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FORD'S GAMMA-GAMMA VILLAGE SIMULATION REVISITED: HIGHLIGHTING THE NEED FOR A NEW MIDDLE-RANGE THEORY OF ARCHAEOLOGICAL TYPES[1]*

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The long-running controversy over typological concept use in archaeological investigations hinges on whether such procedures introduce assumptions, and channel interpretations, in ways that can equate analytical groups with bounded cultural-historical units inappropriately. James A. Ford's writings, in reaction to the arguments of Albert Spaulding, have often been cited as the founding instance of this criticism. To illustrate his concerns, Ford drew a hypothetical village of houses and used these forms to make a number of assertions regarding the nature of artifact variability that, he felt, demonstrated inherent errors with Spaulding's artifact-analysis approach. However, despite the intense character of this controversy, both at the time and subsequently, no one appears to have tested, or confirmed, any of Ford's assertions objectively. Morphometric analyses of Ford's simulation demonstrates all published assertions of which we are aware regarding patterns of variation exhibited by these drawn artifact forms, published in the intervening 67 years, are either wholly or substantially incorrect. Both traditional and new pattern-recognition techniques allow for the identification of more fine-grained structure in artifact variation patterns than is possible using qualitative approaches. These findings argue strongly for a re-evaluation of the role of typology in archaeological research.

KEYWORDS: ARCHAEOLOGY, TYPOLOGY, ARTIFACT, DATA ANALYSIS, CULTURAL TRANSMISSION THEORY, SIGNALING THEORY

INTRODUCTION

In 20th century archaeology, and especially in the heyday of the cultural-history movement, artifact types were constructed using a variety of criteria (e.g., Willey and Phillips 1958). However, the role of typology in archaeological analysis has been the subject of ongoing debate. Central to this debate is the published exchange between James A. Ford (1954a, 1954b) and Albert Spaulding (1953, 1954). Spaulding (1953) proposed use of statistical methods to discover artifact types from recorded data. To many archaeologists, including Ford, this suggested such discovered types were equatable to specific cultures and carried with them a phenomenological, essentialist significance; that such categorizations were, in fact, *real*. This proposition was rejected by Ford and others who asserted that artifact types were artificial groups created by researchers and not equatable to specific culture(s) by virtue of any essential quality. In addition,

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Ford (1954a) noted the number of artifacts recovered from many archaeological sites represented a small portion of the total material culture. Thus, the patterns discovered by Spaulding's statistical techniques were unlikely to reflect true patterns characteristic of past material cultures.

As the New Archaeology grew in popularity through the 1960s, researchers became less interested in traditional culture history and began to explore new ways of analyzing material culture, focusing largely on behavior and social processes (e.g., Binford 1965, 1977, 1981; Binford and Binford 1968; Schiffer 1972, 1976, 1983). This new direction, however, left the typology issue unresolved. Although most researchers saw value in Spaulding's pattern-recognition techniques, they also agreed with Ford's theoretical criticisms.

Though some have maintained types should be constructed for specific analytic purposes, this stance differs substantially from many authors' wholesale rejection of types (see Hill and Evans 1972; Clarke 1968; Whallon and Brown 1982; Adams and Adams 1991; Whittaker *et al*. 1998; Bisson 2000). Others appear to have made a conscious choice to ignore these theoretical criticisms of the traditional culture history paradigm by pursuing culture historical studies unabated (see Loren and Wesson 2010, p. 42–45 for a discussion). Kuhn (1995) described American archaeology as characterized by a 'theoretical fragmentation' (p. 16) while, more recently, Tomášková (2005) described archaeologists' relationship with typology as 'ambivalent', and suggested some view types as 'a necessary evil' (see pp. 79–85). This statement echos Dunnell's (1986) observation that, 'workers tend to divide into two camps on classification. … the large majority, hold that unit formation is a necessary but intellectually uninteresting activity without major significance for the discipline's primary goals.' (p. 149). As an early advocate of quantitative evolutionary approaches to material culture change and research associated with cultural transmission theory (CTT), Dunnell (1986) noted that he, and a few others, regarded classification as, 'the most critical and pressing issue in the field' (p. 150). Dunnell saw Spaulding's work as foundational to later quantitative models of changes in material culture through time and space. Thus, the perception of there being a problem with types and typology in archeology remains.

Both O'Brien and Lyman (2002) and Read (2005) have suggested that Ford and Spaulding were talking past one another in their attempts to describe the processes involved in artifact classification. Ford, they argued, promoted the use of types as ideational classes that serve to interpret cultural history rather than define it. Spaulding, in contrast, was portrayed as promoting the use of empirical patterns, identified from actual specimens, as essentialist categories capable of serving as stable time and cultural markers.

Pestle *et al*. (2013) described the Ford-Spaulding controversy as an –etic (arbitrary) versus –emic (real) argument. However, Dunnell (1986) had already noted, 'Ford's criticisms of Spaulding's approach … go beyond the simple [etic-emic] issue. They stem from a materialist conception of reality'. (p. 182). Dunnell went on to argue, 'From Ford's perspective, Spaulding's types are accidents of sampling without *archaeological* significance' (emphasis in the original p. 182; see also Dunnell 1971; Spaulding 1978). Tomášková (2005) summarized archaeology's typology problem in general terms by noting that 'classification [in and of itself] carries with it the danger of built-in assumptions, channeling interpretations into predictable directions, and thus creating theoretical problems even in the act of creating order' (p. 79).

Interestingly, a close reading of Ford (1954a, 1954b) reveals he was actually reacting quite specifically to the phenomenological aspect of cultural types. Ford (1954a) lamented that types, which originally served a purely descriptive purpose, had taken on a new function (and definition) as culture types and time markers, but despite this, went so far as to say that descriptive types are 'extremely useful' (p. 43). In this context, we feel it important to understand

Ford's (1954a) article as a reaction to his concerns over the idea that types should be regarded as 'natural cultural units' (p. 48), or 'cohesive cultural types' (p. 49), that should be 'concrete' (p. 47), and 'immutable' (p. 47). In this sense, Ford was arguing against the routine reification of type-based categorizations, but not against the use of type-based systems that categorized or described variability itself.

We propose this complex issue be subjected to new forms of empirical analysis. One time-honored method of determining whether an approach to data analysis is useful is to employ a simulated dataset known or expected to exhibit certain patterns (e.g., Raup 1968, 1969; Gould *et al*. 1977; Sokal 1983; Thomas and Reif 1991, 1993; Naylor 1996; McGhee 1999, 2007). Such datasets supply a basis for documenting the appropriateness and comparative functionality of data-analysis procedures because these particular types of variational patterns are known to exist in the dataset at the outset of an investigation. Different data-analysis procedures can then be compared on the basis of how well each finds those patterns. This experimental design, however, presupposes the simulated dataset actually incorporates the trends or features in question.

Fortunately, a simulated archeological dataset of precisely this type exists at the heart of the archeological type controversy—Ford's (1954a) hand-drawn house diagrams of the fictitious village of Gamma-gamma on the island of Gamma. Of the three hand-drawn diagrams Ford (1954a) provided, his Figure 1 (Fig. 1) will suffice for our purposes because extensive interpretations have been made regarding it as well as it being the figure most often reproduced in commentaries and discussions (e.g., Binford 1965; O'Brien and Lyman 2002; Read 2005; Webster 2008).

