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Open Area, Open Data: Advances in Reflexive Archaeological Practice

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ABSTRACT
This article presents a holistic and reflexive process for archaeological fieldwork from inception to publication. The opportunities afforded by maturing digital techniques allowed fundamental rethinking of field and laboratory practice paradigms. A number of normally unquestioned aspects of archaeological praxis were examined with the goal of reorganizing information dynamics. Instead of a series of disparate processes in the field and field laboratory and during study and publication phases, a heterarchically-organized common information framework bonded all aspects of work traditionally only brought together in post-excavation processing, replacing disparate datasets and encompassing ongoing processes such as excavation recording, finds processing, and final analyses. Recording uses a common interface based on the iDig iPad app, and analyses use 3D GIS, based on comprehensive photogrammetry and an underlying all-encompassing data engine. The development and application of the process are described with reference to the excavations, study, and publication of EBA sites on Keros, Cyclades, Greece.

KEYWORDS
archaeological informatics; digital archaeology; open area excavation; single context recording; integrated workflow; archaeological practices; photogrammetry; ceramic analysis; iDig

Introduction: Recent Advances in Fieldwork Methodology

In a significant recent article on digital approaches in the field by Roosevelt and colleagues (Roosevelt et al. 2015), a complete system for digital recording is presented, with emphasis on what they describe as "volumetric" data, that is to say the recording of archaeological contexts in three dimensions rather than two. Their approach is mature and comprehensive, utilizing recent advances in photogrammetry and portable recording technology. In advocating volumetric recording, they highlight both an epistemological concern for the excavation of units defined by stratigraphy rather than by arbitrary divisions (a concern we fully share) and a methodological approach to recording such units. They present the move to all-digital recording as representing a paradigm shift in archaeology, although the question of what constitutes observations to be recorded and the method of so doing should perhaps be considered separately. Whether all-digital recording alone really does constitute a paradigm shift has been a matter of discussion (Gordon, Averett, and Counts 2016). Gordon and colleagues note that paradigm shifts tend to make previous approaches obsolete, whereas it is still the case that all-digital approaches remain cutting edge, still undergoing experiment and testing. They are far from being accepted as the standard way of doing things and are only now beginning to move beyond application in research contexts (in the UK, for example, holistic digital recording is only now being adopted in the commercial sector, which represents the great majority of all field archaeology undertaken there; in a country such as Greece, digital recording remains unknown in the state sector). They also point out that research questions and interpretative approaches can remain almost unaffected by such changes in field technique.

The integrated method we present here moves beyond the straightforward application of digital recording to existing field techniques. In this paper, we describe how we saw an opportunity to integrate digital recording with improved field methods in a holistic approach to reimagining the entire archaeological process. This includes rethinking both the actual practices of digging and integration in the overall information structure and long term process flow of an archaeological project. The new possibilities for integration, for heterarchical as well as hierarchical workflow structures and information flow, and the built-in recursive rethinking of approaches present a real challenge to archaeological practices which too often are simply taken for granted and perhaps point to the directions in which a paradigm shift might take us. This paper outlines a holistic solution with palpable advantages in reflexivity and interpretation, ready for widespread adoption and further adaptation.

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Background: Early Bronze Age Keros, Cyclades, Greece

In 2015, planning began for a new series of excavations at the Early Bronze Age (EBA) sites located on the island of Keros, in the Cyclades, Greece. Known to archaeologists since 1963, the site complex consists of two so-called special deposits, an area of primary metal working (smelting) on Kavos Promontory, a small cemetery (south of the Special Deposit South), and a large area of buildings on Dhaskalio (Figure 1). Previous excavations took place in 1963, 1967, 1987, and 2006–2008, and a survey of the island of Keros was undertaken in 2012–2013 (Doumas 1964, 2007; Zapheiropoulou 1968a, 1968b, 2007a, 2007b; Sotirakopoulou 2004, 2005, 2016, forthcoming; Renfrew et al. 2007, 2013, 2015, 2018, forthcoming; Renfrew, Sotirakopoulou, and Boyd forthcoming). The site complex overall has been described as a sanctuary (Renfrew, Boyd, and Bronk Ramsey 2012; Renfrew 2013).

The excavations of 2016–2018 were planned to take place mainly within the settled area on Dhaskalio, a rocky promontory in the EBA (and now, following sea level change, an islet separated from the main island by 90 m of water: Dixon and Kinnaird 2013). It was already thought that much of Dhaskalio had been covered in constructions during the EBA (Boyd 2013), and experience during the previous excavations had shown that intact surface layers might underlie sometimes thick layers of collapsed masonry. It was also planned to conduct test excavations elsewhere on Keros in locations identified as potential habitation areas during the 2012–2013 surface survey (Renfrew et al. forthcoming).

Excavations on Dhaskalio in 2007–2008 had suggested the potential of the site to advance our understanding of the EBA archaeology of the Cyclades, a period and region that has suffered from the depredations of looting (Renfrew, Marthari, and Boyd 2016) with relatively few major published excavations. The 2007–2008 study showed that extensive, well-preserved deposits of EBA date were present, and almost no remains of later periods had been found, meaning that only natural factors are likely to have disturbed the EBA remains.

Why return to excavate a site so soon after the previous round of excavations? It was apparent from the results of the previous program both that Dhaskalio was a site with great potential to elucidate core problems in EBA Aegean archaeology but also that this potential could only be realized through a research program with a coherent, ambitious, and focused methodology. Research questions, such as the nature of the earlier phases at the site, the full range of activities on the site, and the extent to which the site can be considered domestic (or not), will be fully discussed in future publications. In this article, we discuss the advances in methodology which have facilitated a more precise focus on these research questions. These advances arise partly from lessons learned from the 2006–2008 Keros excavations and partly from a considered adoption and adaptation of new technologies and advances in fieldwork approaches and methods.

Planning and Implementing a New Methodology

A holistic approach to method, recording, and information flow

Colin Renfrew's embrace of multivocality in the preceding 2006–2008 project, demonstrated by the integration of specialist analyses in the project design, arose from his long term commitment to interpretative analyses based on robust datasets deriving from the application of scientific methods in archaeology. This has allowed for significant multivocality in the five volume excavation report (Renfrew et al. 2013, 2015, 2018; Sotirakopoulou 2016, forthcoming; Renfrew, Boyd, and Margaritis 2018). For the new project, multiple specialists were involved in the initial project design and in rethinking every field process and subsystem in order to enhance co-operative, heterarchical, and integrationist aspects.

Our approach bears resemblances to those developed independently by Ian Hodder in a research context at Çatalhöyük (Hodder 1997, 1999, 2002; Berggren et al. 2015) and by the *Framework Archaeology* initiative in the commercial environment in the UK (Andrews, Barrett, and Lewis 2000; Boyd with Renfrew in press). These initiatives additionally addressed the structure of communication flow and the technologies then available to increase the number of participants in the interpretative process. *Framework* in particular was concerned to anchor acts of archaeological

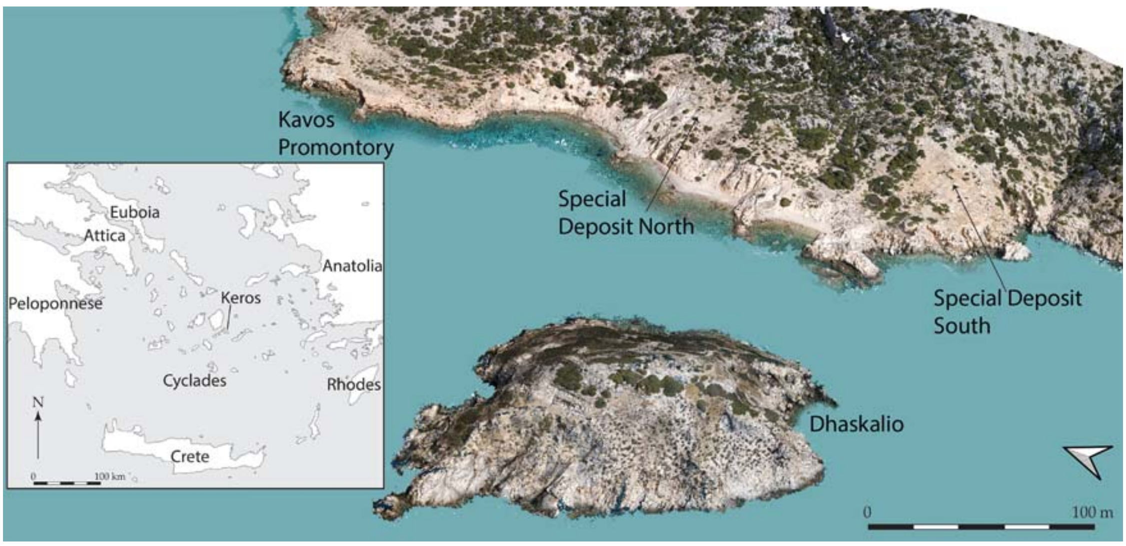

Figure 1. Perspective view of western Keros, showing archaeological zones mentioned in the text. Scale is approximate and relates to the islet of Dhaskalio.

interpretation in the field, while the Çatalhöyük project embraced reflexivity: as Hodder wrote, "Everything depends on everything else. So to interpret involves creating a circuitry between participants in the project and between different types of data" (Hodder 1997, 694). In order to invent that circuitry, and make it central to all our processes, we aimed to integrate adaptations in field practice with a focus on information through systematization in recording, availability, and flow. Our vision became the integration of all processes in a meaningful way, leading to the development of a common information framework within which almost all field, field laboratory, and post-excavation processes could take place. All of these were focused on creating the "circuitry" imagined by Hodder and on the creation of fora in which multivocality and reflexivity could be enacted at all stages of the project from preparation to publication.

