EXPORTING VIRTUAL MATERIAL CULTURE
CHEAP AND EASY METHODS TO PRESERVE AND SHARE DATA

Jill A. Weber and Evan Malone

Jill A. Weber is a Consulting Scholar, Near East Section at the University Museum of Archaeology and Anthropology, University of Pennsylvania.

Evan Malone is the founder and president of NextFab Studio, Philadelphia, PA.

Archaeological materials are best understood when they can be revisited over the long term and following new discoveries, analyzed by multiple experts, and subjected to new analytical techniques. However, artifacts recovered from archaeological excavations are subject to numerous conditions and constraints that are deleterious to their preservation, reduce their analytical value, and make it difficult for them to be shared with other scholars. Currently there is greater sensitivity to transfer of artifacts and other cultural heritage due to political activities in Iraq, and the highly publicized looting of antiquities there. While these laws are broadly understood as intended to protect items of aesthetic and artistic value, they may nonetheless apply to items more purely of research value. Animal bones, for instance, are not generally of aesthetic value but are invaluable tools for reconstructing past economies and ecologies, and provide unique insights into ancient perspectives on the relationships between humans and animals. Due to their abundance in excavations and perceived lack of glamour, materials such as animal bones are considered to be disposable and are more frequently subjected to destructive techniques, such as genetic testing, isotopic analysis, and radiocarbon dating. For the same reason, they may not be stored in the controlled environment of a museum, and there is little effort put into their long-term preservation. Even when such artifacts can be exported for study, they may not be for financial or practical reasons. It is thus necessary to preserve essential information about these remains while still allowing informative analyses and respecting cultural-heritage laws.

The imperative for preservation, recurring analysis, and sharing is heightened for materials that are rare, unique, or have particular symbolic or other significance to the local polity. Such a body of materials has been excavated from the site of Umm el-Marra, northern Syria. An elite burial complex has been uncovered that dates to the second half of the third millennium, BC (Schwartz et al. 2003, 2006). At its center, ringed by monumental human-tombs, are structures reserved specifically for equids. To date, bones from 40 individual equids—including 23 complete skeletons—have been recovered from the structures. Morpho-metric analyses indicate that they belong to a single population that is significantly different from populations of wild or domestic ass, half-ass, and horse—taxa that were also recovered from the site; instead, they display mixed characteristics of both asses and half-asses and can be reasonably identified as such a hybrid (Weber 2008, 2010). This population—further characterized as all-male, draft animals—may be equated with an elite, domesticated ass x half-ass hybrid referred to in texts from the second half of the third millennium. Despite numerous textual references, its bones have never before been positively identified from near eastern sites. The spectacular nature of the finds, and their current singularity to Syria led to its declaration as the 2008 Syrian Animal of the Year by the Society for the Protection of Animals Abroad (SPANa), Syria. Preservation of—and accessibility to—these bones is imperative given their uniqueness, source of national pride, and potential significance for our understanding of human-equine relations in the ancient near east, and for equine studies in general.

To satisfy these goals, we began a project creating 3D digital models of individual elements of these skeletons through 3D laser scanning (Figure 1) with the NextEngine scanning and software platform, and reconstituting the data into physical 3D replicas of the original bones utilizing additive manufacturing techniques of “building.” Previous uses of 3D scanning as a tool in zooarchaeological frameworks (e.g., Betts et al. 2010, and this volume; Niven et al. 2009) largely have been conceptualized for virtual comparative collections to provide indispensable models of bones to individuals without access to physical collections due to distance from a laboratory or the rarity of certain taxa. In our case, we are capturing 3D data of unique, excavated artifacts. Since 2006, we have compiled a library of complete scans of several hundred...
bodies (Figure 1), and have printed a total of 14 replicas of original bones using the 3D scanned data. We believe our goals have been met for cheap and efficient storage, accurate preservation, enhanced analytical potential, and the creation of shareable data. Our total library occupies 180 GB of digital space, easily stored on a single, portable, US $200 external hard drive. These models are quickly and cheaply shared, infinitely reproducible as digital data, and can be transformed into accurate physical replicas; in these ways the materials can be shared as virtual and tangible models.

The strength of the method as an aid to preservation and research lies in the models’ fidelity to the original materials, and advanced capacity for research and comparison. Essential features of the bones are captured in digital format, which can be examined with computer-aided techniques in ways that are not feasible with physical objects. These 3D models are, to some extent, future-proof because new techniques for studying equid taxa can be applied to the digital models or 3D replicas at any future date.

3D Scanning and Building

Non-contact three-dimensional (3D) scanning methods are nondestructive and produce highly accurate 3D digital representations that are readily shared, infinitely reproducible, and cheaply and efficiently stored. Optical scanning systems (used here), typically use one or more digital cameras and specialized visible lighting (laser lines, patterns of white light, etc.) to extract and compute the exterior surface shape (and sometimes also the color and shading) of an object. NextEngine (2010) is a highly portable optical laser triangulation scanner robust enough for use in field archaeological conditions and, at roughly U.S. $3000 for a complete hardware and software scanning system, revolutionary in its affordability. Comparable systems sell for 10 times as much money without comparable gains in accuracy or effectiveness (cf Slizewski and Semal 2009). NextEngine illuminates the object being scanned with multiple linear laser beams that sweep the surface of the object. The shape of the lines is observed by two cameras in the scanner, and a computer program triangulates the location of the points from this information. During scanning, visible light digital photographs are taken through multiple color filters to produce an accurate full-color texture map that is applied to the 3D geometric data. Under ideal conditions for surface opacity and lighting, a NextEngine HD scanner can produce scan data with .13mm accuracy, and can capture an object’s full-color appearance (“texture map”). Virtual models thus retain visual information (such as burn marks or bleaching), enhancing their utility for research.

