5 On-Site GIS Digital Archaeology

GIS-based Excavation Recording in Southern Jordan

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The 1990s witnessed the progressive 'miniaturization' of personal computers and other digital devices. This affected virtually every type of business, research program, as well as the daily lives of millions of people around the world with access to electricity. The development of portable high-speed personal computers and other data collecting devices was not lost on archaeologists who have always had a deep interest in utilizing technological and scientific methods to advance their recording and study of the past (Renfrew and Bahn 2004). In 1997, when the University of California, San Diego initiated the deep-time study of ancient metallurgy and social evolution in Jabal Hamrat Fidan (JHF) region of the Faynan district in southern Jordan, a fairly traditional style of 'analogue' or paper archaeological recording was carried out during the first season of excavation. With the exception of using a very expensive Sony video camera for taking digital still photographs of artifacts to upload images to the project web site, in 1997 field recording was based on the use of traditional 'dumpy' levels and measuring tapes to triangulate the location of finds, light-boxes for tracing daily excavation graphic diary plans each evening, film based photography, and the recording of archaeological context data (loci) on a range of different descriptive paper forms stored in ring-binders. This system was adequate for 1997 because the fieldwork focused solely on the re-excavation of an Early Bronze age village site (Adams and Genz 1995; Levy, Adams, and Najjar 1999) and an Iron Age cemetery (Levy, Adams, and Shafiq 1999).

However, by 1998 it was decided that to contextualize these two excavations it was necessary to carry out a regional archaeological survey along Wadi Fidan that would require a higher level of surveying precision than that provided by simple dumpy levels (Levy *et al*. 2001a). To adequately analyze the settlement pattern data collected in the survey in relation to various archaeological, environmental, and paleoenvironmental data sets, it was clear that Geographic Information Systems (GIS) would be the most advantageous tool to be employed (ESRI 1996). The remote location of our desert research area from both al-'Aqaba and Amman complicated expedition logistics and meant that it was impossible to develop film in our Bedouin village of Qurayqira, which lacked electricity at the time, or build an on-site dark room like the 'state of the art' one used at Tel Gezer back in the late 1960s–early 1970s (Dever and Lance 1978). In 1998, digital cameras began to appear on the market (albeit expensive) and the idea of a complete on-site digital archaeology system for southern Jordan was born that would integrate instrument-based surveying, excavation recording, and field and final laboratory photography.[1] By the end of our 2000 field season, the

1. This early research was part of the Jabal Hamrat Fidan project (JHF; 1997–2003) initiated by Thomas E. Levy and Russell B. Adams in 1997–98 and later joined by Mohammad Najjar of the Department of Antiquities of Jordan in 1999.

first total digital archaeology system was implemented through the use of GIS and new techniques in digital field recording. The two JHF project excavations that season were subsequently published as ‘Digital Archaeology 2001’, the cover story in the *Society for American Archaeology Archaeological Record* (Levy *et al*. 2001b). Since 2003, with the establishment of the Edom Lowlands Regional Archaeology Project (ELRAP), our digital archaeology program has been improved exponentially and this new system is described below. A key factor in the success of the digital archaeology system used in the ELRAP is the full integration of the Field School students in all aspects of the work described here.[2] The entire ELRAP Digitial Archaeology system can be conceptualized as a series of integrated ‘labs’ with GIS as the central data center for digital storage, retrieval, analysis, and publication (Fig. 1).

Archaeological Excavations: Digital Field Recording

Like traditional excavation recording (Hawkes 1954; Renfrew and Bahn 2004), digital data collection for excavation work breaks down into three primary components: surveying, artifact and context recording, and photography. The advantage of on-site digital archaeology is that it embraces the notion that the control of time and the control of archaeological context are the archaeologist’s most precious commodities for modeling and explaining the past at the highest degree of accuracy. It also enables the processing and publication of archaeological data in a much more efficient and timely manner. Spatial data are recorded in two formats to facilitate using the data in GIS: points and polygons. A point is a single x,y,z coordinate that is recorded for a specific special artifact find or elevation recording. A polygon is a closed plane figure with at least three vertices or more (e.g. triangle, rectangle, octagon). Polygons are used to draw, digitally, archaeological contexts (or loci) in the field. A polygon is recorded using a Total Station or EDM (Electronic Distance Measurer) by collecting multiple coordinates of the different vertices of the desired locus. Using the hand-held Recon data collector and SoloField TDS Software, the vertices collected from the Total Station are automatically connected to create the desired polygon dimensions.[3]

Surveying

Surveying is the means by which all spatial information concerning archaeological data, from artifacts to architecture to site plans are recorded.