Rethinking field practice

Leighton (2015) has recently described how the production of knowledge in field archaeology is often, as she puts it, "black-boxed" (Leighton 2015, 68): field practices are taken for granted, and high-level interpretations do not include explicit descriptions and justifications of field technique (see also Hodder 1999, x). Skills acquired as a trainee or student and the framework in which these skills are deployed are not regularly called into question. By comparing the differing approaches of Andean and UK archaeologists, she describes the clash of cultures between two different traditions of practice.

Review of the interaction between different cultural traditions of archaeological field practice in the 2006–2008 project provided the opportunity to rethink aspects of practice that had been effectively, in Leighton's terms, "black-boxed." Our starting point was that the understanding of a complex architectural zone necessitates the excavation of large trenches, in which significant portions of buildings and the spaces between them can be sampled, as a way of recognizing how the architectural systems of the site were structured and interrelated. Furthermore, the understanding of stratigraphy, and of context in particular, within and between such constructions requires a site-wide standardized approach optimized for the complex formation processes expected. These requirements suggested the application of the open area, single context approach, well known and highly developed in some sectors (e.g., UK commercial archaeology: Westman 1994) but not often utilized in Greece (though see Sanders, James, and Carter Johnson 2017, 1–3). Although some archaeologists in northern Europe might assume the single context approach is a widely understood and practiced starting point (e.g., Croix et al. 2019), in fact this is another assumption about the black box of field practice. Single context recording is far from ubiquitous on a worldwide level and remains relatively rare in Greece.

Open Area Excavation

Traditionally, and still today, excavation in the Aegean has often proceeded in small trenches set in a grid over the area to be investigated. The regularly-spaced baulks left unexcavated between the trenches provide the vertical stratigraphic record intended to replace any lack of stratigraphic control (whether intended or not) in the excavation of the material between the baulks. However, the effect of the baulks is to introduce artificial barriers in the excavation of complete contexts, to cause the excavation of defined spaces such as rooms to be split over several trenches (and potentially different seasons), and to create a series of stratigraphic records that can often be mutually irreconcilable. The open area approach, on the other hand, encourages the holistic interpretation of the entire area under investigation, allowing an interpretation that can be developed by excavating in the order best determined by the progress of the excavation without the inclusion of arbitrary barriers.

The point is perhaps best developed through example (cf. Barker 1993, 57–60; Sanders, James, and Carter Johnson 2017, 1–3). On Dhaskalio, the open area approach allows detailed investigation at three scales: within rooms, within buildings, and between buildings. In addition, as excavation proceeds to depth, should earlier phases with differing orientation come to light, the large trench stands a better chance of uncovering enough to allow robust interpretations. The largest single excavation area opened during the recent project was Trench A on the northwestern plateau of the island (Figures 2, 3), measuring 24 × 9 m. On the right in Figure 3, we see a hypothetical arrangement of Wheeler-Kenyon boxes within Trench A, showing how 4 × 4 m trenches with 1 m baulks could have been laid out within the 24 × 9 m area of Trench A (in reality, no such layout was attempted). Apart from the significant reduction of area under investigation (225 m^2 in open area, 160 m^2 in boxes), such baulks would have caused significant difficulty in interpreting many of the spaces and rooms of the trench, in particular in the crucial interface zone 2, where equating contexts between trenches and understanding deposition and erosion would have been impossible.

One way to evaluate the success of the open area approach is to look at the overall plan of the site (see Figure 2). The area recently under excavation (539 m^2) significantly exceeds that opened in 2007–2008 (364 m^2). The new excavations are divided into 10 trenches, whereas those of 2007–2008 were divided into 25 trenches. The average trench size is 54 m^2 in the current excavation and 15 m^2 in 2007–2008. In the larger trenches, we can see that individual rooms, significant sections of whole buildings, and the relationships between architectural blocks and zones are all better represented. We would argue that in excavations like ours, and perhaps in most other cases, the use of open area excavation should be contemplated in preference to Wheeler-Kenyon boxes in most circumstances. Yet it remains the case in Greece, at least, that this approach is currently the exception, not the rule.

Enhanced Single Context Recording

Aegean contexts often consist of repeated depositions of very similar material, whether soil or (as is prevalent at Dhaskalio) collapsed masonry. This has prompted the development of arbitrary systems of excavation and recording, whereby excavation proceeds to a set depth and then "level" or "layer" or "basket" number is changed arbitrarily. Such arbitrary systems are, in practice, often hybrids: clear changes in stratigraphic context may be used as pointers to change layer, but when such clear changes are not observed, layers are changed after a set depth or volume interval. Part of the logic of such systems is a reliance on material culture,

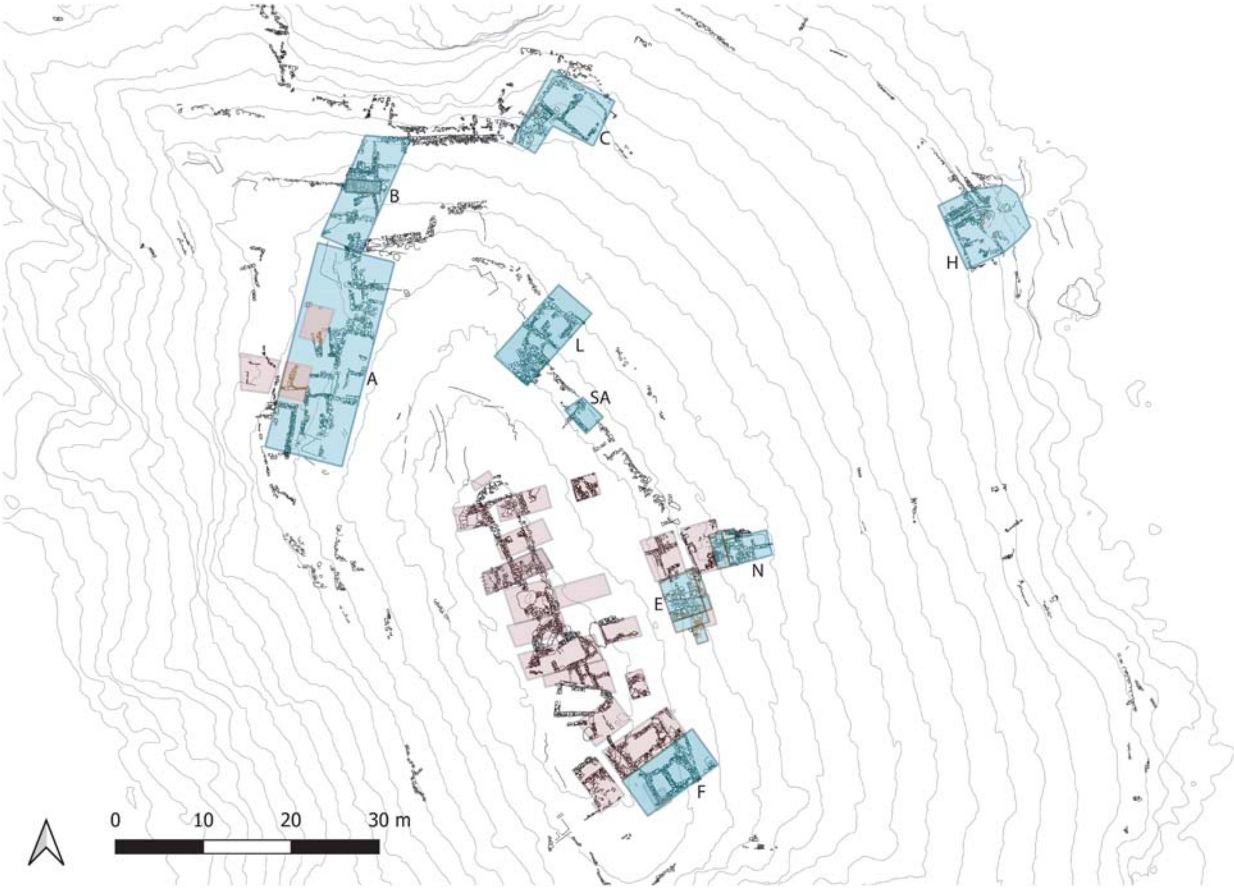

Figure 2. Plan of Dhaskalio showing excavation trenches of 2007–2008 (pink) and 2016–2018 (blue), with trench designations indicated.

Figure 3. Sketch plan of Trench A at the end of the 2018 season. Left: area identifications. Right: hypothetical 4 m Wheeler-Kenyon boxes imposed over the plan. Base sketch by Kristen Mann.

especially the pottery, to indicate stratigraphic changes in post-excavation analysis. However, not only is this a very coarse resolution at which to work, but such systems necessarily involve the excavation of mixed layers whose usefulness is limited. Hybrid systems remain the norm in research excavations, while, particularly in the state sector, arbitrary systems remain in use.

The single context system offers a higher resolution than arbitrary systems. Often described as "excavation in plan," the aim is to dig and record based on the identification and removal in stratigraphic order of complete deposits resulting from different deposition and formation events, rather than employing retrospective stratigraphic interpretations based on variation in pottery styles and the vertical data preserved in the sections at trench edges. As Westman (1994, 10) notes, "a disadvantage of a section drawing is that it cannot show contexts to their full extent and may therefore be misleading." Instead, in classic single context recording, the site stratigraphic record is constructed from a series of overlaid context plans (Westman 1994; Sanders, James, and Carter Johnson 2017, 4–5). The excavator is entrusted with defining digging units based on interfaces between material from differing deposition events. This is done by careful differentiation in such factors as the color, consistency, and compaction of the soil and the nature, size, and frequency of inclusions. The aim is to reconstruct each event (evidenced as the "context") which contributed to the formation of the site prior to excavation: both additive events, where material is added to the site (through construction, collapse, or natural deposition) and removal events (when, for example, a pit is dug, a surface levelled, or erosion events occur). The context record is thus the most basic level of understanding of the site formation process, with multiple contexts representing the formation event model of single context recording. Since single context recording devolves interpretation to the excavator (rather than relying on post-hoc interpretation through vertical stratigraphy visible in baulks and studies of finds groups), it acts to enhance heterarchical structures and knowledge creation (Berggren and Hodder 2003; Eddisford and Morgan 2018).

