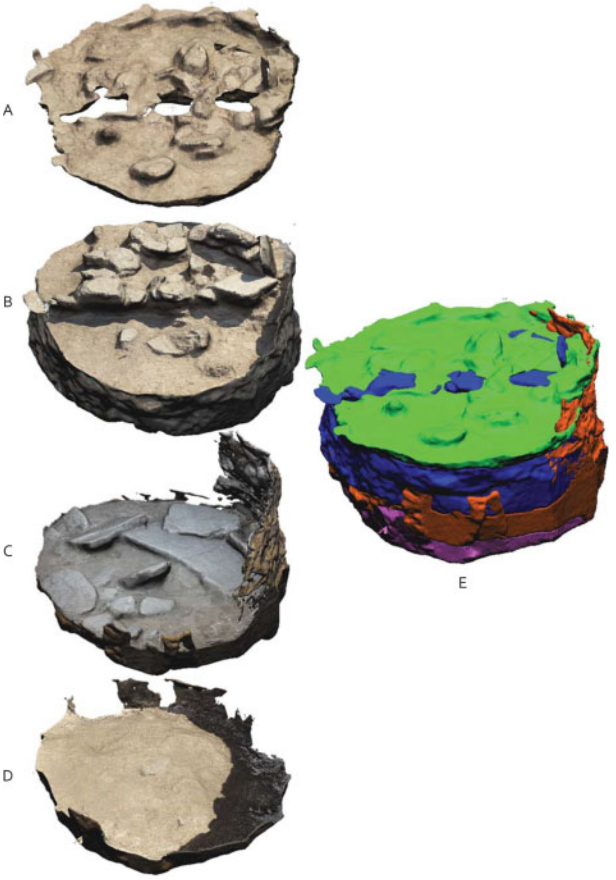

Figure 9 Volumetric reconstructions of each of the spatial contexts excavated from the granary. A) 99.526.31; B) 99.526.39; C) 99.526.43; D) 99.526.47. E) illustrates the four fill deposits color-coded by spatial context and recombined into a "water-tight" model representing the entirety of the contents of the granary (see online supplementary links at http://www.maneyonline.com/doi/full/10.1179/2042458215Y.0000000004).

The orthophoto resulting from the photobatch for the bottom of context 99.526.6 was then consulted in the field using ArcGIS' raster mosaics via RDC to determine how to proceed with excavation (FIG. 8A: left). In general, raster mosaics allow excavators to have a convenient tool for examining a cumulative set of all orthophotos produced from their excavation areas without requiring each image to be loaded into their active map project in ArcGIS. At that stage, the circular arrangement of stones has been assigned a context number (99.526.26) and the area within it was treated as a discrete spatial context, with the newly produced photobatch representing its top surface. In "opening" a new context for excavation, the excavator first opens the Access data entry form for contexts via the RDC connection. The database automatically assigns the next available context number (in this case 99.526.31), which is then marked as a spatial context (as opposed to a group). Excavator name, opening date, and initial details and descriptions specific to the context are all recorded. Data continues to be entered in this form throughout the excavation of the context. Stratigraphic relationships among spatial contexts are indicated in the database only for the "Earlier than" (i.e., below) or "Contemporary with"/"Equal to" relationships. The database automatically indicates the reciprocal relationship on the related context's own form. At this point, excavators often switch to the Evernote app and record narrative notes about the new context. As the final step in the opening process, the excavator uses the tablet stylus to digitize its margins as a polygon in ArcGIS via RDC.

After delineating the horizontal extent of this particular spatial context (99.526.31), the excavator removed all sediment associated with it, using the spatial context ID as the key for all collected samples, which were entered into a sample entry form in Access, as described above. While progress photos were uploaded using the custom photography app, other notes were recorded in Evernote and on the context's data entry form throughout the process of its excavation. Recording its spatial characteristics was unnecessary until it had been completely excavated. In this first phase of granary-content excavation, a change in sediment was observed after only a few centimeters of excavation, and thus the active spatial context was "closed." The closing of the context occasioned the production of another photobatch following the procedure described above. The photobatch for fill 99.526.31 was produced from only 4 CTs and 43 images.