James D. Anderson served as the surveyor for the JHF project, Mark Waggoner as the GIS specialist with Neil Smith as his assistant, and Adolfo Muniz as digital photographer. T.E. Levy is grateful to all of these individuals for their contributions in establishing the foundations of the digital archaeology system described here. The archaeological excavation methods and original ‘paper’ recording system were developed by T.E. Levy and ‘married’ to the digital archaeology system described here. T.E. Levy is grateful to the C. Paul Johnson Family Charitable Foundation and the National Geographic Society for supporting this research. Special thanks to the late Patti Rabbitt (La Jolla, CA) who participated in the early excavation seasons of the JHF project and who generously donated the first digital SLR camera to the UCSD project. Patti truly helped us ‘go digital’ early in the project. In 2006 a number of individuals kindly helped us develop the digital archaeology system described here: Fawwaz Ishakat, Kyle Knabb, and Ben Volta. Aspects of this research were kindly funded though T.E. Levy’s participation in the University of Bergen’s *Global Moments in Levant* project. The ELRAP project is affiliated with ASOR.

2. The digital archaeology system is an integral part of the University of California, San Diego Middle East Archaeological Field School in Jordan

3. It is highly recommended that excavation directors in Jordan obtain an official letter from the Department of Antiquities of Jordan for the airport customs office listing all digital surveying equipment, especially data collectors, being brought into the country. This will prevent this equipment being impounded at the airport on arrival in Jordan.

The primary digital surveying tool used on the Edom Lowlands project is a Total Station. Total Stations were originally chosen for the JHF project in the late 1990s over GPS surveying instruments, because of their relatively low cost (ca. $6k), reliability, precision, speed in acquiring sub-centimeter accurate x, y, and z (elevation) coordinates, as well as the fear that GPS instruments might lose satellite lock in heavily mountainous desert terrain. For the 2006 ELRAP season, we decided to link our earlier work (1998–2002) based on a local survey system in the JHF area with the international UTM (Universal Transversal Mercator) system by resurveying known ground control points (GCP) using a sub-centimeter Leica 500 GPS. Accordingly, before the 2006 season we paid the RJGC (Royal Jordanian Geographic Center) 100 JD to process and obtain the UTM WGS84 coordinates for their cemented ground control point located in the JHF Mountains. Using this point as the beginning GPS reference station, a second rover Leica GPS using RTK (Real Time Kinematic) was used to collect GCPs from our camp out over 12 km to our desired excavation site in 2006—Khirbat an-Nahas—to tie in our old local system to the main grid. The degree of accuracy using the GPS system was $\pm$ 2 cm and completed in one day.[4]

For financial reasons, the ELRAP continues to rely on Total Station technology for field recording; however, to improve the collection of data, an effort was made to purchase more powerful and rugged data collectors (i.e. the TDS Recon). Once the Total Station is setup at the excavation site, data can be collected easily. Students are trained to record points within a matter of hours and with practice master the Total Station and TDS Recon technology. Currently the most advanced and expensive GPS units can reach centimeter accuracy, but still can require an extended period of time to record each point when satellite visibility is low.

The primary drawback to the use of Total Stations over GPS in the field is the requirement of a trained surveyor to establish control points and set-up the instrument over these surveyed points for spatial recording. Establishing new control points is a complicated process that cannot be performed by a novice. The procedure involving triangulation of multiple points requires time and preplanning that must occur prior to excavation. Leading surveying companies such as Trimble and Leica have recognized this problem and have recently released ‘Smartstations’ that use GPS to establish centimeter accurate control points at any location desired and auto-configure the EDM for immediate surveying. As outlined above, these two systems were combined for the ELRAP in 2006 so as to tie our old local grid to the international UTM grid system.

