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Asymmetry of Caddo Ceramics from the Washington Square Mound Site: An Exploratory Analysis

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Abstract

While pursuing a study of 3D geometric morphometrics for ceramic burial vessels that often articulate with the Native American Graves Protection and Repatriation Act (NAGPRA) from the ancestral Caddo region, there have been no shortage of potentially meaningful observations, one of which—rotational asymmetry in coil-built vessels—is discussed here. Using Geomagic Design X (reverse-engineering software) and Geomagic Control X (inspection software), metrics associated with rotational asymmetry were generated then analyzed. Results indicate variable asymmetry among the different vessel shapes (i.e., bottles, jars, etc.), which may augment and strengthen studies and discussion of vessel form. Future directions include the incorporation of directional and—possibly—fluctuating asymmetry measures for the widest vessel profiles. Preliminary results point toward substantive analytical gains that can be used to augment more traditional ceramic analyses as well as geometric morphometric studies of ceramic vessel shape.

Keywords: 3D, Symmetry, Asymmetry, Geometric Morphometrics, Ceramics

1. Introduction

The Caddo peoples inhabited areas of what are today Arkansas, Louisiana, Oklahoma, and Texas from ca. A.D. 800/850-1838 [1]. They were horticulturalists as well as agriculturalists, with a particular focus on maize cultivation [1, 2, 3]. Their ancestral predecessors were various Woodland period

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6 communities that developed between ca. 500 B.C. and A.D. 800 [4]. Caddo
7 communities and separate population groups may have first emerged within
8 two areas: the Great Bend of the Red River in southwestern Arkansas and
9 northwest Louisiana, and in the Arkansas River basin in eastern Oklahoma
10 [5]. However, other important communities developed early on in East Texas
11 and in the Ouachita River basin in southwest Arkansas [5]. Those ceramics
12 employed within the framework of this analysis are from the Washington
13 Square Mound site (41NA49), a Middle Caddo (ca. A. D. 1200-1450) mound
14 site located in Nacogdoches, Texas (Figure 1).

Figure 1: The Southern Caddo Area and the Washington Square Mound site.

15 While elements of Caddo life share many similarities with (U.S.) South-
16 eastern Mississippian cultures, cultural developments in the Caddo area do
17 not appear to have developed in concert with their Mississippian counter-
18 parts [6, 7]. This has led archaeologists to consider Caddo developments as
19 an expression of local and regional processes linked culturally and temporally
20 to preceding Woodland period groups and to interactions between different

21 Caddo groups [8, 1]. Caddo trade networks extended from Cahokia in the
22 north [9, 10], to the Pueblo villages of New Mexico in the west [9], to the
23 Acansa and Taensa Indians on the Mississippi and Arkansas rivers to the
24 east [10]. Manufacturers of such sought-after items as bows constructed of
25 Osage orange (Bois d'arc), decorated fine ware pottery, salt, and food prod-
26 ucts, the Caddo were well situated within local and extended trade networks
27 [11, 12, 9, 13].

28 1.1. *Asymmetry*

29 Coil-built ceramics (like those of the Caddo) are abundant in the archae-
30 ological record of the Americas, and are primarily segregated and assigned to
31 specific temporal and spatial components based upon surficial attributes and
32 decorative motifs. The lack of a substantive discourse among ceramic ana-
33 lysts regarding issues of vessel shape and asymmetry can likely be linked to
34 the perceived inability to fully characterize the enormous scope of variation
35 that occurs throughout ceramic assemblages, coupled with the fact that the
36 majority of analysts primarily work with sherd assemblages more regularly
37 than with whole vessels. Adding to this are the tight timelines associated
38 with cultural resource management (CRM) analyses, the expense and time
39 commitment associated with collecting and analyzing 3D data, navigating
40 burial legislation (NAGPRA, etc.), highly variable bureaucratic semantics,
41 and the oft-burdensome museum or repository bureaucracy involved with ac-
42 cessing and digitizing collections for use as a comparative resource. For these
43 and many other reasons, it quickly becomes apparent why such a deficit of
44 knowledge remains for these data rich-yet understudied-cultural resources.

