1 **The Pueblo Decomposition Model: A Method for Quantifying Architectural Rubble to**
2 **Estimate Population Size**

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1 **Abstract**

2 While most archaeological measures of population rely on material proxies uncovered
3 through excavation (rooms, hearths, etc.), we identify a technique to estimate population at
4 unexcavated sites (the majority of the archaeological record). Our case study focuses on ancestral
5 Tewa Pueblo villages in northern New Mexico. Uninhabited aerial vehicle (UAV) and
6 instrument mapping enables us to quantify the volume of adobe architectural rubble and to
7 construct a decomposition model that estimates numbers of rooms and roofed over space. The
8 resulting metric is applied at ten Pueblo villages in the region to ‘rebuild’ architecture, and
9 calculate maximum architectural capacity and the maximum extent of population size. While our
10 focus is on population histories for large Classic period (A.D. 1350-1598) pueblos in the
11 American Southwest, the model and method may be applied to a variety of archaeological
12 contexts worldwide and is not limited to building material, site size, or construction technique.

13 **Keywords:** Population reconstruction; demographic archaeology; adobe architecture; Ancestral
14 Pueblo; American Southwest

1. Introduction

Reconstructing momentary population, or population counts per unit of time, enables researchers to address a wide range of issues that include people's responses to ecological change, the evolution of social and political complexity, the emergence of new social collectives and identities, and population movement such as migration and coalescence. Momentary population estimates therefore are critical for archaeological interpretations, and yet can be difficult to obtain. Researchers must build bridging arguments to predict *unknown* populations that existed in the past based upon *known* archaeological materials that exist in the present. Estimates may vary depending upon three general factors (Hassan 1978, 1981): 1) archaeological correlates and how these are translated into population estimates, 2) temporal chronology and control, and 3) the model that is constructed to apportion population growth or decline. This paper is concerned with the first factor – the archaeological correlates of population – and how archaeologists can estimate reasonable counts of the maximum number of people who may have lived at a site based on architectural capacity of roofed-over space. This step is essential, for if these figures are inaccurate, then no amount of chronological control or modeling finesse will correct the error.

Archaeologists worldwide have used a variety of material proxies to estimate maximum population size. These include structure, room or hearth counts (Haviland 1972; Ammerman et al. 1976; Webster and Freter 1990; Warrick 2008), roofed area (Casselberry 1974; Naroll 1962), volume of architectural rubble (Adler 1992) and artifact accumulations (Santley 1990; Varien and Ortman 2005). These proxies are converted to numbers of individuals, often through ethnographic or historical indices for per person investment in architectural space. Although such

indices are often debated, archaeological reconstructions of population size rely on the inherent strength of the archaeological measurement.

While much attention has focused on the relationship between material proxies and number of individuals, we believe that an equally important problem is how these proxies, many which are only visible through excavation, are extrapolated from unexcavated contexts. Archaeologists rarely excavate one site completely, let alone test every site in a given region. To estimate regional population, researchers calculate the numbers of known proxies (such as hearths or rooms that are revealed through per unit volume of excavation) and then apply this frequency to a similar per unit measure of unexcavated architecture such as site surface area or number of structures (Warrick 2008, Webster and Freter 1990). Consequently, even large excavation projects must be concerned with how subsurface findings are translated into measures of occupational intensity based upon surficial remains.

This paper addresses the problem by proposing a method to efficiently record observable surface architecture and to develop a model for estimating the maximum number of rooms and roofed-over area for unexcavated contexts. Our case study focuses on ten ancestral Tewa villages in the Rio Chama watershed in northern New Mexico where multi-story adobe villages have collapsed and eroded to earthen mounds, and where there has been relatively little excavation in the region compared to the vast number of sites. Uninhabited aerial vehicle (UAV) and instrument mapping technology enables us to quantify the volume of the collapsed house mounds. We then construct a decomposition model to estimate how much architectural debris is created by the collapse of a given amount of roofed-over living space (Duwe 2011). Finally, the output from the model is applied to nine other sites in the region to ‘rebuild’ pueblo architecture and quantify total roofed-over living area from the volume of rubble, creating a proxy to

1 calculate maximum architectural capacity. We anticipate future research that combines
2 additional lines of evidence such as dates for intra-site occupations and models to apportion
3 population growth for a more fully developed population history of the region