Ford, and subsequent authors, have explicitly denied that typological categories are present in his simulation. But so far as we are aware no previous investigator has checked to determine whether these assertions were correct. Accordingly, we employed quantitative data-analysis and statistical procedures to test the assertions/interpretations made by Ford and other commentators. Our purposes in doing so were to (i.) resolve questions concerning what patterns Ford's Gamma-gamma simulation actually show; (ii.) explore the manner in which modern quantitative data-analysis strategies might contribute to the identification, characterization and testing of artifact variation patterns in archaeological research contexts; and (iii.) contribute toward resolving the controversy as to what use, if any, types and typology might have as a means to study of prehistoric human cultures. In addition, we hoped to (iv.) revive interest in, and discussion of, the type issue within the archeological community so the views of contemporary researchers can be known, disagreements identified, and evidence both for and against particular conceptualizations examined.

MATERIALS AND METHODS

Data

In his description of his Gamma-gamma village house simulation (Fig. 1) Ford (1954a) observed the following.

- i 'Houses illustrated toward the right of the diagram, mostly occupied by older people, were high on stilts, and one is in a tree. They tend to be smaller than average. Toward the left side of the diagram the houses are larger and are on very low stilts, or are built on the ground' (p. 46).
- ii 'Variation toward the top of the diagram tends toward larger size and toward the bottom the houses are small, square and roofs approach the pyramidal in shape' (p. 46).

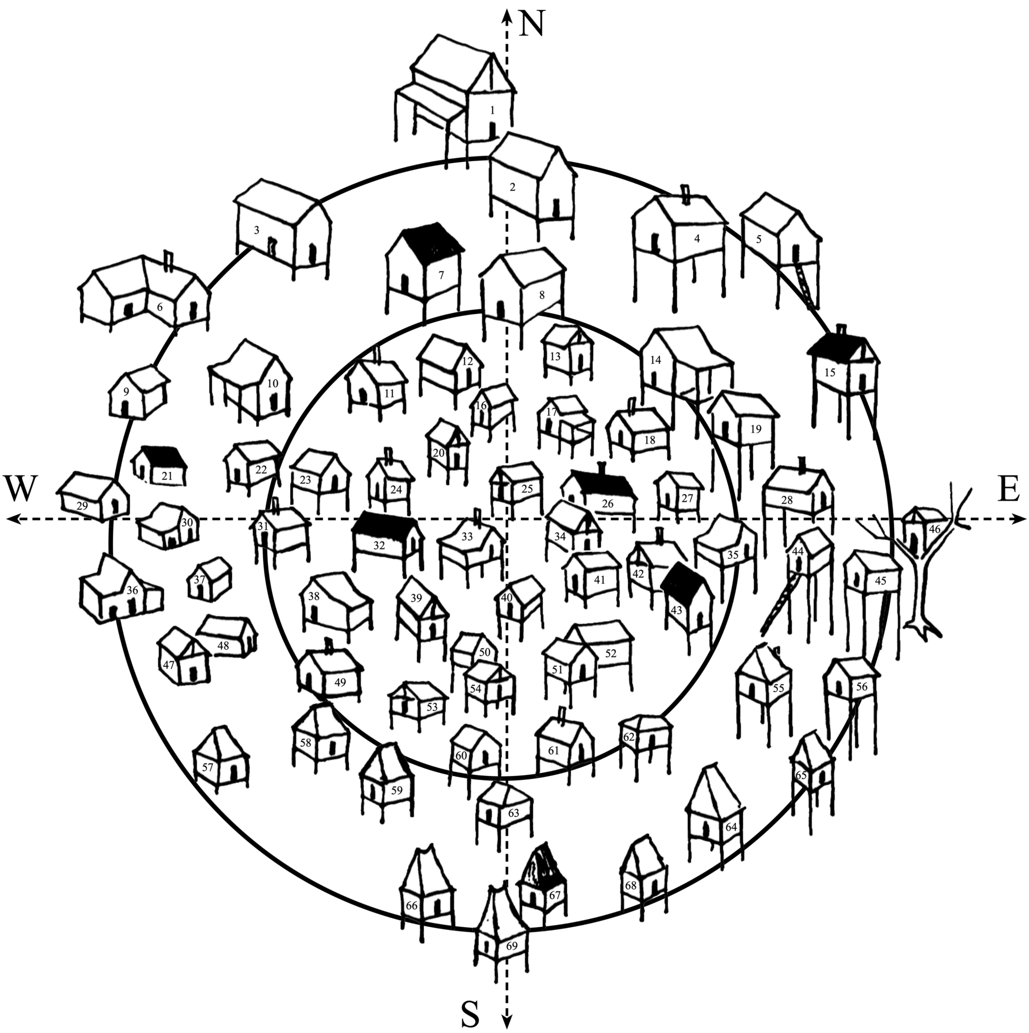


Figure 1 *An annotated version of James A. Ford's (1954a) drawing of a house types in a fictitious village constructed by the notional Gamma-gamma people on the hypothetical island of Gamma in year 1940. Ford's purpose in creating these house forms was to examine the question of whether quantitative data-analysis methods applied to the materials produced by human cultures can, in the absence of historical records, be used to discover and/or characterize ethnologically significant aspects of cultural state or cultural development. The concentric circles on which the house-form glyphs were superimposed were used by Ford to subdivide the village into spatial zones.*

iii 'There are all sorts of variations between the four poles described and, in addition, there are other variables which could also serve as poles in this diagram' (pp. 46–47).
iv 'There is a Gamma-gamma house type with a mean and range of variation' (p. 47).
v 'In Figure 1 what may be considered the mean of the type lies within the inner circle' (p. 47).

In a later review of the archaeological type controversy, Read (2005) added the following.

vi Gamma-gamma house variation forms a joint normal distribution in the N-S and E-W directions, but this structure is irrelevant archaeologically from the standpoint of characterizing Gamma-gamma culture, especially if the sample is limited to a single time and single locality. In other words, descriptions and/or types defined on the basis of a single sample at a single time horizon ‘cannot be used to infer the normative values of … all the makers of the Gamma-gamma houses sharing the same culture’ (p. 59).

vii The manner in which house form is assessed is also problematic, especially when characterization decisions are made primarily with the researcher’s convenience in mind (discussion on p. 59).

viii ‘all Gamma-gamma house height values occur with the same frequency so the house height values have approximately a uniform distribution’ (p. 60).

ix ‘roof height appears to be about the same for all houses … houses in the lower part of [Ford’s] diagram appear to have disproportionately high roofs for the size of the house since roof heights do not vary with the size of the house’ (p. 60).

x ‘one cannot simply assume the spatial and temporal boundaries for sampling—especially convenience sampling—are also spatial and temporal boundaries for cultural concepts’ (p. 59). Thus, it is only when the full range of values that a variable or observation could take theoretically is observed that it is possible to argue that the patterning arises as a result, and constitutes a reflection, of some culturally mandated constraint, perhaps resulting from isochrestic behavior.

xi ‘The horizontal dimension for Gamma-gamma houses ranges from houses on the ground to houses on stilts, that is, there does not appear to be any restriction (= no structure) on the height of a house above the ground’ (p. 59).

xii ‘The same [house height pattern] occurs in the vertical dimension … though not to the same degree’ (p. 59).