In our adaptation of single context recording, we refined the existing paradigm in five distinct areas. The first of these relates to the volumetric approach advocated by Roosevelt and colleagues (2015; cf. Croix et al. 2019). This highlights one weakness in the single context system: the representation of three-dimensional contexts by two-dimensional records, such as plans (horizontal) or sections (vertical), and the Harris matrix (Harris 1975, 1989) derived from them. This weakness exists in many recording systems. Roosevelt and colleagues (2015) codify in practice a set of photogrammetry-based approaches now becoming prevalent in excavation and other fieldwork. The use of digital photogrammetry has, in fact, recently received more attention in field archaeology than other aspects of digital recording (e.g., Olson et al. 2013; Douglass, Lin, and Chodoronek 2015; Olson and Caraher 2015; Dell'Unto et al. 2017; Sapirstein and Murray 2017). Although not yet universally adopted for field recording, photogrammetric techniques are maturing, and standard approaches have been proposed (Sapirstein and Murray 2017; Croix et al. 2019).

The effect of the use of photogrammetry was to replace the context plan and the baulk section drawing with the volumetric model, from which two-dimensional derivatives, such as architectural plans and horizontal and vertical sections, may be generated. As has recently been cautioned, the move from analogue to digital planning and recording entails its own series of detailed protocols, in order that the resulting data are usable and of greater accuracy than the analogue equivalent (Sapirstein and Murray 2017). The role of drawing in interpretation has also been highlighted (Morgan and Wright 2018). We saw photogrammetry at the context level as a significant improvement to the single context paradigm, offering an accessible three-dimensional representation of each formation event. In being fully embedded at the heart of our project methodology, this approach answers the question of the added value of photogrammetry raised by Waagen (2019). We describe our process further below, but a detailed discussion of this aspect of our methodology will follow in a future article.

Our second refinement of standard single context recording practice concerns the process of excavating the context. In some single context systems, digging may sometimes proceed in subdivisions (such as half-sections or spits), depending on the context. However, there are several scenarios in which a more regular record of arbitrary sub-units (ASUs) may be useful. While many categories of find and sample are recorded in three dimensions, the most numerous categories, such as pottery, obsidian, bone, and shell, are not. The use of ASUs allows for these finds to be more precisely located in the three-dimensional record of the site. ASUs also provide a certain safety net: if a mistake is made, only one ASU is contaminated by over-excavation, rather than the whole context. Similarly, any differentiation noted within contexts during analysis of finds and samples can be localized through ASUs and may in some cases provide material for reflection on the understanding of stratigraphy developed in the field. ASUs retain some of the positive benefits of arbitrary approaches long used within Aegean field archaeology, now, however, restricted by contextual boundaries. This system can create a temptation among some to try to dig arbitrarily through the use of ASUs and create contexts afterwards. This risk was mitigated through both the vigilance of supervisors and the field director and through the design of the recording system, which is intended to make such practices difficult (for example, by restricting what can be recorded at the sub-contextual level).

Our third modification in the single context recording system concerns the types of context that may be recorded. Traditionally, these include deposits, cuts, and structures, sometimes with specialized contexts such as graves (Westman 1994). At Dhaskalio, floors and other surfaces form complex and sometimes long-lasting features of great importance because of the evidence they can preserve for specific activities. The definition and treatment of floor spaces had been identified as one weakness in the previous excavations. Moreover, surfaces are not treated as separate context types in traditional single context recording. Other approaches to excavation sometimes recognize their importance without necessarily systematizing an approach to their excavation and recording. The problem of recording the surface is part of a wider question within single context recording, which concerns time depth (Croix et al. 2019). The formation event model does not distinguish well between short and long term events, so that surfaces (used and perceptibly altered over long durations), deposits which gradually accrete over time (such as the infilling of ditches), or gradual erosion events are less well-represented than short-term events due to human action or rapid collapse. One answer to this was a greatly increased focus on micromorphology, as discussed further below. But at a more basic level, we modified the single context recording system to create a new type of context, the surface.

For us, a surface is an area exposed and a focus of activity over a period of time. A surface may lie above a deliberate deposition (a "make-up") or it may be the walked-on part of a built structure. Surfaces may accrete over time, for example if activities generate debris or detritus that is not cleaned away. They may alternatively degrade over time, for example if a thin plaster layer is worn away through repeated use. And they may be repaired or resurfaced periodically. The surface represents a composite formation event (its exposure over time and its focus as a locus of activity). Material recovered directly from the surface is related to the period of use of the surface rather than the fill above or the makeup (or construction) below, and, similarly, samples taken directly from the surface are related to the use of the surface. A common scenario at Dhaskalio is when multiple surfaces are re-laid one on top of the other, creating a palimpsest. The microstrata within the surface material represent the successive resurfacing events, but these are difficult to excavate separately and can usually only be defined micromorphologically.

Although the concept is imperfect, the reason for introducing the surface category to the model was to focus the attention of the excavators on this crucial interface between fill above and floor make-up below, as these events are critical in understanding the history of any given space and the activities taking place within it. Without the surface event, single context excavation treats the surface as simply part of its own make-up and thus mixes two separate formation events (the long-exposed surface and the prior deposition of the make-up of the surface; Figure 4)—unless the amount of accretion on the surface is sufficient for it to be dug as a separate deposit. Our model improves single context recording by associating data, samples, and finds directly with the floor surface and explicitly separating samples and finds related to the prior and subsequent formation events.

Two final aspects of field practice are directly related to considerations of stratigraphy, definition of context, and use of space. The first is the systematic investigation of soil chemistry using hand-held pXRF (portable X-Ray Fluorescence) by specialists present throughout the field season. The utilization of geochemical survey to identify and delineate activity areas is well established in archaeology (Oonk, Slomp, and Huisman 2009; Wilson, Davidson, and Cresser 2008 and references therein), yet its systematic use remains infrequent in routine field excavation. This reluctance is due to a number of factors, including time and cost, but the difficulty in attributing particular elemental results to specific activities is important to acknowledge. The processes and mechanisms by which soil is modified by human action are still poorly understood (Wilson, Davidson, and Cresser 2008; Entwistle, Abrahams, and Dodgshon 1998; Middleton and Price 1996). Problems are not restricted to soil ecology but include basic understandings of how specific human practices might imprint themselves on open soil contexts. Several scholars have noted that elements vary in their interpretive value (i.e., Wilson, Davidson, and Cresser 2008; Aston, Martin, and Jackson 1998), with most agreeing that the elements with the greatest potential to aid archaeological studies are P, K, Ca, Cu, Zn, and Pb. One exception where ambiguity is less apparent is metalworking activity, and especially non-ferrous metallurgy, where very high (x10–x100 background levels) concentrations of Cu, Pb, Zn, and Ag can often be attributed to metallurgical practice with some confidence, especially where such concentrations correlate with other excavation or survey data. The characterization of metalworking areas has been accomplished through systematic soil sampling and laboratory-based analysis (Grattan, Gilbertson, and Hunt 2007; Andrews and Doonan 2003, 42–44), yet it is the ability of portable instruments to undertake analyses in situ, with results in real time, that offers the best opportunity to impact directly on excavation strategy (Oonk, Slomp, and Huisman 2009).

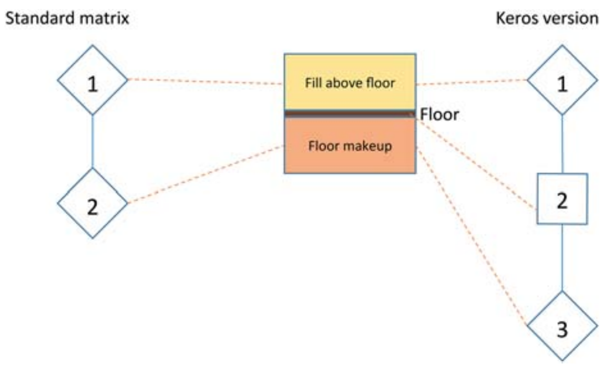

Figure 4. The surface context in standard single context and Keros recording systems.

Traditionally, sampling for soil chemistry has been undertaken in low numbers for analysis in the laboratory. Early in the project design, the decision was instead made to integrate fully the analysis of soil chemistry in the field. It was hoped that measurable differences between and within contexts, based on a much larger number of samples, would be useful in identifying different patterns of routine practice, ultimately offering chemical signatures for certain types of repeated activity. Soil chemistry was undertaken at two levels. At the broader level, a soil chemistry survey of the whole islet of Dhaskalio was conducted with readings taken at 10 m intervals in a grid across the island. This provided insight into the concentration ranges for different elements and showed the spatial structure of chemical variability. Together, these two aspects could be used to identify structured anomalies, where higher concentrations formed discrete spatial trends. These ranges and structures could be used to inform excavation strategies while adding a new kind of data to the interpretive process.

This survey was extended beyond Dhaskalio to the entire Kavos region and beyond on Keros and the neighboring island of Kato Kouphonisi. The Dhaskalio survey revealed widespread and significantly raised levels of copper and lead (the latter localized on the north side of the islet). These elements were both far higher than recorded elsewhere on Keros, suggesting the very wide spread of metalworking activity in the settlement. At a more detailed level, soil chemistry readings were taken on every excavated context in one of the most intensive such surveys ever undertaken. Multiple analyses were made systematically across the freshly cleaned surfaces of excavated contexts at intervals ranging from < 0.5–1.0 m. Analysis locations were agreed upon in discussion with excavators, and summary information and preliminary interpretation, where possible, was provided in real time. These data were useful immediately in the field for differentiation between and within contexts, and for evaluating the potential for contexts to be associated with metallurgical practice. Subsequent analysis during the post-excavation program will lead to the establishment of relationships between enhanced levels of particular elements, find types, and different activities. With large numbers of samples, this means that rather than seeing soil chemistry as a means to identify particular functional activities, it becomes a means by which variation in human activity across space can be identified.