Recording Archaeological Finds and Contexts

Recording is the means by which all data (excavation area, date, square, locus, basket, special find descriptions, etc.) are stored in GIS formatted file systems and linked to the spatial information collected with the Total Station. The primary recording tool is a TDS Recon, using SoloField TDS software. The TDS Recon is a ruggidized, waterproof, dustproof, glare resistant, droppable PDA. It runs SoloField TDS software, which collects user entered data on a specific point (special find) or set of points (a polygon shape representing a locus) and triggers the Total Station to record the coordinates for the point or polygon data. At the end of the excavation day, these data are exported as an ArcGIS shapefile on a GIS designated high-end PC Laptop in the project ‘Clean Lab’.[5] The shapefile contains both the spatial information for every point and polygon as well as a spreadsheet database with the data entered for each recorded artifact or locus.

4. We are grateful to our project surveying consultant, Mr. Fawwaz Ishakat, Hashemite University of Jordan, for carrying out the GPS survey and insuring the highest degree of accuracy for our digital archaeology program.

5. The ELRAP has a base camp on the outskirts of the Bedouin village where a tent camp is built each excavation season. As this camp has no electricity, the project usually rents a house with water and electricity in the village to serve as a clean laboratory for computing, finds processing, ceramic, archaeometallurgy, zooarchaeology, and other labs.

