DIMENSIONING AT THE EPICLASSIC SITE OF CACAXTLA, TLAXCALA, MEXICO: AN EXPRESSION OF PAN-MESOAMERICAN COMPLEX THINKING

Geneviève Lucet

This article discusses the measurement system used at Cacaxtla, Tlaxcala, Mexico. It addresses the ideological concepts this system may have expressed, its relationship to other systems used in Mesoamerica, and its implications for evaluating the hypothesis of a Maya presence at Cacaxtla during the Epiclassic. Measurements used at Cacaxtla combine the practical needs of builders with symbolic expression reflected in architecture. Two moduli served as the basis for the dimensioning: the unit of .488 m and its triple, 1.465 m. This measurement was in turn multiplied by 3, 4, 9, and 12 to obtain the lengths of the main spaces, which served as the basis for the dimensioning system used during different phases of construction. In specific places, three anthropometric measures were used. Additionally, the spatial distribution of pillars according to their sizes confirms the coexistence of two zones within the site that express a duality also present in mural paintings. The moduli and units used at Cacaxtla agree to a considerable degree with those identified for the Maya area and, in some cases, with Teotihuacan and the Nahua culture. I hypothesize that this system was shared by several Mesoamerican cultures and lasted from the Classic to the Postclassic periods.

Este artículo discute el sistema de medición utilizado en la arquitectura de Cacaxtla, cómo se relaciona con el contexto mesoamericano, la información que proporciona sobre la presencia de grupos mayas en el altiplano durante el periodo epiclásico, el pensamiento expresado a través de las medidas de los edificios y la lógica seguida por los constructores para aplicarlas. Las mediciones utilizadas en el sitio epiclásico de Cacaxtla combinan la forma de trabajar de los constructores en el terreno con expresiones simbólicas que se plasman en la arquitectura. Dos módulos constructivos fueron empleados para el dimensionamiento: .488 m y su triple, 1.465 m, el cual a su vez fue multiplicado por 3, 4, 9 y 12 para definir la longitud de los espacios principales. Estos sirvieron para definir el sistema de medidas de las estructuras utilizado durante las distintas fases constructivas del sitio. Tres medidas antropométricas fueron empleadas en lugares específicos. Además, la distribución espacial de los pilares de acuerdo a sus tamaños confirma la coexistencia de dos zonas dentro del sitio, lo que ratifica una dualidad también presente en la pintura mural. Los módulos y unidades empleados en Cacaxtla tienen muchas coincidencias con los que han sido identificados en el área maya y algunas con Teotihuacán y la cultura Nahua, por lo tanto, este sistema fue compartido entre varias culturas mesoamericanas y perduró desde el clásico hasta el postclásico.

The dimensioning of architectural components involves two related elements: the use of a system of measurement with patterns or units and the logic followed by the builders for laying out walls, porticos, and patios that define buildings and open spaces. Both are cultural legacies, acquired knowledge transmitted within social groups and inherited across generations, and thus can serve as indicators of population origins and affiliations.

Measuring units and quantifying schemata based on anatomical references are practices that are innate to humans independently of their cultural origins (Morley 2010; Morley and Renfrew 2010; Urton 2010). Nevertheless, being based on units that vary from one person to another, such references generate inaccurate systems—hence the need for setting fixed standards. The use of standardized building measurements is also a tool that facilitates the organization of work and communication between the various groups involved in the process (for instance, those building walls and the suppliers of timber for roofing). Using a measurement unit known to all—referring to it

Geneviève Lucet ■ Instituto de Investigaciones Estéticas, Universidad Nacional Autónoma de México, Mexico City, 04510, Mexico (genevieve.lucet@gmail.com)

Latin American Antiquity 26(2), 2015, pp. 242–259

DOI: 10.7183/1045-6635.26.2.242

and its multiples—ensures the accuracy indispensable for all building projects (Lee 1996).

Units for measuring distances may differ depending on the object measured. A measurement system may also be defined on the basis of a combination of different units of different sizes with or without an arithmetic relationship between them. Likewise, when analyzing ancient buildings to identify the dimensioning units used, a degree of uncertainty and inaccuracy must be taken into account. Several elements come into play that add variations between the ideal initial measurements and those recorded in the present. These may include: (1) approximations made during construction when an anthropometric measure based on parts of the body was used; (2) lack of precision during the building process (a tolerance of a few centimeters is generally expected, and even more so in preindustrial societies); (3) subsidence and building deterioration caused by natural processes or human activities. Furthermore, (4) current measurements, even when taken with laser systems, add one final source of possible error.

