Research Article

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Born-Digital Logistics: Impacts of 3D Recording on Archaeological Workflow, Training, and Interpretation

<https://doi.org/10.1515/opar-2020-0150>

received December 7, 2020; accepted May 31, 2021

Abstract: Digital technologies have been at the heart of fieldwork at the Kaymakçı Archaeological Project (KAP) since its beginning in 2014. All data on this excavation are born-digital, from textual, photographic, and videographic descriptions of contexts and objects in a database and excavation journals to 2D plans and profiles as well as 3D volumetric recording of contexts. The integration of structure from motion (SfM) modeling and its various products has had an especially strong impact on how project participants interact with the archaeological record during and after excavation. While this technology opens up many new possibilities for data recording, analysis, and presentation, it can also present challenges when the requirements of the recording system come into conflict with an archaeologist's training and experience. Here, we consider the benefits and costs of KAP's volumetric recording system. We explore the ways that recording protocols for image-based modeling change how archaeologists see and manage excavation areas and how the products of this recording system are revolutionizing our interaction with the (digital) archaeological record. We also share some preliminary plans for how we intend to expand this work in the future.

Keywords: structure from motion, photogrammetry, 3D modeling, excavation

1 Introduction

Digital technologies have a long history in archaeology. However, in recent years, the pace of the so-called “digital turn” has increased rapidly; exponential growth in computer processing power, as well as continuous development of both proprietary and open-source software for a variety of tasks, has made the widespread incorporation of digital methods into archaeology more accessible than ever before. Along with these radical changes come questions about how new digital workflows will change archaeological practice and pedagogy. How do we prepare for this new way of investigating the past? What do we gain and what do

Article note: This article is a part of the Special Issue on Art, Creativity and Automation. Sharing 3D Visualization Practices in Archaeology, edited by Loes Opgenhaffen, Martina Revello Lami, Hayley Mickleburgh.

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we lose when we shift from traditional recording methods to digital ones? Here, we explore one component of these questions by considering the impact of digital technologies on archaeological practice at the 2nd millennium BCE citadel of Kaymakçı, located in the Gediz River valley in western Turkey.

The Kaymakçı Archaeological Project (KAP) has used a fully born-digital recording system since its inception in 2014 (see Roosevelt, Cobb, Moss, Olson, & Ünlüsoy, 2015). Archaeologists in the field and those in the lab record data directly into the project's relational database through tablets or computers that interface in real time with a central server via Remote Desktop Connection or file sharing. Excavation area supervisors use Evernote to record excavation activities in daily journals, which allows for the incorporation of annotated photographs, tagging entries for easy searchability, and digital archiving; other project members use Evernote to keep track of other routine processes. Excavation area supervisors also use digital cameras or tablets to record end-of-the-day video logs that are archived on the server for easy reference. Even day-to-day communication is partially digitized, with conversations between project members (particularly between those in the field and those in the lab) happening via Google Hangouts. The use of structure from motion (SfM) recording to collect spatial data at Kaymakçı exists within and depends on this broader digital milieu.

The rapid increase in SfM recording and 3D representations in archaeology signals a major shift in archaeological practice. Although these technologies have existed for decades, we are only now beginning to see their large-scale implementation. SfM recording has significant benefits; it is ultimately more time-efficient and accurate than traditional recording methods in collecting large amounts of information on complex topographies, and it provides new ways to generate, manipulate, and present those data (De Reu et al., 2014; Olson, 2016; Opitz, 2015; Roosevelt et al., 2015). It also creates new possibilities for communication within projects (between field personnel and specialists), within the broader archaeological community, and with the public because of the potential to build capacity for stakeholders to engage more directly with primary spatial data. Some archaeologists, nonetheless, have pointed to the complicated impacts that the digital turn, in general, has had on the development of expertise and processes of interpretation in archaeology (Caraher, 2016; Morgan & Wright, 2018). It is therefore vital that we explore and try to understand the many ways that the use of SfM recording for spatial data collection reshapes our engagement with the archaeological record and more broadly the practice of archaeology.

We find ourselves in the midst of another (potentially major) shakeup in archaeological practice. The unexpected onset and persistence of COVID-19 has suspended many large-scale excavations and may continue to do so; the long-term impacts that this pandemic may have on the global archaeological community are still unknown. Within this context, our goal is to reflect on the lessons learned from the first 6 years of digital archaeological practice at Kaymakçı, and particularly to try to understand better how SfM recording shapes the lived experience of excavation and interpretation. Here we consider the ways that an individual's experience, technical expertise, and position on the project create unique negotiations with the process of SfM recording, and how choices about project structure create and maintain divides in project member experiences in the field and lab. We further explore how basic logistical concerns of this particular digital method – including training, data management, and daily planning – impact and are impacted by conceptual shifts in the way that individuals see the archaeological record and archaeological data. Finally, we consider how the products of SfM recording – particularly digital representations not created through traditional recording methods – shape interpretation in the moments following excavation and far into the future. Throughout these discussions, we seek to acknowledge the complexities and frustrations inherent in how individuals and projects negotiate these aspects of the digital turn in archaeology.

