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Advances in Documentation, Digital Curation, Virtual Exhibition, and a Test of 3D Geometric Morhpometrics: A Case Study of the Vanderpool Vessels from the Ancestral Caddo Territory

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Advances in Documentation, Digital Curation, Virtual Exhibition, and a Test of 3D Geometric Morphometrics

A Case Study of the Vanderpool Vessels from the Ancestral Caddo Territory

Robert Z. Selden Jr., Timothy K. Perttula, and Michael J. O'Brien

Many Native American Graves Protection and Repatriation Act (NAGPRA)-related collections housed in museums and repositories have fallen out of the public domain, and gaining access to these collections can prove difficult, requiring the prior approval both of the tribe in question—in our case, the Caddo—and of the museum facility that curated the collection. Additionally, NAGPRA provides tribes with the authority necessary to reinter artifacts and human remains subsequent to repatriation. However, the Caddo hold a comparatively liberal perspective on archaeological documentation of NAGPRA funerary objects and human remains and regularly permit access to archaeologists, particularly those employing noninvasive and/or nondestructive research

ABSTRACT

Three-dimensional (3D) digital scanning of archaeological materials is typically used as a tool for artifact documentation. With the permission of the Caddo Nation of Oklahoma, 3D documentation of Caddo funerary vessels from the Vanderpool site (41SM77) was conducted with the initial goal of ensuring that these data would be publicly available for future research long after the vessels were repatriated. A digital infrastructure was created to archive and disseminate the resultant 3D datasets, ensuring that they would be accessible by both researchers and the general public (CRHR 2014a). However, 3D imagery can be used for much more than documentation. To illustrate this, these data were utilized in a 3D morphometric analysis of the intact and reconstructed vessels to explore the range of variation that occurs in ceramic vessel shape and its potential contribution to the local ceramic taxonomy. Results of the 3D morphometric analysis demonstrate the potential for substantive analytical gains in discussions of temporal resolution and ceramic technological organization in the ancestral Caddo region.

El escaneado tridimensional (3D) de materiales arqueológicos se utiliza normalmente como una herramienta para documentar artefactos. Con el permiso de la Nación Caddo de Oklahoma, la documentación tridimensional de vasijas funerarias del sitio Vanderpool (41SM77) tuvo como meta, el asegurar que esta información permanezca disponible al público para la realización de investigaciones futuras, inclusive después de su repatriación. La infraestructura digital fue creada para archivar y difundir los conjuntos de datos tridimensionales derivados, asegurándose que estos sean accesibles a los investigadores y al público en general (CRHR 2014a). Sin embargo, las imágenes tridimensionales pueden ser utilizadas más allá de la propia documentación. Para ejemplificarlo, estos datos se utilizaron en un análisis tridimensional morfométrico de vasijas reconstruidas e intactas y con ello explorar el rango de variación que ocurre en la forma de la vasija cerámica, así como su potencial para contribuir a la taxonomía cerámica local. Los resultados del análisis tridimensional morfométrico demuestran el potencial de las ventajas analíticas sustantivas en las discusiones sobre su resolución temporal y la organización tecnológica de la cerámica en la región ancestral Caddo.

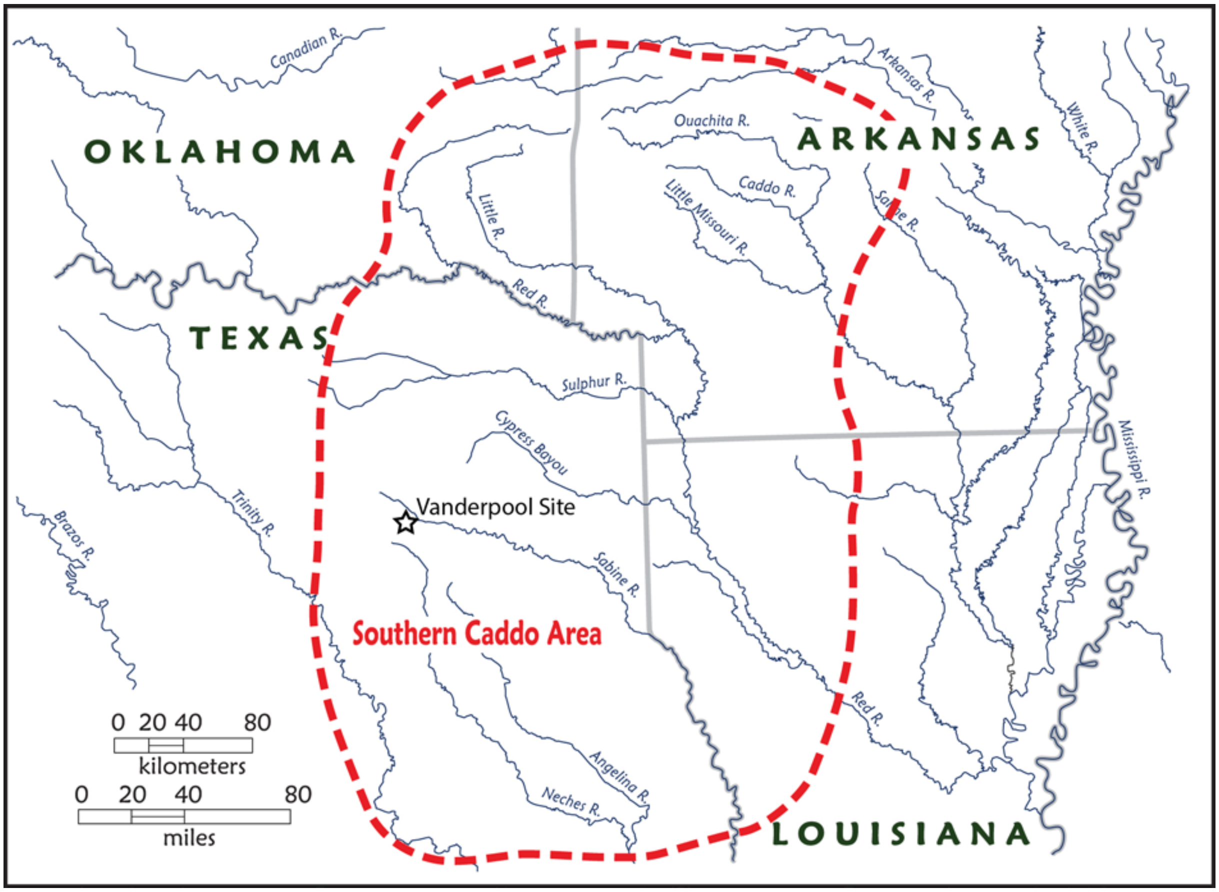

FIGURE 1. The Southern Caddo Area and the location of the Vanderpool site.

methods. In some cases, even destructive analyses (i.e., chemical and residue analysis of sherds from vessels and organic remains preserved on vessels) have been permitted (see Perttula et al. 2011).

These data are invaluable, given that the return of human remains and objects from burial contexts to culturally affiliated tribal entities recognized by the United States often results in reburial, which places these artifacts beyond the reach of future analytical endeavors. NAGPRA, a pivotal piece of civil rights legislation, has effectively returned objects of cultural patrimony found in archaeological and ethnographic collections at museum facilities receiving federal funding back into the hands of the Caddo and other federally recognized tribes.

Our analysis of 27 Caddo vessels from funerary contexts at the Vanderpool site (41SM77) in Smith County, Texas, addresses three goals: (1) to preserve these vessels as three-dimensional (3D) representations that can be employed in analyses subsequent to repatriation; (2) to make those data publicly available for use in future research; and (3) to explore the capacity of these scans to inform upon an analysis of variation in ceramic vessel shape (quantitative shape analysis is termed morphometrics). Although our morphometric analysis is limited in scope due to the size of the collection, it appears to be an area of Caddo ceramic research in which substantive methodological and theoretical gains can be realized.

WHO ARE THE CADDO?

The Caddo inhabited areas of what are today Arkansas, Louisiana, Oklahoma, and Texas (Figure 1) from ca. A.D. 800/850 to as late as 1838 (Perttula 2012). They were horticulturalists who became agricultural farmers, with a particular focus on maize cultivation (Perttula 2012; Wilson 2012). Their ancestral predecessors were various Woodland-era populations that developed between ca. 500 B.C. and A.D. 800. The origin of the Caddo remains a point of much debate, but it is generally accepted that Caddo groups may have first emerged within two areas: the Great Bend of the Red River in southwestern Arkansas and northwest Louisiana and the Arkansas River basin in eastern Oklahoma (Story 1981). However, other important communities developed in East Texas, in the Ouachita River basin in southwest Arkansas, and in other widely dispersed communities, and no *centers* of early cultural emergence have been identified.