4 **2. Case study: the Rio Chama watershed and the Tewa World**

5 Archaeological data (Duwe 2011; Duwe and Anschuetz 2013; Ortman 2012) and Tewa
6 oral tradition (Ford 1993; Ortiz 1969; Parsons 1929, 1994) suggest that at least two generalized
7 populations converged in the late thirteenth and early fourteenth centuries Tewa Basin, the
8 aboriginal homeland of the Tewa Pueblos located between the modern cities of Santa Fe and
9 Taos. These include autochthonous villagers who had lived in the region for millennia and
10 migrant communities from the northern Southwest who were displaced by drought (Ortman
11 2012). Over the next one hundred years of coalescence, these populations negotiated and created
12 the society and cultural traditions recognized today as ancestral Tewa (Anschuetz and Wilshusen
13 2011; Duwe and Anschuetz 2013). Regional population models are key to understanding this
14 history (Boyer et al. 2010; Crown et al. 1996; Dean et al. 1994; Dickson 1979; Maxwell 1994;
15 Mera 1934; Orcutt 1999; Ortman 2012). Such models, while diverse in approach, share a
16 common weakness: imprecise archaeological measurements of population size at the level of the
17 site.

18 In the northern Rio Grande region and in the Southwest more broadly, archaeologists rely
19 on room counts to reconstruct population based upon estimated numbers of persons per room,
20 allowing that some rooms housed whole families while storage rooms housed no one at all
21 (Creamer 1993; Maxwell 1994; Ortman 2012). Researchers have taken two general approaches
22 to extrapolate room count estimates from collapsed adobe house mounds. The first and more

1 traditional approach is to estimate subjectively the number of rooms based on previous
2 excavation at analogous sites. The second is to measure the area of the mound and extrapolate
3 room counts based on knowledge about the spatial extent of a room from either the site itself or
4 comparable ancestral villages (Fallon and Wening 1987; Maxwell 1994; Ortman 2014; Wendorf
5 1953). The latter method provides an empirical basis for the estimate but can remain subjective
6 when used to calculate room counts from multi-storied structures. For example, Ortman (2014)
7 used mound height at Cuyumungue to determine if architecture was one or two stories tall, and
8 then adjusted his estimates to account for upper story rooms. Yet mound height may be difficult
9 to discern in many cases due to local factors such as vegetation, slope and soil composition that
10 contribute to different erosional processes and hence different room story estimates.

11 We propose an alternative method that relies on mound volume (rather than area or
12 height) to estimate room counts and living area. This three-dimensional approach incorporates
13 quantifiable data for more precise and objective estimations of the areal extent of rooms and also
14 their height. Specifically, we use UAV and total station equipment to calculate the volume of
15 house mounds at ten ancestral Tewa sites in the Rio Chama watershed (Figure 1). We use this
16 high-resolution data to create a model to extrapolate room counts and living area from the
17 measured house mound volume and estimate maximum population size at each site.

18 The ancestral Tewa villages of the Rio Chama watershed were occupied in the Rio
19 Grande Classic period (A.D. 1350-1598) and consist of some of the largest prehispanic sites in
20 the American Southwest. As a consequence of a century of population coalescence, these sites
21 represent the places where disparate people came together to forge a new identity and society.
22 The population history of ancestral Tewa villages in the Chama therefore is critical to our

understanding of Tewa origins and social persistence. Yet, before we can begin to explore these estimates we have to understand what a pueblo is comprised of, and why and how it decomposes.

3. The life of a pueblo

Architecture, like all material culture, can be viewed as having a life of sorts (Appadurai 1986). This includes a building's birth (construction), use, and eventual demise. To visualize this life history Figure 2 illustrates both occupied and maintained pueblo architecture (from modern Taos Pueblo) and how similar structures decompose after four centuries of collapse, deflation, and erosion. While some material is certainly lost, we assume that when a pueblo collapses the majority of its constituent parts (such as walls, floors, and roofs) will remain in a reconfigured, mounded state.

The principle element of Pueblo architecture is the room, used primarily for residence and storage. Rooms are organized into contiguous, sometimes stacked clusters or roomblocks that maintain shared walls, floors, and roofs. In northern New Mexico these architectural elements are built primarily with earth, stone, and wood. Walls are constructed using 'coursed adobe,' in which local clay is mixed with water and applied in layers as the wall is built upwards (Creamer 1993:16; Jeançon 1923:9; Wendorf 1953:36). Wall interiors often display one or more layers of plaster (Stubbs and Stallings 1953:29). Vigas, or logs of local timber, serve as the main support members for the roof. The vigas are overlaid with latillas (poles of a smaller diameter), placed at right angles to the vigas, and finally covered with a layer of thatching and dry adobe (Creamer 1993:20). Floors are nearly always comprised of a layer of compacted adobe and are sometimes finished with stone or clay slurry (Jeançon 1923:14; Wendorf 1953:43).