Again, an orthophoto of the bottom of fill 99.526.31 was delivered to the excavator over the network upon processing (FIG. 8B: left), and it served as the representation of the top surface for the underlying context. This second context, another deposit of fill, was opened with a new data entry form, a new context number (99.526.39), and a new polygon. After the removal of several dozen centimeters of fill, the context was closed and another photobatch documented its bottom surface (FIG. 8C: left) again representing also the top surface of the subsequently excavated deposit of fill, given spatial context number 99.526.43. Upon the full excavation of fill 99.526.43, its bottom photobatch (FIG. 8D: left) also represented the top of a final deposit of fill, 99.526.47. The photobatch for this lowest context associated with the interior of the granary (FIG. 8E: left) thus illustrated the stone-paved floor of the feature (99.526.85). In all, the granary contents were excavated as four distinct spatial contexts, based on the excavator's interpretation of the feature's stratigraphy, and was documented by five photobatches. Although the granary contents were interpreted as four separate episodes of infilling, they could easily have been grouped together, as were the architectural elements of the granary itself, with group context number 99.526.80. Volumes that are part of group contexts, then, can be kept separate or merged into a single volume as needed.

Because each excavation episode was documented using image-based modeling techniques, a 3D volumetric representation of each spatial context could be produced by a participant with appropriate technical training. This was accomplished using two software products, the aforementioned Agisoft PhotoScan Pro and CloudCompare, a free program designed for manipulating 3D point clouds distributed under a General Public License (GPL). The workflow used in Agisoft PhotoScan Pro to process each photobatch produced orthophotos for use by the excavators, but it also produced point clouds, 3D representations of the surface remaining after the excavation of each spatial context.

To produce a volumetric representation of a spatial context, the point cloud representation of its top surface when it is opened (produced by the photobatch associated with the context above it) must be combined with the point cloud surface of its bottom, produced by the photobatch made when the spatial context is closed. For the granary contents, four volumetric representations were produced using the five surface representations (FIG. 9: left). These five surfaces include the bottom of 99.526.6 (FIG. 8A: right), the context situated immediately above the granary, and the bottoms of each fill deposit excavated from its interior: 99.526.31 (FIG. 8B: right), 99.526.39 (FIG. 8C: right), 99.526.43 (FIG. 8D: right), and 99.526.47 (FIG. 8E: right). In this case, the fill episodes were relatively simple in their juxtaposition, with minimal interdigitation and with the bottom of one coterminous with the top of the next. Therefore, the volumetric reconstruction of the granary was rather straightforward, though this system works equally well where there is only partial overlap of adjacent contexts. The polygons digitized by the excavator upon opening a spatial context serve as a particularly useful aid to the technical specialist in reconstructing such partially overlapping contexts.

The most crucial tool used in producing volumetric representations in CloudCompare is the Poisson Surface Reconstruction tool. This tool produces a "watertight" envelope that best fits both top and bottom point-cloud surfaces and fills any latent holes or gaps in the datasets (FIG. 9). The Poisson Surface Reconstruction Tool is one of many particular solutions to a best-fitting problem (Kazhdan *et al.* 2006), but has demonstrated itself as quick, versatile, and accurate. From CloudCompare, the 3D volume can then be exported in a variety of formats and imported into any number of software programs for management, analysis, and interpretation.

Implications

A paradigm shift

The advances in archaeological practice embodied in the recording system described above, as well as in recent experimentations by others with recording digitally and in 3D, represent a significant paradigm shift in archaeological recording. The shift is part of the increasingly digital culture of archaeology, referred to elsewhere as a "digital heritage ecosystem" (Limp *et al.* 2011), represented by fully digital methods, workflows, and data, not limited to excavation. With tablet computers running Evernote, Access, and ArcGIS via RDC, and Wi-Fi-enabled digital cameras and GNSS instruments in hand, this shift meant avoidance not only of paper, but also of tape measures, line-levels, and drafting sheets. With these traditional—even "signature"—tools of the archaeologist now rendered unnecessary, if not obsolete (Smith and Levy 2014: 166–167), a shift to a digital paradigm is unmistakable.