2 Structure from Motion Recording at Kaymakçı and Beyond

At Kaymakçı, spatial data – as well as most other kinds of data – are connected to a “spatial context,” the most basic spatial unit of excavation in the KAP recording system, which follows a modified single-context excavation process (see Roosevelt et al., 2015). On one level, a spatial context represents a volume (of a

deposit, of an object, etc.) that can be grouped with other contexts to form larger units (e.g., features, houses, excavation areas, sites) yet can never be divided. On another level, the spatial context also acts as a “container” that “holds” all associated objects, samples, digital data, etc. Indeed, everything contained within a given context derives all of its spatial data from that context. Most spatial contexts equate to “archaeological entities” or “archaeological events” (Leighton, 2015) in that they represent past deposits or actions (e.g., pit fills) that are stratigraphically distinct. In addition, spatial contexts provide the opportunity to capture “excavation events” (Leighton, 2015): arbitrary division of deposits, cleaning contexts, artifacts, or specific samples (e.g., paleoethnobotany, sediment chemistry, etc.) that require their own spatial data. This process of recording spatial contexts captures multi-perspectival and interrelated variations in digital data entry. On the one hand, archaeologists cater to subdisciplines through these collection practices; yet on the other, the broadening of inter- and transdisciplinary foci allow for an influx of new ideas to analyze micro- and macro-histories. This scalar approach is realized through a volumetric approach.

At Kaymakçı, SfM recording replaces traditional spatial recording methods such as measuring points in 3D space with strings and plumb lines, hand-drawn plans and profiles, and elevations collected in the field with a GPS or total station. Instead, the plans and profiles that result from these techniques are generated digitally (Roosevelt *et al.*, 2015). The volume and location of a spatial context are recorded using a series of georeferenced models that represent its “bottom” and “top” surfaces. Bottom surfaces are the first spatial data connected to any given context, collected after excavation and capturing the negative impression of the context. Bottom surfaces are then combined with the corresponding top surface(s) (or, the bottom surface(s) of the context(s) immediately overlying/surrounding the target context) to create a “watertight” volume from which a 3D representation of the context can be constructed (see Nobles & Roosevelt, 2021, this Special Issue). In some cases, a “top” and “bottom” will be recorded in immediate sequence for a single context; most often such contexts represent objects, for which the top and bottom models create a discrete volume. Some contexts, however, cannot be recorded easily or usefully with the project’s SfM recording techniques, usually because they are too small (e.g., a single, small object), already dislodged from original positions, or owing to processing capacity (e.g., gridded sampling for paleoethnobotany). In these cases, the context is termed an “approximate context” and spatial data are recorded as a single set of xyz coordinates using RTK-GNSS equipment. The original position of such items is recorded also in photographs, and the items themselves may be volumetrically modeled once removed. The integration and analysis of 3D volumes from all spatial contexts (whether generated from the top and bottom surfaces of spatial contexts or from subsequent individual modeling of approximate contexts) is a continuing goal (see Nobles & Roosevelt, 2021).

Although 3D technologies have been used in archaeology for decades, and although SfM recording in particular has gained rapid popularity, only a few projects have entirely replaced traditional methods of spatial recording with digital alternatives. There are significant costs and logistical challenges associated with this transition; such a system requires a robust digital infrastructure, capable of transferring and storing large amounts of data as well as running intensive software processes. It also requires a high degree of specialized knowledge, which increases the burden on project participants and/or requires hyper-specialization of project personnel (for “slow archaeology,” see Caraher, 2016). Furthermore, the shift to born-digital recording may incur some interpretive disadvantages, including disengagement from the materiality of the archaeological record and increased rigidity in the ways in which that record can be displayed in (digital) drawings and plans (Morgan & Wright, 2018).

Once a project makes the decision to “go digital,” strict protocols need to be followed for collecting and processing digital spatial data for SfM recording. Such logistics include the following: collecting digital photographs and reference coordinate data; recording relevant data in the database; uploading these data to a computer/server for processing; building the model in specialized software (often Agisoft Photoscan/Metashape); creating output files (orthophotos, DEMs, point clouds, etc.) and storing them in a standardized file hierarchy; and building and displaying 3D volumes using a variety of software applications. Digital practices at Çatalhöyük, for example, are instructive. Each team that used digital spatial data was responsible for collecting and processing those data from start to finish (Berggren *et al.*, 2015; Forte, Dell’Unto, Issavi, Onsurez, & Lercari, 2012; Forte, 2014). Following this framework, each team member is

trained not only in the protocols set forth for their specialty (e.g., excavation or human remains), but also in the protocols of image capture and modeling. An alternative example is that followed by the Tel Akko Total Archaeology Project, which had a designated team to collect, process, and manage all digital spatial data (Olson, Placchetti, Quartermaine, & Killebrew, 2013). Following this model, any given project member has fewer responsibilities and a narrower set of required skills; the “digital team” is essential to produce a holistic picture of an excavation area or a site.