Oddly, each of these interpretations are assertions. In no case was any quantitative data or data-analysis result presented to support any of these claims. More importantly though, Ford’s, Read’s and others’ claims about the utility of types have been regarded by many as having been *demonstrated* by these assertions, each made on the basis of *qualitative* inspections of the Gamma-gamma house-form sketches. Surely some objective evidence that these assertions are correct must be brought forward before they can be accepted. Yet, the manner in which Ford’s points have been interpreted appears to have mitigated against the necessity for such tests being made, either for his Gamma-gamma simulation or, by extension, for any archeological artifact dataset.

Linear distances & ratios

A variety of data can be collected from Ford’s house forms (see Supplementary Data [SD] 1: Plate 1). One challenge is that Ford’s drawing shows houses oriented at an angle to the viewer who also appears to be located above the hypothetical Gamma-gamma village, as though they were standing on an adjacent hill. If these were photographs of actual houses, the measurement of lengths or heights from structures oriented at an azimuth angle and (negative) altitude relative to the viewer would produce apparent lengths that differ to a greater or lesser extent from their true values. However, Ford’s drawings are not depictions of actual houses. Because these structures do not actually exist in three dimensions, there can be no question of any difference between their apparent and “true” forms. All statements made by Ford and others regarding this collection of forms have been based solely on what is visible in Ford’s drawing. Accordingly, no pertinent criticisms can be made for employing “apparent” rather than “real” distances in either

Plate 1 *Isolated digital scans of the 69 Gamma-gamma village house forms included in Ford's (1954a) simulation. Each of these house forms was placed at the center of an 85 column × 100 row pixel matrix and converted to a row vector for analysis.*

Table 1 *Variables used to assess patterns of Gamma-gamma house variation**

Measurement no.	*Description*	*Mean*	*Std. dev.*
1	House position *x*-axis (= x-coordinate of lowermost corner or stilt)		
2	House position *y*-axis (= y-coordinate of lowermost corner or stilt)		
3	Stilt length	5.737	4.161
4	House length (= along side with door)	6.917	1.787
5	House depth (= along side at right angles to door)	7.994	2.665
6	House Area (= 4 × 5)	56.364	28.968
7	House aspect ratio (= 4 ÷ 5)	0.935	0.327
8	House wall height	5.959	1.638
9	House volume (= 4 × 5 × 8)	370.632	336.709
10	Roof height	5.164	1.826
11	Rel. roof height (= 10 ÷ 8)	0.892	0.308
12	House height (= 8 + 10)	11.123	2.889
13	Roof margin length	8.489	3.209
14	Roof apex length	7.614	3.610
15	Roof apex–margin ratio (= 13 ÷ 12)	0.881	0.183

*All variables represent magnitudes estimated directly, or calculated, from Fig. 1. All linear variables in mm.

the qualitative or quantitative analysis of these forms because there are no "real" distances or angles, only the forms and locations of Ford's drawings. By the same token, the positions of these house drawings relative to one another as assessed from the drawing must be regarded as accurate insofar as there is no third or depth axis that can be corrected via perspective calculations. The same can be said for subdivision of the Gamma-gamma village into inner and outer zones via concentric circles because these boundaries were part of Ford's original drawing. For the purposes of spatial analysis, absolute scale is also irrelevant. Consequently, the distances employed in our calculations were measured as distances (in mm) from an original scan of Ford's Figure 1 that measured 3,400 pixels (287.8 mm) wide and 3,373 pixels (285.5 mm) tall (Supplementary Data [SD] Item 1). Table 1 lists all linear distances measured and ratios calculated to evaluate statements and assertions made about Ford's Gamma-gamma house-form simulations. A complete matrix of these raw data is provided as SD2.

Images

In addition to the characterization of house forms based on linear distances and ratios, analyses were also performed directly on their digital images so all available morphological house-form information could participate in our analysis of form variation (SD3). Each house's form was standardized to a common size (so house shape could be analysed independent of size), orientation (via mirroring, so the artificial left-facing/right facing placements would not play any role in shape-similarity assessments), and placed the center of a standardized digital image frame 100 pixels long and 85 pixels tall. This house-form collection is available as SD4. These digital representations of the houses contained were converted from the original (RGB) scan to greyscale images using an eight-bit greyscale palette owing to the fact that grey pixels were present in the original scan along the line margins as a result of the halftone representation of the published version of Ford's original figure. Following image-size and frame-size standardization, the matrix of pixel brightness values was reformatted to a series of 8,500-variable row vectors (available as SD5).

Data-analysis methods

Univariate normality evaluations were undertaken using the Cramér-von Mises goodness-of-fit test (Cramér 1928; von Mises 1928; Anderson 1962). The null hypotheses of distributional normality was rejected if this test returned a p-value of less the 0.05. In certain cases, it has been asserted that aspects of the hypothetical Gamma-gamma house-form drawings are consistent with expectations of a uniform distribution (see item viii above). This assertion was also tested using the Cramér-von Mises goodness-of-fit test with the null hypotheses rejected at any p-value less than 0.05.

Assertions involving the existence of directional gradients in house-form variation were tested using ordinary least-squares (OLS) regression analysis under the assumption that the gradient being referred to was linear. Of course, non-linear, curvilinear, exponential, broken stick, and so forth gradients could also be tested. In our view, such an ecumenical interpretation of 'gradient' was neither Ford's intended interpretation nor the manner in which his statements have been interpreted and/or used by others. Accordingly, we considered assertions regarding the presence of directional gradients in our measurement values supported if an analysis of variance (ANOVA) of OLS linear gradient-modeled data found the distribution of residual values about a non-zero slope sufficiently small to support the existence of trend at the 95 percent ($p < 0.05$) confidence level.

Although there are many approaches to problem of identifying subordinate groupings in artifact types we have opted for use of the Gaussian mixture model (GMM) as a generic, robust, well-supported, well-understood, and widely used approach to the general unsupervised learning problem (see Nasios and Bors 2006).

With respect to the assessment of overall shape covariation structure in Gamma-gamma house forms, we employed a covariance-based principal components analysis (PCA, see Jackson 1991; Davis 2002; MacLeod 2005) of the 100 x 85 grayscale pixel-value image-data matrix in the manner described recently by MacLeod (2015, 2018). This approach avoids the need to degrade the quality or completeness of Ford's images via a priori selection of a few linear distances or landmark locations, thereby allowing the maximum amount of pictorial information to be used. In addition, this approach allows incomplete drawings (due to obscuration via image packing) to be included in the analysis.

Finally, to determine whether a morphological discontinuity exists between house forms located in the innermost of Ford's Gamma-gamma village zones (= within the inner circle of Fig. 1) canonical variates analysis (CVA) was applied to house-shape projections into the principal component subspace that accounted for 95 percent of these drawings' shape-covariance structure (see MacLeod 2018). A number of recent authors in various natural history, machine learning, and archeological fields have employed a combined PCA-CVA approach to the analysis of group characteristics in a multivariate context (e.g., Christenson and Read 1977; Anderson and Willis 2003; MacLeod 2015, 2018; Marrama and Kriwet 2017). A 1000-iteration bootstrap variant of Hotelling's T^2 test was used to estimate the statistical significance of the resultant group mean-vector separations (Manly 2006; Manly and Alberto 2017). The hypothesis of group distinction was rejected if the probability that the observed difference between group mean vectors exhibited a value that was less than 5 percent ($p < 0.05$) of the bootstrap estimated mean-vector difference distribution based on randomized group assignments (with replacement).