We view this shift in a positive light, allowing for long-term increases in accuracy, efficiency, and data sharing. Yet others might fret that such developments are potentially "de-skilling" (W. R. Caraher, personal communication 2014), or at least that they diminish the reflexive value of mechanical or analog archaeological methods. On the contrary, we argue that skills are not lost, but only shifted from analog to digital. Furthermore, by reducing needs for mechanical recording of spatial and some aspatial characteristics of archaeological contexts and samples (e.g., elevations and color), we are, in effect, increasing efficiency and thereby providing greater opportunity for in-the-field reflection about depositional and post-depositional processes and the human behavioral and natural conditions that drive them. In essence, by fully digitizing otherwise time-consuming and less-accurate processes of manual recording, we enable fuller engagement with the material record in the field while simultaneously increasing the technical literacy of project participants.

Beyond being digital, the recording system compels a conceptual shift such that archaeologists must think volumetrically about the total archaeological record, through both the system's definition of spatial contexts and their 3D documentation. Accordingly, excavators must be more mindful than in traditional recording systems of eventual digital reconstructions of all excavation events, not just of stratigraphic or architectural entities. As a prosaic example, scarps, walls, and floors are frequently swept and cleaned as routine events of excavation, removing small amounts of material that are rarely recorded as separate spatial contexts in traditional recording systems, unless they produce material finds. Each one of these events creates negative spaces, however, and these are captured by sensitive 3D recording systems (see the vertical wisps of sediment in FIG. 9, for example). Accordingly, excavators must constantly attend to the removal of sediment: no removal of material is too small to be modeled. In a more wide-ranging sense, shifts away from 2D abstractions of contexts have positive effects not just in the representation of 3D volumes, but even more so in thinking about them. In a 3D system, mentally connecting the volumetric physicality of the excavation process with recorded results is more intuitive and better representative of archaeological depositional processes. Because one's mind's eye now conceptualizes stratigraphic and architectural entities in 3D rather than 2D space, minor differences and similarities become apparent more naturally. Already we have seen excavators frame excavation strategies around such concepts, needing to remain mindful of the volumetric juxtaposition of spatial contexts at every step of the process, thereby increasing engagement with the material archaeology at hand.

Accuracy, resolution, and efficiency with simplicity and consistency

An early criticism of digital field recording methods worried they were unable to maintain levels of accuracy achieved by traditional architectural drafting, for example, at common scales of 1:20 or 1:25. Recent studies, however, cite Root Mean Square Errors (RMSE) of 8–10 cm for traditional drafting (Prins *et al.* 2014: 193), while RMSE levels associated with digital recording like that used in our system vary depending on the size of areas modeled and the methods of capture. Typically low RMSE levels reach 1–3 cm for excavation areas of 25–700 sq m (Olson *et al.* 2013: 257; Prins *et al.* 2014: 193; Quartermaine *et al.* 2014: 116), and sub-centimeter levels for smaller areas (de Reu *et al.* 2013: 1111). The high-resolution of our image-modeled data, in fact, creates challenges for the storage of volumetric entities (see below). With anticipation that such challenges will be met in the near future, however, we prefer to preserve the detail of non-uniform volumes rather than abstract them to polyhedra, as practiced by others recording in 3D (Smith and Levy 2014: 167), even if our methods may be less efficient in the short term.

While limited research has quantified the effects of "going digital" on efficiency, tablet recording in Pompeii fieldwork is reported to have increased productivity—however defined—by greater than 300% with around one-third the typical staff (Poehler and Ellis 2012: 2), and tablet recording in osteological lab work is said to have resulted in a 16% increase in data-recording efficiency while greatly reducing error (Austin 2014: 19). Simply by recording spatial and aspatial field data digitally and in real time, systems such as ours avoid potential sources of error deriving from analog to digital transcription and increase efficiency by repurposing time otherwise spent detecting and correcting such errors.