1 While the Pueblos hold claim to some of the oldest continually occupied villages in the
2 United States, the use life of an individual structure can be surprisingly short. Elements in the
3 environment serve to weather earthen walls and roofs through wind, freeze and thaw cycles,
4 precipitation, the absorption of groundwater, and insect infestations (Goodman-Elgar 2008;
5 Schiffer et al. 1987). These processes can be held at bay with regular maintenance and repair
6 (Cameron 1999a:29), but when people no longer inhabit a house, and the architecture is not
7 maintained, roofs and walls quickly collapse. This has the effect of removing structural height
8 and internal spaces, effectively compacting the structure with some initial loss of material due to
9 other taphonomic processes. The resulting mound of adobe is formed through further erosion and
10 redeposition.

11 Although we cannot directly account for the loss of adobe fill due to natural processes,
12 we argue that each of the 10 sites in our analysis share similar construction techniques and
13 environmental conditions driving erosion and redeposition. Therefore, while loss of materials is
14 negligible, it is also likely proportional among the sites, making site comparisons appropriate. If
15 we assume that the majority of adobe used to build an ancestral Tewa village is still present at a
16 site, albeit in a melted and collapsed form, then volume measurements of these house mounds
17 should enable us to extrapolate the number of rooms and roofed-over living space at each site.

18 **4. Calculating architectural rubble volume**

19 To quantify the volume of architectural rubble we produced three-dimensional
20 topographic models for each adobe house mound at the ten selected sites and calculated the total
21 volume of adobe in each site. Two methods were employed to create these models: low-altitude
22 aerial photography using a UAV and survey instrument mapping with a total station (Table 1).

1 The two methods were selected to map different sites based upon the availability of pre-existing
2 map data, labor, time, site-visibility, and site accessibility. Subsequent volume figures were
3 calculated using ArcGIS and Global Mapper.

4 *4.1. Volumetric data and instrument mapping*

5 The creation of a topographic surface map of large ancestral Tewa sites using a total
6 station required many points to capture changes in elevation across the site. Six sites were
7 previously mapped with a total station: Howidi'owingeh, Ku'owingeh, Ponshipa'akedi'owingeh,
8 Hupovi'owingeh, Posi'owingeh, and Tsama'owingeh (Duwe 2011). Pesede'owingeh was also
9 mapped with a total station (as opposed to the UAV) because heavy vegetation covered the site,
10 making it difficult to see from the air. Mapping was performed using a Leica TC 307 Total
11 Station that is accurate to approximately 3 mm in favorable conditions. In most cases one or two
12 arbitrary datums were established at the highest point on the landscape. A Trimble GeoExplorer
13 2008 Series GeoXH GPS was used to record the UTM coordinates of these datums and all points
14 shot with the total station were georeferenced into a fixed, global coordinate system (NAD 83).
15 Each site was gridded into 5 x 10 meter units and points were taken at the corner of each unit.
16 We also recorded points across architectural features, providing an average of 1,000-3,000 points
17 per site devoted to capturing subtle relief. A digital elevation model (DEM) was constructed in
18 ArcGIS 10.2 based on the resulting three-dimensional point cloud.

19 *4.2. Collecting volumetric data with a UAV*

20 Low-altitude aerial photography is an emerging technology in archaeological research
21 that serves as a rapid and relatively inexpensive technique for the large-scale mapping and spatial

analysis of archaeological sites (e.g., Casana et al. 2014; Graves and Willis 2011, Liebmann et al. 2013; Lin et al. 2011; Verhoeven 2009)¹. Using this method we mapped three sites with no existing topographic data (Te'ewi'owingeh, Poshu'owingeh, and Sapa'owingeh) and three others (Howidi'owingeh, Hupovi'owingeh, and Ponshipa'akedi'owingeh) to compare the data produced by the total station and UAV. We used a Swinglet Cam UAV outfitted with a Canon IXUS 220HS 12-megapixel digital camera to capture high-resolution photographs of each site. Multiple overlapping flyovers at different elevations were conducted. Twelve control points marked with aerial photo targets established spatial controls across each site prior to flight. After the flyovers were completed, a Sokkia Radian IS RTK unit was used to establish the precise UTM locations of 12 targets. These coordinates served to geo-rectify the digital images, establishing the precise location of the imagery to within 10 cm under optimal conditions. The resulting output was processed using Structure from Motion software to derive a three-dimensional polygonal mesh of the ground surface. The software ortho-rectified the series of images to establish a uniform scale, remove any distortion, and produce digital ortho-photos and a DEM (Figure 3).

4.3. Calculating adobe house mound volume

To calculate the volume of the adobe house mounds in cubic meters (m³) at each of the ten ancestral Tewa sites, we created a model of the natural ground surface, representing how the topography of the site would appear without architectural rubble. We then 'subtracted' this model from the original DEM (which include the volume of architectural house mounds), resulting in volume figures for each mound.

¹ Federal Aviation Administration and National Environmental Policy Act regulations must be strictly adhered to prior to any implementation of UAV research on Federal (in this case Bureau of Land Management and National Forest) land.