KAP has used a hybrid system that involves field-based team members working independently from a lab-based digital team that processes models. This is in part due to limited capacity in rural areas of western Turkey for high-speed, reliable internet, and the physical distance between the excavation and the lab. Excavation area supervisors (who oversee excavation areas; hereafter “supervisors”) are responsible for all digital data collection tasks in the field, including collecting photographs and coordinate data, uploading these data to the server, and recording necessary metadata in the database. The lab-based “3D Spatial” team is then responsible for processing these data into spatial context models, building 3D volumes, and data management of models and all associated files in folder hierarchies and the database. This system has by no means been static; rather, there has been significant variation in the size and composition of teams based on the conditions and resources available during any given field season. During some seasons, project members have rotated between the field and the lab; these are most often excavation area assistants working with supervisors (hereafter, “assistants”); yet supervisors, too, have skated between both spheres. Owing to the complexities of the system and of coordinating expertise in the field, in 2018 a Field Supervisor became the point-person for field-based 3D spatial data capture for SfM recording and other aspects of excavation as well as a liaison with the lab teams.

One of the unintended outcomes of the use of the hybrid structure at KAP is a persistent divide between the experience and perspectives of project members working in the field versus those working in the lab. While some project members have been able to gain experience in all aspects of SfM recording, most have more experience either gathering data in the field or processing data in the lab. This divide has significant implications both for the lived experience of day-to-day excavation and recording and for the use of data from image-based modeling beyond the excavation.

3 Field Logistics for Structure from Motion Recording

The day-to-day experience of excavation – whether using traditional or digital methods – involves a complex series of concerns and negotiations. Logistical concerns involve setting daily goals, ensuring workforce efficiency, collecting accurate data, and planning for periods of closure during days off and, importantly, at the end of the season. Connected to these logistical concerns are cross-cultural interactions and negotiations with archaeologists from across the world and vocational staff from the area. On a conceptual level, there are moments that define “acts of interpretation,” from changes in soil color and texture to stratigraphic relationships and site formation processes. Training, too, is a concern; even outside the context of a field school, the differing levels of experience and technical expertise of individual participants necessitate constant learning to ensure consistent and high-quality data collection. A significant shift in methodology, such as the introduction of SfM recording, necessarily has a significant impact on this kaleidoscope of daily concerns and the deployment of expertise.

3.1 Divisions of Labor

It is worth considering, first, the various personnel on site and how each interacts with excavation and SfM recording. For example, in any given excavation area at Kaymakçı, two formally and academically trained project members work alongside locally hired practitioners who do not have such formal training, yet have gained specific skill sets in this vocational setting. Excavation area teams thus usually consist of two fully

trained archaeologists – a supervisor and assistant – and five or six vocationally trained excavators. The supervisor is ultimately in charge of the management of the excavation area, from daily logistics to interpretive acts like drawing plans and writing reports. Assistants may stay in one excavation area or rotate between areas, depending on the conditions of any given season, and may be either very experienced in excavation or students who are relatively new to field archaeology. Excavators do the majority of the physical excavation at the site; their skill sets improve with experience, and thus they also train newcomers. Those handling field data in the lab are also academically trained.

The nature of the division between the field-based and lab-based aspects of SfM recording shapes an individual's perception of data collection and the archaeological record. The more responsibilities a person has in one sphere, the less likely they will gain expertise in another sphere, such as the work of the 3D Spatial Team; the exception to this pattern is the Field Supervisor, who needs expertise in all processes. The result is a burgeoning divide of expertise in fieldwork, data collecting, and SfM modeling. A disconnect, then, comes in understanding the full scope of all components of the recording and modeling process. Assistants more easily rotate through multiple roles, and thus have more opportunity to gain experience with both data collection in the field and model processing in the lab. They become a valuable bridge in the full process. However, an area assistant's comfort with modeling and their role on the excavation will necessarily be highly individualized given the diversity of experience(s). The challenges of gaining and communicating technical expertise in SfM recording are an additional factor in the relationship between supervisors and assistants – already complicated by archaeological expertise, project logistics, personality, and language – through which both daily practice and ongoing training are negotiated.

Excavators, almost always native Turkish speakers, are arguably the most divorced from SfM recording precisely because their field of expertise does not come from classroom-based learning and conceptual discussions of SfM, but rather extensive, first-hand practice with soil extraction during excavation. Over multiple years of exposure, both the SfM expert and excavator more easily collaborate in precise recording and data capture during the process of excavation. The process must also consider hurdles in language barriers; modeling-savvy supervisors and assistants with sufficient Turkish are necessary to offer sufficient training in SfM recording. As experts in excavation adjust to SfM methods, best practices in extraction will also be refined. In this way, the interface between the archaeological record and archaeological practice (“at the trowel's edge”) and the eventual digital products centers on the relative experience and spheres of expertise of all those involved.