45 Recent forays into the symmetry and asymmetry related to ceramic arti-
46 facts are more regularly focused upon decorative elements [14] than issues of
47 vessel shape or form [15]. It is within a study of the latter where the various
48 components of this effort begin to take shape [16], raising potentially signifi-
49 cant questions regarding the ceramic technological organization of the Caddo
50 people. Using the results of this analysis, differences in Caddo fine wares and
51 utility wares could be compared to explore whether a ceramic vessel with a
52 lower deviation from rotational symmetry might have been seen as more at-
53 tractive, which may provide further insight into the value of specific elements
54 of the Caddo ceramic economy. Measures of symmetry and asymmetry are
55 also compared between the variable categories of vessel shape (bowl, bottle,
56 etc.) to investigate whether, and what manner of, variation may exist among
57 them. Further still, these metrics might help to clarify additional patterns

that are becoming more apparent in studies of geometric morphometrics for ceramic artifacts [17].

1.2. Research Potential

The degree to which this approach might better demarcate between elements of elite and commoner production strategies [18] remains unknown; however, it may be possible to leverage morphological components from ceramics with known cultural associations (i.e., elite, commoner, etc.) to elaborate upon differential production strategies and manufacturing processes [19]. For instance, should a higher degree of symmetry be found to correlate with elite burials or ceremonial contexts, and not with those contexts associated with Caddo commoners, arguments for the attractiveness of symmetry [20, 21, 22] and shape [23, 24, 25, 26] for specific elements of these vessels might be more gainfully argued in concert with the associated qualitative attributes. The notion of attractiveness in this context could help us to better couch our ideas related to the Caddo ceramic economy.

While exploratory, this approach may also yield additional insight into whether it is possible to discriminate between basic vessel forms (i.e., bowl, bottle, jar, etc.) using attributes associated with rotational asymmetry. Results from the analyses of rotational asymmetry are discussed herein, and future directions posited that include using landmarks and semi-landmarks from the geometric morphometric analysis to incorporate analyses of directional and fluctuating asymmetry. Results of these analyses are then added to those data from a previous documentation effort. Outcomes of the analysis have implications for the organization of craft production [27], to include explanations of technological varieties, which inform upon basic tenets of the local economy [28]. This method may also prove fruitful in addressing variable asymmetry between coil- and wheel-built vessels, helping to further refine our ideas associated with variable ceramic manufacturing practices and processes [29].

2. Methods

The three-dimensional (3D) scan data used in this analysis were collected using a ZScanner 700CX running VXelements software via the scanner direct control feature in Geomagic Design X, and all data are open access and available for download on Zenodo [30, 31, 32, 33, 34, 35, 36, 37, 38, 39]. The use of Geomagic Design X in this research program streamlines the 3D

scanning process by allowing analysts to scan, post-process, and generate reference geometry-and in this case also a rotationally symmetrical surface, landmarks, and sliding adaptive semilandmark data points-in a single interface [40].

2.1. Missing Data

As research efforts aimed at the development and integration of geometric morphometrics for Caddo ceramics continues, peripheral (unexpected) analytical insights are beginning to arise on a more regular basis. As those methods associated with the analyses have matured [17], the number of 3D meshes suitable for analysis initially declined. This occurred in part to a necessary developmental phase within the larger research design, where every nearly-intact vessel was scanned. That practice resulted in the collection of 3D meshes that can continue to be used to test and improve upon methods associated with these analyses. As the analysis of each collection draws to a close, methods continue to be revised to align with iterative improvements in the evolution of the methodological approach. Initially, the landmarks (LM) and semilandmarks (sLM) used in the analysis were applied a manner that actively avoided areas of missing data [17]; however, in the pursuit of a more standardized and replicable approach, many vessels from the initial analysis could no longer be used due to the overlap of splines with an area of missing data.

The integration of Geomagic Design X and Geomagic Control X in this research design has greatly streamlined the analytical process. Using this software, we can scan directly into the same platform used to post-process the meshes and populate reference geometry, then populate LM and sLM data for the geometric morphometric analyses. Other similar software packages exist (PolyWorks, etc.), and while this approach is focused only upon Geomagic Design X and Control X, similar approaches could be employed using those programs as well. Once processed, it is important to outline how mesh defects and missing data were addressed for each scan (keeping in mind that each is unique).