In order to construct a model of the natural ground surface we measured the ground elevation immediately surrounding each house mound (based on the spatial extent of the mound) and substituted these elevations for the original elevation within the mound boundaries. The extent of the mounds was determined from previous detailed instrument mapping (Duwe 2011). At sites with no previous survey mapping (Te'ewi'owingeh, Poshu'owingeh, and Sapa'owingeh), the extent of the adobe mounds were drawn based on the three-dimensional surface model produced by the DEM. We then created a DEM of the estimated natural ground surface using these modified three-dimensional points. Using ArcGIS we clipped the original DEM (of the site surface including the mounded relief) based on the extent of each mound. The Measure Volume Between Surfaces tool in Global Mapper was used to subtract the estimated natural ground surface model from each of these newly clipped mound models. This method provided the volume of collapsed adobe for each house mound within a site. The total reconstructed volumes of surveyed sites are listed in Table 5.

4.4. Comparison of techniques

Although the method used to calculate mound volume is identical across all ten sites, we employed two methods to produce three-dimensional point clouds and the resulting DEMs: low-altitude aerial photography and survey instrument mapping. To ensure that these data were accurate, we compared volume estimates of a single long linear mound from each of three sites that were mapped by both methods: Howidi'owingeh, Ponshipa'akedi'owingeh, and Hupovi'owingeh. These particular areas were chosen because of their relatively straightforward mound extent (as opposed to more complex rectangular roomblocks with open central plazas). Table 2 presents the measurements and descriptive statistics for individual room blocks obtained

by each technique. A two-tailed student's t-test for independent means demonstrates no significant differences at the .01 level in the mean values of mound volume estimates generated by the total station and by the UAV ($t = 0.0474$, $df = 4$, $p = .9645$). The two methods produce remarkably close results and neither appears to over or underestimate volume based on the comparison.

5. The pueblo decomposition model

The previous step calculated the volume of adobe architectural rubble in each collapsed roomblock for the ten ancestral Tewa sites. Of course, at one time the adobe in the house mounds was reconfigured quite differently, comprising the walls, the floors, and the roofs of pueblo architecture. To extrapolate the number of rooms originally present at each site we needed to calculate the average amount of fill per room that would be created through melting and collapse and then divide this value into the measured mound volume. To determine this 'fill per room' figure we built a pueblo decomposition model that incorporates known information about a representative site (the number of ground-floor rooms, wall length, and floor and roof area) to calculate a hypothetical total number of rooms. The total number of rooms are then divided into the measured volume to produce an average 'fill per room' figure across the site.

The decomposition model requires both architectural data and mound volumes from the same site. Ideally, this could be achieved by recording the three dimensional topography of the site (and measuring mound volume) prior to excavation, where room counts, wall length, and floor/roof area could be measured and calculated. However, this information was not available and instead we devised an alternative way to gather this architectural data at the site of Ponshipa'akedi'owingeh.

1 In July 2012 recent monsoonal rains at Ponshipa'akedi'owingeh encouraged the growth
2 of extensive stands of Russian knapweed (*Rhaponticum repens*) that exposed the tops of adobe
3 roomblock walls on six of the site's seven house mounds, resulting in highly visible room
4 outlines (Figure 4). This afforded us the opportunity to map the architectural corners of
5 numerous walls with a total station. We georeferenced the points to the site's datum and entered
6 these data into ArcGIS where we drew known walls and clearly demarcated 490 rooms. Based
7 on our knowledge of the dimensions and orientations of these rooms, as well as the extent of the
8 mounded adobe, we inferred the location of hypothetical walls and counted an additional 604
9 rooms. We estimate a total of 1,094 surface rooms at Ponshipa'akedi'owingeh (Figure 5, Table
10 3). Using these data we then calculated the total wall lengths and floor/roof area for each house
11 mound.

12 With this information, in addition to the mound volume measured by the UAV, it was
13 possible to build a decomposition model to estimate the total number of surface and multi-story
14 rooms at Ponshipa'akedi'owingeh and calculate the average value of adobe volume per room.
15 This room volume was applied to the other nine remaining Classic period Pueblo sites in the Rio
16 Chama watershed to estimate total room counts. The following sections detail each step of the
17 process.

18 5.1. One-story volume estimates

19 Through our mapping of the architecture at Ponshipa'akedi'owingeh we propose that
20 there were a *minimum* of 1,094 rooms represented by the volume of the adobe house mounds
21 (Step 1 of Table 5). To estimate the volume that this known number of rooms produced, we built
22 a decomposition model that combines both the information recorded in site mapping (length of
23 walls, area of floor/roofs) with assumed values from published reports of regional pueblo

architecture (Table 4). The model calculates the total volume of adobe required to build one-story of rooms based on the volume of walls, roofs, and floors. This is achieved by calculating the wall volume, roof volume, and floor volume for each house mound using available data from Ponshipa'akedi'owingeh (total wall length and floor/roofed area, Step 2 of Table 5) and assumptions regarding architectural practices from excavated sites in the region (Figure 6). These individual calculations (Step 3 of Table 5) were then summed to produce a hypothetical one-story volume estimate for each house mound (Step 4 of Table 5). We purposely calculated floor space for the entire roofed area (including walls), even though there are typically no floors under walls. This was to account for wall foundations that are comprised of stone cobbles of approximately the same depth (Jeançon 1923; Wendorf 1953).