As with the adoption of most new technologies, perceived short-term inefficiencies (Howland *et al.* 2014: 188) are gradually replaced with increases in efficiency as experience is gained and time and resources are dedicated to incremental improvement of tools and methods. Our work thus far has focused on establishing a complete digital culture, while minimizing the time and costs of further development. In this way we gain experience and identify precisely those challenges needing resources for subsequent phases of implementation.

Beyond being digital, core concepts of the data structure are simplicity and consistency. The system handles all traditional archaeological data with only three data structures: the area, the context, and the sample. Everything excavated or analyzed fits into one of these categories with no exception. As described above, traditional small finds, for example, are really just objects requiring higher degrees of spatial specificity. This spatial specificity, including orientation, is implicit in the volumetric spatial context of our system that encapsulates the sample, the small find, itself. The system thus avoids the unnecessary complexity of two parallel spatial data structures—points and volumes—that must later be merged to enable comparative analysis.

This structural uniformity offers advantages, especially with respect to cross-material analyses that are often challenging to implement because of subdisciplinary separations within traditional recording systems. Within our system, for example, all faunal, lithic, and ceramic materials are recorded consistently in the sample data structure, whereby common characteristics are recorded in different rows of the same column (e.g., weight, count, color, chronology, and analytical or conservation treatments), enabling easy cross-material comparisons.

Similarly, the advantages of simplicity and consistency in data structures are inherent in considering inter-site data comparison of open-access published original datasets (see below). Archaeologists record similar core sets of data—spatial data and material analyses—even if adopted terminologies differ among projects. When a project introduces more than one data structure for essentially the same type of data, however—e.g., small find vs. spatial context—a superfluous complexity is introduced, inhibiting direct comparison among sites before semantic mapping between counterpart terms (e.g., Shen *et al.*'s 2008 SchemaMapper). Furthermore, in addition to simplicity in data structure, data comparison is further facilitated by our system's complete avoidance of abbreviations in data storage, increasing the potential for cross-disciplinary and cross-site understanding of original raw data—a concept essential to its eventual open-access publication (Kansa and Kansa 2013).

Current challenges and future opportunities

Software and hardware limitations are the primary challenges in the recording system proposed here, while future opportunities are restrained only by one's imagination. Our system of recording contexts in their full volumetric reality has been described above, yet significant challenges remain in integrating non-uniform volumes with relational databases. While PostgreSQL with PostGIS, among other open-source and commercially available GIS and geodatabase management systems, can handle 3D objects in multipatch and other formats, the volumes we produce from excavation are of such high resolution they are currently ill-suited to such systems (Breunig and Zlatanova 2011: 801). This leaves us in the same position as many colleagues, in the ongoing exploration of alternative software and file formats, for the perfect set of tools to integrate volumetric entities fully into interactive archaeological management systems (Losier *et al.* 2007; Katsianis *et al.* 2008). Such alternatives include 3D CAD drafting programs such as Rhino 3D, in which volumes rendered as meshes can be measured, cross-sectioned, selectively displayed, and rendered in full photorealistic color. Other CAD programs are capable of handling SQL statements also, which are key to the concept of fully integrated database management systems. Eventually, use of a fully 3D, volumetric information system (VIS) would allow area supervisors to work immersed in a 3D environment, enhancing decision-making and interpretive processes while still in the field.

The challenge of further improving field-recording efficiency might also be rectified with the steady development and integration of both software and hardware capabilities. Some projects already employ well-integrated solutions whereby coordinate data are transferred directly from survey instruments to databases (Smith and Levy 2014: 167). In place of our two-stage capturing process—first photography then GNSS survey—an integrated system that leverages something like Swift navigation's affordable yet highly accurate Piksi GNSS system (http://www.swiftnav.com/piksi.html) to geolocate 3D capturing devices themselves—whether cameras, structured-light sensors, or something else—would reduce by half the steps of 3D recording. Entirely new technologies and/or equipment, such as structured-light, LED, or 3D motion and depth sensors like the affordable Sense scanner (http://cubify.com/en/Products/Sense) and Google's Project Tango (https://www.google.com/atap/projecttango/), may offer further possibilities to accelerate 3D model capture. As technologies develop, processes inherent in fully 3D recording systems will only get easier to use, more affordable, and even more accurate, just as new opportunities will continue to increase. This process is being furthered not by academic researchers so much as by commercial opportunities inherent in the growing "maker culture" (e.g., 3D scanning and printing) and industries such as those involved in micro-location and robotic navigation (e.g., Google's Project Tango and Self-Driving Car project, https://www.google.com/atap/projecttango/#project). With such engines driving technological advances, users investing in off-the-shelf solutions will see even higher returns on investment.