2.1.1. Methods used to Address Missing Data

When the scanning process is complete, the file is opened in Geomagic Design X where the processing of those files begins. In general, two kinds of missing data are regularly encountered with 3D scanning practices; one where those data are genuinely missing from the original model; the other where

129 those data were not collected by the scanner. It is important to identify
130 which relates most readily with those data missing from each scan. This
131 information can be used to help identify regions of certain artifact forms that
132 require more attention during the scanning process, perhaps due to areas of
133 high reflectivity or other known (and quickly remedied) issues. If those data
134 missing from the mesh are present on the artifact, it is best to begin with
135 scanning that particular piece a second time. Those data can then be merged
136 with data from the first scan, beginning post-processing by using the best
137 possible scan with the fewest missing data.

138 Prior to addressing missing data, each scan is processed using the Healing
139 Wizard function. The Healing Wizard function runs a variety of checks
140 for non-manifold poly-vertices, folded poly-faces, dangling poly-faces, small
141 clusters, small poly-faces, non-manifold poly-faces, crossing poly-faces, and
142 small tunnels for each scan. This step corrects abnormalities in each mesh,
143 decreasing the chance of encountering an error while addressing areas of
144 missing data.

145 To align each scan, a reference vector (revolving axis) was inserted, fol-
146 lowed by a reference point at the confluence of the vector and the mesh at
147 the central base (projection). Region groups were then used to define the
148 basal plane. All three elements (vector, point and plane) of reference geome-
149 try were utilized in an interactive alignment, with the reference plane as the
150 moving plane, the reference vector as the moving vector, and the reference
151 point as the moving point. Alignment has proven to be an important factor
152 in downstream analyses (and landmark/semilandmark application), particu-
153 larly when making the transition from Geomagic Design X and Control X to
154 SolidWorks or other CAD-based software.

155 Due to the variable nature of the archaeological record, some ceramics are
156 well-preserved while others fragment, weather and decompose at fluctuating
157 (often much quicker) rates, depending upon a wide range of factors. The bulk
158 of Caddo ceramic vessels scanned for the geometric morphometrics project
159 are comprised of this latter group, and were—most often—reassembled by the
160 repository or curation facility.

161 *2.1.2. Addressing Areas with Missing Data*

162 The splines used in the geometric morphometric analysis dictate the loca-
163 tion(s) of missing data that must be addressed prior to populating LM/sLM
164 data. Each situation requires a unique solution, and each has the capacity
165 to impact the analysis. In an effort to select the method that deviates least

166 from the original surface geometry, an area adjacent to the hole is cut out
 167 and deleted to create another hole of similar size. A Caddo NAGPRA ves-
 168 sel from the Turner Collection with an area of missing data will be used to
 169 illustrate this approach.

170 To begin, the aligned mesh is exported as an ASCII.stl that will be used
 171 as the control. A hole is then cut in the existing mesh adjacent to the missing
 172 data. The mesh is saved as an ASCII.stl, and will be imported and patched
 173 using each of the three functions (defeature, edit boundaries, and fill holes),
 174 then each mesh is saved as a unique ASCII.stl. Since the control model was
 175 aligned prior to exporting the mesh with the hole, that alignment carries over
 176 to each of the resultant meshes (control, hole, defeature, edit boundaries, and
 177 fill holes). Once complete, those meshes produced by each of the three hole-
 178 filling functions are compared against the control in Geomagic Control X.

179 Geomagic Control X is inspection software traditionally used to compare
 180 3D CAD models against meshes to identify areas of wear on machined parts.
 181 In this case, the nominal data (control) is contrast against each of the three
 182 hole-filling functions (scan data) to identify which deviates least from the
 183 original mesh (Figure 2). These results guide the decision-making strategy
 184 with regard to the post-processing procedure for areas of missing data, al-
 185 lowing modelers to make more informed decisions about which function to
 186 use.

Figure 2: Control data contrast with (a) defeature, (b) edit boundaries and (c) fill holes.