The final refinement in single context recording concerns the deep integration of the study of micromorphology into field practice and site interpretation, again involving the constant presence of the specialist in the field. The importance of micromorphology as a sub-contextual window onto site formation events has recently been highlighted by Croix and colleagues (2019), who contend that one of the key weaknesses of the single context approach within the contemporary expectations of archaeology is the inability of archaeologists to excavate microformation events. In keeping with our emphasis on understanding stratigraphy in three dimensions, it was felt essential to have sedimentological input at all stages of excavation, developing a micromorphological sampling strategy that targeted the actual contexts being dug during, rather than after, the excavation. Additionally, the micromorphologist acted as a roving specialist in the stratigraphy of the site, advising during excavation and reserving columns of unexcavated material for sampling (compare Farid 2015 for a similar approach adopted at Çatalhöyük). By integrating the work of the micromorphologist within the daily and routine practices of excavation, we united the requirements of micromorphology and good excavation practice within a single paradigm, as well as tackling a weakness of the single context recording system. The size of the micromorphological sampling program (producing more than 200 samples) will ensure that micro-scale interpretation plays an important part in the assessment of context and site formation processes.

Rethinking data: recording, availability, and flow

The greatest obstacle to an integrated workflow is the splintering of datasets among participants and locales. Our experience of the 2007–2008 excavations on Dhaskalio was that they produced a series of disparate and unconnected datasets at different times during excavation, analysis, and publication (Table 1). Yet the data themselves consist of interlinking observations derived from material that, prior to our intervention, was buried in a nexus whose complex relationships contained the keys to the questions we were asking. Excavation investigates those relationships while simultaneously destroying them. One goal for the new project was to find a way to recreate more of those relationships than a traditional recording (such as that shown in Table 1) allows for. This aim required us to imagine and then create a framework for data capture, storage, and query that could encompass all the activities of the project.

We turned first to consider recording in the field. The 2007–2008 method involved hand-written records in field notebooks without pre-set fields or enforced requirements for recording. This inevitably resulted in considerable differences in detail and recording approach between trenches. The experience of the subsequent interpretation stage made it clear that standardized recording forms, of the type often associated with the single context approach (e.g., Westman 1994; Connolly 2009), would greatly improve the comparability of data across the site. Such sheets minimize the amount of information recorded in the catch-all "description" field by having pre-set fields for large ranges of information, such as the color, composition, compaction, and inclusions in a fill, relationships, spatial data, and possible contamination.

The basic requirement for a digital recording system would be for it to replace an entire suite of such paper forms without compromising the design of the recording methodology. It goes without saying that many solutions to such problems have been reported (for a recent overview, see papers in Averett, Gordon, and Counts 2016, especially Wallrodt 2016). Several systems were considered to this end, but one stood out as a mature product which could, with the active involvement of the developer, meet the needs of our excavation. This product was iDig, an app for Apple iPads. It was sufficiently customizable to replace paper recording in the field. In addition, it offered time-saving features such as wireless total station data capture, in-field Harris matrix generation on the fly, and direct-to-database photography using iPad cameras. In short, it seemed possible that iDig could capture all field data, with the only

Table 1. Datasets produced during the 2007–2008 excavations.

Field	Field laboratory	Subsequent specialist study	Writing up
• Field diaries (paper) • Finds bags with labels (paper) • Sample bags with labels (paper) • Photographs (digital) • Photo log books (paper) • Plans (paper) • Sections (paper) • Site plans (digital) • Aerial photography (digital) • Wall database (digital) • Micromorphology notes (paper) • Petrology and geology notes (paper)	• Pottery specialist's notes (paper) • Pottery weights and counts (digital) • Special finds notes and drawings (paper) • Special finds register (paper) • Special finds register (digital) • Field diaries (digitized) • Field diaries (scanned) • Bags and labels from flotation and other procedures (paper) • Datasets from studies of material categories (digital, sometimes also paper) • The excavation database (digital)	For each specialist: • Notes (paper or digital) • Datasets (usually digital) • Photographs (digital) • Drawings (paper then digital) • Written reports (digital)	• Individual chapters (digital) • Spreadsheets generated during the writing-up process (digital) • Photographs and drawings reworked for publication (digital)

exceptions of photogrammetry (carried out using hand-held or drone-mounted cameras) and digital stills taken with hand-held cameras when the in-built cameras of the iPads were deemed not of sufficient quality. By keeping almost all data from the field within iDig, we could accomplish the initial goal of maintaining the relationships between data within a single framework. We also found workarounds to link to the photogrammetry and the separate digital stills. The adoption of iDig seemed a very important step toward the simplification and integration of the overall excavation data structure, although one which required significant planning.

In order to obtain real-time benefits from the recording system, it could not be limited to field processes alone. Data would also be generated in the field laboratory, both from finds processing (ceramics in particular) and from the flotation and sorting of environmental samples. In order to create the "circuitry" referred to by Hodder, finds and environmental specialists had to be working on their material with access to the excavation data; and, excavators ought to be digging with access to information on the finds which had recently come out of their trenches.

The problem was to envisage modalities whereby all these streams of data could effectively be brought together to ensure a multi-level information flow that could empower more effective decision making in every sub-system of the excavation. Discussion, both structured (at daily meetings) and informal, could easily be envisaged, but all of the aims being addressed were tending toward a more radical solution. This would be a common information framework, articulated through a single data recording system open to all users and structured for all the different types of data that might be recorded. It eventually became the aim of the excavation to open data sources to all users on an always-available, as-needed basis. The sections below discuss first the parallel implementation of iDig and photogrammetry for field recording, and then the creation of the wider common information framework using iDig to encompass the datasets produced by field laboratory specialists.

Recording in the Field with iDig

The iDig interface (Figure 5) is split between a list of selectable records, or the contents of a record, on the left and a visualization of the data under consideration on the right. This is in effect a GIS-like interface, as all data are geospatially located and can be imaged in accurate spatial relationships with each other. The app works at a trench level: the design assumes that different trenches within the same site are recorded on separate iPads. (A desktop version of iDig, which brings all trenches into a single recordset and visualization, is currently under development.)

The structure of the data and what is recorded are highly customizable via a text-based preferences file (see Supplemental Material 1, https://github.com/archaeodata-code/Keros-Naxos-Seaways-iDigToDBase). iDig has a number of built-in record types, each of which can be renamed, and for each type, the data to be recorded can be specified (Table 2).

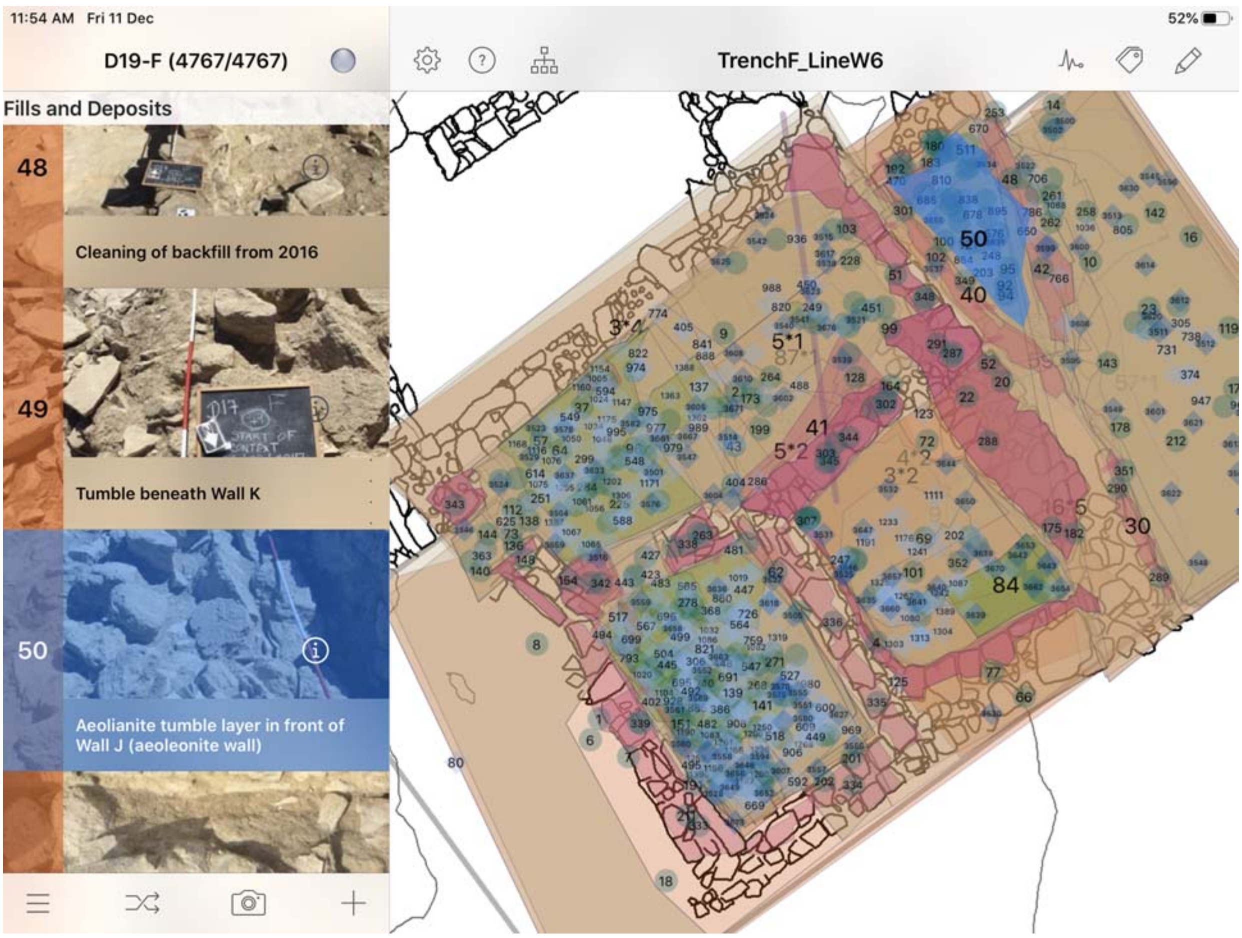

Figure 5. iDig screenshot. Left is a list of items; right is a georeferenced visualization of the dataset. The item selected (left, blue) is highlighted right (blue).