Although elements of Caddo life share many similarities with Southeastern Mississippian cultures, cultural developments in the Caddo region do not appear to have developed in concert with Mississippian groups (Blitz 2010; Livingood 2008). This

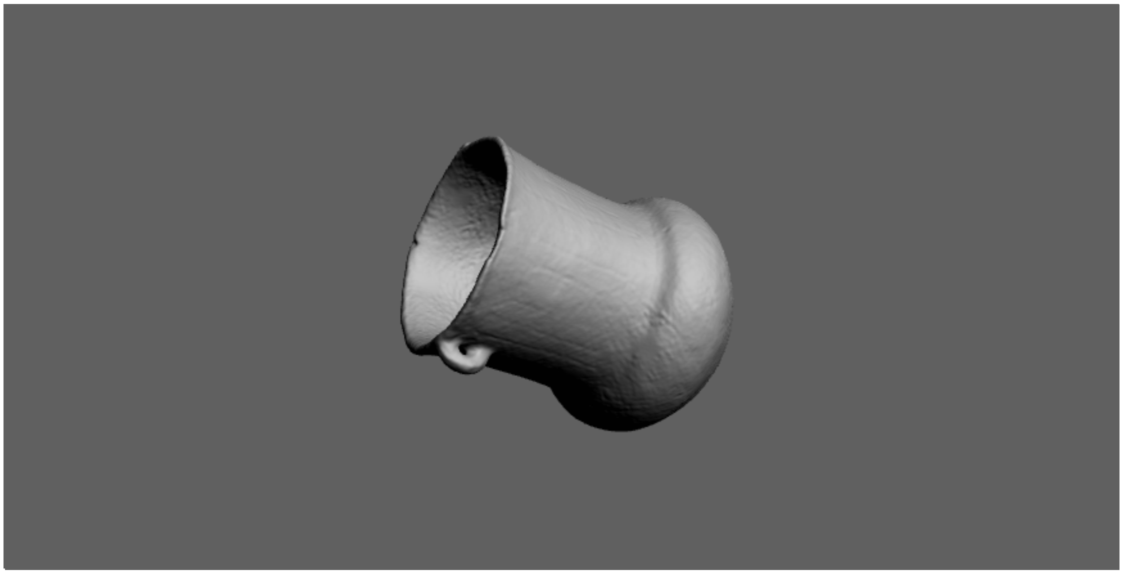

FIGURE 2. 3D scan of FIN-S6. Note: This is a 3D figure that can be activated by clicking on the image. Once active, the image can be rotated, sliced, measured, and otherwise manipulated.

has led archaeologists to consider Caddo developments as an expression of local and regional processes linked temporally and culturally to the preceding Woodland-period groups (Perttula 2009, 2012), which are also marked by intra-regional interaction between the different Caddo groups.

3D DIGITAL PRESERVATION OF CADDO NAGPRA VESSELS

The 3D documentation effort was focused upon a NAGPRA collection that may be repatriated. Repatriation often signals the loss of primary source data, but 3D digital preservation may be useful in mitigating much of that loss. While there is no such thing as a perfect proxy, the use of 3D imaging technology can certainly provide a platform through which comparative analytical gains can still be realized subsequent to repatriation.

Digital technologies add value to archaeological research by diminishing traditional barriers to access, providing researchers with the capacity to reexamine, compare, and integrate primary sources in ways that have not yet been achieved or even contemplated. Digital products and archives form a substantive research infrastructure that has evolved into what was recently dubbed a “digital heritage ecosystem,” of which digital representations of cultural heritage form a key component (Limp et al. 2011).

Three-dimensional models can be employed in a virtual workspace to illustrate the dimensions, shape, and designs of ceramic artifacts without affecting the integrity of the physical artifact (Figure 2) (see also Means et al. 2013); however, the research capabilities garnered by this practice can reach far beyond (Wachowiak and Karas 2009). Among the possible practical uses for these data are quality control and reverse engineering—synonymous with documentation and replication activities in cultural heritage work (see Wachowiak and Karas 2009)—as these represent the impetus of a more concerted and comparative dialogue aimed at exploring vessel manufacture, shape, provenance, and craft specialization.

Technological Underpinnings

Initially, it was not a goal of this project to create the digital infrastructure needed to archive and disseminate the resultant 3D datasets; however, due to the large size of this 3D dataset, it was fiscally impossible to ingest these data at the Digital Archaeological Record (tDAR), which led to a creative solution that employs a suite of digital resources that are available through the Center for Regional Heritage Research (CRHR) at Stephen F. Austin State University.

Hosted by the Center for Digital Scholarship (CDS), CRHR:ARCHAEOLOGY (CRHR 2014a) represents the most stable local archive for digital datasets associated with East Texas archaeological investigations and research. Built using CONTENTdm—digital collections management software—the faculty and staff at CDS created a unique interface that capitalized on software and hardware that the University already owned. The website incorporates a pre-designed cascading style sheet (CSS) template that allows for a more complex design, which may have otherwise required an unrealistic investment of time (Ellis and Wackerman 2014).

Additional challenges were encountered with the display of the 3D imagery. Challenges with rewriting the computer code took the longest to solve. Eventually, the publicly accessible 3D PDF and STL files were made available, and scans were also made available through the CRHR’s ScholarWorks (CRHR 2014b) webpage, which is linked to the metadata in CRHR:ARCHAEOLOGY (CRHR 2014a). With the capacity to handle large datasets (often associated with 3D undertakings), we now have the cyberinfrastructure and storage capabilities needed to make these digital resources available. However, due to a restriction placed on the texture (color) file by the Caddo, the publicly accessible scans are available only in grayscale (or a uniform color), although color scans can be made available to researchers on a case-by-case basis.

Metadata

Among the most important aspects of this endeavor was the identification of those data that would accompany the 3D scans into CRHR:ARCHAEOLOGY (CRHR 2014a). Through a cooperative partnership, tDAR and the Center for Advanced Spatial Technologies (CAST) at the University of Arkansas created a list of metadata categories necessary to accompany the import of 3D imagery. This ensures that all 3D scans possess similar attribute data, enabling them to be searchable in a more global context. This effort was conducted in conjunction with traditional documentation of the Vanderpool vessels (Perttula et al. 2013), and those data accompanied each vessel through the ingest process.

Data incorporated into CRHR:ARCHAEOLOGY (CRHR 2014a) based upon tDAR and CAST standards include a summary of the object, an object number, conditions (indoors/outdoors), scanner details, company name, and turntable (whether or not one was used). Additional data were also included from the recent, more traditional, analysis of Vanderpool vessels. Data fields for that component are: site name or site number, vessel number, non-plastics and paste, vessel form (shape), rim and lip form, core color, interior surface color, exterior surface color, wall thickness (rim, body, and base in mm), interior surface treatment, exterior surface treatment, height (in cm), orifice diameter (in cm), diameter at bottom of rim or neck (in cm), base diameter (in cm) and shape of base, estimated volume (in liters), decoration (including motif and elements when apparent), pigment use and location on vessel, and the type and variety (if known).

In concert, these two markedly different classifications of metadata are joined in the Vanderpool collection (CRHR 2014c) and are presented as 3D imagery accompanied by all of the valuable information garnered through a physical analysis of the vessels. All of the data included in the final ingest are searchable by a simple click (e.g., if a user wants to view all of the engraved vessels, all that is necessary is to click on the term "engraved"). This provides a substantial research resource for furthering our knowledge of the unique cultural heritage associated with ancestral Caddo populations in the southern Caddo area.

While the production of this new digital research resource extends the reach of current efforts to document and preserve the material culture of the Caddo, it also incorporates analytical data from previous physical analyses of the vessel, affording researchers with the ability to use those data for comparison or perhaps to refute or refine the data based upon metrics taken within a digital platform. Certainly analytical components used to characterize non-plastics and paste, core color, and pigment are valuable measures that would be difficult to distinguish using a 3D model. However, metrics associated with wall thickness (rim, body, and base in mm), height (in cm), orifice diameter (in cm), diameter at bottom or rim or neck (in cm), and estimated volume (in liters) may be better calculated within a digital model. While it is not the point of this study to undertake a comparative analysis of these attributes, calculating these metrics is a noteworthy endeavor that may produce interesting and thought-provoking results regarding the methodological procedures currently employed by archaeologists; this study has produced all of the necessary data to carry that to fruition.

BEYOND DOCUMENTATION

While 3D documentation represents a valuable undertaking, completed scans too often signal the end of a project. The production of a 3D scan as a deliverable is noteworthy, but what can we do with these scans once we have them? While digital repositories are interesting and the 3D imagery is fun to play with—and a useful educational tool—more work is warranted to push us beyond our current documentation efforts, so that we might truly explore where this technology can lead us and what manner of research questions we can answer with it.