The first of these factors is built into the system and will be multiplied proportionally in relation to the overall dimensions involved. If the modulus used is small, the multiplying effect upon repetition is greater than if a larger modulus is involved. Hence, the larger the modulus identified, the lesser the margin of error. The remaining factors (2–4) are related to the measurement taken as a whole and represent an absolute error that in most cases does not exceed a couple of centimeters.

The manner of counting also exerts an influence on measurements. In a decimal system, multiples of 10 or 5 are preferred, whereas Mesoamerican systems were vigesimal. Divisions become unwieldy when having to handle non-integer results, which are not intuitive; in contrast, this problem disappears if a tool such as a string is used instead of numerical values: to divide one only has to fold the string onto itself, so that the measurement becomes "a string folded into *x* equal parts."

Among Mesoamerican cultures, numbers also may be considered a symbolic representation related to worldview. The meanings of the symbolic essence of constructions would be expressed through the use of specific numbers (Clark 2008, 2010; Sugiyama 1983, 1993, 2010).

Cacaxtla

Cacaxtla is located at a distance of 100 km from Teotihuacan, and some of its substructures indicate the influence of the metropolis. Nonetheless, its period of splendor was around A.D. 700–800 and the settlement was abandoned during the tenth century (García 1978; García et al. 1995; Molina 1977). The site belongs to the Epiclassic, a period characterized by complex political, social, economic, and cultural movements resulting from the abandonment of Teotihuacan, the great city of the Classic period. Far from the *altiplano*, Maya cities survived several centuries more before disappearing toward the end of the millennium. Cacaxtla is distinguished by its extensive murals that cover several walls, a long batter or *talud*, a bench, and two pillars inside a room.

The mural paintings were carefully protected when the inhabitants decided to carry out architectural modifications resulting in their burial (Brittenham 2009). They have been an invaluable source of information for studying the history of the site. Extensive debates have arisen regarding their unmistakable similarities—but also considerable differences—with the mural paintings of the lowland Maya during the same era. Some authors think that the artists came from the Maya area (Graulich 1988; McVicker 1985), while others (Brittenham 2009, 2011) believe they were from the *altiplano* and would have learned their trade in the Maya area and hence developed skills that enabled them to set forth a local discourse using Maya styles and techniques. Most scholars recognize that the rulers who commissioned the work were from the central highlands of Mexico; a more marginal hypothesis is that a Maya group could have conquered Cacaxtla and established a Teotihuacan–Maya shared government (Graulich 1988, 2001).

If the rulers were local people, their interest in using a Maya style of painting has been interpreted as a public declaration of affiliation with the dominant culture of the period and as a way of casting a veil over their previous affiliation with the culture of Teotihuacan through the use of an eclectic style of art (Kubler 1978; Nagao 1989). In any case, the absence of Mayan writing would be explained by the position of the site in a zone inhabited by speakers of a non-Mayan language

(Walling 1982). According to the latter studies, available evidence indicates a mixture of cultural expressions. The most visible elements are not systematic indicators of an origin: some could have been copied, sometimes with a deep knowledge of their meaning and at other times by being reinterpreted with varying degrees of syncretism.

New codes of expression may be adopted for a variety reasons. Pictorial representations, with their high degree of visibility and various expressive components—such as style, icons, and forms of writing—are ideal means of conveying a message and so new elements may be imported for political purposes. On the other hand, the use of a system of measurement in building is anchored to a complex and traditional practice that includes planning, design, geometry, and calculation. It is a type of knowledge that is transmitted via practice and manifests ancestral cultural heritage. It is part of the way of thinking of the builders, and it may well prove extremely complicated for them to adapt to new systems of measurement.[1] A system of measurement in architecture is a cultural good that may be regarded as a parameter of identification.

Different systems of measurement have been reported for Teotihuacan and the Maya area. If comparable systems could be attested for other sites, this would offer proof of the existence of cultural connections. At Cacaxtla, such information would provide new parameters for understanding the complex system of relationships in the Mesoamerican Epiclassic, in particular regarding Maya presence in the central highlands after the fall of Teotihuacan.