RESULTS

Univariate normality tests

Of the 13 measured variables and ratios collected from Ford's house-form sketches, only the house aspect ratio was found to conform to expectations of a normally distributed variable (see Table 2). This result is not surprising. Since a normal distribution's form is predicated on the concept of many influences varying at random, this distribution is quite difficult to approximate by hand for lists of numbers, much less drawings. Regardless, any assertion that Ford's drawings portray a "joint normal" pattern of variation (see Read 2005) is clearly unsupported by our analysis. The single exception is a ratio formed by two non-normal variables that is significant statistically only in a marginal sense. The most appropriate interpretation of this result is as an example of the central limit theorem.

Gradients

At least five assertions have been made with regard to the existence of gradients in Ford's (1954a) Gamma-gamma house simulation: that these drawings exhibit a left–right (E-W), gradient involving both (i.) house size (= volume) and (ii.) stilt height, along with a bottom-top (N-S) gradient in (iii.) house size (= house volume), (iv.) shape (= house aspect ratio) and (v.) roof shape (= roof apex-margin ratio). The relevant data plots and statistical tests for these variables against house location along the simulation's horizontal and vertical axes are shown in Table 3.

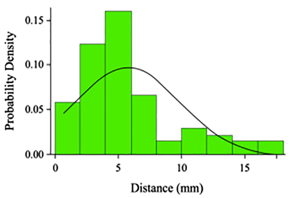
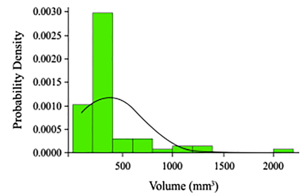
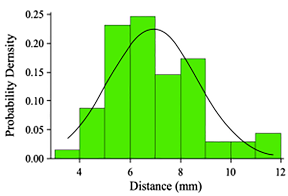
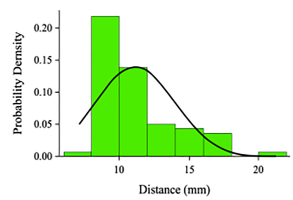
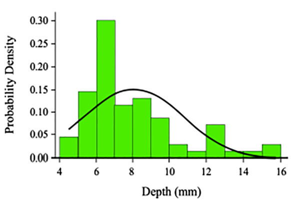
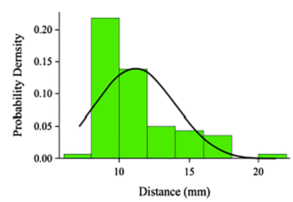
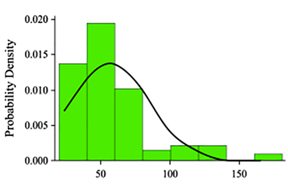
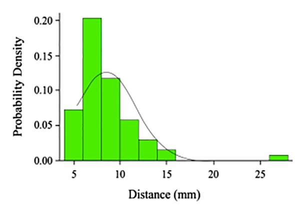
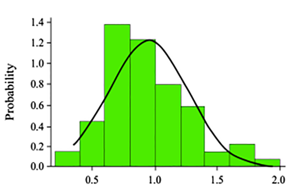
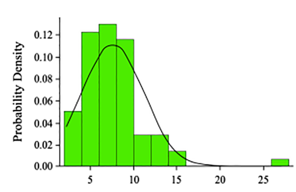
In each case the assertions made by experienced archaeological researchers and published in the peer-reviewed archaeological literature were shown to be without objective foundation. In two instances distributions of form indices identified as having a particular character on the basis of qualitative inspection failed standard statistical tests. In another two instances gradients asserted to exist failed standard regression-based statistical tests. In one instance a marginally significant gradient was found, but the slope of the OLS regression line was so small (0.003) it is very doubtful that simple qualitative inspection could have identified it. In four of these instances examples of statistically significant spatial patterning had been missed by all previous commentators.

These results shed light on how Ford's simulation was constructed and reveal unanticipated discontinuities that could, reasonably, serve as the basis for empirical group designations. To our way of thinking, the idea that such patterns, had they been recovered during the course of a normal archeological excavation, could not, or would not, be regarded as having any interpretive value — especially if this was the only sample of cultural artifacts available — is simply not tenable.

Multipolar patterns

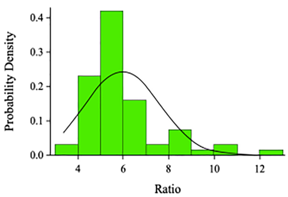
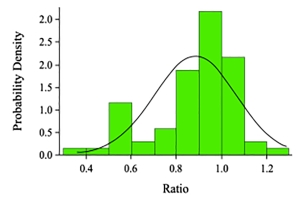
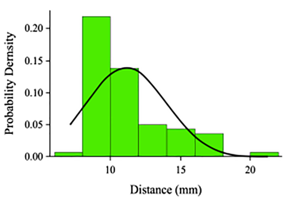
In addition to linear gradients, Ford and other commentators have made various assertions regarding the geographic location, and archaeological value, of statistical means (e.g., typical house forms) and multipolar patterns of variation. Facilitation of these assessments was the reason Ford (1954a) subdivided his village illustration into two zones (see Fig. 1). Based on visual inspection of Figure 1 it seems reasonable to suspect the outer zone includes house forms that deviate strongly from a hypothetical mean (e.g., houses 1, 6, 36, 46, 66, 67, 69), which is located within the inner zone. Nevertheless, rather typical house forms are also located within the

Table 2 *Results of normality tests using a bootstrapped version of the Cramér-von Mises goodness-of-fit test*

Measurement	*Statistic*	*Measurement*	*Statistic*
Stilt length 	$\mu = 5.737$ $\sigma = 4.161$ $\phi = 0.410$ $p = 0.000$	**House volume** 	$\mu = 370.63$ $\sigma = 336.71$ $\phi = 1.870$ $p = 0.000$
House length 	$\mu = 6.917$ $\sigma = 2.665$ $\phi = 0.133$ $p = 0.040$	**Roof height** 	$\mu = 5.164$ $\sigma = 1.826$ $\phi = 0.847$ $p = 0.000$
House depth 	$\mu = 7.994$ $\sigma = 2.665$ $\phi = 0.476$ $p = 0.000$	**Relative roof height** 	$\mu = 0.892$ $\sigma = 0.308$ $\phi = 0.695$ $p = 0.000$
House area 	$\mu = 56.364$ $\sigma = 28.968$ $\phi = 0.837$ $p = 0.000$	**Roof margin length** 	$\mu = 8.489$ $\sigma = 3.209$ $\phi = 0.662$ $p = 0.000$
House aspect ratio 	$\mu = 0.935$ $\sigma = 0.327$ $\phi = 0.120$ $p = 0.060$*	**Roof apex length** 	$\mu = 7.614$ $\sigma = 3.610$ $\phi = 0.201$ $p = 0.005$

(*Continues*)

Table 2 *(Continued)*

Measurement	*Statistic*	*Measurement*	*Statistic*
House wall height 	μ = 5.959 σ = 1.638 ϕ = 0.600 $p = 0.000$	**Roof apex–margin ratio** 	μ = 0.881 σ = 0.183 ϕ = 0.567 p = *0.000*
House height 	μ = 11.123 σ = 2.889 ϕ = 0.540 $p = 0.000$		

μ = sample mean, σ = sample std. deviation, ϕ = Cramér-von Mises Index, p = p-value.
*Statistic significant at the $p = 0.05$ level.