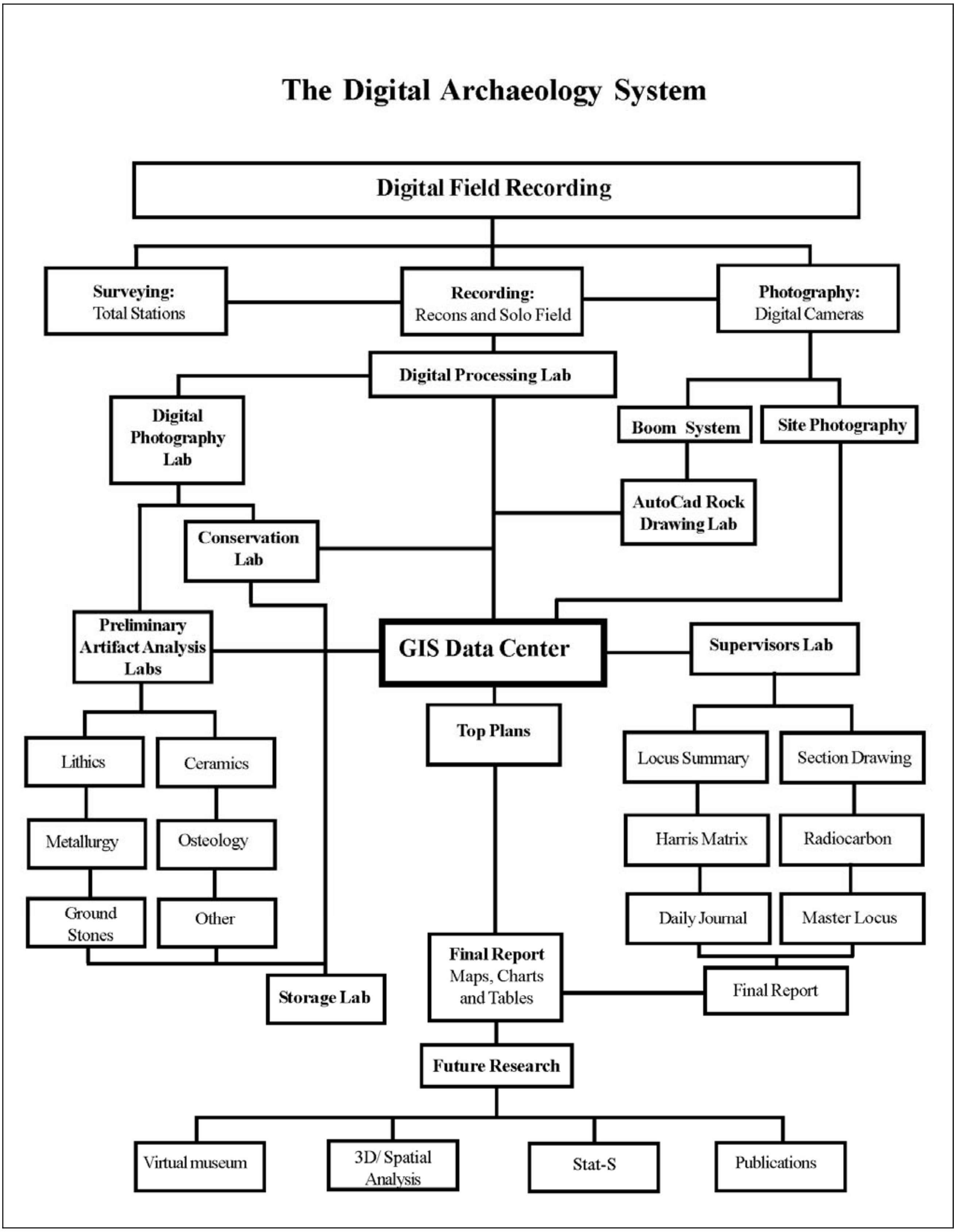

Figure 1. Flow chart of Digital Archaeology

In 1999, a new number field called the 'EDM number' was assigned to every special find and polygon in addition to its locus and basket information (Levy *et al*. 2001b). The EDM number is a unique sequential number assigned to every special find or locus recorded with the Total Station. The EDM number provides the key number field in GIS for all data to be linked with its spatial information. The added benefit of the EDM number is that it allows new data to be joined to the GIS by this primary field key. For example, the metallurgical specialist can join all the measurement and classification data of a specific special find to its data in GIS by the EDM number. The EDM number is also used to link digital field photographs and lab photographs to the GIS system. Finally, the EDM number also provides a check on basket numbers to make sure that there are no mistakes or overlap (see below: **GIS Data Center**).

Digital Photography in the Field

Digital photography is used in the field to record archaeological sites, architecture, loci, and *in-situ* artifacts. In the field, digital cameras serve two basic functions. First, they are used for capturing high resolution photographs of architecture, *in situ* features, and artifacts during excavation. Many excavations rely upon a professional photographer to take all site photos—a long tradition on American excavations in the Levant (Dever and Lance 1978). The advantage of using film was the assurance that the excavation photographer would capture the appropriate material with a professional eye and have the correct focus, lighting, and exposure. Advances in digital cameras through automation have made the need for a professional photographer continually on-site obsolete. In 2004, the ELRAP team recognized the advantage of immediate viewing of photographs on digital cameras—especially for images used in production of maps (see below). If a mistake was made, the photo could be immediately discarded and re-shot. We also found that having a supervisor trained with a few simple photography skills would give a greater precision to what he or she desired to photograph. Thus, by 2006 each area supervisor's dig kit included a small Nikon digital camera (ca. 4 Mega Pixels), a professional menu board and letters, and photographic scales (north arrow and meter stick). By also training students in on-site digital photography, we effectively have a photographer at each excavation area making it unnecessary to have a professional photographer on site during the day. However, for final excavation photographs and the most significant loci, the publication quality photos are professionally taken by the project directors.[6]

The second use of digital cameras in the field is for digitizing site architecture using a boom system that eliminates the need for a professional on-site architect to produce site plans. A compact high definition (Nikon Coolpix P4 8mp) digital camera is suspended securely on a boom pole ca. 7 m above the ground. The boom pole is attached to the camera rig, protected in a plastic enclosure, using a ball joint and leveled to the gravity vector in order to get a perfectly vertical 'aerial' photograph of the desired architecture. In the past, in order to geo-reference the photograph for digitization in AutoCad, a range pole was placed in the photograph and two surveyed coordinates using the EDM were recorded in the photograph (cf. Levy *et al*. 2001b). In subsequent years, we used spray-paint to mark the reference coordinates.[7] By the 2006 season, we discovered an alternative non-invasive method of marking features with masking tape, drawing a cross on the tape, labeling it, and recording the center of the cross's x,y, and z coordinates using the Total Station. By using the high resolution 8mp Nikon camera, these relatively small 'Xs' could be clearly seen in the image—even though the photos were shot from a height of ca. 7 m.

6. On the ELRAP, both project co-directors (T.E. Levy and M. Najjar) take these publication-quality final field photographs.

7. The use of spray-paint was abandoned because it scarred the rocks with 'graffiti' in the excavation area.

'Dirty' Digital Processing Lab (DDPL)

After excavations are completed for the day, all artifacts are brought from the field to the 'Dirty' Digital Processing Lab for initial processing. This lab's primary function is to make sure every artifact recorded in the field has been labeled correctly and corresponds to its digital record now stored in the Recon data collector. Each day, data from each excavation area Recon are downloaded from the GIS server and imported into the daily basket list database. The daily basket list is used to check all the field tags, make sure there are no misplaced artifacts, and also as a preliminary check to make sure data were entered correctly in the Recon; all mistakes are noted. The excavation area supervisor or assistant is then called into the DDPL to correct and explain all mistakes. In the field, the assistant supervisor is responsible for keeping a paper copy of all data entered into the Recon as an extra check. Thus, there are three checks (supervisor hard copy, tags, and digital entry) to insure no data are lost or left uncorrected due to human error. Once the mistakes are identified and solved, all three checks are updated. Thus, the mistakes common to human error, are eliminated prior to creation of GIS daily top plans and labels for digital photography of all the artifacts. The final task of the DDPL is to send artifacts for publication quality photography, preliminary artifact analysis, conservation, and storage of in crates that are inventoried for final storage at the Department of Antiquities of Jordan or at UCSD.