Table 2. List of iDig types, and their labels within the Keros recording schema.

iDig type	Keros label
Context	Fill or deposit
Feature	Structure
Interface	Cut
Event	Surface
Partition	ASU
Artifact	Special find
Sample	Sample or bag
Image	Photograph or photogrammetry record
Plan	Base plan or photo
Other	Topo point
Section	Section
Group	Pottery join

In order to guarantee a unique label for each record, a number field at the start of the record is used to give the next number in sequence. In addition to typewritten data, records can contain topographic data (captured directly from total stations by wifi or Bluetooth, or entered by hand), relationships to other records, and photographs. Relationships are as follows: physical relationships (is above, is below, is next to, cuts, or is cut by), stratigraphic relationships (is after, is before, is coeval with, cuts, or is cut by), and container relationships (belongs to or includes). The latter category allows for (say) a sample to belong to a fill or deposit, and for the fill or deposit to include the sample. These relationships allow iDig to generate Harris matrices on the fly, updated with every change of relationships in the dataset.

iDig was developed and tested over several years (by B. Hartzler and lately by Georgios Verigakis) at the Athenian Agora excavations conducted by the American School of Classical Studies in Athens with the support of the Packard Humanities Institute. This extensive period of development and testing is amply attested to by iDig's overall polish, quality, and reliability. In this sense, iDig answers the implied criticism of Gordon, Averett, and Counts (2016), who note that many recording systems are DIY in nature. iDig provides a user interface that is both visually appealing and easy to use. Training users is as simple as working through a few scenarios, and from there, they easily pick up the rest. With a tap, several swipes and perhaps a keyword search, the user can easily navigate to the major types of data. Teams in the field bring up data capture forms with one to three taps. Once in a context, capturing total station data requires only two taps per point. In this regard, the application is a pleasure to use.

iDig has several unique features that are clearly an advance over traditional means of recording and understanding a trench. The ability to relate contexts in all the ways needed to create stratigraphic matrices on the fly is immensely useful. Other tools in the app allow one to trace a line across a trench plan and bring up a vertical section sketch calculated from the total station points describing the contexts. Ortho-rectified and georeferenced trench plans and photos may be imported. Staff instantly become reliant on these photos and on iDig's ability to render contexts and finds superimposed over them. Overall, iDig's GIS-like interface presents data to the user in all its spatial relations, a feature which is now so embedded in our daily processes that it is easy to forget how startling it is in comparison to database-like recording interfaces. In combination, these aspects of iDig allow the real-time interpretation of excavation results.

iDig adopts a maximal flexibility and "minimal parenting" approach. Via the preferences file, fields in iDig can have value lists associated with them or can build a value list as data are entered. Fields can be set to be multiline (free text) or multi-value. Multi-value fields allow the storage of multiple distinct items in the same field. For example, one can relate multiple items to the current item. Fulfilling the "minimal parenting" model, the one thing that cannot be done is tightly to control how data are entered. For example, one cannot specify that a field must be an integer, nor can one specify that an entry must be a valid selection from a value list. This offers users freedom in the field to deal with unforeseen circumstances, but requires oversight and not inconsiderable data clean-up at later stages.

The dynamic nature of the preferences file allows a project continually to develop data-gathering parameters. One need simply edit the preferences file, restart iDig, and then new or reorganized data fields with which to gather information become available. This flexibility facilitated on the fly improvements as needed.

Some drawbacks remain. The beautifully rendered stratigraphic matrices (Figure 6) and section drawings cannot be exported (except as screenshots) and remain locked within iDig. Psychologically, the enticing rendering of the matrices perhaps deters excavators from constantly questioning their developing stratigraphy. The "minimal parenting" approach creates the potential for data to evolve in unplanned and unwanted directions. As the volume of data grew, the list of items iDig had to display became tedious to swipe through, and this inconvenience could not always be resolved by means of a keyword search. Other concerns relate primarily to the iPad as a tool. Particularly in hostile field conditions, with strong winds and bright sunlight, data entry can become little easier than simply writing on a paper form. The fragility of the iPad glass screen is a concern. The damage rate, and the resulting impact to the project budget, was not negligible, despite the use of protective cases. The current lack of an Android version, and the fact that iDig cannot run successfully on the lowest specification iPads, do add to the project budget.

The biggest concern with iDig however, relates to the gathering of data from the various individual iPads. Most commercial implementations of mobile computing rely upon client-server models which typically have some form of underlying database. In this model, changes to the central data are arbitrated by the server and database in real-time. When not connected via a network, individual devices have a copy of the central data. When they reconnect, complicated protocols arbitrate changes to the data, even when made across multiple devices.

The original design scenario for iDig did not anticipate the need for such a complex model. iDig was originally designed as an in-trench recording tool, with no need for multiple clients to access the same datasets. Each trench formed a different dataset, held on a separate iPad. When a need for more than one iPad in a trench became apparent, a simple method for synchronizing data between two iPads was developed: peer-to-peer synchronization via any available wireless network. This works by comparing the complete dataset in two iPads and pulling changes across from one to the other. iDig lists changes in the receiving iPad before implementing them, allowing user review. New data can be accepted with minimal checking, but where two

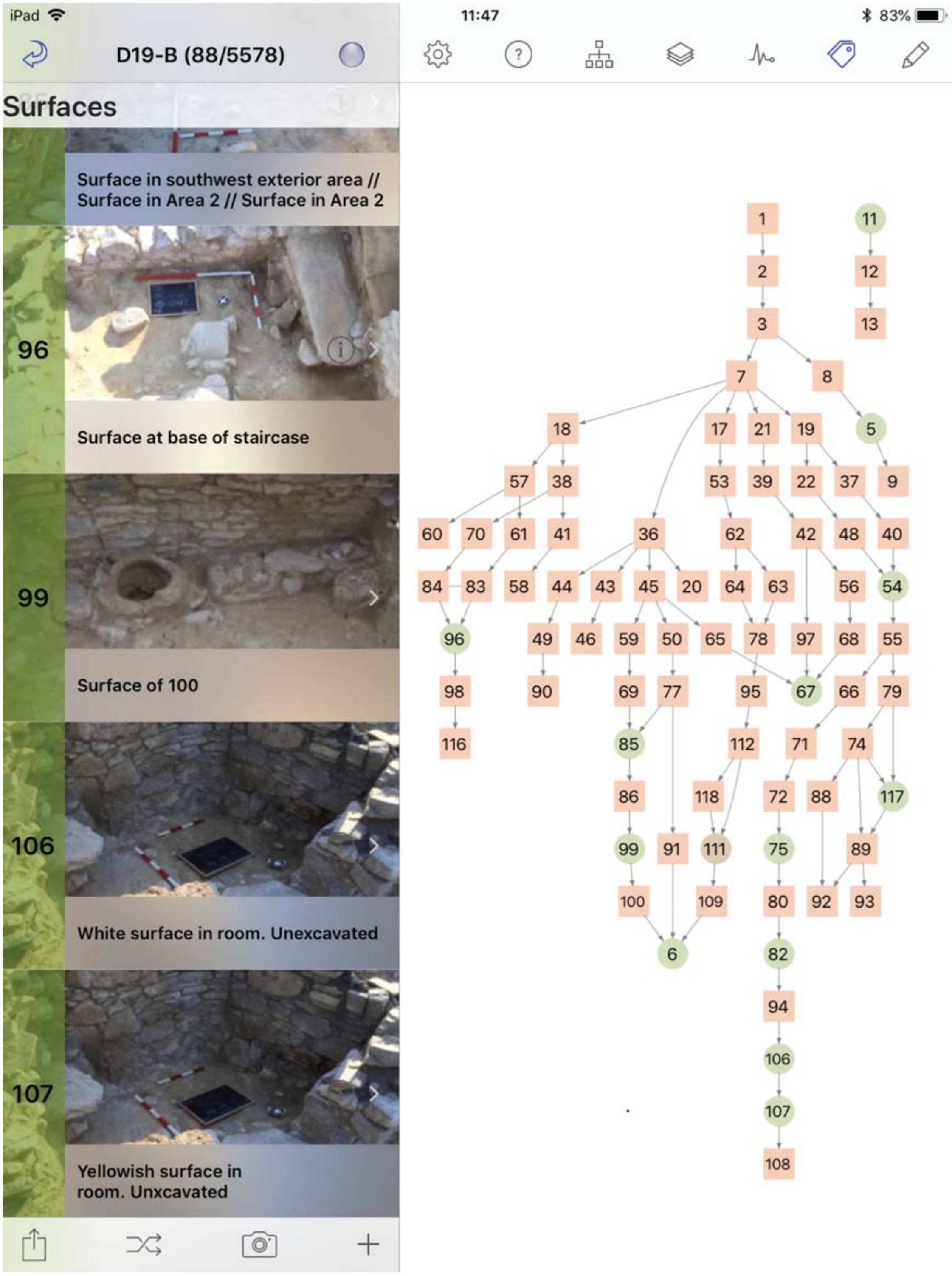

Figure 6. Screenshot of iDig, showing temporal matrix for Trench B.

existing records differ, the user controls which changes to accept or whether to merge records. By syncing each iPad in turn, a single dataset results, identical on each device. The design of the peer-to-peer synchronization is extremely robust and, when working well, results in the data for a trench being identical across devices. Multiple copies in circulation are also a safeguard against failure of any one device. Moreover, on a remote island such as Keros, the investment in network connectivity required by a client-server model would have been significant (cf. Roosevelt et al. 2015).