Investment in technical expertise and digital equipment is, of course, critical. It remains financially impossible for most archaeological projects to attract technical specialists from industry. The increasing usability of digital tools (such as the smartphones and tablets discussed above), however, suggests that technical training for archaeologists will go far to distribute digital know-how at relatively low cost and that most projects will adopt similar digital cultures. The primary equipment expense to implement the KAP system involved the onsite network. Excavations near urban areas might avoid this expense while at the same time taking advantage of the possibilities offered by a digital culture.

Because our project was born digital by investing early in digital infrastructure, we are now in a position to use that platform to innovate in as many directions as we can devise. Devoting resources to the research and design of new possibilities for digital field recording, in general, is more feasible when the platform for improvement is already fully digital. As an example, while our PV system was intended primarily to power the recording system, it also allowed for the establishment of both a weather station to record environmental conditions and an IP-enabled security camera. The weather station now logs temperature, humidity, precipitation, and wind on a continuous basis, data that will be used to understand better the environmental conditions affecting the conservation and restoration of archaeological remains at Kaymakçı as well as to approach Bronze Age spatial organization and design with respect to natural elements (Frank *et al.* 2014). The camera reduces the burden of onsite security while maintaining high standards of heritage protection and allows for visual inspection of site conditions throughout the year and throughout the world. This sharing of weather and camera data is emblematic of the great opportunities the system provides for knowledge sharing in general.

Internally, efficient knowledge sharing across digital platforms facilitates cross-disciplinary collaboration in ways previously unanticipated, such that decision-making in excavation areas as much as in labs can be iterative, group processes. Furthermore, participants unable to join the fieldwork can remain part of conversations, in all ways but physically, and can follow excavation progress through written journals, photography, and videos as necessary.

Looking outwards, efficient knowledge sharing equates with quick and accessible publication of data. The systematic and real-time digitization of excavation data enabled by our system not only goes a long way toward mitigating the destruction inherent in the discipline, but also makes possible online and open-access dissemination of an excavation's complete archaeological record, allowing for the reproducibility of process that makes archaeology a science. Such open-access data archiving is now required by many granting organizations and publication venues, and leveraging digital infrastructures for this purpose is the only manageable way forward (Ogburn 2010; Kintigh 2006; Austin 2014). Parallel to this push for greater data-sharing is the recognition across most academic fields of the importance of data-storage standards for long-term data preservation. Researchers are increasingly seeking solutions from institutions traditionally responsible for preserving knowledge: governments, universities, libraries, and archives. In academic archaeology, long-term data archiving occurs now in repositories at universities and in public services such as the Digital Archaeological Record (tDar) in the United States and the Archaeology Data Service (ADS) in the U.K.

Data sharing allows for the sort of broad-brush, inter-site comparisons that can increase understanding of some of the greatest concerns of humanity more so than can single datasets: climate change, social inequality, and urbanism, for example. If archaeologists argue that their work provides such public benefits, they must be willing to provide full access to their complete and original data as well as to their analytical results (Gestrich 2011). A significant goal for archaeology, then, is the free and open accessibility of such datasets. The most efficient way to reach this goal is to generate publishable or near-publishable quality data at the time and place of collection, so that additional data preparation—sure to slow publication—becomes unnecessary.

Final publication, furthermore, will be innovative and intuitive with digital open-access dissemination technologies. We envision future interactions with all excavation results through multilevel and multimedia presentations. Traditional narratives of excavation process, analysis, and interpretation will be accompanied by interactive 3D environments displaying site and sample models relevant to each narrative. Narratives will be appropriately interlinked and connected to original structured field data, archived with interfaces such as Opencontext.org. Original data, then, will contribute to the global Linked Open Data movement that enables continued creative remixing and reevaluation (Elliott *et al.* 2014; Heath and Bizer 2011).