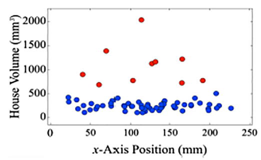
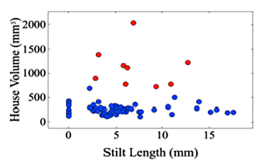
simulation's outer zone (e.g., 9, 29, 37, 47, 48), whereas somewhat unusual forms are found within its inner zone (e.g., 17, 33, 35, 38). These observations beg several questions, among them (i.) what is mean Gamma-gamma house form; (ii.) where is the mean–or typical–form actually located based on a geometric assessment of form similarities; and (iii.) whether the patterns of variation among and between the house forms located in these distinct zones exhibit continuous or disjunct patterns of variation?

With regard to the determination of the mean house form, Ford (1954a) declined to describe it but stated that it does exist and 'lies within the inner circle', (p. 47). Although the existence of a hypothetical mean is obvious, determination of its precise character represents a challenging, but not an impossible or arbitrary, task. Form represents a latent variable that combines aspects of size and shape. These concepts are difficult to separate and analyze qualitatively via visual inspection but, yield quite readily to quantitative analysis.

In our investigation house size was taken to refer to living space and quantified via estimation of house volume (see Table 1). If these were real houses distortions caused by perspective would, of course, need to be taken into consideration. However, Ford's house sketches are not real, three-dimensional objects. Thus, we have estimated house size in the only way Ford and others could have estimated it, by combining apparent house lengths, depths, and wall heights (see also SD2).

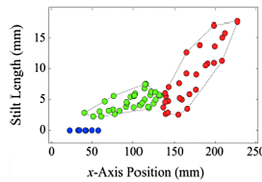
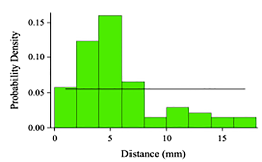
Figure 2 shows the histograms of apparent house sizes for Ford's inner and outer zones. Whereas the outer zone includes one house of anomalously large size, the ranges and forms of house size distributions in both zones are remarkably similar. This lack of obvious difference was confirmed to be nonsignificant statistically via a standard two-sample Welch test ($t = 2.537$, dof = 65, $p = 0.721$, see Welch 1938, Zar 1999).

Table 3 *Results of tests of gradient-based assertions made by Ford 1954a, Read (2005) and others with regard to Ford's Gamma-gamma house-form simulations*

Assertion	*Chart*	*Test*	*Outcome*	*Comments*
Left–right gradient in house size (Ford 1954a).		OLS regression of *x*-axis position on house volume; ANOVA.	$F = 0.10$ with dof = 1,67; $p = 0.75$	Intermediate-sized house forms occur toward the left, in the middle, and toward the right end of the *x*-axis with equal frequency whereas the largest house form occupies a centrally placed position. Application of GMM analysis indicates differences between the small (blue symbols) and intermediate + large (red symbols) house-size groups are sufficient to support recognition of a distinction between them on the basis of differences in their distributions. An ANOVA accepted the null hypothesis of no linear gradient between these variables.
Inverse association between house size and stilt length along a left–right gradient (Ford (1954a).		OLS regression of stilt length on house volume; ANOVA.	$F = 0.49$ with dof = 1,67; $p = 0.49$	Large and intermediate-sized houses are associated with small and intermediate-length stilts occur with equal frequency. Long stilts are associated with small house sizes in the upper reaches of the stilt-length range, but the lack of a pronounced negative trend in these data compromises the assertion of a simple inverse relation. A more reasonable interpretation is that these data fall into two groups: small and intermediate sized houses for which there is no trend in stilt length and small houses that are only associated with long stilts. An ANOVA accepted the null hypothesis of no linear gradient between these variables.

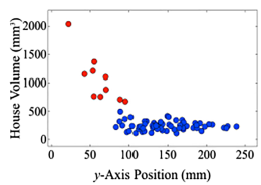
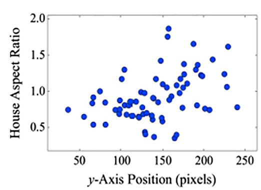
(*Continues*)

Table 3 (*Continued*)

Assertion	*Chart*	*Test*	*Outcome*	*Comments*
Left–right gradient in stilt length (Ford 1954a).		OLS regression of stilt-length vs. *x*-axis position for the two putative gradient-based groupings with test for equality of slopes.	$t = 6.719$*, dof = 56, $p = 0.05 \times 10^{-7}$	Eight houses at, or close to, the extreme eastern side of the simulation were drawn as being placed directly on the ground (blue symbols). The first houses to exhibit stilts of measurable length (2.24 mm) form the lowermost margin of a density group in which stilt length increases with left–right (E-W) location at a moderate rate (green symbols). However, the right half of Ford's diagram is populated by a density group in which the rate of stilt-length increase, and range of stilt-length variation, is much greater than that of the former group (red symbols). A *t*-test for the difference of OLS regression slopes between these two density groups rejected the null hypothesis (= no difference) at a very high confidence level, thus rejecting the interpretation of a single, smooth gradient existing within these data.
Stilt length conforms to a uniform distribution with no breaks (Read 2005).		Cramér-von Mises test of observed stilt lengths referenced to a uniform distribuition.	$\phi = 3.04$, $p = 6.15 \times 10^{-8}$	These data exhibit a pronounced left skew indicating an overabundance of houses with low and lower intermediate-length stilts. The Cramér von Mises test for conformance to expectations of a uniform distribution rejected the null hypothesis at a very high level of significance.

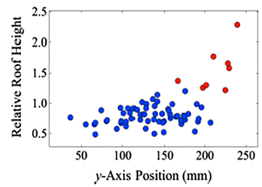
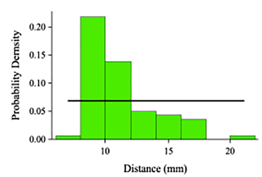
(*Continues*)

Table 3 *(Continued)*

Assertion	*Chart*	*Test*	*Outcome*	*Comments*
Top-bottom gradient in house size (Ford 1954a).		OLS regression of stilt length vs. *x*-axis position for the two putative gradient-based groupings with test for equality of slopes.	$t = 8.530$*, dof = 65; $p = 0.01 \times 10^{-12}$	The plot of house size versus *y*-axis position refutes the contention that these data reflect a smooth, linear gradient. From coordinate position 75 to 250 mm no gradient is present in house size values. Within the northernmost interval (from 0–75 mm) house sizes descend from 2000 to 500 mm^3. This trend can best be described as a series of size clusters surmounted by a single, very large outlier. GMM analysis recognized that the character of these larger sized houses located within the northern 40% of the simulation (red symbols) form a distinct group that differs from the remainder of the sample. A *t*-test for the difference between OLS regression slopes for these two density groups rejected the null hypothesis (= no difference) at a very high confidence level, thus rejecting the assertion of a smooth gradient existing within these data.
Top-bottom gradient in house shape (Ford 1954a).		OLS regression of *x*-axis position on house aspect ratio calculated from basal length and width dimensions; ANOVA.	$F = 13.5$* with dof = 1,67; $p = 0.48$.	The plot of these variables reveals a wide scatter of values. Although an ANOVA shows the slope of the linear gradient defined by these data is (marginally) significant at the $p = 0.05$ level, the value of the slope itself (0.003) is so small as to be, in effect 0.0, especially in terms of the accuracies typical of simple visual inspection. Accordingly, we reject Ford's own and other commentators' suggestions that such a gradient is obvious from a simple, visual inspection of Ford's diagram.