187 In this particular case, the fill holes feature deviates least from the original
 188 3D mesh. Call-outs were only issued for those deviations over 0.02mm, and in
 189 this instance, the maximum deviation from the control data was 0.0184mm
 190 using the fill holes function. Prior to employing the fill holes function as
 191 the remedy for this area of missing data, a clean cut was made in the mesh
 192 around the hole and a second pass of the healing wizard was used to correct
 193 for any errors created by the cut. The final mesh was then ready for use in
 194 the analysis.

195 Among those lessons learned throughout this process is a subjective triage
 196 system that dictates which vessels get scanned, and which do not. In short,

197 some areas of missing data cannot be remedied while maintaining a high
198 degree of confidence regarding the resultant geometry. While the three func-
199 tions discussed here are ample to address the bulk of our concerns involving
200 how we might best approach missing data in these smaller areas, more robust
201 methods are warranted for larger holes, for which processing time increases
202 exponentially.

203 In the sample of scan data collected for the 3D geometric morphometrics
204 study, around 15 percent are unable to be used due to the location of a large
205 (often around 50mm and larger) missing sherd. Certainly methods exist to
206 address the majority of missing data in those meshes; however, these are not
207 included in the study of geometric morphometrics. Instead, those meshes are
208 used to document design-based elements and motifs [17].

209 *2.2. Quantifying Deviation from Rotational Symmetry*

210 Using 10 3D scans of Caddo burial (NAGPRA) vessels from the Wash-
211 ington Square Mound site (41NA49) in Nacogdoches, Texas, a method was
212 devised to assess the deviation of coil-built ceramics from a rotationally sym-
213 metrical surface. For this analysis, a unique surface was generated for each
214 of the Caddo vessels in the sample (Figure 3). To create the symmetrical
215 surface, the widest point of each vessel was identified while each vessel was
216 oriented along the basal plane. For the purpose of this research design, this
217 same point was then used in the geometric morphometric analysis. This ap-
218 proach provided those data needed to revolve the widest profile 360-degrees
219 around the vector (central axis). To identify the widest point of the vessel,
220 a mesh sketch was created using the reference point as the central point of a
221 circle. The sketch (circle) was extruded in both directions to create a surface
222 that covered the vessel completely, and deviations between the surface and
223 mesh were calculated to identify the widest point of the vessel. A reference
224 plane was then inserted along the widest profile, coplanar to the central vec-
225 tor. That plane was then used as the basis for a second mesh sketch of the
226 widest profile, which was subsequently revolved around the central axis to
227 create each rotationally-symmetrical surface.

228 The surface and the mesh were then imported to Geomagic Control X (in-
229 spection software), where deviations between the mesh and the symmetrical
230 surface could be calculated for the whole vessel (Figure 3), and the indi-
231 vidual splines used in the analysis of geometric morphometrics (Figure 4).
232 Further, it is possible to export the landmark and adaptive sliding semiland-
233 mark points used in the geometric morphometric analysis to identify their

Figure 3: Deviation between rotationally-symmetrical (nominal) surface and 3D scan data for Lot 239 from the Washington Square Mound site.

deviation from the rotationally-symmetrical surface.

3. Results

Results of the asymmetry analysis (Figures 3 and 5) identified a percentage of each vessel that was within the specified (0.3mm) tolerance. These results were used in a comparison of fine wares and utility wares, and a comparison of vessel forms. The vessel in Figure 3 demonstrates the dynamic discrepancy that can be seen between the mesh and the rotationally-symmetrical surface. This is noteworthy for several reasons; principally to illustrate that the many vessel profiles found in the archaeological literature may be accurate, but are representative of only a very small part of the whole (note the small green area from the base to the rim in Figure 3). The dynamic nature of ceramic artifacts is known to analysts, but our capacity to demonstrate these dynamics has to this point been limited by our

Figure 4: Vessels can be sectioned, where the deviations for a specific spline can be extracted for a more in-depth analysis.

247 systematics.

248 Of the two archaeological features where these vessels were recovered,
 249 only Feature 31 (F31) included both fine and utility wares. For that reason,
 250 a comparison of the fine (engraved) and utility (punctated, brushed and
 251 incised) wares was only conducted for F31, which yielded a substantial deviation
 252 between the two (Figure 8a). Further, once segregated by vessel form
 253 (bottles, jars and an olla for F31), all were found to be within a range unique
 254 to each vessel shape (Figure 8b).