Methods

Architectural composition and style, the arrangement of buildings, and the dimensions of the site are elements that support the hypothesis that a particular measurement system was used for building Cacaxtla. The monumental core of the site is characterized by the presence of many porticos surrounding plazas and on the edge of the platform. This is evidence for the builders having sought a regular pattern by using a constant in measurements to establish recurring rhythms (Figure 1). In the same way, the regularity of the buildings and the proportions of inner and outer space indicate that these buildings were thought out and planned before construction. In addition, most structures conserve their original lime plaster finish, which facilitates taking measurements required in order to know their original dimensions.

A question of methodology that had to be considered at the outset was to determine whether one should start by seeking to apply a known system of Mesoamerican measurement or by working empirically on the basis of the measurements found. I opted for the latter approach so as not to bias results with preconceived ideas and not to rule out the possibility for the existence of a system that was peculiar to Cacaxtla.

Initial analyses involved applying statistical calculations to all measurements, but this method was not useful because it ignored the fact that degrees of variation between the original design and what is currently measured are not invariable for all categories of architectural elements. In addition, it was necessary to take into account several other variables in measuring the buildings—whether, for instance, the layers of finishing materials applied on the core of the structural elements were taken into account, or just the distances between structural elements. The solution for the analysis of data was to group measurements by building type. The first category chosen for study was one of the most easily controlled. Moreover, it was a category in which the builders might conceivably have been most interested in the careful application of dimensions—namely, the measurements of porticos, the pillars forming them, and the spaces separating them. The measurements taken were analyzed and compared arithmetically in search of repeating moduli; once such units were identified and verified, they were applied to the remaining building types. The measurements were weighted according to their role in the logic of construction and the importance of the object or the space where they were taken.

Prehispanic Dimensioning Systems

There are several sources available for the study of measurement systems. Sixteenth-century texts can serve as a basis for understanding the Nahua measurement system. The main source is found in the archaeological sites themselves; however, some studies have added anthropological and ethnohistorical data.