5.2. *Coefficient of unaccounted rooms and total rooms*

The previous step calculated the hypothetical volume of fill for each house mound at Ponshipa'akedi'owingeh assuming the site was one-story tall. Of course, archaeologists believe that many ancestral Tewa villages contained multi-story roomblocks, including the excavators at Ponshipa'akedi'owingeh (Bugé 1978, 1979). To understand which roomblocks may have had multiple stories and additional rooms we divided the observed volume of adobe (measured by the UAV) by the one-story hypothetical volume calculated in section 5.1 (Step 5 of Table 5). This produced a coefficient of how much adobe fill is unaccounted for by the decomposition model.

For example, Roomblocks 1, 3, and 5 all have a coefficient of 1.1. This means that there is nearly a one-to-one relationship between the hypothetical one-story volume and the observed mound volume, suggesting that these were one-story structures. Conversely, Roomblock 4 has a coefficient of 2.0, suggesting that there is twice as much observed mounded adobe than predicted

by the decomposition model for a hypothetical one-story volume. This roomblock likely contains double its ground-floor rooms. The number of stories in each roomblock is still difficult to determine, but it is possible to differentiate between a single and multi-story structure using this technique.

To calculate the total estimated number of rooms in each roomblock of Ponshipa'akedi'owingeh (both ground floor and upper story) we multiplied this coefficient by the total number of ground-floor rooms determined through wall mapping. This provided an estimate of the total number of rooms represented by the adobe mound (Step 6 of Table 5).

5.3. Average volume of adobe fill per room

To determine the average volume of adobe fill per room we divided the observed volume of adobe fill (measured by the UAV) by the total number of rooms calculated in section 5.2 for each house mound. This provided us with an average volume index of fill/room (Step 7 of Table 5). We averaged this figure across the six roomblocks and calculated an average adobe volume/room index of 9.68 m^3 (Step 8 of Table 5). This is a somewhat generalized figure because rooms share walls, but it nonetheless provides a more precise estimate of room counts based on adobe mound volume for the other nine Classic period sites.

5.4 Applying the model to other ancestral Tewa sites

Based on excavation data (Bugé 1978, 1979; Fallon and Wening 1987; Jeançon 1923; Wendorf 1953) construction technique, architectural layout, and room function appear to be similar between Classic period ancestral Tewa sites in the Rio Chama watershed. Therefore we found it reasonable to apply the averaged adobe volume/room index from

Ponshipa'akedi'owingeh to contemporaneous sites in the Rio Chama watershed. To estimate room counts at the nine other sites we simply divided the volume/room index of 9.68 m^3 into the observed adobe fill volume of the house mound at each site and rounded these values to the nearest whole room number (Table 6). This approach was somewhat modified at Ponshipa'akedi'owingeh where only Roomblock 7 was calculated this way (the other roomblocks were calculated in the model) and Howidi'owingeh where only half the site was analyzed (room counts from the excavated eastern portion were added from the site report; Fallon and Wening 1987).

Our calculations were similar to earlier estimates by field archaeologists with some noticeable differences (Table 6), including Maxwell's (1988) estimate of low room counts at Posi'owingeh. We believe this discrepancy stems from Maxwell's use of mound area and our examination of mound volume. Posi'owingeh has the highest house mounds among sites in the Rio Chama watershed (Duwe 2011), and by not accounting for the additional multi-story rooms Maxwell's estimates were considerably less than ours. We believe that this demonstrates the applicability of our model to estimate multiple stories and additional rooms.

6. Estimation of maximum architectural capacity

Once room counts were calculated, we could convert this measurement to estimated numbers of individuals. While room counts are often used in Southwest archaeology as a proxy for population, we follow a number of researchers in estimating population based on roofed-over space (Naroll 1962). To convert room counts to roofed-over space we multiplied the average size of rooms at comparable regional sites by the number of rooms (Table 7). Published statistics for room area vary widely from $4.8\text{-}12.7 \text{ m}^2$ at Te'ewi'owingeh (Wendorf 1953) to $4.3\text{-}11.5 \text{ m}^2$ at

Poshu'owingeh (Jeançon 1923). We used the most recent excavation data available for the Rio Chama watershed, the site of Howidi'owingeh (Fallon and Wening 1987), which reported an average roofed-over living space of 9.76 m².