Three problems arise to disrupt this otherwise well executed design: maintaining records in the trench, the amount of data recorded per trench, and the multiplication of devices on a large and complex project such as Keros. In our largest trench, an ideal number of iPads was seven, and we found the only practical way to achieve this within the limitations of the peer-to-peer model was artificially to divide the trench into three sub-trenches. Mitigating the drawbacks of this solution has consumed much valuable post-excavation time and energy. The problem of data volume derives from iPad memory limitations and is complicated by the number of edits to very large trenches. By the end of our third season in the field, we had pushed iDig well beyond its recommended limit of 1000 data objects, with one trench at over 7000 objects. On only a handful of occasions over our three seasons did we experience anomalies that required careful work to re-sync devices to ensure that data integrity was maintained. However, syncing did become more cumbersome in large trenches, as iDig would not pick up all changes on the first sync attempt. Instead, multiple iterations of syncing had to be made until the final sync showed no additional changes. This became both time consuming and unnerving. As our experience has shown, the peer-to-peer syncing model will need to be redesigned as iDig is deployed on larger-scale projects.

A further problem with the peer-to-peer syncing model arises when recording moves beyond the field and into the field laboratory, discussed further below.

Implementation of a Total Photogrammetry Strategy in a Large Excavation

From the start, it was decided to build an extensive and evolving three-dimensional spatial record of the project area, natural topography, architectural features, and all contexts. The latter complemented the stratigraphic record in iDig. To create 3D models, the project employed Agisoft Photoscan (now Metashape), a semiautomated structure-from-motion software, which uses overlapping digital photographs taken from multiple viewpoints around a subject. This process is referred to simply herein as "photogrammetry." The products of photogrammetry are georeferenced 3D models, digital elevation models (DEMs), and orthographic photomosaics (orthophotos). A brief summary of the approach used is provided below, and a complete description will be the subject of a forthcoming article.

Extensive and intensive coverage was undertaken at a range of scales beyond the individual context, thereby including the excavation trenches, the entire island of Dhaskalio, and the wider area. Photography for wide areas required an inexpensive radio-controlled quad-copter (UAV; a DJI Phantom 3 Advanced with a 12 megapixel ultrawide lens camera), and intensive recording employed handheld cameras that were sometimes mounted on short 1.57 m poles. The midrange coverage was most often photographed with pole-mounted cameras, but large trenches and even large contexts were sometimes documented with the UAV. Surveyed targets, which were coded for automatic recognition in the software, providing georeferencing data for the models, were included in every photographic sequence. These were placed at 2–3.5 m intervals around trenches (Sapirstein and Murray 2017), as well as inside trenches on walls and around the wider area, with a minimum of three targets required for each scene.

An area of about 500 × 500 m, including Dhaskalio and the west coast of Keros, was captured in orthophotos at a resolution of 5 cm pixels, and Dhaskalio itself was captured at 2 cm pixels. These low-resolution, wide-coverages were used for GIS basemaps and for architectural recording. At a smaller scale, excavation trenches were recorded on a weekly basis, achieving 2 mm pixel resolution. These were used for architectural recording, basemaps in GIS and iDig, and additionally acted as 3D snapshots of the excavation. Weekly updates to the iDig baseplans from photogrammetry allowed excavators, and especially specialists who worked remotely, to visualize their current work overlaid on top of fresh orthophotos and line drawings.

The most intensive capture documented every single stratigraphic context excavated during the 2016–2018 campaign, 1070 in all, at 2 mm pixel resolution, with the workflows having been tested in the 2016 season of the American School of Classical Studies at Athens excavation at Corinth. Combined 3D models allowed visualizing stratigraphic relationships, with the aim of effecting a total model of the excavation within which it would be possible to "re-excavate" each context virtually. Each context was represented by two models made before and after excavation, which, when combined, could represent the volume removed by the excavation of the context—and thus represent the volume created by the formation event concerned.

Recording 3D models represented a considerable investment of personnel and equipment in the field and in the office. The extensive surveying and trench photogrammetry were undertaken primarily by the excavation architect and assistants, while members of the excavation team were trained to photograph the contexts. Several people in the office were employed to keep a number of computers running photogrammetry processes. Within Photoscan, Python scripts and batch workflows standardized all work.

In tandem with photogrammetry, trench-based laser scanning was carried out at the end of each season. This produced trench models of higher accuracy and resolution than those obtained by UAV photogrammetry, and it is hoped ultimately to use the laser-scanned trench models side by side with the complete suite of context models in an environment facilitating metric processes and visualizing different stages of the excavation.

Designing a Reflexive Strategy for Contextual, Real-Time Pottery Analysis

Pottery, plentiful in prehistoric Mediterranean excavations, offers much useful basic information that can be assimilated during a field season, such as chronology and function. The pottery was already well-understood in terms of typology and provenance from the previous excavations (Sotirakopoulou 2016; Hilditch 2013, 2018). It was decided early on that the aim would be to process all pottery on a 24–48 hour cycle, and much thought was given to the maximum amount of information that could be recorded within this timeframe, given the expected volume of pottery (based on the earlier excavations) and the need to keep up with incoming material (in the end, we recorded about 109,000 sherds).

One goal was to move beyond anecdotal dissemination of information during the field season, so that answers to simple questions like "what phase does the pottery in this context belong to" could be found within iDig. Just as the adoption of single context recording systematized the data formerly recorded in field notebooks, so the adoption of standardized ceramic recording set out to systematize what was being recorded in the field laboratory. Discussion over how to implement this led to what became a second, more ambitious, goal in field laboratory recording: that rather than recording unsystematic, preliminary observations whose use in the final study was minimal, recording should instead aim at systematic observations that would not need to be repeated in subsequent study seasons. In other words, that the final study of the pottery should begin during the excavation, as soon as it was brought back from the field and washed.

Implementation was a threefold problem: deciding what to record, translating the recording process into the iDig framework, and providing the human resources necessary to carry out such recording under the time constraints. In order to keep up with the volume of incoming material and yet still to record sufficient data as to be useful both during the excavation and as a foundation for subsequent study seasons, we dedicated six persons to the pottery team in each field season (out of a total team size of up to 90 persons). This was a significant increase in resources, but the experiment paid off in every regard, as will be explained below. The advantages of known ceramic types and predictable volumes of material would not necessarily be available to other projects wanting to adopt our strategy, but iDig's flexibility through its preferences file would allow other projects to build and modify their recording system on the fly in response to material coming in until all recording requirements were covered.

One important decision was what would be the basic recording unit for the ceramic finds. The expected volume of pottery ruled out a single sherd recording system. Equally, the pressures of recording within the timeframe of the excavation made recording at a context level difficult, as gathering and opening all the bags from one context at the same time in order to generate a single data record would be impractical. Some contexts were excavated over several days, and so recording at context level would prevent the operation of the 24 hour recording cycle. The only practical decision was therefore to record at a bag level. This had the advantage that the bag record would already exist in the dataset, having been created in the field, and so pottery recording would simply add to an already existing record. This procedure has the disadvantage, of course, that in iDig one has to look at all the bags from a context in order to apprehend the phasing or, say, the predominance of storage shapes. This compromise was regarded as acceptable, as, initially, few contexts had very large numbers of bags. Metrical data from pottery bag records have subsequently been merged in pottery context records in the project database, with the disadvantage that getting these data back into iDig is not simple. A context-level aggregation function would be a desirable addition to iDig's functionality.

In order to maintain consistency in the recording, the six recorders were divided into three teams of two. Generally, each team worked on only two or three trenches. Moreover, they would try as much as possible to process the bags from each context one after the other, in order to get a feel for the context, notice differences between contexts, and be aware of possible joins (Meyer et al. in prep).

Recording of each bag followed a set process to record data under different headings. First, all the sherds were divided according to fabric. Fabric analysis plays a crucial role in the study of the ceramic assemblage of Dhaskalio, since all pottery is imported, and fabric is usually a clear indicator of provenance. The extent of the fabric recording undertaken is unique for the study of pottery in the Aegean: most other projects undertake fabric studies on a subset of the assemblage during post-excavation study. The present project, on the other hand, has now approximately 99,500 sherds classified as to fabric. This forms a foundation for the statistical study of diachronic or spatial patterning in the assemblage, pointing to functional patterns across the site or to changing import networks through time.

Once sorted by fabric and recorded, sherds diagnostic as to vessel type or decoration were separated from non-diagnostic sherds and given closer treatment. Approximately 22% of the assemblage is diagnostic in this way. Vessel types were recorded by specific shape, surface treatment, and decoration using the same typological classification as in the previous excavation, both as individual sherds and as numbers of vessels. Meanwhile, the remaining non-diagnostic sherds were counted and weighed.

This extensive recording of fabric, shape, surface treatment, and decoration permitted a detailed picture of the ceramic assemblage to be built up in tandem with the excavation. Daily procedures included discussion between trench supervisors and pottery specialists, in formal (team meetings), semi-formal (scheduled conversations after return from the field), and other settings. The level of feedback in both directions informed the creation of the record and created a dynamic bond between field and laboratory processes, the value of which was felt strongly by all involved. Beyond the developing understanding of each trench context by context, it was also possible to begin consideration of chronological, functional, and provenance questions within and between trenches during the timeframe of the excavation. A secure basis for the final study was already in place by the end of the excavation, and the study of the non-diagnostic material was, for most purposes, already complete by that point. Post-excavation study is focusing on further analysis of the diagnostic sherds, but little further work on the non-diagnostic material is necessary.