To consider the other side of this equation, the divide between the field and the lab may also mean that the lab-based participants on the 3D Spatial team who process models have little opportunity to experience data collection in the field and thus to put the process of constructing volumes into wider archaeological contexts. The initial “top” and “bottom” surfaces are therefore experienced and lived as deconstructed and decontextualized abstractions of the archaeological record. Frequent communication with supervisors and other field-based personnel helps to mitigate hurdles associated with “holes” in data. The connectivity with the field extraction process is crucial given that the construction of volumes is to some extent an interpretive process. Unsurprisingly, the best 3D volumes are those created from an integrative process between excavation metadata and the lab process.

Ultimately, this disconnection between field and lab may result in the isolation of various aspects of SfM recording within “black boxes” (cf. Latour & Woolgar, 1979, p. 51), depending on an individual participant's experience, training, and role on the project. On a day-to-day basis, this often creates frustration. In setting up a born-digital archaeological field project, our experience is that the pedagogical approach requires constant refinement. Such integrative management mitigates the hurdles of not only how data are collected, but also how they are processed and interpreted – that is, our ability to avoid complete darkness within the “black box.”

3.2 Envisioning the Excavation Logistically and Conceptually

Beyond issues concerning training and the expertise of individual participants, we have found that the implementation of SfM recording shifts archaeological practice. The intersection of logistical concerns and

the way that the archaeological record is conceptualized complicate the day-to-day work of extraction. Here we focus on the experience of the excavation area supervisor, given their role as the primary manager and interpreter of a given excavation area.

On a very basic level, the use of SfM recording changes the dynamics of time management and routine activities. When thinking through these daily practices, it is helpful to consider the ratio of “time to excavate” and “time to record” for any given context; in general, a large and/or complex context takes a long time to record – via either SfM recording or traditional methods – while a small and/or simple context takes less time to record. An experienced supervisor is able to estimate excavation time, and therefore, to make the most efficient use of limited time on site. However, SfM recording adds not only new variables to an individual supervisor’s time management, but is dependent on efficient time management of other teams, including the 3D Spatial team and those in any other active excavation areas that rely on the same digital team and overall capacity. This added complexity can challenge the managerial skills of the most experienced supervisors. This also reflects a transitional moment in archaeology, whereby one (pre-digital) knowledge set is adapting to a new (digital) normal.

The use of SfM recording alters routine cleaning activities traditionally associated with pre-digital recording. For projects like KAP with goals to record all excavation areas in their full 3D, volumetric, and geographically referenced detail, it is necessary to account for total removal of material from the excavation area, including that removed during routine cleaning activities like sweeping and scarp trimming. In this way, projects must adapt long-used archaeological practices to new digital workflows. Routine acts like cleaning surfaces for photographs (which will then allow for illustrations) must be fully integrated into the volumetric recording process. This can be more burdensome for experienced supervisors comfortable with traditional recording methods that they have honed for maintaining clean and orderly excavation areas (e.g., scarp trimming before pictures, taking down temporary baulks during excavation). Indeed, these practices often directly contradict the best practices of a volumetric recording system. Considering all these factors, the particular logistical requirements of SfM recording challenge the cognitive capacity of a supervisor and team members, requiring new skill sets that foresee gaps in spatial interfaces. Most important of these new skill sets is the ability to “think in 3D,” that is, to mentally engrain the three spatial dimensions and original complexity of stratigraphy and to retain that 3D complexity in the production of documentary 3D products that are far more complex than representations abstracted to 2D forms.

The logistics of SfM recording also complicate the excavation of both especially large/complex and especially small contexts. On one end, a very large or very complex context often requires a large number of photographs to record, increasing the time for data collection, data transfer to the server, and the time to build a model. It might therefore take many hours or even the whole excavation day (in rare cases) to build a single model. Best practice will deploy strategic planning of digital model processing during off-times of excavation, and thus maximizing in-field time. Very small contexts suffer the opposite problem, in that there is only limited possibility to reduce the time necessary for data collection, transfer, and processing. For example, we might compare three contexts excavated in the same area on successive days: two fills and a small ceramic cup, the latter of which required recording both a “top” and a “bottom” (Table 1). Even discounting the time necessary for collecting photographs and GPS points, uploading data to the server, and file management, the difference between the processing time for the cup and for the smaller fill is not significant relative to the difference in context size/complexity. This further demonstrates that, in the case

Table 1: Processing time (in Agisoft Photoscan) for three contexts

Context number	Context type	Total processing time
99.526.467 “bottom”	Medium fill	55 min 58 s
99.526.446 “bottom”	Small fill	29 min 28 s
99.526.452 cumulative	Small ceramic cup	20 min 58 s
99.526.452 “top”		12 min 20 s
99.526.452 “bottom”		8 min 38 s

of particularly small contexts like single ceramic vessels such as 99.526.452, the “time to record” significantly outweighs the “time to excavate.”