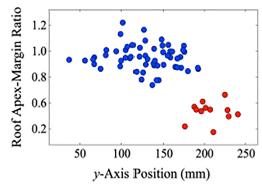
(*Continues*)

Table 3 *(Continued)*

Assertion	*Chart*	*Test*	*Outcome*	*Comments*
Top-bottom gradient in roof height relative to wall height (Read 2005).		OLS regression of stilt length vs. *x*-axis position for the two putative gradient-based groupings with test for equality of slopes.	$t = 2.828$*, dof = 65; $p = 0.003$	House forms in the upper 80% of the Gamma-gamma simulation exhibit no obvious gradient in the relative roof height. Just eight (11%) exhibit relative roof height ratios of greater than 1.25. All are located in the lower third of the illustration's vertical range and five (63%) represent the extreme southern set of house form sketches. The most reasonable interpretation of these data is that the bulk of the simulation was drawn with no regard to any top-bottom relative roof height gradient and a few, extreme, "tall roofed" forms were added to the simulation's lower (S) end. A GMM analysis (color groups) confirmed the unique character of these lower (S) relative roof height ratio values. A *t*-test for the difference between OLS regression slopes characterizing these two density groups rejected the null hypothesis (= no difference) at a very high confidence level.
House height (wall height + roof height) conforms to a uniform distribution (Read 2005).		Cramér-von Mises test of observed heights referenced to a uniform distribuition.	$\phi = 8.85$, $p = 4.14 \times 10^{-14}$	These data exhibit a pronounced left skew indicating an overabundance of houses with low heights. The Cramér-von Mises test for conformance to expectations of a uniform distribution rejected the null hypothesis (= no difference) at a very high level of significance.

(*Continues*)

Table 3 (Continued)

Assertion	Chart	Test	Outcome	Comments
Top-bottom trend in roof shape from simple gable to “pyramidal” (Ford 1954a).		Two-group *t*-test for difference between the subcluster sample means.	$t = 16.30$*, dof = 18; $p = 0.016 \times 10^{-12}$	By using the term “trend” Ford (1954a) implied the existence of a continuous pattern of variation with a non-zero slope oriented coincident with his diagram’s vertical axis. A scatterplot of the ratio in question relative to house *y*-coordinate positions shows there is abundant evidence for a profound and easily recognized disjunction in ratio values with 12 house forms (17%) representing a distinct subcluster of extreme trapezoidal roof morphologies and the remainder exhibiting simple cantilever roofs. Houses comprising the smaller subcluster are all located at the extreme lower end of the simulation’s vertical axis with 8 of its members (12.5%) occupying the southernmost positions. There is no evidence of any trend in the ratio of roof apex length vs. roof margin length in either group. A two-group *t*-test for the difference between sample means returned a highly significant result.

*Significant at $p = 0.05$.

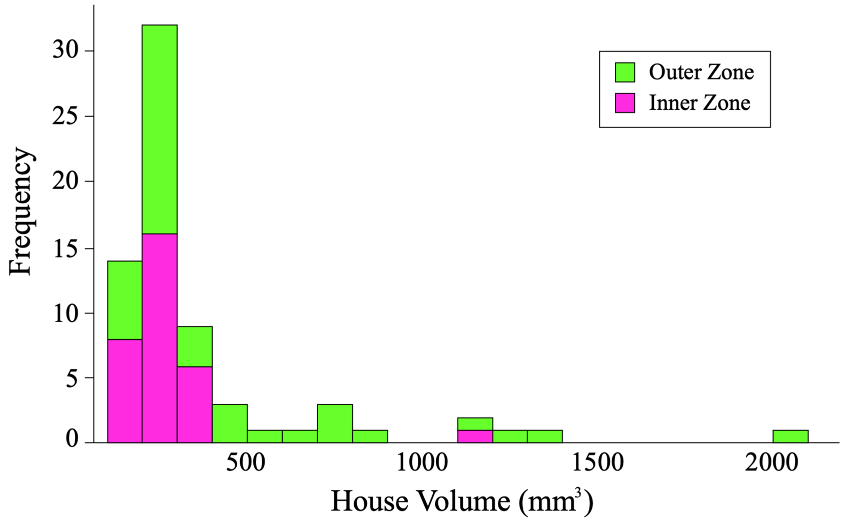


Figure 2 *Frequency histogram of apparent Gamma-gamma house volumes for Ford's inner and outer village zones (see Fig. 1)*

The mean house form might also be characterized, at least to some extent, using the subset of the 13 variables intrinsic to the house forms themselves. Mean values can be calculated for each of these variables and that set compared to the values obtained from the actual drawings to gain a sense of the realized houses to which the mean house form might be similar (see Table 1).

Inspection of these results suggests the mean house form is characterized by moderately tall stilts with a low, square living space and a moderately trapezoidal roof that was nearly as high as the house walls. Although this description conjures a crude image, details of this mean form will differ between readers because of the nonspecific nature of these textual descriptions. More importantly, this characterization of the simulation's mean house form might be objected to by some, not on the basis of what it includes, but rather on the basis of what it leaves out. What is the color of the roof of the mean house? Are the wall joins perfectly straight or irregular? How many doors and windows does the mean house exhibit? Is there a porch?

Any character-based representation of even simple morphologies will inevitably fail to capture the totality of variation displayed by any sample of house forms because some aspects of form are difficult to represent in text-based descriptions while others might not have been regarded as having been important enough to quantify at the outset of an analysis. The unavoidable difficulties that arise as a result of an artifact being represented by a small set of observations and/or measurements embody the concerns Ford and others have had concerning characterization variables that were chosen for the 'convenience' of the investigator. Because potentially important data can be left out of any measurement set, suspicion with regard to the importance or completeness of results generated by quantitative analyses of limited datasets is not irrational. Nonetheless, precisely the same criticisms can be leveled at any qualitative analysis, especially if it is difficult to describe which observations on which particular forms were responsible for which interpretations. In addition, qualitative analyses are subject to a wide range of inferential challenges that quantitative, statistical, hypothesis-testing procedures have been developed specifically to overcome.