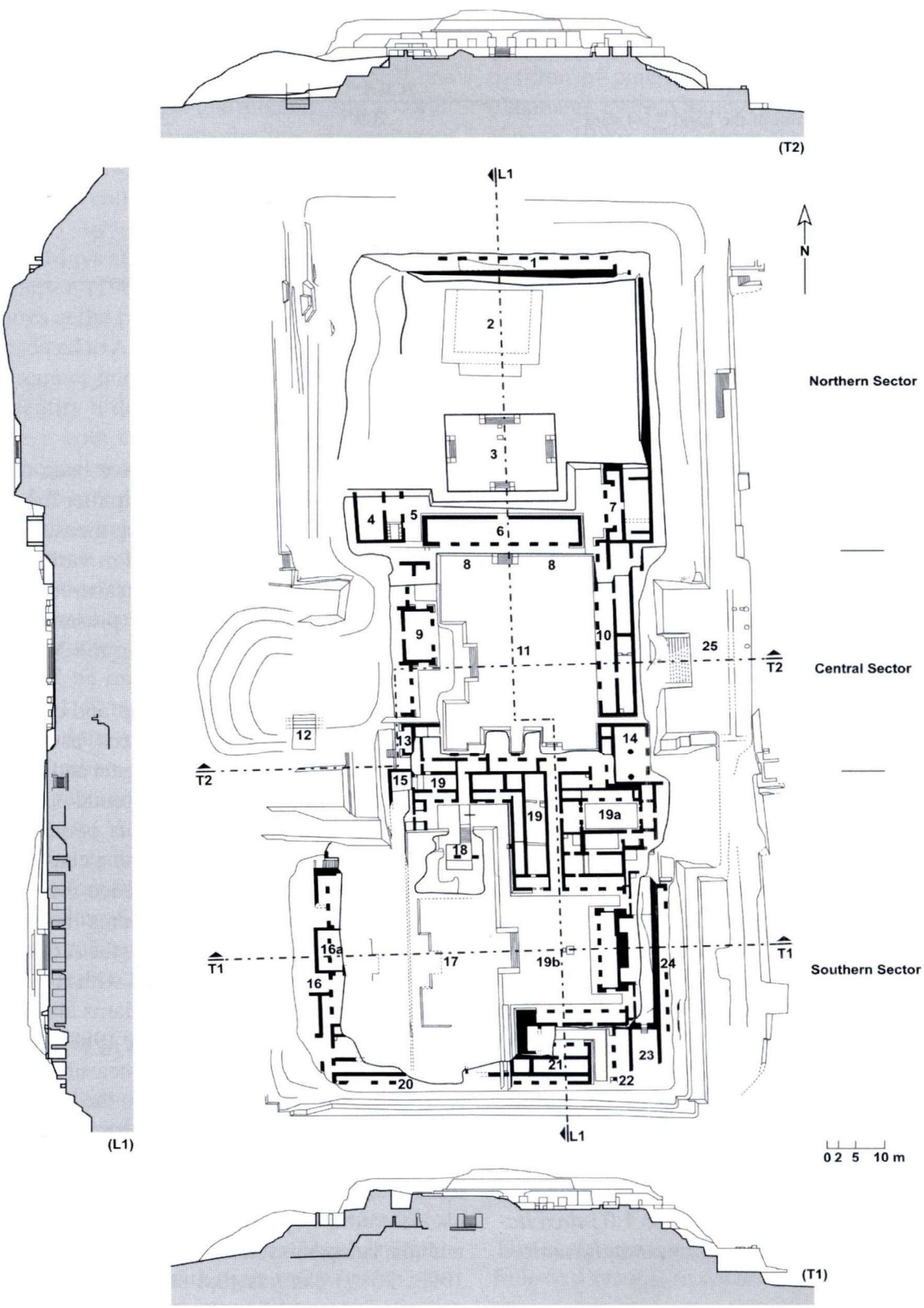

Figure 1. Plan and cross sections of the Great Platform of Cacaxtla (Lucet 2013). (1) North Portico; (2) Mound Y; (3) Sunken Patio; (4) Building C; (5) Corridor of the Slope-and-Panels; (6) Building B; (7) Building A; (8) Slope of the Battle; (9) Building E; (9a) Superstructure of Building E; (10) Building D; (10a) Superstructure of Building D; (11) North Plaza; (12) Teotihuacan Structure; (13) West Room; (14) Building of the Columns; (15) Hollowed Wall; (16) Venus Complex; (16a) Venus Room; (17) South Pyramid; (18) Red Temple; (18a) Red Temple Corridor; (19) The Palace; (19a) Patio of the Rhombuses; (19b) Plaza of the Altars; (19c) Portico A; (19d) Portico B; (20) South Portico; (21) Building F; (22) Portico F; (23) Room of the Stairs; (24) West Portico; (25) Plaza of the Eastern Stair.

Table 1. Some Aztec Measures According to Various Authors.

Aztec Unit[a]	Description[a]	Length (Clark[a])	Length (Dehouve[b])
macpilli	"palm of the hand," 1/4 vara	.209	.208[c]
omitl	"bone"	.334	.23–.334
yollotli	"heart," 1 vara	.835	.833
mitl	"arrow, dart," 1.5 varas	1.254	1.25
cenequeztzalli	"stature," height of a man	1.60	1.60[d]
maitl o cemmatl	"hand," horizontal braza, 2 varas	1.672	1.666
niquizantli	vertical braza, 2.5 varas	2.09	-

Note: All dimensions in m.
[a]Clark 2008, 2010.
[b]Dehouve 2011.
[c]*iztetl*.
[d]*nequetzalli*; the author expresses doubts about its conversion to the metric system.

The Nahua measurement system has been extensively studied by Víctor Castillo (1972) and Marcos Matías Alonso (1984) using information found in the narratives of missionaries and their indigenous pupils. The system was built upon multiple anthropometric measures. Understanding its operation and establishing its metric equivalencies is a complex undertaking because there are contradictions among the sources. At times, it is difficult to tell when the authors refer to Prehispanic or to Spanish units, since some measures—such as the arm-span, the rod, or the foot—occur in both cultures.

Conversions to the metric system may vary greatly (Table 1). For instance, according to Barbara Williams and María del Carmen Jorge y Jorge (2008) the "bone" measured .5 m, whereas for Dehouve (2011) it has a length that varied between .23 and .334 m. Dehouve relates several measures to the palm and comments that the *yollotli* (rod), measuring approximately .83 m, seems to have been a modular base. In the measurements for the Tlaltecuhtli stone, López Luján reports that the sculpture measures 4.17 m x 3.62 m, i.e., 5 *yollotli* or 15.01 *tlaxcitamachihualoni* (measuring one third of a *yollotli*) by 4 *yollotli* plus 1.03 *tlaxcitamachihualoni* or 13.03 *tlaxcitamachihualoni* (López 2010).