3D Sketches of Decorative Motifs

One tool that has been very helpful in documenting decorative motifs, whether engraved, incised, or punctated, is the 3D sketch (Figure 3). We used Geomagic Design X to create the 3D sketches, which can then be isolated from the 3D model. Like the 3D imagery of the vessels, the sketches can be sliced, measured, and manipulated in a variety of ways. This is particularly appealing with bottles, where traditional illustrations and roll-outs often distort the decorative motifs due to errors in converting a 3D design into an accurate 2D representation. One aspect that may have been missed in a 2D representation is the eight-pointed star that becomes apparent when looking at the 3D design in a plan view (Figure 3). While it is not the point of this paper to delve into the interpretive value of decorative metaphors, we thought it worth mentioning.

Virtual Environments

The inclusion of 3D data within a virtual environment, in this case, a virtual museum in the United Kingdom (UK), was a happenstance occurrence, and one that expands the use-life of the 3D scans by making them available to a broader audience. During the morphometric analysis, and while the construction of CRHR:ARCHAEOLOGY (CRHR 2014a) was underway, the Vanderpool collection was the topic of numerous blog posts; one of which spurred this novel collaboration.

The virtual museum (Melaney and Rigby 2014) was rendered in an AVAYALIVE ENGAGE virtual environment by Mark Melaney and Ken Rigby of MellaniuM, Inc. in Preston, UK. In this case, the virtual museum provided the option to link the exhibit of FIN-S7 (Selden 2014a) directly to the metadata in CRHR:ARCHAEOLOGY (CRHR 2014a). The end result is an interactive environment (think videogames) where users can view an accurate virtual rendering of the vessel in both two and three dimensions, as well as an academic poster related to this project, all while having no adverse impacts to the physical specimen (Figure 4).

3D Morphometrics

Before profitable discussions of cultural transmission in Caddo communities can be undertaken using ceramic vessel shape, there is a need to explore whether there are substantive, and measurable, amounts of variation in Caddo ceramic vessel

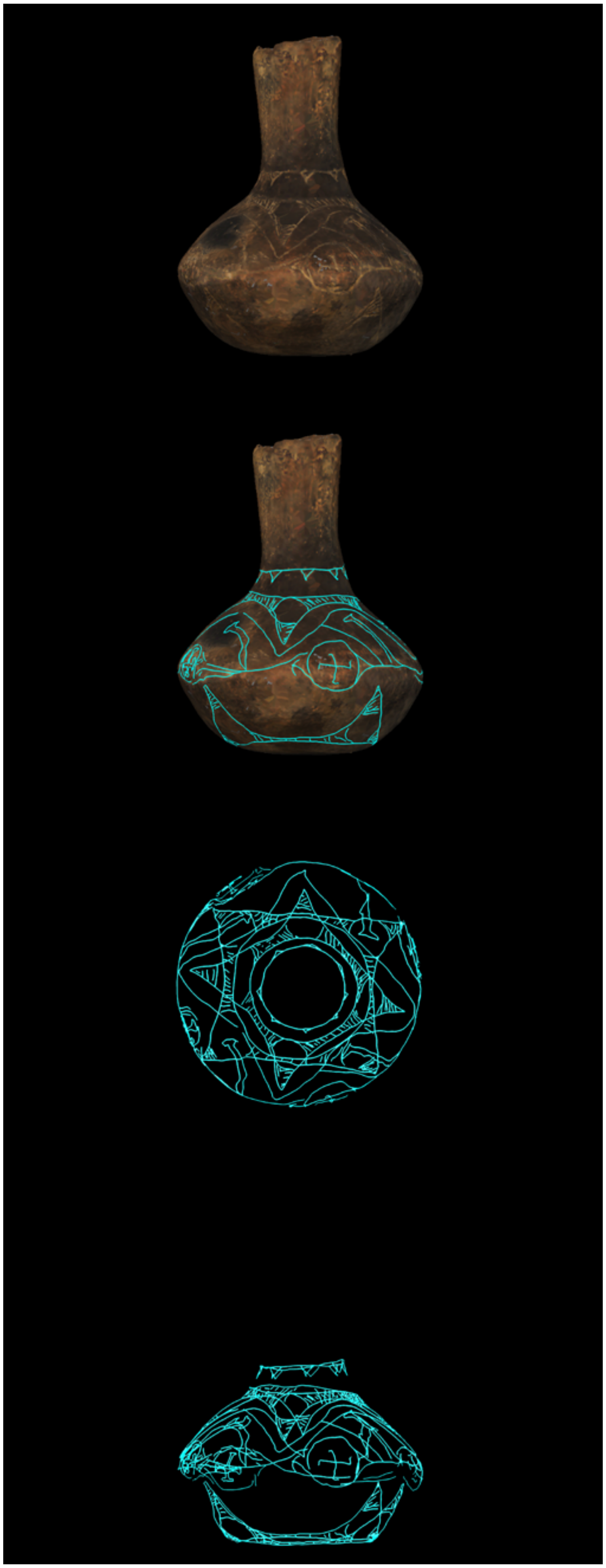

FIGURE 3. 3D sketch of decorative motif on FIN-S18.

shapes. We began our exploratory study of morphometrics with NAGPRA vessels from the Washington Square Mound site (41NA49) (CRHR 2014d) in Nacogdoches County, Texas (Selden 2013). That analysis served as the basis for the study reported here, which developed during a subsequent NAGPRA documentation effort at the Gregg County (Texas) Historical Museum (GCHM) (Perttula et al. 2013). The collection from the Vanderpool site represents a fraction of the total number of vessels documented during the course of that work, in which it became clear that some varieties of vessel shape occurred more regularly within and across these assemblages than did others.

Analyses of stone tools and debitage using 3D geometric morphometrics have received considerable attention in the archaeological literature (Bretzke and Conard 2012; Clarkson 2013; Lin et al. 2010; Lycett and von Cramon-Taubadel 2013; Lycett et al. 2010; Sholts et al. 2012). Similarly, 3D scanning technology as an archaeological tool to study ceramics has been outlined by Karasik and Smilansky (2008), and 3D data have been employed as a means to better document (Grosman et al. 2008), classify (Gilboa et al. 2004; Karasik and Smilansky 2008), and illustrate (Gilboa et al. 2012) prehistoric ceramics, but to our knowledge this approach has not been used in a study of vessel shape (see also Smith et al. 2014).

Cultural Transmission and Vessel Shape

The potential for vessel shape to inform upon processes of cultural transmission in ancestral Caddo communities is of considerable interest. While the current Caddo ceramic taxonomy relies on decorative elements and motifs (Early 2012; Suhm and Jelks 1962), attributes well suited to studies of cultural transmission, such studies have not been a focus of the analysis of archaeologically recovered pottery on Caddo sites. The development of a ceramic taxonomy of Caddo vessel shape seems well suited to complement currently employed seriations of ceramic styles (see Girard 2012; Kelley 2012; Perttula et al. 2011), adding further depth and complexity to our understanding of the manufacture and use of ceramic vessels by Caddo peoples. This approach would also allow for the exploration of temporal and spatial variation in vessel shape that highlight local variants, while identifying others that appear more standardized, occurring more uniformly within and across arbitrary chronologies and spatial constructs.

In a recent study, Hosfield (2009:46) identified four modes of cultural transmission that "formed the basis for classifying and identifying the routes of craft skills learning": vertical, oblique, master/apprentice, and horizontal. Data for that study came from 72 case studies, and there were multiple instances where two different modes of transmission were noted in a single group or culture. Whether potential differences in these modes of transmission might become evident when the currently defined Caddo ceramic taxonomy that is defined by decorative elements and motifs is paired with a parallel taxonomy constructed on the basis of vessel shape is unknown. Further complicating this route of inquiry is the fact that no formal studies of cultural transmission have been undertaken in the ancestral Caddo region (since Krieger 1946). However, we believe that incorporating the previously defined ceramic taxonomy in this study of variation in vessel shape would provide greater depth to the discussion