Figure 2. Photograph of Area M at Khirbat en-Nahas, 2006, showing person holding the Boom pole. Part of rock drawing made using ArcMap is superimposed on the corner of the building.

Rock and Architecture Drawing Lab

With the invention of the boom system, we have eliminated the need for a trained site architect (see Fig. 3). The advantage of the boom system is that the actual rocks, installations, and wall lines can be traced with centimeter accuracy. Once the day's excavations are completed, the boom camera photographs are downloaded onto the server and imported into the GIS program. Previously this was done in AutoCad—which had a steep learning curve and required training an entirely separate set of students. With the development of ArcGIS 9.1, it is now possible to carryout all the digitizing tasks in ArcMap that were previously done with AutoCad. Briefly, the recorded reference points for the boom shots are either called up from the day before or imported if new. The pictures are geo-referenced to the reference points (see above: **Digital Photography in the Field**) and the ArcMap 9.2 rectification tool is used to orient and scale the picture in relation to the excavation area map stored in the GIS. Once geo-referenced, the rocks and all other pertinent features are traced with the ArcMap editing tools. Since ArcMap can maintain scale, the photograph can be zoomed in to insure accurate drawing of every rock and line feature. The result is architectural plans that include the smallest rocks that fill in the gaps in walls. Given that everything is now drawn in ArcMap GIS, the data can be simply manipulated in any of the 3D modeling programs available in ArcMap for daily top plans, 3D excavation area or site modeling, and other uses.

Final Digital Photography Lab

Every significant artifact is digitally photographed in the Digital Photography 'Clean Lab' for future analysis, preservation, recording, and reference in GIS. There are two artifact photo booths in the 'Clean Lab' designed for achieving the diffused lighting and background environments needed for publishing quality photographs. Generally, between two to six photographs are taken of each artifact to capture its different angles. Having a Digital Photography Lab in the expedition base camp allows for artifacts to be captured in a professional way before being stored or transferred to another location. Digital photography enables more artifacts to be photographically recorded, and more image files to be stored systematically than film. The artifact's photo files are labeled with the same easy identification and spatial reference in GIS. Thus, the photo EDM number is listed first which provides the x, y, and z coordinates of the image. This is followed by an abbreviated description of the angle shot (e.g. 50001_ t.jpg would designate EDM number, locus number, and a photograph taken of the top or dorsal side of the artifact). Then all the photo files for a specific artifact are combined into a 'retriever' file under its EDM number (e.g. 50001.ret). A retriever file is a file created using a program called Retriever that can call up all linked photos for immediate viewing as thumbnails or select for individual large-scale viewing. The advantage of using a retriever file is that it can be hyperlinked to an Excel or Access database file as well as ArcGIS. Since the retriever file is named according to the EDM number and all our databases use the EDM for joining and accessing artifact data, the retriever information can be queried and called up just as easily as any other information joined in ArcGIS. This allows for rapid access of all the excavation artifact photographs within the current programs used by the ELRAP for analysis including Excel, Access, ArcGIS, or any other program that has hyper-linking capabilities.

Conservation Lab

This wet lab serves the function of 'first response' restoring and conserving of artifacts found during excavations. Generally artifacts requiring conservation go first to the Digital Processing and Photography Labs. The Conservation Lab coordinates with the Photography Lab for taking 'before' and 'after' digital photographs of the artifacts being treated.

Preliminary Artifact Analyses Labs

The ELRAP project has specialist artifact labs for preliminary analyses of archaeometallurgy, ceramics, groundstones, lithics, and zooarchaeology that are run primarily by doctoral students working with the Principal Investigator. Some of the preliminary tasks include washing, sorting, labeling, weighing, counting, and measuring of artifacts and ecofacts. Data are recorded on hard copy forms and entered in digital datasheets that can later be linked, by locus number, back into GIS for preliminary distribution studies, more in-depth analyses back at the university, and ultimately, final publication.