Some of the constraints of recording this information in iDig will be set out below. These, however, should be seen against the great advantages that we found. Recording the pottery in the same database as the field data meant full reflexivity in information availability. As all field data, including context descriptions, field photos, and the Harris matrix, were available in the field laboratory during the initial recording stage, recorders had a much better understanding of individual contexts and how they related to each other spatially and chronologically. Field data were consulted constantly during processing in the field laboratory. Conversely, in the field, information gained from the pottery was available the next day to the excavators. Hence, the process of recording became a holistic, multivocal exercise where the data which each participant was making available became enmeshed in decision making and further data interpretation.

iDig in the Field Laboratory

The use of iDig had not previously been extended in this manner. Its trench-based paradigm did not anticipate multiple users in different locations working on the same datasets. Changes made in the field laboratory to records previously created in the field could generate complex conflicts if edits were also made in the field on the same day: during the synchronization process, two different new versions of the same record would conflict. This would necessitate a manual process of reconciling the edits made on each iPad, requiring the presence of both users who had made updates, and requiring them to remember what they had been doing, so that an agreed composite record could be created and become the final (for that day) version. These conflicts during synchronization became a time-consuming problem.

In addition to pottery processing, other field laboratory processes were added to the developing common information framework based on iDig. All environmental studies were organized and overseen by a single specialist, building on the experiences of the previous project (Margaritis 2013). One person with relevant in-field experience was responsible for ongoing decisions in relation to the different sampling procedures required for each discipline, as well as for ensuring the integration of the different techniques with each other and the overall excavation aims. We carried out as much of the flotation and subsequent sorting of heavy residues as possible in tandem with excavation—a considerable undertaking, as we aimed to take a much greater number of samples than during the previous excavation period. We also aimed to integrate the resulting recording into iDig. Specialists would add their data for finds to the records made initially in the field. But new finds were also generated in the field laboratory. Sometimes finds of one category would be found in the wrong bag (e.g., a shell in a pottery bag), and these would need to be placed in a new bag with a new label and, crucially, a new number. Sorting of heavy residues from flotation produced new finds in many different categories. New record numbers could not easily be generated in the field laboratory, as they would conflict with numbers being created that day in the field. Not being able to give numbers in the field laboratory until the field iPads were available became a source of backlog and error. Ad hoc solutions such as setting aside different blocks of numbers also produced their own problems.

To solve these problems, we implemented a firewall between the field and field laboratory: a clear separation of excavation and lab records that nonetheless maintains a clear chain of custody back to the original archaeological context. Within iDig, the preferences file was modified to implement the concept of a "lab analysis record" (a subtype) that "belongs to" a "field sample record." This allowed work to proceed in both the field records and the lab records without any conflict between edits. While we initially took this step to solve a tactical issue regarding sequential numbering and syncing, we have now evolved it into a robust set of subtypes, each with their own specific data profile, which allows different specialists to work concurrently on the same set of materials from a given trench, all while avoiding any data integrity issues.

The integration of field laboratory data increased the scope of data under iDig's control, and by extension, the number of iPads to be synchronized. On Keros and Dhaskalio, up to nine trenches were being excavated concurrently, and, at the same time, there were five to seven specialist iPads processing in the lab. Furthermore, the desired reflexivity requires all the trench supervisors, specialists in the field and lab, directors, and assistant directors to have updated data daily. It was necessary to design a syncing protocol whereby there was a daily rhythm and order to which iPad was synced to which other iPads (Figure 7). Each sync between two iPads requires diligent attention and careful choices. It is a task that cannot simply be handed off to the least busy person. As trench sizes grew, a typical sync procedure could consume fifteen to thirty minutes. A master iPad sat at the middle of this protocol, the only iPad to sync with other iPads on both sides of the firewall. Accomplishing all of this via peer-to-peer synchronization became

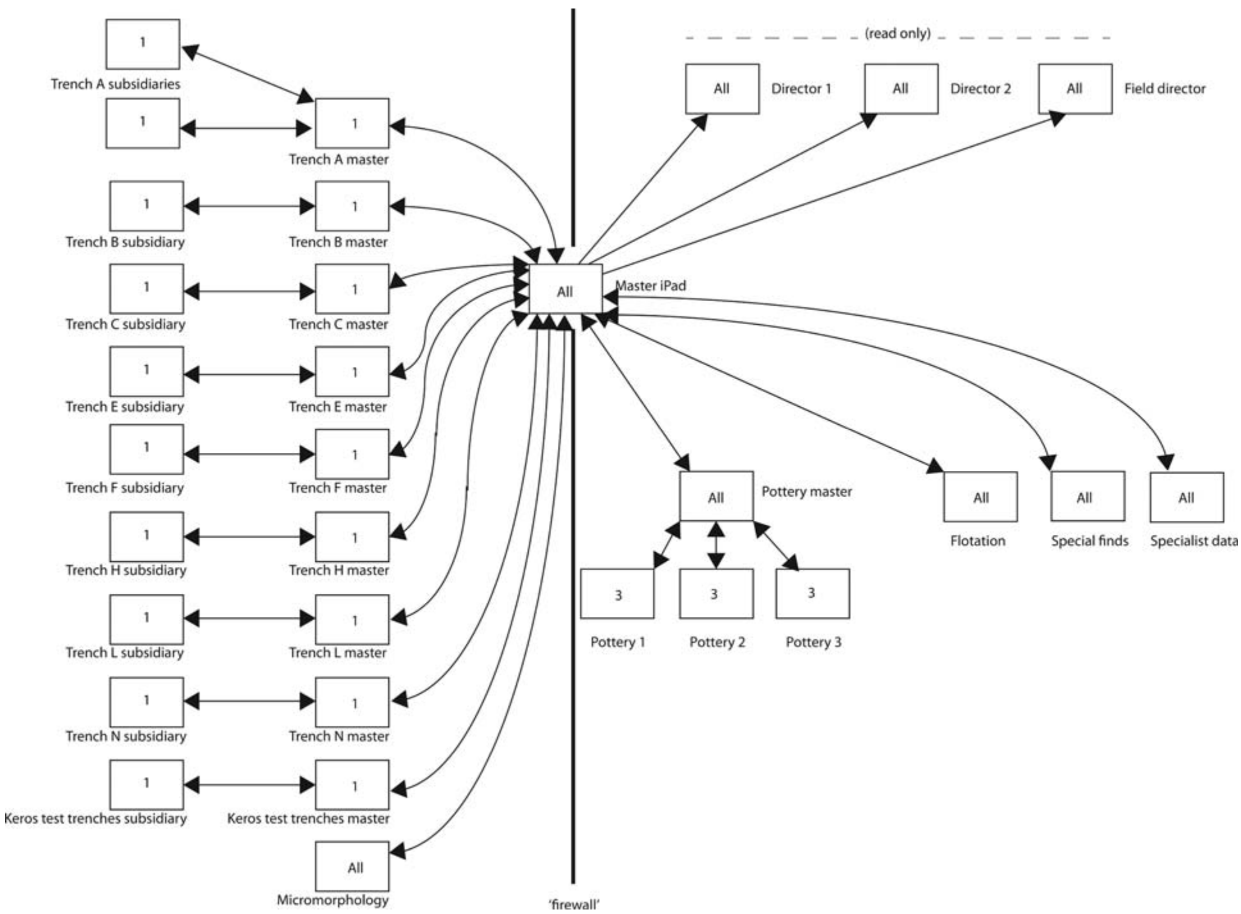

Figure 7. Flow diagram showing all the iPads in use in the 2017 Keros field season and their place in the daily syncing regime. Each rectangle represents one iPad, and the number in each rectangle represents the number of trenches synced on that iPad.

a herculean task: by the end of a 6 week season, the evening sync required 2–3 hours' work after other (data-generating) tasks had been completed. This entailed one person organizing and carrying out the sync, and, in turn, each individual (trench supervisors and specialists) working with the data specialist to discuss and resolve sync issues.

The investment of time described here is significant, and at the scale of operation, the overhead is considerable. Changes in how iDig operates might have made things easier. However, in describing the practicalities, it is easy to overlook the advantages gained. The entire project was recorded in a single database, open and available to all participants. The answer to any question lay within the iDig dataset, and anyone with an iPad could find what they wanted in a matter of seconds. This represents an immense step forward in information curation and availability in a field project.

Taking the project dataset into the post-excavation phase

Excavations, and subsequent post-excavation analyses, are a set of inter-locking, data intensive processes. Arguably the norm in current practice is to envision these processes as linear, with field lab processes downstream from excavation processes and specialist analyses downstream from field lab processes. Our goal was to re-envision this as an interactive cycle to the greatest extent possible. Accomplishing this with iDig required a rethink of the iDig paradigm. With the help of the developers, we have extended this paradigm to include multiple seasons and non-field data sources. Now the question was to what extent this could operate as a data capture and curation tool through several years of post-excavation analysis.

This question was complicated by iDig's limitations as a database. Searching for individual records is easy, and the result beautifully presented in a pseudo-GIS visualization. But iDig has no database-like facility for data querying or amalgamation. To move from the browsing of individual records to more systematic data analysis, one must at present export iDig data either to a database or to a GIS. (The desktop version of iDig, currently under development, will offer database and GIS functionality without data export).

iDig exports data to CSVs created per trench, with each data type getting its own file. These raw CSV files present a series of interpretive and processing challenges. In addition to data capture fields, numerous system fields are exported, and decisions must be made as to whether and how to use these fields. The flexibility in iDig to ascribe many, for example, "belongs to" relationships, creates another type of challenge. These relationships get flattened on export into a single cell holding the keys to multiple other items. These relationships take some unpacking before they can be meaningfully represented in a database.

To tackle these challenges, and as well to deal with some other nuances in how iDig represents context geometry, a series of processing modules was developed using the Python programming language (see Supplemental Material 1). These modules remove extraneous fields from the individual CSV files, lift the data out of the trench paradigm and into a site-wide paradigm, unpack and rebuild relationships, create GIS files for each context, and implement a data quality program. The Python modules use a JavaScript Object Notation (JSON) to define each table (and the set of tables) according to Frictionless Data's standards (Frictionless Data, n.d.). These JSON files provide data mapping, data quality control, and facilitate the building of structured-query language (SQL) tables in standard relational and spatial databases. While the Python modules are in some ways unique to our project, they were designed with general use in mind. The current version (along with the Keros preferences file) is made available with this article for any project to use and adapt. The end product of these processes is an SQLite database which can be accessed via GIS or traditional database front-ends, as well as a GIS GeoPackage. Our intent is to continue to develop these modules over the life of the project and to extend them to prepare data for archaeological data repositories such as Open Science Framework (osf.io; cf. Lukas, Engel, and Mazzucato 2018; Wright and Richards 2018).