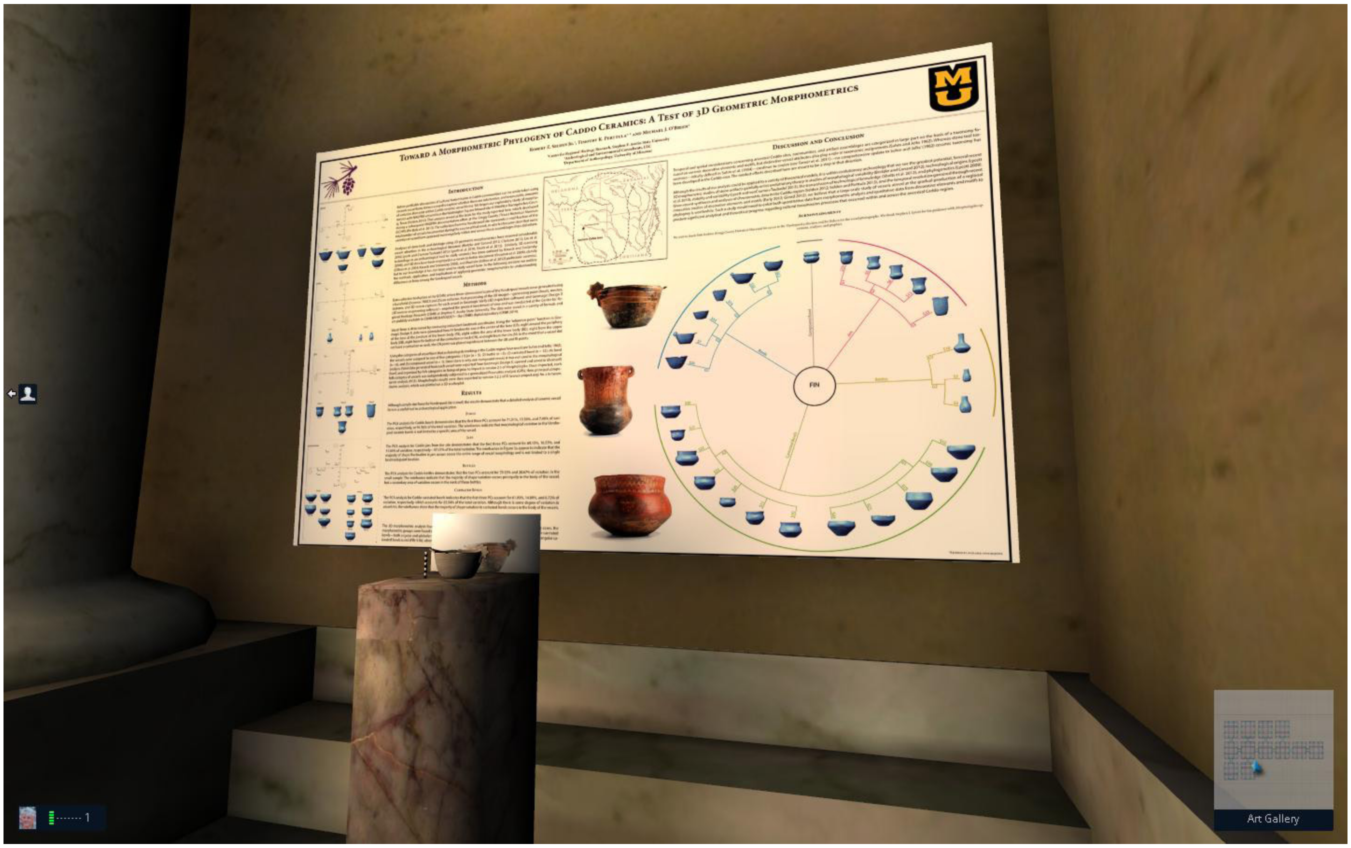

FIGURE 4. Image of virtual environment illustrating 3D and 2D imagery of FIN-S7 and project poster.

and may be warranted to reach the analytical units necessary to further current dialogues regarding cultural transmission.

In an overview of a previous study (citing Lipo [2001]) that sought to use ceramic seriations to posit changes in population structure, Cochrane (2011:47) pointed out that "it is possible to identify those population boundaries that are defined primarily by decreasing transmission frequencies due to increasing geographic distance, and those boundaries that may represent social or functional impediments to transmission." Thus, it is probable that a research design aimed at aggregating imagery (both 2D and 3D) and decorative attributes, including vessel ceramic type and vessel shape (see also Krieger 1946), of Caddo vessels could increase our knowledge of the frequency, scale, and direction in which cultural transmission occurred across the larger ancestral Caddo region. In the following sections we outline the methods, application, and implications of applying geometric morphometrics to understanding differences in shape among the Vanderpool vessels.

METHODS

Data collection took place at the GCHM, where 3D scans of the Vanderpool vessels were generated using a handheld ZScanner 700CX and VX Elements software. Post-processing of the 3D images—generating point clouds, meshes, textures, and 2D screen captures for each vessel in Geomagic Verify (3D inspection software) and Geomagic Design X (3D reverse-engineering software)—required the greatest investment of time and was conducted at the CRHR. The data were saved in a variety of formats and are publicly available in CRHR:ARCHAEOLOGY (CRHR 2014a), the CRHR's digital repository.

Vessel shape is determined by measuring redundant landmark coordinates. In this study, landmarks were defined as any point with x, y, and z coordinates that could be used to represent the shape of a vessel. Using the *reference point* function in Geomagic Design X, data were generated from 41 landmarks: one in the center of the base (CB), eight around the periphery of the base at the juncture of the lower body (PB), eight within the area of the lower body (BD), eight from the upper body (UB), eight from the bottom of the carination or neck (CN), and eight from the rim (RI) (see Supplemental Data). In the event that a vessel did not have a carination or neck, the CN point was placed equidistant between the UB and RI points (Figure 5).

Using the categories of vessel shape that archaeologists working in the Caddo region commonly use (see Suhm and Jelks 1962), the Vanderpool vessels were assigned to one of five categories: (1) jar (n = 5), (2) bottle (n =3), (3) carinated bowl (n = 12), (4) bowl (n = 6), and (5) compound vessel (n = 1). Due to the fact that there is only one compound vessel in the Vanderpool collection, it was not used in the morphological analysis. Point data gener-

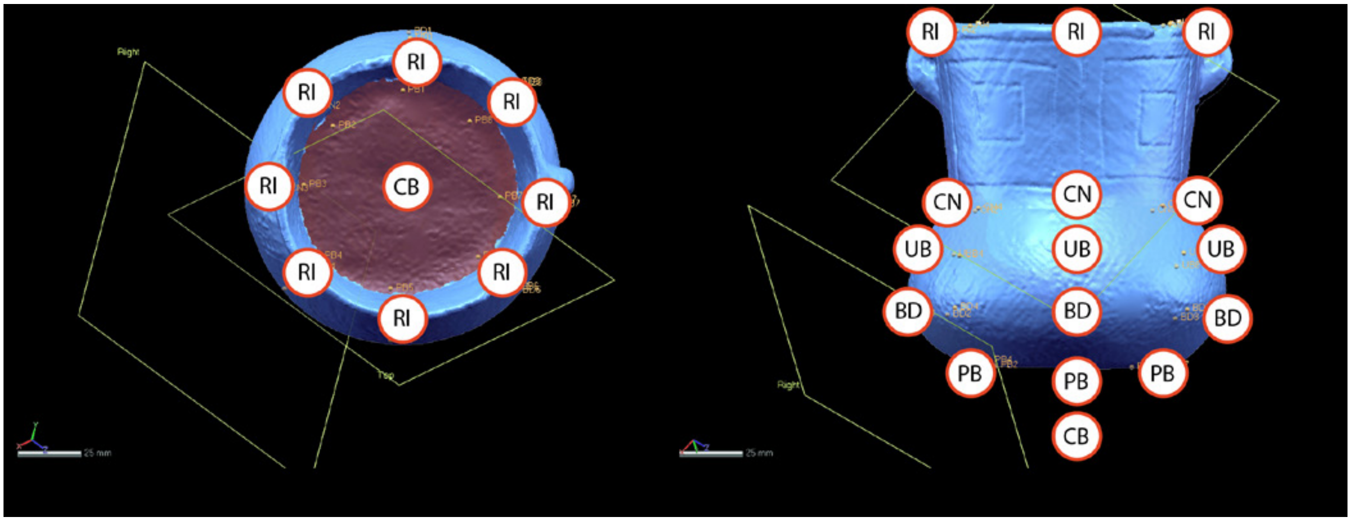

FIGURE 5. Location of landmarks on Caddo ceramic vessels. Measurements taken only from the outside of the vessels; location of CB landmark is on the exterior and is shown on the interior for illustration purposes only.

ated from each vessel were exported from Geomagic Design X, opened and saved in Microsoft Excel, and organized by folk (jar, bottle, bowl, etc.) categories in Notepad prior to import in version 2.5 of Morphologika. Once imported, each category was independently subjected to a generalized Procrustes analysis (GPA), then principal components analysis (PCA). Morphologika results were then exported to version 3.2.2 of R (www.r-project.org) for a k-means cluster analysis, which was plotted on a 3D scatterplot.

While Karasik and Smilansky (2011) have reduced 3D datasets to 2D representations prior to shape (morphometric) analysis, we believe that a more inclusive approach aimed at highlighting the variability within the whole of the vessel provides a better platform of analysis. It should be noted that Karasik and Smilansky (2011; see also Smith et al. 2014) assume that they are dealing with a ceramic manufacturing process (produced on a wheel), which is markedly different from the ceramic manufacturing process employed by the Caddo (coil-built vessels). Additionally, the method developed by Karasik and Smilansky (2011) was designed to classify sherds, not whole vessels. Ceramics produced on a wheel are more symmetrical and uniform throughout, while coil-built ceramics often have considerable slope and warping in the areas of the rim and body (i.e., FIN-S20 [Selden 2014b]). The study of 3D morphometrics capitalizes on this variation, which may be missed, or minimalized, in the analysis of a single 2D cross-section.