Conclusions

The purpose of this article has been to introduce recent advances in archaeological practice that move beyond the concept of excavation as destruction to one of excavation as digitization. Inherent in this conceptual shift are radical changes to the way excavation recording is conducted, involving the abandonment of manual or mechanical techniques in favor of more accurate and efficient recording routines and the adoption of fully digital and volumetric documentation to preserve more of the archaeological record than is typical of 2D abstractions. Such routines are enabled by a recording system that privileges simplicity and internal consistency, both for the production of near-publication-ready data at the point of collection and for its potential for meaningful analysis across contexts, excavation areas, and even sites and regions.

To encourage others to produce similarly structured data, ready for analysis and comparison, we focused on non-custom-made software and hardware solutions, which themselves are shifts away from the custom solutions recently implemented by others. Although adoption of off-the-shelf hardware and software necessitated more energy in their integration, we benefited significantly from continual improvements facilitated by developers with larger budgets than those of most archaeological projects. Furthermore, this recording solution should be relatively easily adopted by projects that already employ some of its components (e.g., Access entry forms and ArcGIS geodatabase management). The potential is great for others, especially those starting new projects, to follow in similar footsteps, partaking in this exciting period of change in practices.

The shift to a digital culture in archaeology represented by this and other recently developed recording systems represents a new paradigm in archaeological practice and offers many opportunities. As we argue, this shift is quite positive, encouraging archaeologists more than do traditional recording systems to conceptualize the archaeological record in its volumetric physicality and allowing them to record more accurately and efficiently than ever before, leaving more time for engagement with the material itself. Furthermore, taken to its logical conclusion, the system proposed here could be simplified even further from three data structures—area, context, and sample—to two, with the omission of the area data structure made possible by that fact that all necessary spatial information is embedded at the context level. This omission of the excavation area data structure leads to questioning the need for physically defined excavation areas themselves. Rectangular excavation areas, after all, were developed primarily for the purpose of controlling spatial, in addition to stratigraphic, information, as most notably developed in the Wheelers' box-grid system (Wheeler and Wheeler 1936).

With many 3D recording systems currently in use, archaeological practice has the potential to advance beyond the box-grid and even open-area excavation, wherein the context becomes not only the most basic, but the only unit of spatial information. With an abandonment of both the tools and spatial divisions of traditional archaeological excavation, we may be describing the most radical change to archaeological practice since the introduction of structured excavation and recording over a century ago.

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Christopher H. Roosevelt (Ph.D. 2003, Cornell University) is an Associate Professor at Boston University and Director of the Kaymakçı Archaeological Project. His research interests include archaeological and spatial technologies, especially as implemented in the archaeology of Bronze and Iron Age Anatolia and the eastern Mediterranean.

Peter Cobb (M.S. 2008, University of North Carolina at Chapel Hill) is a Ph.D. candidate in the Art and Archaeology of the Mediterranean World program at the University of Pennsylvania. His research interests include the ceramics of western Anatolia during the second millennium B.C.

Emanuel D. Moss (M.A. 2013, Brandeis University) is a doctoral student at the CUNY Graduate Center in New York, NY. His research interests include the relationship between visualization technologies and the production of knowledge, particularly in archaeological and heritage contexts.

Brandon R. Olson (M.A. 2009, the Pennsylvania State University, State College) is a Ph.D. candidate in the Department of Archaeology at Boston University. His research interests include fluctuations in settlement and land use as a result of changing hegemonic powers initiated by Greek and Roman expansion in the Levant. He seeks to harness the analytical qualities of Geographic Information Systems and 3D modeling in every stage of the archaeological process to identify, characterize, interpret, and disseminate diachronic and episodic change in human settlement.

Sinan Ünlüsoy (Ph.D. 2009, University of Tübingen) is an Assistant Professor at Yaşar University, Izmir, Turkey. His research interests include the Aegean and Anatolian Bronze Age as well as archaeological stratigraphy.

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