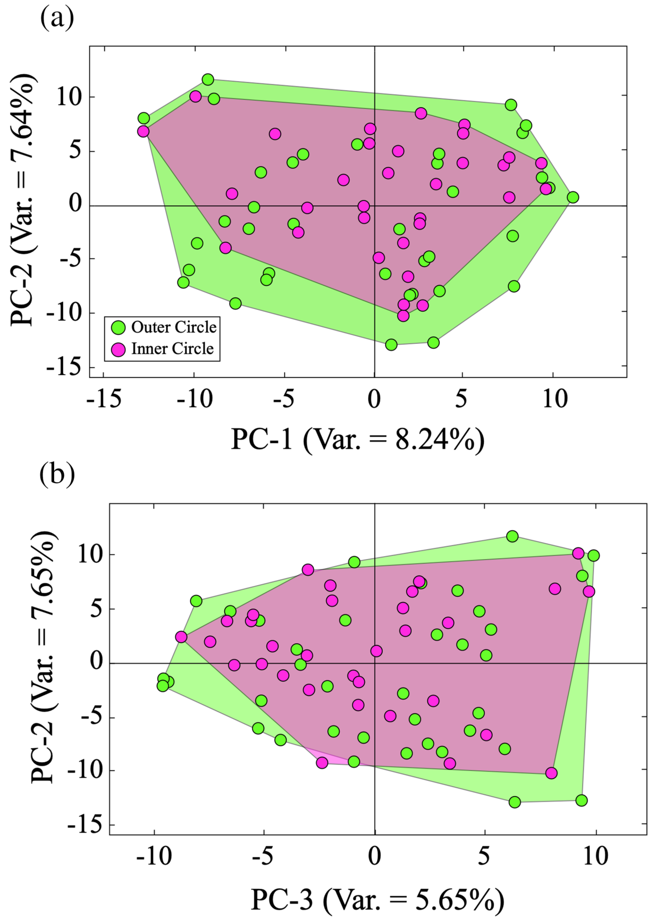


Figure 3 *Scatterplots of Ford's (1954a) house forms projected onto the first three principal components (= eigenvectors) of the image covariance matrix. Note overlapping distributions of house icons located within Ford's inner and outer circles and existence of extreme forms within the set of inner-circle houses.*

One viable alternative to the character-based assessment of archeological artifacts, and one that is particularly well-suited to the analysis both of Ford's house-form simulations and to archaeological artifacts in general, is to capture all the morphological information available in an unstructured manner, via the representation of objects as 2D digital images or 3D scans, and base exploratory quantitative analyses on these data (see MacLeod 2015, 2018; MacLeod and Steart 2015).

Figure 3 illustrates house-form ordinations within the orthogonal subspace created by the first three principal components of the pooled, orientation-corrected, image covariance matrix of Ford's house shapes (see also SD6). Shape, rather than form, was focused on in this analysis because the hypothesis that Ford's Gamma-gamma village zones exhibited significant variation in house size has already been rejected (see above). Because these data were mean centered prior to analysis, the hypothetical mean house shape is located at the origin of these plots' coordinate systems.

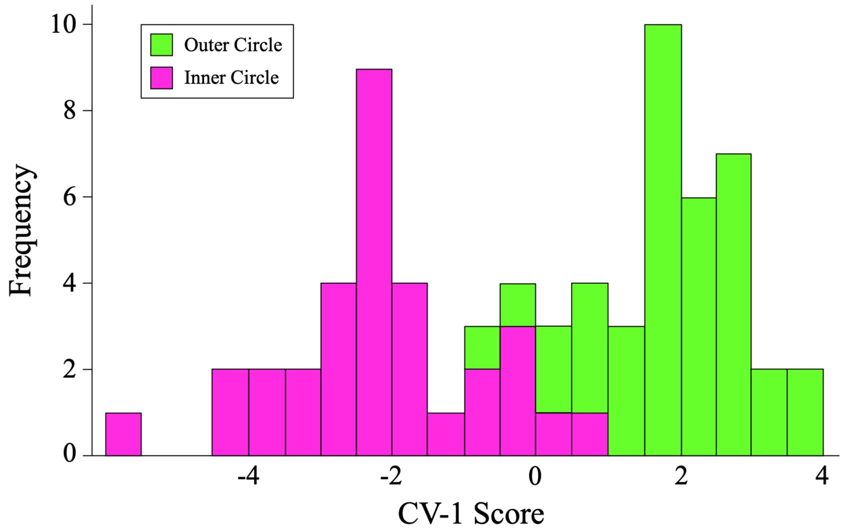


Figure 4 *Projections of Ford's (1954a) Gamma-gamma house forms on the single linear discriminant function that best separates inner-circle and outer-circle groups of house images based on a prior PCA to achieve dimensionality reduction. Note almost perfect separation between these groups based on overall form (= size & shape) distinctions.*

Table 4 *Confusion matrix for post-hoc identifications of Ford's Gamma-gamma house forms based on a linear discriminant analysis of between zone-group differences*

Groups	*Outer Circle*	*Inner Circle*	*Total Correct*	*Group Totals*	*Percent Correct*
Outer Circle	35	2	35	37	94.60
Inner Circle	3	29	29	32	90.63
Total Correct	35	29	64	69	92.75
Total Estimated	38	31	69		
Percent Estimated Correctly	92.11	93.55	92.75		

Inspection of these ordinations agrees with the qualitative impression that the Gamma-gamma simulation's outer zone contains more extreme house shapes. At the same time, there is no question that a number of extreme house forms are also located within the inner zone and that the outer zone contains many houses whose shapes are indistinguishable, at the group level, from those found in the inner zone. The fact that such a large region of overlap exists between these two house-form groups suggests strongly that distinctions among them might not be as great as the similarities between them. However, these subspace ordinations cannot be used to infer that no such distinctions exist because only three PC axes have been used in Figure 3 to represent patterns of house-shape variation that actually exist in a much higher dimensional space. Moreover, PCA operates on the pooled covariance/correlation matrix and so makes no attempt to take any group-level differences into consideration (see MacLeod 2015, 2018).

Returning to the question of locating of the mean house shape, because this location falls well within the variation fields of both Ford's inner and outer circle zones, there is no reason to suspect that the mean is characteristic only of house shapes residing in the Gamma-gamma simulation's inner zone. This is clearly contrary to Ford's (1954a) assertion regarding the zonal position of the mean house form. If all 55 principal components that account, collectively, for 95 percent of the house-form covariance structure are taken into consideration, the house whose shape is closest to the location of the hypothetical population mean is house no. 51 (see Fig. 1), which does lie within the inner zone. Nonetheless, the house whose shape lies second closest to the hypothetical mean is no. 44, which lies within the outer zone. Of the ten house shapes located closest to the hypothetical mean, four (44, 56, 37 and 22) lie within the outer zone. Of the closest 20 house forms, no fewer than nine lie within the outer zone. Because outer-zone house forms represent considerable proportions of the mean's 'nearest neighbours', we contend it would be inappropriate to conclude that there is unambiguous evidence the central tendency of these forms would be restricted to the inner zone of Gamma-gamma house forms based on form-similarity grounds alone, especially given the modest population size.

Attention should also be given to the issue of whether a morphological distinction exists between house forms in these inner and outer zones. This question is drawn from the tone of the discussions provided by both Ford (1954a) and Read (2005), neither of which state explicitly, but both of which imply, that variation in all parameters in all directions for the Gamma-gamma village diagram are continuous with uniform frequencies throughout their range. The measurement/ratio plots provided in Table 2 have already shown this not to be true for either the left–right or (especially) top–bottom directions.