While logistical concerns of SfM recording may discourage the excavation of small contexts, conceptual interests dictate the opposite. Because this type of recording system produces a georeferenced and highly accurate 3D representation of each excavated context, it arguably leaves less room for mistakes, such as digging a little too far into the layer below the target deposit. While a supervisor can record, in metadata and related data, explanations about what happened and how the context should be interpreted, the outcome of such a mistake is ultimately an inaccurate 3D model that persists through the metadata and thus through all subsequent engagements with the model. For projects like KAP that use a modified version of the single-context recording system, the pressure to ensure that a context is excavated as accurately as possible is compounded by the rule that contexts can be grouped into larger interpretive units but never divided. This pressure may be alleviated by employing a more flexible recording system such as that proposed by Croix *et al.* (2019), which takes a metacontextual approach to allow for further refinement of archaeological units following excavation.

Conceptual factors such as these encourage a “splitting” rather than a “lumping” mentality during excavation, meaning that supervisors are incentivized to excavate in smaller contexts that will theoretically produce not merely more data, but importantly more accurate data. A splitting mentality might encourage the arbitrary division of contexts that are considered too big, or it might lead a supervisor to close a context just in case the deposit has ended to prevent the accidental removal of material from the deposit below. The strongest impact at KAP, however, is on the excavation of multicomponent features such as stone walls, hearths/ovens, and semisubterranean circular features. Rather than treating a feature as a single unit, the splitting mentality encouraged by the recording method incentivizes the division of a feature into many discrete components, both for the purposes of excavation and interpretation. This has positive benefits of significantly increasing the amount of data collected from component parts of the feature and thus creating digital objects that are more flexible and manipulatable in virtual space. However, this practice comes with logistical costs, particularly in terms of the amount of (limited) time that can be dedicated to any one feature.

To explore further the tension between the logistical and conceptual concerns of this recording method, let us consider the extraction of oven 99.526.79. Oven 79 is located in excavation area 99.526 (Figure 1); this area was likely dedicated to open-air activities during the Late Bronze (LB) 1 phase (ca. seventeenth to fifteenth centuries BCE), but was built up in the subsequent LB 2 phase (ca. fourteenth to thirteenth centuries BCE) with features including a large rectilinear building, a circular feature interpreted to be a storage silo, perhaps for grain, and oven 79 (see also Nobles & Roosevelt, 2021; Roosevelt *et al.*, 2018). One of at least six ovens and open hearths of diverse types uncovered in area 99.526 during the 2016 field season, oven 79 reflects the general type of these features from LB 2 contexts across the site: a cobble base, a stone or earthen rim, a sterile earthen fill, and a baked surface; given comparative and interpretative data, a domed earthen superstructure is likely, and hence its interpretation as an oven versus an open hearth.

Oven 79 was not originally recognized as an oven and was the first feature of this type excavated at Kaymakçı. Accordingly, we set two goals early on: first, to understand better its stratigraphy by sectioning it; and second, to excavate each component of the feature as a discrete spatial context (Figure 2). The southern half of the feature, comprising ca. 0.34 m³ of soil, was excavated in nine contexts over the course of 6 days. The first few contexts excavated were a series of thin surfaces showing that the feature had been refinished repeatedly over the course of its use; these contexts produced a large number of samples and other data, but also took significantly less time to excavate (estimated ca. 10–20 min) than to record (estimated ca. 60 min). Larger components of the feature, such as the earthen rim, were much more balanced in excavation and recording times and also produced valuable material samples that can be tied to the discrete volume of the rim rather than the feature as a whole. As excavation continued, however, the need to balance the excavation of oven 79 with contexts in other parts of the excavation area, as well as the significant amount of time required to excavate and record each discrete component of the feature, led to a shift in priorities. In excavating the more poorly preserved northern section of the oven, we chose to remove material in two large contexts for the sake of efficiency, rather than seeking to match the contexts

Figure 1: (a) A plan showing area 99.526 prior to the beginning of the 2016 field season. The feature that would later be recognized as Oven 79 is circled in red. (b) A photograph showing Oven 79 during excavation, following the removal of the top layer in the southern section.

excavated in more detail on the southern side of the feature. Figure 2 shows how this decision has impacted the virtual representation of the feature in the long term; without this explanatory meta-narrative of the

Figure 2: A visualization of the contexts in Oven 79 (note that two contexts are missing because volumes have not yet been constructed). To the left is a volumetric view of the feature; in the middle is an exploded view of the feature; and on the right is a traditional abstraction of the feature's stratigraphy.

excavation process, the discontinuity could potentially be interpreted as real differences between the two halves of the oven. It is unlikely that significant data were sacrificed by this strategy; yet the meta-narrative of practice is a crucial part of the long-term dataset.

This example illustrates the complex negotiations between logistical concerns (which discourage a splitting mentality) and conceptual concerns (which incentivize a splitting mentality). To put this example into broader perspective, a typical 19×19 m excavation area at Kaymakçı generally produces over 100 contexts in a given season, and perhaps even as many as 200 (including both spatial contexts and approximate contexts); during the 2016 season in the 9×9 m area 99.526 – characterized by a large number of multicomponent features like oven 79 – we excavated approximately 400 contexts (also including both spatial contexts and approximate contexts). Had each one been tackled through sectioning like with oven 79, much less would have been achieved – and yet to what benefit? Had there been discrete features, we would have paused and evaluated accordingly. This particular excavation area in this particular season was certainly an outlier; however, it remains a valuable, if extreme, example of how the logistical and conceptual concerns of SfM recording can intersect to increase the complexity of excavation as well as the burden on all participants: supervisors, assistants, excavators, and the 3D Spatial team.