To convert roofed-over space to numbers of individuals it was necessary to divide the figures for the roofed-over space by a constant (the area of roofed-over area per person, Table 7). Population estimates are arrived at by dividing the total roofed over space in square meters by one of four constants for per-capita investment in architecture: 3 m² (Clarke 1971), 5.3 m² (Hill 1970), 6 m² (Casselberry 1970), and 10 m² (Naroll 1962).² Researchers working in the Chama Valley have used calculations that assume a 5.3 m² to 6 m² living requirement per individual (see for example Anschuetz 1998; Maxwell 1994), or they assume one person per room if average room sizes are in the range of four to ten meters squared in areal extent (Duwe 2011; Ortman 2012). These constants yield estimates of between 12,975 and 43,250 people living in the large Classic period villages of the Rio Chama watershed (if 100 percent occupancy is assumed, see Table 7). We feel most comfortable with the conservative estimate of 10 m² per person occupancy (12,975 people), based upon the availability of agricultural land for food production and regional environmental productivity (Anschuetz 1998, 2007).

² Casselberry (1974) uses worldwide ethnographic data to suggest a ratio of 1 person per 6 m² of floor space for groups living in multifamily dwellings. Clark (1971) and Hill (1970) offer ratios of 1 person per 3 m² and 1 person per 5.3 m² of floor space, respectively, based on their reviews of ethnohistorical Pueblo architecture and population. Naroll (1962), who includes single-family households, offers the most conservative estimate of 1 person per 10 m² of floor area. As Maxwell (1988:9-10) recognizes, even though ethnographic data identify a positive relationship between dwelling size and the number of its residents, decisions governing building size are the products of many other factors as well. Such conditioning variables include co-residential group organization, household activity regimes, volume of storage space, practical engineering parameters imposed by construction materials and architectural design, and status of principal household members within their communities.

7. Discussion and Conclusion

The resulting estimates of population represent the maximum architectural capacities for ancestral Tewa villages (and the watershed as a whole) if these villages were completely occupied at 100 percent capacity. However, this approach ignores the processes of accretional site growth (and decline) for large and long-occupied villages. Archaeologists acknowledge that a site need not be occupied fully throughout its entire use life (Shacht 1984). Case studies in the Pueblo Southwest illustrate that a village can grow gradually (Riggs 2001) and can be occupied sparsely for long periods of time (Creamer 1996). Over the course of time, pueblo rooms are constantly remodeled and their function changes, from habitation, to storage, to fill (Cameron 1999; Crown 1991). Therefore, while our maximum architectural capacity figures provide an upper limit to how many people may have lived in the Rio Chama watershed, our model only accounts for the first (but critical) step in estimating momentary population histories. We anticipate future research that combines additional lines of evidence such as dates for intra-site occupations and models to apportion population growth for a more fully developed population history of the region. Such estimates also may be evaluated against calculations of built agricultural space and the energetic requirements of farming to determine the maximum number of people that the land could sustain.

Our model demonstrates that a three-dimensional approach to extrapolate room counts and living area provides Southwestern archaeologists a precise, objective, and consistent tool for estimating the maximum architectural capacity of an ancestral Pueblo village. We argue that the analysis of adobe volume is the best way to encompass the variability inherent in long-lived, multi-story sites. While we do not address how population growth and decline is apportioned, the construction of momentary population estimates still rely on accurate archaeological correlates

1 of maximum site population in order to address questions of anthropological concern. This is
2 illustrated at the site of Posi'owingeh where our calculation increased the total number of site
3 rooms by a factor of 2.2 over previous area-based estimates (Table 6). In Tewa oral tradition
4 Posi'owingeh was the location of a pivotal historical event: the coming together of disparate
5 peoples that dramatically transformed social and ceremonial organization for the entire Tewa
6 world (Ortiz 1969:16). As the second largest site in the Rio Chama watershed, our revised
7 figures appear to agree with Tewa tradition and suggest that Posi'owingeh may have been a
8 primary place of population coalescence. This finding has a substantial impact on our
9 understanding of the development of Tewa society, but would have gone undetected without
10 good measures for room counts and living area from the site's massive adobe mounds.

11 This research addresses larger concerns in archaeology as well. The material proxies of
12 population remain the primary and most crucial element in establishing momentary population.
13 Moreover all archaeologists, even those running larger excavation-based projects, should be
14 concerned with surficial archaeology as they extrapolate measurements of population to
15 unexcavated portions of sites. Besides being non-destructive and cost-effective, the use of
16 sophisticated, but readily available, methods such as surface mapping through ground-based and
17 aerial techniques can significantly improve the quantification of unexcavated space making
18 extrapolations more accurate. Such methods for quantifying rubble volume and estimating
19 roofed-over space can be adapted easily to archaeological contexts worldwide, and are not
20 limited to building material, site size, or construction technique.