Storage Lab

The final destination for the majority of artifacts after processing, photography, and preliminary analyses is storage. Once artifacts have been subjected to preliminary analyses, the DDPL organizes the storing of artifacts in rectangular plastic red crates (ca. 50 × 30 × 30 cm) readily available in Amman and ideal for permanent storage. The field Storage Lab arranges artifacts in the crates according to excavation area and material culture in a logically organized system that allows easy future access. A master Excel database is produced using the complete loci and basket information available on the Recons for all artifacts recovered during the excavation. The master database is then updated with the storage crate/box number in which the artifact is stored. This crate/box inventory database is rejoined to the master database in GIS so that future researchers can query the database to find in which boxes the artifacts they desire are located.

Field Supervisors Lab

The 2006 ELRAP excavations focused on three areas: Area A Fortress, Area F Fortress interior, and Area M Metallurgical Building complex. To insure that everything recorded in the field is digitally stored, a lab was specifically designed for field supervisors to allow them to enter all their data from journals, locus summaries, Harris matrix, section drawings, photography, daily graphic diaries, and son on, into a digital format, to be stored in a series of folders structured the same for each excavation area. All of these data are stored on the project server that can be accessed by anyone on the local ELRAP network. Student volunteers assist the supervisor in daily data entry on dedicated networked laptops. During the excavation and post-excavation field writing, each supervisor has a dedicated laptop for writing up their final report. The laptops are wirelessly networked with the main ELRAP server so that they can access their site photos, digital artifact photographs, all the databases, and any maps, charts, or tables generated for them in ArcGIS.

The ELRAP GIS Data Center

The goal of making all the excavation data digital is to be able to store them in a Geographic Information System. Once the data is stored in a GIS it can be used to create daily top plans, end of the season final reports (maps, statistics, and charts), artifact specific analyses (pottery, archaeometallurgy, zooarchaeology, etc.), and future research and professional publication. ArcGIS at its core is a relational database, which means data from different databases can be linked by a common number field—the EDM number. This allows all databases and later analytical studies to be joined to the current GIS by this common field. Having multiple databases joined together with spatial data enables the user to conduct complex multi-variable studies. For archaeology, it allows all the realms of material culture to be linked together, associated with precision spatial data, and analyzed as complete data sets. Furthermore, storage and retrieval are organized by the GIS, which allow a higher degree of centralization and control of the data than could be achieved with paper/analogue based studies. GIS significantly shortens the time between excavation and publication, which still remains a considerable problem in archaeology today. The remaining discussion describes the equipment required to run a GIS Lab in the field, the individuals involved, the creation of daily top plans, and production of final reports suitable for publication.

Organization of the GIS Lab

The centrality of the GIS Lab for all digital data processing and storage generally necessitates state-of-the-art portable computers as well as high speed local networks, and data storage systems. Over the past three excavation seasons, the ELRAP digital archaeology system has used two dedicated computers per excavation area as the minimum for efficient data processing. The high-end laptop is used by the GIS area specialist for all GIS activities including architecture and rock drawing. A fast laptop is also used for running Adobe Photoshop and Pagemaker for use by the digital photographer. Medium range laptops are dedicated for all forms of data entry by the supervisor, assistants, and computer-savvy students (see **Supervisors Lab**) and report writing. One of the latter computers is also dedicated to the DDPL for downloading Recon data, managing the daily digital basket list and other processing databases, and uploading data to the server. Finally, the specialists running the different preliminary artifact analyses often use their own laptops that can be networked to the ELRAP server.

Beginning in 2006, the server ran on one of the high-end laptops configured as a server networked to a gigabit hub gateway and linked with a wireless router for the medium range computers. For back up, a 400 GB external hard drive was used for copying all data on a daily basis. ArcGIS is designed to run proficiently over networked systems and enables a high degree of control of the data and prevention of dispersed copies of old projects and data. The other advantage of running off the server is that any computer can access the shared data so that areas are not tied to one computer. The transition to gigabit Ethernet has increased data transfer by ca. 10×, which saves time loading and transferring data on the networked laptops. During power outages, which do occur on occasion in our Bedouin village, the laptops switch automatically to battery power, allowing another ca. 3 hours of work without electricity. Two to three printers are also connected to the network for printing of spreadsheet, photos, labels, top plans, or any other digital data presentation.