3.3 3D Models as “Real” Objects

The knowledge that SfM recording will ultimately create an accurate facsimile of each spatial context of an excavation area influences how an individual – whether a project participant, another archaeologist, or a member of the public – views an excavated context as “real” and/or “lived.” Supervisors, assistants, and excavators live the discovery, recording, and often destruction of contexts differently. All recording methods, including those that use digital tools, involve the destruction (e.g., of a fill or a dismantled wall) or decontextualization (e.g., of a whole ceramic vessel) of the archaeological record. What remains are data dispersed throughout databases, drawings/GIS files, and sample boxes in storage depots and other locations that are used to interpret that record after excavation and are ideally preserved in perpetuity. SfM recording allows construction of 2D orthophotos and 2.5D digital elevation models (DEMs). Volumetric

modeling of 3D spatial contexts from point clouds accurately preserves the extent and position of contexts as they were prior to excavation and enables further visualization of the destroyed/decontextualized archaeological record. Just as 2D representations are imperfect abstractions of archaeological entities, 3D models can never perfectly preserve or recreate the physical deposits/objects they represent, even if they enable perceptions of excavated contexts from vantage points unable to be illustrated by 2D representations.

The nuance of reality captured in spatial contexts represented by volumetric entities impacts the way one perceives a context during and after excavation. A given context associated with multiple digital objects may “feel” more real than other kinds of data. In large part, this derives from the visualization of digital objects – and the ability to manipulate them in a static (computer) environment. Indeed, this digital reality creates a new dynamic with those features that remain *in situ*, walls in particular. Because the current process of building orthophotos, DEMs, and 3D volumes is initiated only after the removal of a context, features that remain *in situ* do not undergo these individual digital conversions. Although *in situ* features still exist in the physical world, they do not exist in the digital world except as records in the database, drawings in plans, and in parts of orthophotos, DEMs, and point clouds representing other contexts or the entire excavation area at the beginning and end of each season of excavation. The “reality” of excavated contexts and “unreality” of *in situ* contexts, thus, shift the way that an individual will engage with a given context and the site as a whole. While individuals who were present during original excavation or who are familiar with the site may not perceive significant differences between digital and *in situ* contexts, the farther one moves away from the physical site itself – whether a project member writing reports in the off-season, a future archaeologist working with legacy data, or a member of the public exploring the site through digital publications – the more likely one is to prioritize engagement with contexts that exist digitally over those that do not.

This perception can have significant implications for the interpretation and reinterpretation of the site in the long term. Currently, when one works with 3D volumes, in particular, one must do so in a way that divorces them from associated metadata and related data stored in excavation databases (see Nobles & Roosevelt, 2021); when looking at a volume or set of volumes on its own in a 3D visualization/modeling program without associated data, it may be impossible to distinguish one type of context from another (e.g., a thin deposit from a cleaning context compared to a thin floor deposit). In a situation where one is also separated from the materiality of the site and is therefore more likely to prioritize engagement with contexts that exist digitally over those that do not, one might perceive insignificant material removals represented by digital volumes (e.g., cleaning contexts) as “more real” than significant features that remain *in situ* and thus unrepresented volumetrically because they can only be represented as such after removal (e.g., walls). These inaccurate perceptions might shift the archaeological narrative about the site or about the process of excavation in subtle ways depending on who is engaging with the data.

4 After Excavation: Representing, Revisiting, and Re-Excavating the Site

Beyond the impact of the digital “reality” of modeled contexts, the products of 3D modeling have other repercussions on the continuing interpretation of the archaeological record after one leaves the field. After an excavation area supervisor or area assistant leaves the field at the end of the day (or the end of the season), their interpretation of the archaeological record is further mediated through SfM recording and the digital artifacts it creates. At KAP, daily plans are drawn in a GIS (ArcMap, in this case) primarily using data – including orthophotos and DEMs – generated from the 3D recording of the bottom of each spatial context. The availability of these data creates flexibility for supervisors or assistants as they interpret an excavation area. Tracing the outlines of contexts and visible objects from orthophotos in a GIS allows them to be tagged with context numbers so that they can be queried, spatially characterized, and turned on and

off at will to recreate stratigraphically or thematically focused plans. Working with associated DEMs also allows investigation of absolute level differences at any point across a context, rather than at only the handful of elevation points recorded by traditional field measurements. These resources, therefore, introduce changes in the way one works with traditional 2D representations of excavation data.