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Figure Captions

Figure 1. Map of Classic period sites in the Rio Chama watershed examined in this study.

Figure 2. A) The multi-story adobe architecture of modern Taos Pueblo, and B) the collapsed adobe house mounds of Hupovi'owingeh.

Figure 3. An aerial image mosaic collected by the UAV overlaid with contours from the resulting DEM from the site of Ponshipa'akedi'owingeh (LA 297).

Figure 4. Defined walls of Ponshipa'akedi'owingeh (LA 297).

Figure 5. Wall outlines, mound extent, and calculated room counts for each roomblock at Ponshipa'akedi'owingeh (LA 297).

Figure 6. Architectural assumptions used in the roomblock decomposition model and formulas used to calculate hypothetical one-story roomblock volume (base drawing from Riggs 2001, Figure 3.3).

Site Name	Site (LA)	Dates of Occupation	Reference	Cartographic Method
Howidi'owingeh	71	A.D. 1377-1537	Duwe 2011	UAV/Total station
Te'ewi'owingeh	252	A.D. 1365-1600	Duwe 2011; Wendorf 1953	UAV
Ku'owingeh	253	A.D. 1366-1500	Duwe 2011	Total station
Poshu'owingeh	274	A.D. 1375-1500	Beal 1987; Jeancon 1923	UAV
Ponshipa'akedi'owingeh	297	A.D. 1312-1550	Duwe 2011	UAV/Total station
Pesede'owingeh	299	A.D. 1365-1600	Eiselt et al. 2013	Total station
Sapa'owingeh	306	A.D. 1385-1526	Eiselt et al. 2013	UAV
Hupovi'owingeh	380	A.D. 1363-1550	Duwe 2011	UAV/Total station
Posi'owingeh	632	A.D. 1344-1500	Duwe 2011	Total station
Tsama'owingeh II	908	A.D. 1324-1550	Duwe 2011; Ortman 2012	Total station
Tsama'owingeh I	909	A.D. 1251-1500	Duwe 2011; Ortman 2012; Windes and McKenna 2006	Total station

Table 1. Ancestral Tewa villages in the Rio Chama watershed examined in this project. Occupation dates were derived from a combination of dendrochronological and ceramic mean dating.

LA #	Site	Roomblock	Total Station	UAV
71	Howiri'uinge	RB 2	2141.8	1973
297	Ponshipa'akedi	RB 5	2502.5	2746
380	Hupovi'uinge	RB	1564.1	1559.3
	Mean		2069.5	2092.8
	Standard Deviation		473.4	602.3

Table 2. Comparison of volume estimates (m^3) between the methods of survey instrument mapping (total station) and low-altitude aerial photography (UAV) from large linear roomblocks at Howidi'uinge, Ponshipa'akedi'owingeh, and Hupovi'uinge.

	Roomblock						Total (n=1,094)
	1 (n=63)	2 (n=216)	3 (n=182)	4 (n=105)	5 (n=274)	6 (n=254)	
Length	4.96 (0.61)	4.27 (0.74)	3.72 (1)	3.31 (0.59)	4.06 (0.96)	4.39 (1.08)	4.1 (0.99)
Width	2.09 (0.31)	2.43 (0.36)	2.49 (0.44)	2.49 (0.33)	2.46 (0.43)	2.47 (0.43)	2.44 (0.41)
Area	9.73 (2.02)	9.61 (2.36)	8.5 (3.12)	7.51 (1.95)	9.15 (2.94)	9.87 (3.04)	9.18 (2.85)

Table 3. Mean (and standard deviation) in meters of the length, width, and area of rooms from six roomblocks at Ponshipa'akedi'owingeh (LA 297).

Features	Value	Reference
Wall width	0.32 m	Average from LA 71 (Fallon and Wening 1987), LA 252 (Wendorf 1953), and LA 908 (Greenlee 1933).
Wall height	2.60 m	Average viga height at Arroyo Hondo (Creamer 1993) and Pindi Pueblo (Stubbs and Stallings 1953), plus estimated roof coping (0.30 m, Mindeleff 1891:151).
Roof thickness	0.30 m	Range of 21-31 cm at Arroyo Hondo (Creamer 1993); estimated on higher end due to larger values across the Southwest (0.55 m; Riggs 2001:95).
Floor thickness	0.10 m	Average range of 3-10 cm at Arroyo Hondo (Creamer 1993) and LA 71 (Wendorf 1953). Fill was used to prepare floor leading to higher estimate.

Table 4. Data from excavated pueblo sites in northern New Mexico used to establish assumed values in the decomposition model.