There were also instruments such as the *octácatl*, a measuring rod; the *cemmécatl*, a length of twine or string made from braided fiber; and the *tlalmécatl*, a string for ground measurements (Castillo 1972). Francisco Guerra (1960) mentions a stick called *tlacaxilantli* that would have corresponded to the distance between the human navel and the floor and that would have been divided into halves and fifths to obtain smaller measures. More than references to a precise measure, these standards were instruments used in various ways depending on the object being measured. The use of twine has continued until the present time, as shown by research carried out in the Maya area (Powell 2010).

Exact measurement, recording, and quantification were of concern to the Aztecs, as shown in documents such as the Codex Vergara and the Santa María Asunción Codex, dated to around A.D. 1539–1543, where information on plots of land is accompanied by ground features and a census of the families and owners in the Texcoco zone of the Valley of Mexico. These documents have served as a source for understanding how the Aztecs computed the surface of plots of land with remarkable accuracy (Jorge et al. 2011; Williams and Jorge y Jorge 2008; Williams and Harvey 1988).

Bruce Drewitt (1987) finds a measurement system with a modulus of .805 m as the basis of the urban layout at Teotihuacan, according to information obtained from the survey of the city (Millon 1973; Millon et al. 1973). He also shows the use of multiples of this unit in correspondence with the calendar system. Saburo Sugiyama (1983, 1993, 2010) extends that study and proposes a measurement unit based on a modulus of .83 m that is equal to the Nahua *yollotli* and the Spanish *vara*. In addition, he shows that the units used for the layouts of the great pyramids and complexes correspond to calendric quantities, so that the urban space is related to cycles of the Sun, Venus, and the Moon, as well as the 260-day ritual calendar. This is evidence for precise, large-scale planning of the city with a complex vision of space-time relationships. Following the same line of work, a value close to this modulus and a worldview representation with the use of significant numbers from a symbolic point of view have been sought in the architecture of Teotihuacan (Haselbach 2003).

In the Maya zone, Patricia O'Brien and Hanne Christiansen (1986) have studied ten Puuc-style structures at the sites of Chichen Itza, Uxmal, and Kabah, dated to A.D. 750–1000. Following careful measurement and rigorous mathematical study, they identify a double measurement system and validate it with ethnohistorical data. They name the principal unit of 1.47 m the *zapal*, divided into 16 *kab* of 9 *xóot* each or 9 *oc* of 16 *xóot* each. Thus, there were 144 *xóot* in each *zapal*, and a *xóot* is almost exactly equivalent to 1 cm. Using ethnohistorical data, the authors identify a system of length measurements related to the foot, the hand, and other body measurements, so that 9 *xóot* could be one hand, 16 a foot (without the toes), and 1.47 m the distance along outstretched arms. In addition, ancient Mayan texts refer to several numbers used in measurements: 3, 4, 9, and 12 appear in the *Chilam Balam of Chumayel*, 4 in the *Popol Vuh*, while 9 was a sacred number related to the training of artisans according to Landa's *Relación de las cosas de Yucatán*.

A modulus of 70 cm (Royall 2010) is reported from Paquimé, a site outside Mesoamerica in the north of Mexico.

Layout and Geometry

The dimensions of buildings are in most cases the result of the method and instruments used to lay them out. Thus, the use of a string as a ground layout tool may lead to solutions that do not always correspond to the base units of measurement. For traditional dwellings, present-day Maya people start their layout with a generally square base, and the string is folded in two to draw the circular ends (Powell 2010). There are variants to this system, which result from moving the center of the arc being traced, thus varying the final proportions of the building. While the initial form may have been based on measurements and geometry, the final result is the consequence of tracing a layout and no longer adheres to measurements.

Geometry has served as the basis for the composition of paintings, bas-relief, or architecture (Chanfon 1979; Clancy 1994; Harrison 1994; Vinette 1986). The square was a recurring form and expressed the conception of the universe with four points oriented along the cardinal directions, in addition to the vertical axis that unites the various levels of the universe (López and López 2001). This spatial perception was part of the conceptual scheme that became generalized in the Mesoamerican world, especially for ritual spaces. Thus, the plazas and principal interior spaces of Cacaxtla have the proportions of a square or a double square (Lucet 1999, 2013). In architectural composition, the geometric properties of figures served to arrange buildings in a hierarchy, taking advantage of axes of symmetry and reflecting a complex, conscious handling of the spatial qualities of shapes.