The orthophotos, DEMs, and 3D models are also valuable tools for interpreting (and reinterpreting) the site, despite the fact that they do not perfectly recreate contexts as they existed prior to excavation. Orthophotos and DEMs are more dynamic than still photographs taken during excavation, allowing for ad hoc measurement and image capture in cases where the recording of such data may have been insufficient because of challenging field logistics. 3D volumes are very useful for isolating and visualizing physical relationships between contexts in three dimensions. For example, it is relatively easy to isolate contexts associated with the hearths and ovens in area 99.526 discussed above to compare how each feature was constructed and to explore the physical relationships between them in real space (Figure 3). Similarly, 3D volumes allow for detailed side-by-side comparison between similar features in different areas to compare construction, use, and preservation. Both of these types of spatial comparison are also possible with traditional recording methods, but are made vastly more efficient and flexible with digital methods. Additionally, 3D representations of features, rooms, and whole excavation areas will eventually allow for new ways of displaying, analyzing, and comprehending other kinds of data, such as the distributions of artifacts and ecofacts. These digital representations not only create new ways to visualize data, but also offer invaluable opportunities for interpreting archaeological processes, in general, and the site, in particular, for researchers and the public and lay the foundation for future 3D spatial analyses. 2D representations of archaeological sites have long been valuable tools for communicating narratives about the past; 3D

Figure 3: 3D representations of Hearths 99.526.385 (on the left) and 99.526.386 (on the right), with each context comprising the hearths in a distinct color. These hearths are of a different type than Oven 79 and are composed of a mudbrick rim, earthen fill, and surface of reused sherds. The 3D representation shows both the physical relationship between the hearths and the difference in preservation, with 386 being much better preserved than 385.

volumes that accurately represent each context in their entirety can form the basis for visually communicating narratives about the archaeological process in more persuasive ways than can text alone.

It is again important to acknowledge, however, the complex ways in which working with SfM recording and born-digital data changes the way we engage with the process of interpretation. Writing about the digital recording methods used at Çatalhöyük, Berggren et al. argue that access to 3D models and GIS “improve[s] excavation recording methodologies by facilitating the reflexive engagement of the excavator in the archaeological process” (2015, p. 443). At excavations where drawing digitally is standard, researchers are continually moving between the physical archaeological record and the digital facsimile of that record, constantly creating and revising interpretations. Digital drawing further allows for repeated interpretation through iterative drawing based on models and orthophotos, something not possible with traditional methods. Researchers returning to excavation area analyses at the end of seasons or during off-seasons have full access to all the digital materials used to make initial interpretations and can therefore more easily revisit and revise interpretations. Other archaeologists – new supervisors and assistants taking on areas started by others, the Field Supervisor (at KAP), someone researching archived project data in the future, etc. – also have access to all these data and therefore have more data on which to base new drawings and reinterpretations, as well as more power to identify mistakes or poor interpretations, should they exist. Just as with other legacy data, however, such down-the-line reinterpretations lack the crucial element of direct engagement with the materiality of the archaeological record; this cannot be helped. Morgan and Wright (2018) identify close engagement with the materiality and sensorial aspects of the archaeological record as one of the primary interpretive benefits of hand-drawing in the field; although this engagement is not necessarily lost in the transition to digital methods, it is certainly lost when interpreting data after initial excavation, when access to excavated contexts is no longer available. Here, it is important for those working with 3D representations to recognize that the digital “reality” of these contexts does not make up for that loss of connection with the materiality of the site.

We also acknowledge how some project members may be alienated from various aspects of this interpretive process. The hybrid organizational structure used by KAP comes into play here; the divide it creates between field personnel and the 3D Spatial team means that – while supervisors and assistants use orthophotos, DEMs, and 3D volumes in the process of interpreting their excavation area – they are generally not involved in the creation or management of these files. There is, therefore, a danger that supervisors and assistants may view the creation of these files as a black box and discount the interpretive acts involved in their creation. Furthermore, an unfamiliarity with the programs and files in which models are created and viewed makes it more difficult for area supervisors to take advantage of their benefits, such as looking at bottom surfaces to clarify physical relationships that are not clearly represented in photographs, daily journals, or other records. Yet, those in the lab are also removed from extraction and recording processes and thus they, too, live only one component of revealing and recording the past. The complex negotiation of experience, expertise, and training – discussed above with respect to collecting data for SfM recording in the field – therefore continues not only for supervisors and assistants in the moments immediately following excavation, but also far into the future.

5 Moving Forward

We are on the cusp of a major shift in archaeological practice. The digital turn in archaeology broadly, and the rise of SfM recording in particular, have substantial long-term benefits for the field. Among these benefits are the collection of more data, more accurate data, and more flexible data that allow us to ask new questions and tell new stories about the archaeological past. However, we must also recognize the substantial impact that this shift in practice has on the lived experience of archaeology, particularly in the ways that it makes daily work more complex and frustrating for individuals working in various roles on site. SfM recording does not create the complexities of experience, expertise, and training that surround excavation and interpretation; these exist in all archaeological situations in myriad ways depending on the nature

of the archaeology practiced. However, SfM recording does shift these negotiations in particular ways that need to be accounted for in an individual's approach to a project and in the structure of the project itself. Recognizing these impacts is especially vital in the short-term. Given the rapid pace of change, it has not been possible for the majority of universities and field schools to account for this shift in the way that archaeology is discussed and the way that archaeologists are trained, nor do all agree that this is necessary or desirable.