3D GEOMETRIC MORPHOMETRIC RESULTS

Although the sample size from the Vanderpool site is small, results demonstrate that a detailed analysis of ceramic vessel shape is a useful tool in archaeological application.

Jars

The PCA analysis for Caddo jars from the site demonstrates that the first three PCs account for 69.15 percent, 16.53 percent, and 11.69 percent of variation, respectively—97.37 percent of the total variation (see Supplemental Data). The wireframes in Figure 6a appear to indicate that the majority of shape fluctuation in jars occurs across the entire range of vessel morphology and is not limited to a single landmark/point location.

The five jars represent three different vessel shapes. Group 1 contains FIN-S25 (Selden 2014c); Group 2 contains FIN-S5 (Selden 2014d), FIN-S6 (Selden 2014e), and FIN-S13 (Selden 2014f); and Group 3 contains FIN-S33 (Selden 2014g) (Figure 6b). The Group 1 vessel, from Burial 4, is grog-tempered with appliqued lug handles and vertical pinched lines on the body (Perttula et al. 2013). The Group 2 vessels come from Burial 3. They are tempered with grog and hematite (FIN-S5 [Selden 2014d]), bone (FIN-S6 [Selden 2014e]), and grog (FIN-S13 [Selden 2014f]). Two have distinctive engraved designs (FIN-S5 [Selden 2014d] and FIN-S6 [Selden 2014e]), and one is decorated with tool punctations and horizontal brushing (FIN-S13 [Selden 2014f]) (Perttula et al. 2013). The Group 2 engraved jars have a clay pigment (white/FIN-S5 [Selden 2014d] and red/FIN-S6 [Selden 2014e]) rubbed in the engraved decoration. The Group 3 vessel (FIN-S33 [Selden 2014g]), from Burial 5, is grog-tempered and has vertical rows of tool punctations on the rim and body.

Bottles

The PCA analysis for Caddo bottles demonstrates that the two PCs account for 79.33 percent and 20.67 percent of variation in the small sample (Supplemental Data) (Figure 7a). The wireframes indicate that the majority of shape variation occurs principally in the body of the vessel, but a secondary area of variation occurs in the neck of these bottles. The three bottles are placed into two groups (Figure 7b). The Group 1 vessel, from Burial 4 (FIN-S18 [Selden 2014h]), is grog-tempered and has an engraved decorative motif (Perttula et al. 2013:27–28). The Group 2 vessels, from Burial 3, are bone- (FIN-S3 [Selden 2014i]) and grog- (FIN-S4 [Selden 2014j]) tempered and decorated with engraved designs (Perttula et al. 2013). Unlike the two engraved jars from Burial 3, none of the bottles from Burial 3 demonstrate evidence of pigment use (Perttula et al. 2013).

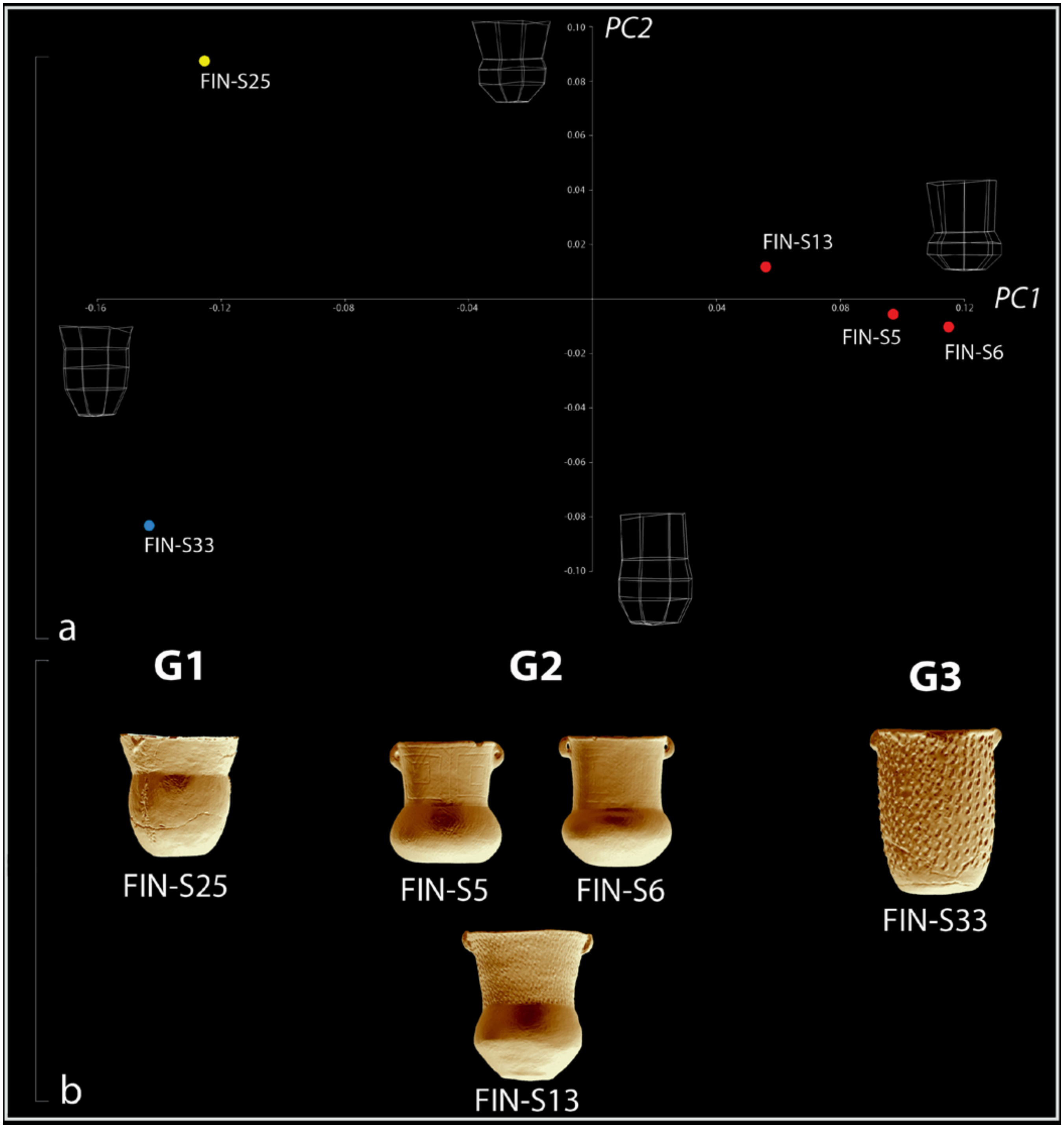

FIGURE 6. Results of geometric morphometric analysis of Caddo jars from the Vanderpool site: (a) a plot of PC1 and PC2 with wireframes; and (b) the constituents of the resulting statistical groups..

Carinated Bowls

The PCA analysis for Caddo carinated bowls (bowls with inverted, everted, or direct rims) indicates that the first three PCs account for 61.93 percent, 14.89 percent, and 6.72 percent of variation, respectively, which accounts for 83.54 percent of the total variation (see Supplemental Data) (Figure 8a). Although there is some degree of variation in vessel rim, the wireframes show that the majority of shape variation in carinated bowls occurs in the body of the vessels.

The 12 carinated bowls were segregated into two clearly distinct vessel shapes, one angular (Group 1) and the other globular (Group 2) (Figure 8b). Group 1 contains FIN-S12 (Selden 2014k),