The GIS Team

Prior to departing for Jordan, the specialist who overseas all ELRAP GIS projects and Server maintenance trains two students for each excavation area in preparation for the expedition. The student *GIS area specialists* are trained in producing daily excavation area top plans for the supervisors and the final excavation reports. With two students per area, they can be rotated daily to prevent fatigue and allow them to participate in other post-field lab activities. Having dedicated students producing top plans frees up the supervisors and assistants to focus on their journals and field reports. The supervisors are expected to oversee the GIS top plans to insure the integrity of the data. After the first week of field excavations, new students are brought in to learn how to use GIS in the ELRAP digital archaeology program.

Daily Top Plans and Publication Quality Maps

Top plans, once known as daily graphic diaries, are daily printed maps that display the current loci being excavated, exposed architecture, as well as the location of all special finds. Prior to going digital, top plans were traced daily by hand on a light box by the area supervisor. Special finds were roughly measured in the field using measuring tape and a simple 'dumpy level' to measure elevation

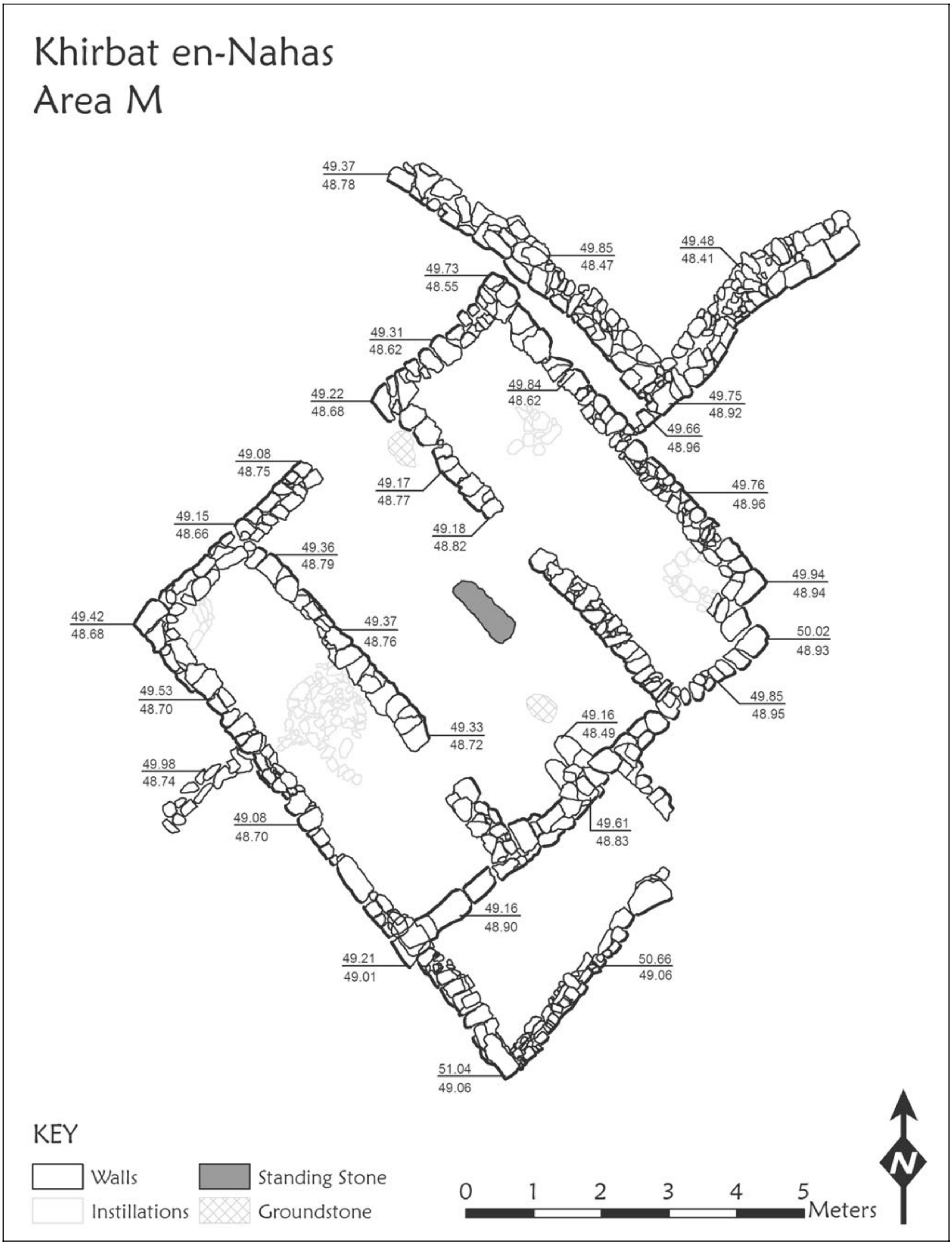

Figure 3. Final map of Area M, Khirbat en-Nahas (2006)
made with geo-referenced digital Boom photography and ArcView GIS

to illustrate the data mentioned above. The drawbacks of this system are that it is time consuming, lacks precision and accuracy, and is only in hard copy form. If any type of spatial study was to be conducted, it would require an entire year or more to digitize the top plans into ArcGIS, and the data would still be dependant on the accuracy at which the supervisor or site architect drew the original top plans.

Producing top plans with GIS is a fast process and allows for specially crafted Top plans for each area according to what the supervisor desires to see for the next day's excavation. The point and polygon data for every area has already been downloaded as shapefiles[8] in the DDPL and is directly uploaded to the server to be accessed by the GIS area specialists. From their networked computer they can directly import the shapefiles into their current ArcGIS project. First, the point data (special finds and elevations) are automatically assigned symbols so that each type of special find can be distinguished visually on the map.[9] Supervisors have a printed key of the descriptor codes that they carry in the field. Second, detailed labels for these special finds (e.g. '50001 HA Hammerstone') are generated on the map. Depending on the preference of the supervisor, any type of label information can be generated for their point data. Third, the polygons (loci) are imported into GIS. The polygons are assigned different colors according to whether they represent the opening, modification, or closing of a locus. This procedure allows the supervisor to immediately recognize what new loci were opened the previous day as well as those that were closed. Labels are also generated that can depict dates of the loci or elevation