255 3.1. Future Directions

256 The development of the landmark configuration used in the geometric
 257 morphometric analysis can be seen as the first step in a hierarchically-
 258 nested method of inquiry. Additional modifications to the configuration of
 259 landmarks and sliding adaptive semilandmarks will be based upon specific
 260 research questions for the ceramic vessel assemblage(s) under study, and

Figure 5: Results of the asymmetry analysis.

will likely consist of splitting each of the splines at well-defined junctions (base/body, body/rim, etc.) where the evolution of specific elements of ceramic vessel design (bottle necks, body, rim, etc) might be further explored.

In an effort to better understand how studies of asymmetry employing geometric morphometrics articulate with one another, a citation network was generated that includes publication and citation data harvested from Scopus (Figure 7). Once built, the network allows for the identification of methods and case studies that are most relevant to this research design, while also aiding in the identification of useful works that may not have been captured by the initial literature review.

The splines, landmarks and semi-landmark configurations developed for the geometric morphometric study can also be used to explore the variation that occurs in directional and—possibly—fluctuating asymmetry [41] (Figure 8); both of which are becoming more regularly incorporated in analyses of geometric morphometrics (see Figure 7). It is possible that measures of directional and fluctuating asymmetry will be found to be more readily

Figure 6: Comparison of (a) fine and utility wares from F31, and (b) bottles, jars and olla from F31.

incorporated in the analysis than measures of rotational asymmetry.

4. Discussion

The extent to which these data might inform upon variations in Caddo manufacturing practices for a specific temporal span is currently unknown. Testing these results by including samples from additional sites and temporal components should help to clarify whether—and to what extent—these data might inform upon possible shifts within, and between, groups of makers that employed differing methods of manufacture that may have resulted in variable degrees of conformity to rotational symmetry. As the resolution of the temporal dynamics in the East Texas region of the ancestral Caddo territory continues to be synthesized [42], refined [43] and further explored [44], the fluid and dynamic nature of the Caddo ceramic economy should similarly increase in resolution. That same line of questioning may also inform upon whether those vessel shapes that transcend specific temporal boundaries have a consistent measure of rotational symmetry.

In a recent study of 3D geometric morphometrics for Caddo ceramics [17], several potentially meaningful results were achieved. Among these was the successful discrimination between the vessel shapes (bowls, jars, etc.). Within that study, subdivisions of vessel shape were identified, which were subsequently found to correlate with various qualitative attributes. This led to the discovery that variations in bowls, jars, and bottle categories may—in some way—be related to offerings, and that angular carinated bowls were

Figure 7: Interactive citation network of publications and cited works for asymmetry studies that employ geometric morphometrics. Data harvested from Scopus. This interactive graph includes all nodes in the network ($n=2472$), and all edges ($n=3337$). Nodes are sized by OutDegree. View and interact with this network [here](#).

299 associated with the use of red pigment in engraved designs, while globular
 300 carinated bowls were associated with the use of white pigment in engraved
 301 designs [17]. Additionally, the carinated bowls were the only vessel shape to
 302 be included in all burials [17]. The extent to which analyses of geometric
 303 morphometrics and rotational asymmetry will complement one another is
 304 yet unknown; however, there is precedent in the biological sciences [45, 46],
 305 and the functions needed to generate similar analyses for fluctuating and
 306 directional asymmetry are included in many of the current software packages
 307 used to study geometric morphometrics.

308 These preliminary results point toward the potential for significant the-
 309 oretical gains; particularly for discussions related to the ceramic economy,
 310 where value is ascribed. While the notion of the attractiveness in a symmet-
 311 rical shape is not a novel idea, the systematics associated with quantifying
 312 asymmetry for ceramics have long escaped us. The approach posited here
 313 allows for the collection of those metrics in three-dimensions. Importantly,
 314 the analysis also demonstrates that the many profiles contained in the pub-
 315 lished literature may be very useful for ongoing discussions of ceramic shape
 316 [47], but these 2D representations should only be revolved to illustrate vessel

Figure 8: Results of a) generalized Procrustes analysis, b) analysis of fluctuating asymmetry and c) analysis of directional asymmetry.

317 shape; and not to analyze it.

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 323 and constructive criticisms on an earlier iteration of the citation network.

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