Step	Section described	Value	RB 1	RB 2	RB 3	RB 4	RB 5	RB 6
1	5.0	Ground floor rooms	63	216	182	105	274	254
2	5.1	Wall length (m)	526.1	1616.7	1224.9	664.4	1925.9	1887.1
2	5.1	Roofed area (m2)	608.6	2114.0	1585.9	791.7	2561.0	2546.4
3	5.1	Wall volume (m3)	437.7	1345.1	1019.1	552.8	1602.4	1570.1
3	5.1	Roof volume (m3)	182.6	634.2	475.8	237.5	768.3	763.9
3	5.1	Floor volume (m3)	60.9	211.4	158.6	79.2	256.1	254.6
4	5.1	Total hypothetical volume (m3)	681.1	2190.7	1653.5	869.4	2626.8	2588.6
	4.3	Measured mound volume (m3)	726	3,195	1,791	1,736	2,746	4,375
5	5.2	Coefficient of unaccounted rooms	1.1	1.5	1.1	2.0	1.1	1.7
6	5.2	Total rooms	67	315	197	210	286	429
7	5.3	Volume/room index	10.8	10.1	9.1	8.3	9.6	10.2
8	5.3	Average volume/room index	9.68					

Table 5. Data from Ponshipa'akedi'owingeh (LA 297) used to create the average volume of adobe fill/room metric.

LA #	Site Name	Volume (m ³)	Rooms	Previous Room Estimates
71	Howdi'owingeh	12,528.8*	1,428	1,671 (Fallon and Wening 1987)
252	Te'ewi'owingeh	8633	892	600 (Wendorf 1953)
253	Ku'owingeh	5,042.1	521	554 (Maxwell 1988)
274	Poshu'owingeh	10,783	1,114	1,214 (Maxwell 1988)
297	Ponshipa'akedi'	264.2*	1,535	1,507 (Maxwell 1988)
299	Pesede'owingeh	5,741.3	593	375 (Maxwell 1988)
306	Sapa'owingeh	54,599	2,541	2,561 (Maxwell 1988)
380	Hupovi'owingeh	9,175.4	948	1,074 (Maxwell 1988)
632	Posi'owingeh	21,348.1	2,204	1,024 (Maxwell 1988)
908	Tsama'owingeh II	12,873.1	1,330	1,176 (Maxwell 1988)
909	Tsama'owingeh I	1,822.4	188	120 (Windes and McKenna 2006)
TOTAL			13,294	11,876

Table 6. Comparison of total mound volume for each site, room counts, and previous project's room count estimates. *Volume does not represent entire site.

LA #	Site Name	Rooms	Roofed-over area (m ²)	Estimated architectural capacity			
				3 m ² (Clark 1971)	5.3 m ² (Hill 1970)	6 m ² (Casselberry 1970)	10 m ² (Naroll 1962)
71	Howdi'owingeh	1,428	13,937	4,646	2,630	2,323	1,394
252	Te'ewi'owingeh	892	8,706	2,902	1,643	1,451	871
253	Ku'owingeh	521	5,085	1,695	959	847	508
274	Poshu'owingeh	1,114	10,873	3,624	2,051	1,812	1,087
297	Ponshipa'akedi'	1,535	14,982	4,994	2,827	2,497	1,498
299	Pesede'owingeh	593	5,788	1,929	1,092	965	579
306	Sapa'owingeh	2,541	24,800	8,267	4,679	4,133	2,480
380	Hupovi'owingeh	948	9,252	3,084	1,746	1,542	925
632	Posi'owingeh	2,204	21,511	7,170	4,059	3,585	2,151
908	Tsama'owingeh II	1,330	12,981	4,327	2,449	2,163	1,298
909	Tsama'owingeh I	188	1,835	612	346	306	183
TOTAL		13,294	129,749	43,250	24,481	21,625	12,975

Table 7. Comparison of rooms, roofed-over area, and maximum architectural capacity estimates using multiple living area/person constants in the Rio Chama watershed.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Ponshipa'akedi'owinge
LA 297
Data Used for Room Estimates

True North

- = Wall
- = Hypothetical wall
- = Mound (volume)
- = Kiva

Figure 6

Wall volume = 2.6 m (est. wall height) x 0.32 m (est. wall width) x Total wall length (m)

Roof volume = 0.3 m (est. roof depth) x Total roofed area (m²)

Floor volume = 0.1 m (est. floor depth) x Total roofed area (m²)

Wall volume + Roof volume + Floor volume = Total hypothetical volume (one-story)

Wall volume = 2.6 m (est. wall height) x 0.32 m (est. wall width) x Total wall length (m)

Roof volume = 0.3 m (est. roof depth) x Total roofed area (m²)

Floor volume = 0.1 m (est. floor depth) x Total roofed area (m²)

Wall volume + Roof volume + Floor volume = Total hypothetical volume (one-story)