or any other needed information. Fourth, the supervisors are then called in to look over their top plan and give any input or corrections. The supervisors' checking of the top plan serves as a fourth check on the entire digital system. Once the drawing of the boom photography of site architecture is finished using the editor tool in ArcMap 9.2 it is ready for GIS analysis. Since the architecture is already geo-referenced it immediately drops into place on the top plan. The final step of producing the top plan is to update the printing template so that it represents the data collected that same day. The top plans are printed on tabloid size paper over the networked printers. Multiple copies of different sizes can be produced for the area's supervisor. From start to finish, daily top plan production averages between 30 minutes to one hour depending on the amount of finds and loci excavated that day. With careful editing, the data collected from 'boom' photography, rock drawing, and site surveying can be coupled together in GIS and used to produce publication-quality maps (see Fig. 3).

Conclusion

The primary goal of the digital archaeology system is to facilitate the production of publication-quality final reports by the end of the excavation season (Levy *et al*. 2003, 2005). Since spatial and statistical data can be produced on the fly, supervisors and specialists have a wealth of information for producing an accurate and detailed report which can include maps, charts, and tables of any data collected in the field or from the preliminary Artifact Analysis Lab. Digital photographs and site photos can be directly dropped into their report as figures.

The task of the GIS area specialists is to combine all the data collected on a daily basis into final loci and special find spatial databases. This includes joining all databases generated by the Artifact Analysis Labs as well as the Digital Photo Lab, DDPL, and Storage Lab. The digital master locus lists and locus summaries are joined to the loci polygon data. The area and volume are also computed in ArcGIS for each locus and entered as new columns in the database. The digital Harris Matrix is

8. Shape files are ArcGIS's file format for storing both spatial data as well as database information.

9. Our current list of identifiable special finds appears on a Descriptor Code list that is stored in the Recon data collector and includes over 180 different codes.

dynamically hyperlinked to the GIS to facilitate rapid retrieval of stratigraphic information. Once all the data are joined and correlated, analytical studies and maps can be produced for each area or the entire site by the expedition directors. These maps may be queries of the spatial distribution of specific special finds, architectural maps by strata, or any other type of study. The fully combined GIS project's limitations are primarily the imagination of the supervisors, material culture specialists, and the expedition directors. While the digital archaeology system described above was born in the desert of southern Jordan, it has great potential for archaeological research around the world.

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