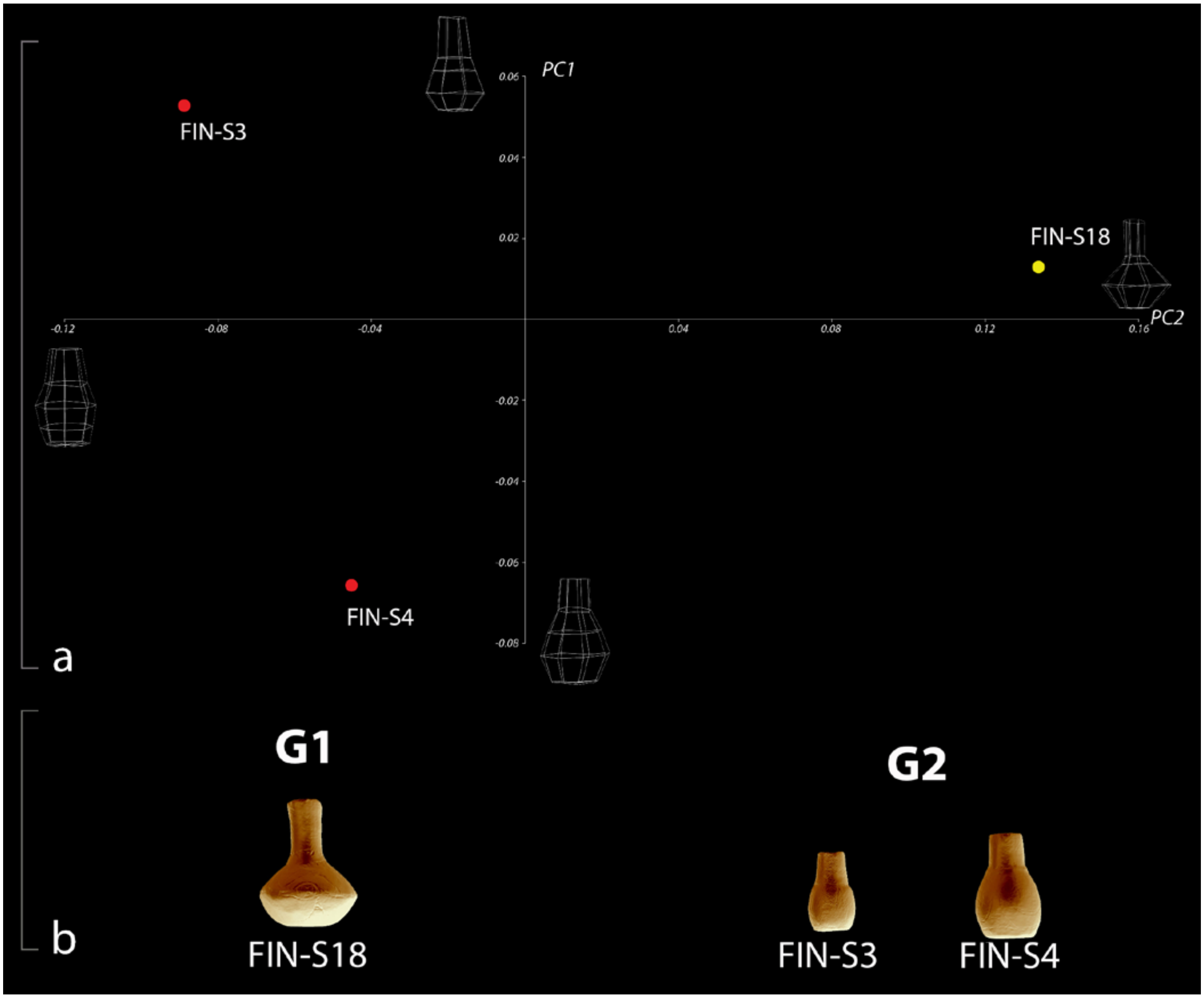

FIGURE 7. Results of geometric morphometric analysis of Caddo bottles from the Vanderpool site: (a) a plot of PC1 and PC2 with wireframes; (b) the constituents of the resulting statistical groups.

FIN-S16 (Selden 2014l), FIN-S19 (Selden 2014m), FIN-S21 (Selden 2014n), and FIN-S34 (Selden 2014o), and Group 2 is comprised of FIN-S10 (Selden 2014p), FIN-S11 (Selden 2014q), FIN-S20 (Selden 2014b), FIN-S23 (Selden 2014r), FIN-S24 (Selden 2014s), FIN-S27 (Selden 2014t), and FIN-S30 (Selden 2014u). Although differences in this vessel shape have been recognized (see Krieger 1946:233; Suhm and Jelks 1962:123), this analysis demonstrates that statistically significant differences exist between the two groups.

Carinated bowls represent the only category where similar vessel shapes are found across multiple burials (Burials 3–5). Of those vessels in Group 1—angular carinated—two (FIN-S12 [Selden 2014k] and FIN-S16 [Selden 2014l]) come from Burial 3, two (FIN-S19 [Selden 2014m] and FIN-S21 [Selden 2014n]) are from Burial 4, and one (FIN-S34 [Selden 2014o]) is from Burial 5. With the exception of FIN-S19 (Selden 2014m), which is brushed, the remainder of Group 1 carinated bowls are engraved (Perttula et al. 2013). Only one of the carinated bowls (FIN-S16 [Selden 2014l]) has pigment (red) in the engraved lines (Perttula et al. 2013).

Vessels in Group 2—globular carinated—come from Burial 3 (FIN-S10 [Selden 2014p] and FIN-S11 [Selden 2014q]), Burial 4 (FIN-S20 [Selden 2014b], FIN-S23 [Selden 2014r], FIN-S24 [Selden 2014s], and FIN-S27 [Selden 2014t]), and Burial 5 (FIN-S30 [Selden 2014u]) (Perttula et al. 2013). All of the globular carinated bowls have engraved design motifs, and only one (FIN-S20 [Selden 2014b]) has pigment (white) in the engraved lines (Perttula et al. 2013). There are distinct temporal and spatial differences in pigment use on Caddo fine ware vessels in this part of East Texas (Perttula et al. 2011:279–280). With the exception of FIN-S10 (Selden 2014p) (Patton Engraved *var. Allen*), all of the angular and globular carinated bowls are defined varieties of Poynor Engraved. Poynor Engraved and Patton Engraved vessels share a similar spatial distribution in East Texas, but Pat-

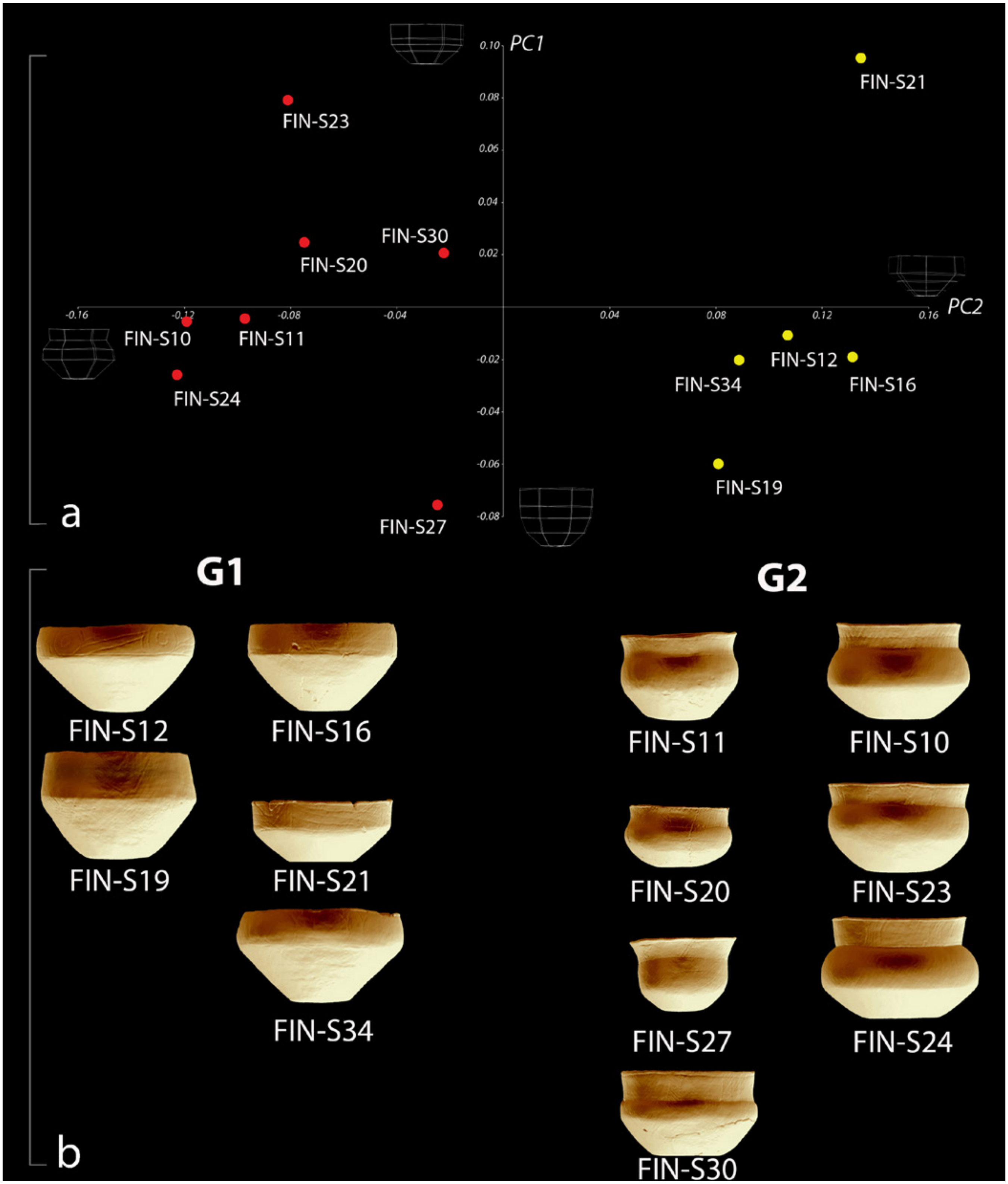

FIGURE 8. Results of geometric morphometric analysis of Caddo carinated bowls from the Vanderpool site: (a) a plot of PC1 and PC2 with wireframes; and (b) the constituents of the resulting statistical groups.