As noted above, a logical case, based on qualitative inspection, can be made for the inner zone containing more 'conservative', and the outer zone more 'extreme' forms by virtue of examples residing at the ends of a continuous spectrum of house-form variabilities (see Fig. 3). Size has already been ruled out as a characteristic that can be used to discriminate between inner and outer house-form zones. But the broad region of apparent overlap in the house shape distributions does appear to suggest interzone continuity rather than difference. This perception was likely the reason previous authors and commentators regarded this simulation's pattern of variation as being continuous and so rejecting a 'type-based' interpretation to inner/outer zone distinctions. But can this assertion be tested quantitatively?

A linear discriminant analysis of the 55 image-covariance PC scores shows that houses located in the inner and outer village zones can be discriminated with almost perfect mutual exclusion (Fig. 4). Of the 69 house forms sketched by Ford, only 5 (7.2%) were allocated to erroneous zone groups based on their shape (see Table 4). Arguably, even this minor discrepancy may be overstated, arising as a result of an arbitrary point being used to locate each house's position relative the zone boundary.

Of the five house forms misallocated by this analysis, three (7, 31, 43) occur close to the inner–outer zone boundary and so would be considered 'likely' candidates for misclassification owing to Ford's use of perfect circles to define that boundary. This (somewhat arbitrary) decision certainly does not reflect the actual irregular boundary of house forms clustered in the simulation's central region. In this way, our analysis may have uncovered a minor technical error in Ford's original simulation. If Ford (1954a) had used a less-Euclidean, and more specific, irregular boundary to define the border between his village simulation's zones our analysis might have achieved an even better discriminant result. Nonetheless, a 1,000 iteration bootstrapped estimate of the T^2 probability distribution for these data confirmed the statistical significance ($p < 0.05$) of the distinction between inner and outer-zone house forms (see SD7).

DISCUSSION

Ford (1954a) set out to criticize archaeological applications of typological analysis for (i.) regarding implicitly the use of types as essentialist categories, (ii.) positioning their discovery as the starting point of analysis, and (iii.) subsequently creating hypotheses that relied on the reality of type-based groupings being accepted a priori. In these terms we regard Ford's criticisms as being absolutely correct and well made. But in abjuring the utility of typology for artifact analysis generally–as some have (mis)interpreted his work to suggest–a resolutely Pyrrhic victory was achieved; one that has not managed to be respected by many archaeological researchers on practical grounds but that, nevertheless, ran a great risk of subverting archaeological research by raising illegitimate questions about, and generally discouraging the application of, statistical approaches to data analysis. In our view, the points Ford raised in this context cannot, and should not, be used to justify any reticence or prohibition concerning the employment of descriptive, type-based categorizations. If a spatially and temporally limited sample is the only sample available, it is perfectly reasonable to advance provisional interpretations on the basis of typological results because these can be tested further if, and when, additional data become available. It is when making interpretations of quantitative results based on small and/or potentially non-representative samples that archaeologists should recall Ford's well-founded cautions and refrain from over-stating the veracity of their interpretations and/or the degree those interpretation are supported by the artifacts to hand.

Despite Ford's efforts to create what he, and others, regarded as a continuously and uniformly varying set of house forms, Ford himself introduced various levels of complex structure into his Gamma-gamma simulation. The inadvertent introduction of this structure not only worked against the points Ford was trying to make, they make precisely the opposite case, not only regarding the difficulties humans have in creating artifacts that fail to exhibit patterns that betray the signatures of their creators, but also with regard to the utility of quantitative analyses as an aide for the identification of pattern-based–or type-based–approaches to archeological investigation. Note that our analyses did not begin with a type-based classification system. Instead, as our results produced evidence of patterns consistent with type-based distinctions, provisional type categorizations were erected to the extent those served a descriptive function and could be supported empirically. These were then tested statistically to guard against confirmation bias. Moreover, both the cultural and taphonomic reasons why these patterns existed, and the generality of the distinctions themselves, remain open to subsequent analysis and testing. It is only after the repeated finding of similar patterns by independent analyses of new data, along with independent analysis of confirmatory data, that descriptive type-based categorizations can, or should, be regarded as having culture-historical significance.

By relying solely on the qualitative inspection of the Gamma-gamma village sketches, Ford and others missed much information about the structure of variational patterns that actually exist in his hypothetical, but still geometrically complex, simulation of archaeological 'artifacts' (which itself can, and should, be regarded as an archaeological research artifact). If patterns such as the ones our analysis has discovered and documented had been discovered in a set of actual artifacts from an isolated locality, there is little question they would be interpreted, correctly, as provisional, but potentially strong empirical evidence of culturally patterned behavior.

The results we have presented illustrate why archaeologists must test their data for well-structured patterns of variation rigorously and quantitatively wherever possible, rather than assuming either than such considerations are unwarranted or that simple visual inspection is adequate to this task. Further, archaeologists should take full advantage of new and emerging artificial intelligence and machine-learning techniques as these can be employed to achieve a profound increase in researchers' abilities to quantify, locate, identify, and test patterns of artifact variability (Nash and Prewitt 2016; MacLeod 2018). The sensitivity and performance of these techniques greatly supersedes the capabilities of methods employed by previous generations of archaeologists and will only get better with time.

As an interesting historical side issue, it should be appreciated that James Ford's (1954a) Gamma-gamma village simulations represents what might be one of the earliest uses of a hypothetical simulation to explore and inform the analysis of morphological variation in any natural-history context. There is much value in simulation-based approaches to the exploration of strategies by which many types of data can be accessed and analysed, especially as new data-analysis techniques and approaches are developed. Archaeology can benefit from archeologists paying more attention to this mode of investigation, especially since it was pioneered, it would seem, by one of its own.

CONCLUSIONS

Data analysis of the sorts we have advocated above constitutes a lower-range theory that is relevant to the first step of the scientific method: observation. These tools give researchers the ability to make more fine-grained observations, and to quantify and test patterns that would be missed otherwise. For this reason, we feel it would be beneficial for archaeologists to construct a new body of middle-range theory to account for our newly enhanced ability to observe archaeological patterns.

Data analysis can never be a substitute for careful reasoning by researchers with specialist knowledge and experience. It must be used to aid and support archeological reasoning by extending the powers of the human senses and perception, and by making patterns invisible to the unaided eye visible so they can be documented, identified, discussed, and interpreted. Typology is a more general approach to the investigation of nature, extending from the typologies created for the purpose of cataloguing and managing collections of archeological objects as objects, to those that reflect shared conceptual discontinuities in the mental/cultural landscapes subscribed to by the members of ancient cultures. It is this distinction to which Ford (1954a) alluded. Getting from the former to the latter is now, and always will be, a primary challenge of archeological research. Although mathematics can be of great assistance to the attainment of this goal, there is no, nor will there ever be, any easy, straightforward, and infallible way to arrive at this destination. Nevertheless, the fact that quantitative data-analysis strategies are neither simple, nor infallible, is no reason to discourage their employment in a wider range of archaeological contexts than these approaches enjoy currently. More importantly, the continuing development of new and ever more sophisticated ways of applying quantitative data-analysis procedures to the problem of identifying patterns in data derived from cultural artifacts promises to stimulate, invigorate, and perhaps to revolutionize archaeology.

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SUPPLEMENTARY DATA

All data, software code listings, images and intermediate results files are available at https://doi.org/10.5061/dryad.v6wwpzgrh and/or from the corresponding author upon request.

PEER REVIEW

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Data S1 Supporting Information