In this article, we have identified some ways that we have seen the use of SfM recording for spatial data collection shape archaeological practice at Kaymakçı. We have discussed how an individual's experience, training, and role on the project have unique impacts on how that individual negotiates one's own work and one's relationships with project participants. We have shown how the logistical and conceptual demands of SfM recording are in tension with each other, and how supervisors at Kaymakçı have negotiated this tension. And, we have explored the impacts that the digital "reality" of 3D volumes and the flexibility of digital objects have on interpretation in the short and long terms. Through all these discussions, two final themes emerge that will continue to shape our work with SfM recording in the future.

One hurdle identified here that must be addressed is the persistent divide between participants in the field. This has multiple layers. Excavators, as locally hired vocational staff, are often not trained at all in digital interfaces and stratigraphic interpretation; they become expert in technique through practice, and yet at this time their voices are usually silent (cf. Mickel, 2021). In turn, supervisors and assistants, those trained at the university-level and specific to archaeology, engage with both the lived experience of excavation, working with the excavators, and the structure and expertise of data collection for SfM recording. Those in the lab, again trained at the university-level and often specific to archaeology, become expert in the processing of 3D models and the management of associated files; they are connected with the supervisors and assistants in this transfer, but removed from the excavators. In these spheres of expertise, the potential for the formation of "black boxes" that obscure important interpretive moves increases at each juncture. The particular nature of this divide at Kaymakçı is the result of our hybrid organization of tasks associated with SfM recording; one can assume that projects following different models will have their own struggles that result from their respective organizational structures. It is vital, therefore, that projects and individuals using similar methods recognize the respective consequences and account for them as part of their particular archaeological practice. We may take this a step further to think about the implications of the divides created by experience and expertise among unaffiliated parties: for specialists not directly involved in excavation or processing, other researchers, and the public. As we explore options for visualizing and sharing these data in the future, it is important to account for how the expertise of varied individuals will shape their engagement with archaeological data in the long term.

A final challenge identified in this article is the separation of digital representations of contexts from their associated and vital aspatial information. This, like many of the issues discussed here, is a problem not unique to digital archaeology; the discipline is rife with examples of finds having been separated from labels or excavation notes that are misplaced or do not survive transformation from one medium to another. The environments in which born-digital data exist, however, provide new ways to mitigate issues of data accessibility, even if a lack of software tools still prevents display, manipulation, and analysis of both 3D and 2D entities along with related attributes. A long-term aim of KAP is to help create and actively encourage the creation of a Spatial Data Infrastructure (SDI), volumetric information system, or something approaching a 3D GIS that not only integrates 2D and 3D models with associated aspatial excavation and sample data, but which will also make these materials available to the public and other researchers. We envision such accessibility through an online platform, provided support and commitment can be found and maintained. Such an integrated tool would enable full stratigraphic exploration and spatial analysis by anyone, greatly improving the potential of revisiting and (re)interpreting excavations. Additionally, it would help archaeologists fulfil the widely acknowledged yet still only partially realized potential of 3D recording and modeling, helping to push the field in positive directions.

On balance, the move towards increased use of digital technologies, like SfM recording, has been beneficial to archaeology. However, it is vital that we continue to turn a critical eye towards the broader effects and unintended consequences of this digital turn. The KAP example highlights some of the

challenges in the radical shift to entirely born-digital spatial recording, but also illustrates how an awareness of these challenges allows us to build practices and projects suited to the new normal in archaeology.

Abbreviations

DEM	digital elevation model
GIS	geographic information system
KAP	Kaymakçı Archaeological Project
LB	Late Bronze [age]
RTK-GNSS	real-time kinematic global navigation satellite system
SfM	structure from motion

Acknowledgments: For Kaymakçı excavation permissions and assistance, we thank the General Directorate of Cultural Heritage and Museums of Turkey's Ministry of Culture and Tourism, and its annual representatives, as well as the director and staff of the Manisa Museum Directorate. We thank also all members of the KAP team who have conducted work relating to this research – including excavation area supervisors, assistants, and excavators, as well as members of the 3D Spatial team – and remain grateful for both their commitment and their patience with Kaymakçı's still new and evolving recording system.

Funding information: Support for excavation for the Kaymakçı Archaeological Project was provided by the National Endowment for the Humanities (Award RZ5155613), the National Science Foundation (Award BCS-1261363), the Institute for Aegean Prehistory, the Loeb Classical Library Foundation, the Merops Foundation, the Boston University Vecchiotti Archaeology Fund, Koç University, and private donors. Any opinions, findings, conclusions, or recommendations are those of the authors and do not necessarily reflect the views of the supporting institutions.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: All data associated with this article are planned for archiving with Koç University's publicly accessible Research Data Repository as well as eventual accessibility through a project-based web-GIS and online database.

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