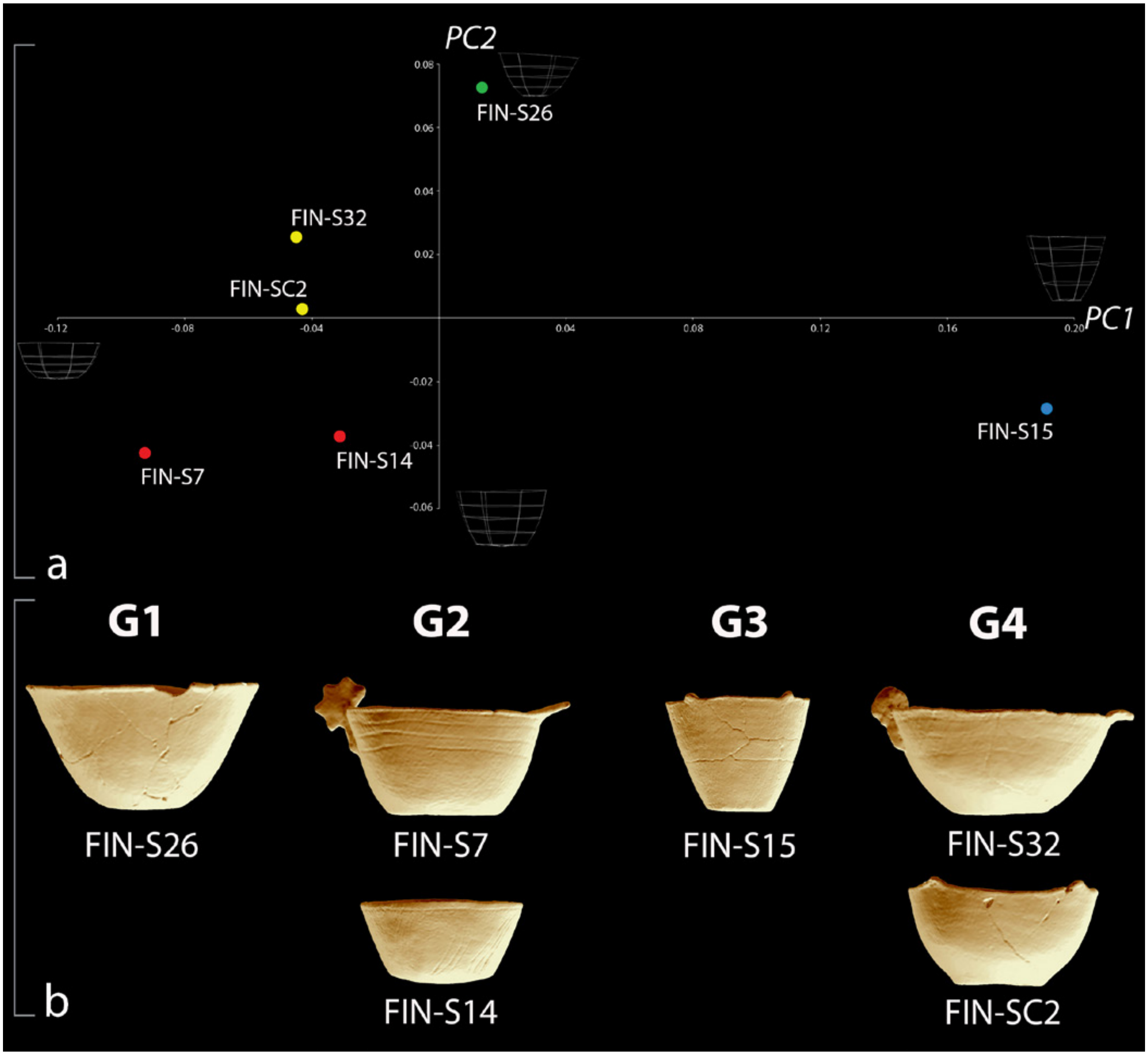

FIGURE 9. Results of geometric morphometric analysis of Caddo bowls from the Vanderpool site: (a) a plot of PC1 and PC2 with wireframes; and (b) the constituents of the resulting statistical groups.

ton Engraved vessels date after ca. A.D. 1650, whereas Poynor Engraved vessels date from ca. A.D. 1400–1650 (Perttula et al. 2011; Suhm and Jelks 1962).

Bowls

The PCA analysis for Caddo bowls demonstrates that the first three PCs account for 71.51 percent, 15.56 percent, and 7.49 percent of variation, respectively, or 94.56 percent of the total variation (see Supplemental Data) (Figure 9a). The wireframes in Figure 6a indicate, as with jars, that morphological variation in the Vanderpool ceramic bowls is not limited to a specific area of the vessel.

The six bowls segregate into four vessel shapes (Figure 9b). Group 1 contains one bowl (FIN-S26 [Selden 2014v]), Group 2 two bowls (FIN-S7 [Selden 2014a] and FIN-S14 [Selden 2014w]), Group 3 one bowl (FIN-S15 [Selden 2014x]), and Group 4 two bowls (FIN-S32 [Selden 2014y] and FIN-SC2 [Selden 2014z]). The Group 1 vessel comes from Burial 5, Groups 2 and 3 from Burial 3, and Group 4 from Burial 5 (FIN-S32 [Selden 2014y]) and Burial 1 (FIN-SC2 [Selden 2014z]). There is a single bone-tempered Patton Engraved bowl (FIN-S15 [Selden 2014x]), one grog/bone-tempered bowl (FIN-SC2 [Selden 2014z]), one grog/hematite-tempered bowl (FIN-S26 [Selden 2014v]), and three grog-tempered bowls (FIN-S7 [Selden 2014a], FIN-S14 [Selden 2014w] and FIN-S32 [Selden 2014y]). Vessels in Group 2 (FIN-S7 [Selden

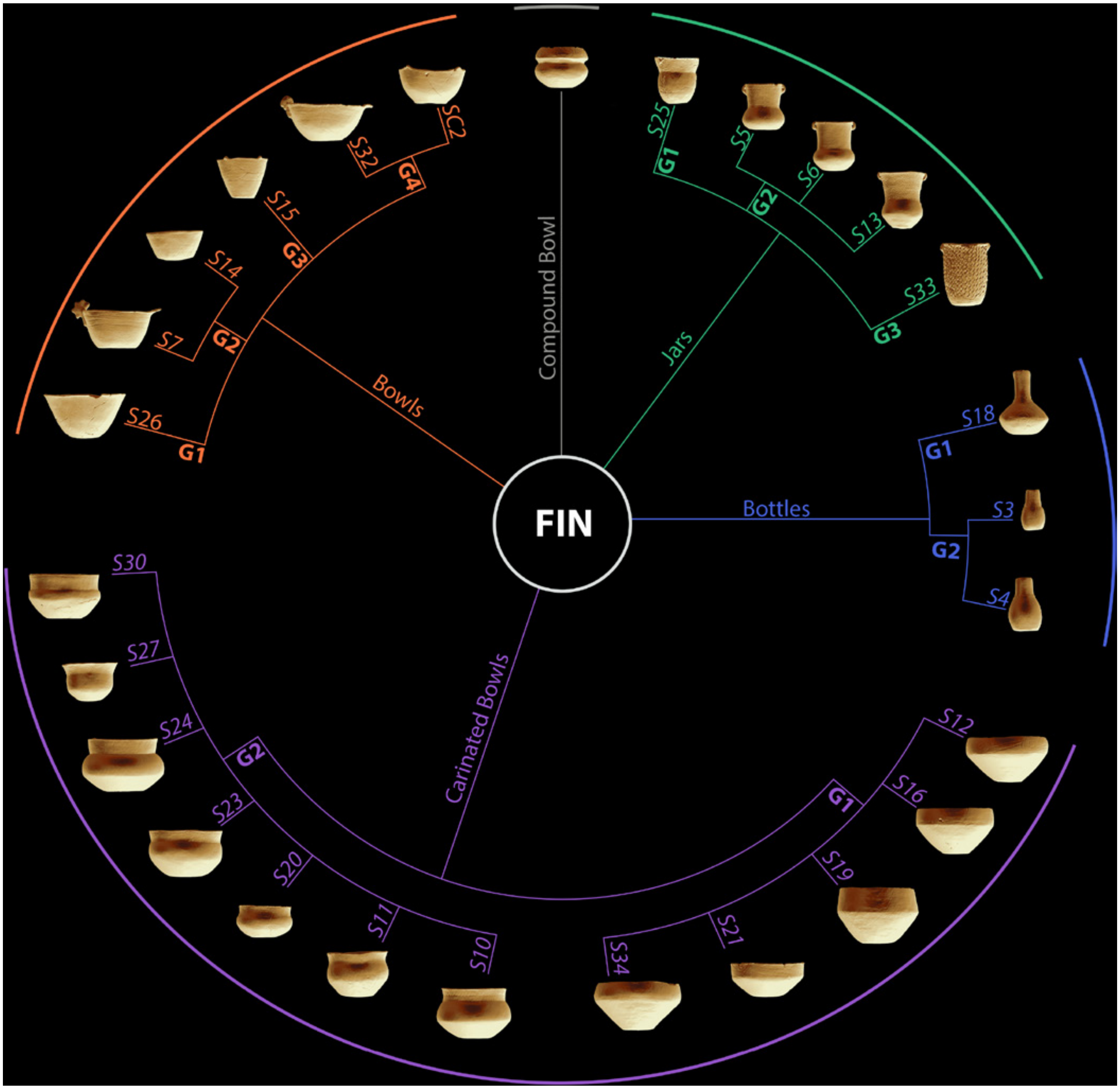

FIGURE 10. Synthesis of geometric morphometric analysis illustrating folk categories, statistical groups (GI, G2, etc.), and vessel numbers. .