With a set of clean data files that can be imported into a database or GIS, it would have been possible to take the decision to stop using iDig for data entry and simple searches. Arguably, a client-server solution would make more sense when, after the conclusion of the excavation, participants were now working in locations around the world, instead of just being concentrated on site and in the field laboratory. However, given our investment in the iDig platform and the existing and now well-practiced workflows in the finds laboratory where much of the work would continue to be undertaken (now located in the Museum of Naxos, rather than the field laboratory on Kouphonisi), we decided to continue with iDig data entry, using the regularly-updated database and GIS for in-depth data query and analysis.

Some categories of data cannot easily be entered wholesale into iDig. These are specialist analyses that by themselves generate complex databases or multi-sheet spreadsheets. Typically, such detailed datasets are impenetrable for those with no training in the specialism concerned. However, to maintain the integrity of the common information framework which we were building, it was imperative to consider how these datasets could be represented. We therefore invited all of our specialists to generate summary data, understandable by a non-specialist, for entry into iDig. The reasoning is that what specialists want to know about a context or find should all be stored in our central common information framework, and they should rarely have to seek additional information beyond that. Hence, a specialist studying fish bones (for example) might be interested to see what other organic evidence was found in a context. She will find via our common information framework (whether viewed through iDig, GIS, or database) summary information relating to archaeozoological, archaeomalacogical, and archaeobotanical macro and micro remains—enough information to understand the context in which her material was found. In this way, the specialists themselves decide how to summarize their data in a way that others using the dataset will find easy to understand and useful. Working with this dataset, we expect that users will very rarely feel the need to consult the full dataset of another specialist, and this is the aim of the system.

At this stage of development, the only major category of data that remained outside the system was the mass of photogrammetric data. Initially, we experimented with importing georeferenced finds data into CloudCompare complete composite models. This usefully led to spatially accurate representations of artifact findspots within the model. Current work is focused on porting our models into ArcGIS Pro, which can present our entire GIS dataset within a 3D environment (Jensen 2018), as well as open and query tables in the SQLite database. iDig's focus on 3D georeferenced data means that the data needed to represent the whole site in GIS already exist. The advantage of a 3D GIS platform over virtual reality solutions (cf. Lercari et al. 2018) is the possibility of access to all excavation data within a single platform, making the tool that is being built data-driven and research-oriented. This work is advanced, and shows clearly that all the investment in photogrammetric recording will pay off in an immersive (if processor-sapping) GIS environment. In this way, data can be visualized at any scale from context to trench to site and in any combination of data from excavation, finds, samples, and analysis. As we move into the writing-up stage, it is expected that the 3D GIS environment will be our main source of analysis. This solution will be described in full in a forthcoming paper.

Progress and Problems in the Totally Integrated Workflow

If we now compare Table 1, listing disparate datasets produced during the 2007–2008 excavations, with a representation of our common information framework in Figure 8, it should be clear that a very different structure applies to the 2016–2018 excavations. This represents a significant consolidation in terms of data centralization and availability, in interactivity and reflexivity, and in workflow integration.

In assessing the results of our new methodology, the analysis of costs and benefits is still at a preliminary stage. The open area, single context approach has clear benefits in terms of understanding the formation events which created the site and in standardizing the recording process. Digital recording in the field saves time in removing the need for subsequent digitization of paper-based data, and the intuitive iDig system has made enthusiastic converts among field officers and specialists. None would claim, however, that field recording is made much faster by iDig—but photogrammetry is certainly faster than traditional drawing. There has also been a financial cost in terms of support personnel and equipment (especially iPads), which smaller excavations perhaps could not contemplate.

Missing from Figure 8 is what Croix and colleagues (2019, 1593) call "metacontext," by which they mean the description of the interpretative process. In the field, we used diaries (initially hand written, subsequently digitized) to record the progress of the excavation and the thought processes involved in daily decisions such as changing context (recorded more analytically in terms of contextual difference in iDig) or where to allocate resources. Digital diaries have now been integrated into the ArcGIS platform. On a different level, there is the metacontext of the whole interpretative process, which perhaps requires further documentation than we are currently providing.

The recording of traditionally disparate datasets within the common information framework (see Figure 8) has undoubtedly been a major advance, both in the reflexive integration of field and field laboratory practices and in integrating processes traditionally seen as post-excavation with those of the field season. Everyone working during the study seasons and in the writing up stage will have abundant information at their fingertips offering them the chance to reflect on interpretation during the data production phase.

Setting up this system was experimental and high risk, although had the system not worked, it would have been relatively simple to go back to paper recording. We benefitted in 2017 and 2018 from full-time support for data processes and have put considerable resources into moving data from iDig into database and GIS systems. However, our solutions to these problems are now available for other projects to benefit from (see Supplemental Material 1). Such projects will need to have the benefit of one person able to read and modify the text-based iDig preferences file and JSON files and with advanced beginner level knowledge of Python for any changes needed for the export scripts. In addition, depending on the scale of the project, the same person is needed part or full time to manage the data processes.

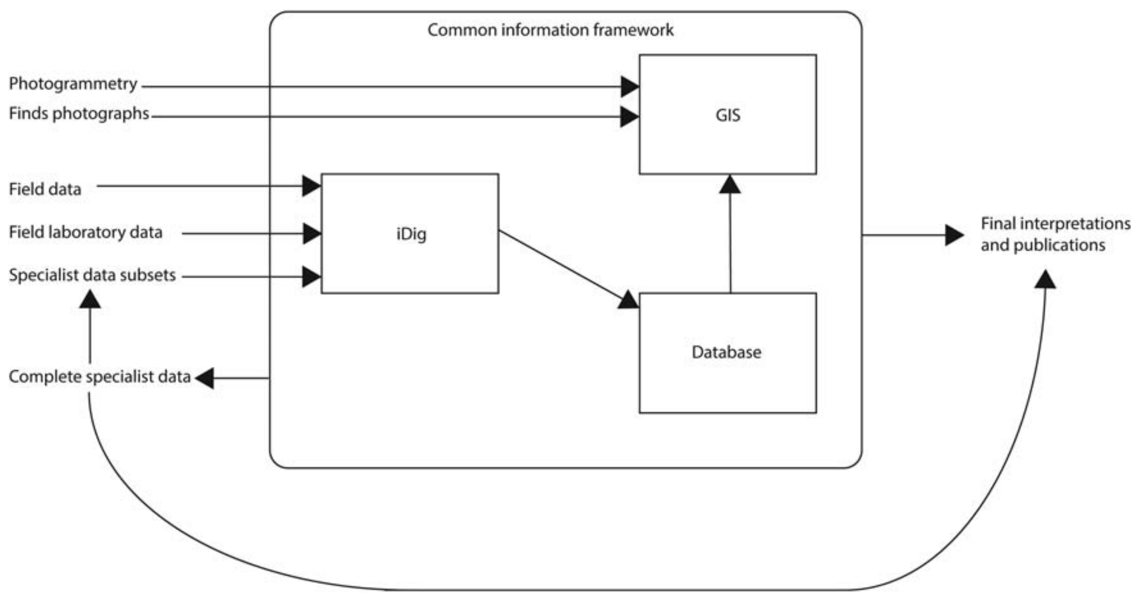

Figure 8. The integrated Keros data model.

Conclusion: A Framework for Practice, Reflexivity, and Data Flow from Project Inception to Publication

The challenges of envisaging and implementing the strategy we have set out here have been formidable. The willing participation of a large group of enthusiastic colleagues was an essential element of its success. The hard work is now paying off, and part of our purpose in describing our method so fully is that our efforts may inspire adoption and adaptation on other projects.

A first challenge for us was in rethinking field practice and in questioning the taken-for-granted. The success of this approach was founded on the participation of a large cohort of colleagues in the writing of the field manual and the configuration of iDig before the first field season, and in the willing participation of our field crew in refining the method on site. A clear focus on context, dug as a unit, described in iDig, recorded as a photogrammetry volume, and intensively sampled for more than a dozen specialisms has created a methodological rigor and a clear sense of purpose. A second challenge was to integrate the ceramic and other field laboratory studies with the process of excavation in the field. In so doing, we had to reimagine the purpose of the study so that the data created in the field laboratory were as fundamental as any excavation data. A third challenge has been to manage the development of an ever-expanding common information framework, so that almost all data are situated and analyzed in this one repository (see Figure 8).

The value of the method outlined here may be seen in the casual familiarity that everyone working with our finds has with the excavation dataset. This is reflexivity in action, now extended in time until the endpoint of the project, and indeed beyond, when the entire dataset will be publicly available.

Gordon, Averett, and Counts (2016, 11) refer to an "innovative and experimental DIY spirit" in the adoption of digital techniques. However, the two principal digital recording tools described here—photogrammetry and iDig—are now approaching maturity. Certainly, the tipping point where these can be adopted by a much wider range of projects has now been reached. We would argue that in most cases the benefits of such adoption now outweigh the costs. The opportunity to re-examine every aspect of data production, analysis, and dissemination brings with it clear prospects for new kinds of collaboration and ultimately the production of new kinds of interpretation.

Our experiment in all-digital recording and in integrating all aspects of field, field laboratory, and post-excavation study is now in a new phase, as we seek to leverage the gains made into a new kind of informed post-excavation study. We believe that the result will be a much more heterarchical interpretative process where the input of all those producing data, analyses and interpretations can be felt by everyone involved, and where interpretations can be built up through multiple conversations mediated by the freely available view of the data open to everyone involved.

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