When a tangible reproduction of an object is required, reconstruction of the virtual model into physical form can be readily achieved using “3D printing,” or “additive manufacturing.” This technology builds objects from 3D digital models by digitally decomposing the model into a stack of two-dimensional “slices,” then depositing layers of material under computer control in the shape of each slice. A variety of additive manufacturing processes exist, but one particular variant very well suited to the replication of ceramic and bone archaeological materials is the ZCorporation 3DP process, which uses ink-jet technology to deposit adhesive that binds thin layers of plaster powder together, and has the capability of building full color models by depositing colored adhesive. This process can build objects as large as 355 x 254 x 203 mm with a resolution of .12mm in all three dimensions.

Model Fidelity and Accuracy

The accuracy of the models can be seen in Figure 2, which shows measurement error for all 3D printed and digital model measurements relative to the measurement taken from the original physical object (the horizontal axis at zero error). Standard deviations of measurement-error for both the virtual and 3D printed replica are under 5 percent and 3 percent, respectively. No significant trending is indicated,
suggesting that neither the 3D printing nor the 3D scanning are systematically distorting measurements.

The error is less for the 3D prints, making the printed material values closer to the original bones. We posit that the virtual measurements may be the most accurate of the three, and that the outliers indicate errors introduced by manual measurement of physical objects (original and 3D printed replica) with mechanical measurement tools. Inspection indicated that these errors could be accounted for by inconsistent measurement placement and orientation, as well as transposition of measurement values into incorrect columns.

The capacity for the digital models to enhance standardization and accuracy of recording is shown in Figure 3. The proximal phalanx is shown in Rhinoceros (2010), a surface-based design software package. The virtual model can be precisely oriented in virtual space and once oriented, distances from any vertex to any other (in this case for greatest length) may be obtained with essentially infinite precision. The virtual model can be annotated, for instance by highlighting and labeling vertices or surfaces as landmarks for measurement, reducing sources of subjectivity in measurement. This approach trades the uncertainty introduced by the vagaries of manual mechanical measurement of the physical object for the uncertainty introduced by the capture and processing of the laser scan data, which at least is likely to be less variable. The virtual model may also be “sliced” in any orientation (Figure 4) at any point to inspect and measure a cross section, and surface area and volume measurements can be easily made.

The Cheaper and Easier World of 3D Scanning and Building

Beyond the NextEngine laser triangulation scanner, Rhinoceros 3D modeling software, and the Z Corp. Spectrum Z510 3D printer employed in this study, there are a wide range of scanning, modeling/analysis, and 3D printing tools available on the market, though prices are often many thousands of dollars. Fortunately, access for archaeological use is becoming easier as university engineering and design departments and industrial service companies are increasingly investing in these tools. 3D printing services are now easily and inexpensively obtained from numerous online companies (Red-eye 2010; Shapeways 2010), which provide upload of model files, instant quotations, a selection of materials and finishes, and deliver within days. 3D scanning services are available but still quite expensive, and thus justified only for the rarest and most difficult to scan items. Inexpensive (Rhinoceros 2010) and free, open source (Netfabb 2010) software packages are available, which have many of the same capabilities found in the costly industrial tools, and which have vibrant user groups willing to assist new users and help to customize software for novel uses. Similarly, inexpensive hobby-oriented 3D printer kits (Bowyer 2010; Fab@Home 2010; MakerBot Industries 2010) and 3D scanner kits (David 2010) are available, which though currently capable of building (or capturing) only small, relatively inaccurate models, have exploding international user communities and very rapid technological advance. Finally, advances in technology have made possible smaller, cheaper, and more readily accessible machines for realizing virtual 3D models. A new global social trend toward collaborative tinkering with technology has led to the emergence of “hacker spaces” or “maker spaces” (FabLab network 2010; Hackerspaces 2010)—community technology laboratories worldwide—which frequently have modest, and sometimes quite sophisticated, 3D scanning and 3D printing tools, and skilled users often willing to donate time to interesting projects.

The variety and accessibility of these resources should enable almost any archaeological materials, regardless of aesthetic value, location, portability, or exportability, to be accurately documented in 3 dimensions, shared, replicated, and analyzed. This has the benefit of reducing the aesthetic bias in preservation and storage so that data from “common materials” can be more easily retained for future analysis and com-

Figure 3. Measurement and annotation of a 3D digital model.

Figure 4. Cross-section selection and recording in a 3D digital model.
parison. The ability to print the digital models is vital as some archaeological research, educational, and promotional activities are boosted by the ability to touch and present physical objects. Manipulation and study of cheap, reproduction artifacts can also help to generate interest among younger students in archaeological disciplines. Fun and creative use of 3D data—such as creating perishable (but accurate) models in cheese or chocolate—may be useful for engaging the public.

References Cited
Fab@Home 2010 Fab@Home, the open-source personal fabricator project. Electronic document, http://fab@home.org, accessed November 19, 2010.


Notes
1. Under the co-direction of Dr. Glenn Schwartz, the Johns Hopkins University, and Dr. Hans Curvers, the University of Amsterdam
2. An equid is any member of the genus *Equus*, such as a horse, ass, or zebra.
3. The results of genetic testing carried out by Sophie Champlot and Eva-Maria Geigl at the Institut Jacques Monot are pending.