2014a]) and Group 4 (FIN-S32 [Selden 2014y]) are distinctive effigy vessels with bird effigy heads and tab tails.

Summary

The 3D morphometric analysis found considerable diversity in vessel shape across the assemblage (Figure 10). The morphometric groups associated with jars, bottles, and bowls correlate with specific burials; however, carinated bowls—both angular and globular—occur across burials 3–5. In this sample, pigment associated with angular carinated bowls is red (FIN-S16 [Selden 2014l]), whereas white pigment is associated with globular carinated bowls (FIN-S20 [Selden 2014b]).

The bone-tempered vessels (FIN-S3 [Selden 2014i], FIN-S6 [Selden 2014e], and FIN-S15 [Selden 2014x])—a bottle, jar, and bowl, respectively—were confined to Burial 3. A bone/hematite mix was used in two globular carinated bowls (FIN-S20 [Selden 2014b] and FIN-S24 [Selden 2014s]) in Burial 4, and grog/bone temper in the single vessel (FIN-SC2/bowl [Selden 2014z]) from Burial 1. Among those vessels with hematite included in the temper are one grog/hematite-tempered jar (FIN-S5 [Selden

2014d]), two grog/hematite-tempered angular carinated bowls (FIN-S12 [Selden 2014k] and FIN-S16 [Selden 2014l]), and one grog/hematite-tempered globular carinated bowl (FIN-S11 [Selden 2014q]) from Burial 3. However, Burial 4 vessels included hematite inclusions in a broader variety of vessel shapes, ranging from a grog/hematite-tempered angular carinated bowl (FIN-S19 [Selden 2014m]); two grog/hematite (FIN-S11 [Selden 2014q] and FIN-S27 [Selden 2014t]), two bone/hematite (FIN-S20 [Selden 2014b] and FIN-S24 [Selden 2014s]), and one grog/hematite/organic-tempered (FIN-S23 [Selden 2014r]) globular carinated bowls; and a single grog/hematite-tempered bowl (FIN-S26 [Selden 2014v]). Grog is the most ubiquitous temper within the collection, present in Burial 3 in a jar present in Burial 3 in a jar (FIN-S13 [Selden 2014f]), a bottle (FIN-S3 [Selden 2014i]), a globular carinated bowl (FIN-S10 [Selden 2014p]), and two bowls (FIN-S7 [Selden 2014a] and FIN-S14 [Selden 2014w]); in Burial 4 in a jar (FIN-S25 [Selden 2014c]), a bottle (FIN-S18 [Selden 2014h]), and an angular carinated bowl (FIN-S21 [Selden 2014n]); and in Burial 5 in a jar (FIN-S33 [Selden 2014g]), an angular carinated bowl (FIN-S34 [Selden 2014o]), a globular carinated bowl (FIN-S30 [Selden 2014u]), a bowl (FIN-S32 [Selden 2014y]), and a unique vessel with conjoined carinated bowls (FIN-S31 [Selden 2014aa]).

DISCUSSION

This study demonstrates a creative solution to the challenge of storing digital media (and making it publicly accessible), illustrating the benefits of a virtual collaboration and the promise of an analytical approach aimed at exploring the variation in Caddo vessel shape. Admittedly, there are drawbacks to using this approach—the amount of time invested, for instance. However, our point was to illustrate how we might begin to push beyond traditional 3D documentation efforts and expand our current research domains by incorporating (and exploiting) 3D datasets that are readily available. Although the production, curation, and virtual exhibition of 3D models may not be relevant to all 3D research projects, our analysis of morphometrics illustrates that archaeologists could benefit (analytically) from the incorporation of the numerous publicly accessible 3D datasets that are becoming available, an avenue of research that is by no means limited to pottery.

While our study of morphometrics uses a small sample of 3D imagery, the digital collection of 2D and 3D imagery and data related to Caddo vessels continues to grow. Currently, we are aggregating over 2,000 2D images from ceramic vessels in the ancestral Caddo region, all with the metadata fields that were discussed above, with the hope of using them in an analysis of 2D morphometrics. A variety of efforts to document the vessels continue throughout East Texas and the larger Southern Caddo Area, and these undertakings have produced all of the data needed for us to expand our efforts to explore questions of vessel shape more thoroughly. Additionally, we are returning to a number of the previously documented 2D collections to add a 3D component.

With regard to morphometrics, there will be some changes made in our placement of landmarks as we move forward. In the present study, landmarks were defined as any point with x, y, and z coordinates that could be used to represent the shape of a vessel. Moving forward, we will be revising that definition of landmarks to reflect geometrically homologous points on the vessel. These homologous points will be augmented with a variety of semi-landmarks that will populate the area between the various (and well-defined) homologous landmarks. For future analyses we also plan to abandon the method of adding and exporting landmarks in Geomagic Design X for TPSdig2.

To build upon our analyses of vessel morphometrics, paradigmatic classifications of decorative motifs and elements on Caddo utility wares have been developed (see Perttula 2014), and a complementary classification of Caddo fine wares will soon be added. These classifications provide the means to compartmentalize the distinctive character of ceramic styles that occur on the rim and/or the body of Caddo ceramics, which can be extended to include morphometrically defined vessel shapes. Once defined, the paradigmatic classifications can be expanded as needed, providing a way for users to more fully characterize the variation in both decorative motif and vessel shape. This method of classification marks a dramatic departure from the previously defined taxonomic definitions for the Caddo region (see Suhm et al. 1954) that were based primarily upon decorative motifs.

CONCLUSION

Temporal and spatial considerations concerning ancestral Caddo sites, communities, and artifact assemblages are categorized in large part on the basis of a taxonomy that is focused on ceramic decorative elements and motifs; however, other distinctive vessel attributes also play a role in taxonomic assignments (Suhm and Jelks 1962). Whereas stone tool taxonomies in the Caddo region—initially defined in Suhm et al. (1954)—continue to evolve (see Turner et al. 2011), no comprehensive update to Suhm and Jelks' (1962) ceramic taxonomy has been developed in the Caddo area; however, efforts to update the dated Caddo ceramic taxonomy are currently underway (see Perttula and Selden 2014), and the modest efforts described here are meant to represent another step in that direction.

Although the results of our analysis could be applied to a variety of theoretical models, it is within evolutionary archaeology that we see the greatest potential. Several recent 3D morphometric studies of stone artifacts gainfully enlist evolutionary theory in studies of morphological variability (Bretzke and Conard 2012), technological origins (Lycett et al. 2010), stability and variability (Lycett and von Cramon-Taubadel 2013), the transmission of technological knowledge (Sholts et al. 2012), and phylogenetics (Lycett 2009). Given recent syntheses and analyses of chronometric data in the Caddo region (Selden 2012; Selden and Perttula 2013), and the temporal resolution garnered through recent innovative studies of decorative elements and motifs (Early 2012; Girard 2012), we believe that a large-scale/complementary study of ceramic vessels in both 2D and 3D, aimed at the gradual production of a regional taxonomy inclusive of both shapes and styles of ceramic vessels, is warranted. This will require the synthesis of quantitative data from morphometric analyses and qualitative data defined from decorative elements and motifs that we hope will achieve significant analytical and theoretical gains and better illustrate the fluid temporal and spatial dimensions of Caddo life associated with ceramic technology.

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Supplemental Materials

Supplemental materials are accessible via the SAA member login at http://saa.org/home/tabid/

Supplemental Data. Results of Generalized Procrustes Analysis (GPA) and Principal Components Analysis (PCA) Generated by Morphologika

Data Availability Statement

All data associated with this analysis are freely available on CRHR:ARCHAEOLOGY (CRHR 2014a), the digital repository of the Center for Regional Heritage Research at Stephen F. Austin State University, where we recently published two blog posts to help users navigate our digital collections (http://wp.me/p41HMA-j0 and http://wp.me/p41HMA-l1).

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