In spite of its close connection to architectural dimensioning, the manner of applying measurements on the ground has been little studied. Questions remain regarding the elements considered and the order followed in measuring out structures and plazas, whether measurements were taken from the inside or outside of a building, or whether the rhythm of a façade was paramount and took precedence over the dimensions of the rooms. Data recorded by Sugiyama (1993, 2010) at Teotihuacan correspond to the edges of large structures and to the axis of symmetry of the Avenue of the Dead. O'Brien and Christiansen (1986) measure the exteriors and interiors of buildings without distinction, as well as doorways and façade stones. According to Powell (2010), a layout is effected to define the inside or outside, and additional controls ensure that diagonals have equal lengths.

Data Selection and Collection

The assignment of architectural measurements follows a process in which the main elements take precedence over secondary elements, which must conform to relative or residual measurements of the former. What are the elements that are likely to provide useful information on the system of measurements used at Cacaxtla?

The importance of each building or room within the complex is one criterion. For instance, a space used for religious functions transcends the status of an ordinary building. It is the habitat of a deity or the place for rituals, and it is very likely that this will be reflected in its location, dimensions, and geometry, exhibiting the builders' ideal of perfection. In this hierarchical order, the elements surrounding a main plaza—namely, the building's façades—may have received special attention in following aesthetic standards.

Builders would have given special attention to the width of building, as this is limited by the resistance of the materials that support the roof. They knew, at least empirically, that the length that should not be exceeded for specific beam section. For the same reason, the measurements of lintels above openings are controlled.

Measurements collected at Cacaxtla were classified into simple architectural categories: the height of pillars, the space between them, the space between central pillars when different from the lateral spaces, the width of doorways, the interior length and width of rooms, the measurements of open spaces, and those of staircases, including their balustrades. With the exception of Building B, structures at Cacaxtla are not isolated and do not have a well-defined exterior dimension.

In the case of long bays that were subdivided into rooms, only the initial lengths of the spaces were included in order not to artificially multiply a measurement that actually corresponds to a single structure. Where dimensions of all four sides of a room were available, those corresponding to opposite sides were kept without averaging in order to deal directly with the initial measurement and not a mathematically derived quantity.

Finally, the structural transformations of the site during the centuries it was inhabited were taken into account (Lucet 1999, 2007, 2013). Mesoamerican cultures tended to renew their buildings regularly so that dimensions or placements of spaces may have depended on the existence of previous walls or buildings.

When the system of construction involves superimposing several material layers, it is pertinent to ask whether the measurement should include the entire resulting thickness or only the structural core. At Cacaxtla, the system consisted of erecting a structural core with *tepetate* stone and earth, applying a layer of earth, sand, and lime to a thickness of between 5 and 8 cm, and covering it with lime mortar 1 to 2 cm thick and a fine layer of white plaster (Magaloni et al. 2013). This technique results in a significant difference between measurements taken before and after the application of covering layers and is a variable that needs to be considered.

In order to achieve representative data of the original measurements, only references to components with original finishes in good condition, presenting few deformations, were considered. Structures were measured from points on the wall surfaces because in most cases the corner arrises were damaged or severely rounded. Measurement points were chosen close to the floor to avoid vertical deformation in the structures. For each distance, care was taken to record the data from the same position of the total station to prevent an increase in measurement errors due to translation of the coordinate system. A laser scanner was used for Building B. To define the constructive modulus of Cacaxtla, the data originate exclusively from the laser record and, to corroborate the modulus found, some distances measured with a tape measure were included.

Data Analysis

Recurrent Measurements in Pillars and Spaces between Pillars

The width measurements of pillars (*P*) were found to cluster into two ranges (Table 2): (1) 1.175–1.226 m (μ = 1.199 m; σ = .014 m; 30 pillars in 11 porticos) and (2) 1.437–1.505 m (μ = 1.467 m; σ = .016 m; 28 pillars in 10 porticos). The distances between pillars (*I*) clustered into three ranges. The first two roughly correspond to the ranges of *P* identified above: (1) 1.171–1.211 m (9 spaces from 5 porticos) and (2) 1.431 – 1.494 m (12 spaces from 5 porticos). The largest number of *I* values, however, cluster in the range 1.895–2.02 m (μ = 1.953 m; σ = .03; 35 spaces from 10 porticos).

These ranges of *P* and *I* were taken together to compute their representative means. The values obtained—1.198 m, 1.465 m, and 1.953 m—represent 44 percent, 40 percent and 0 percent of *P* measurements, and 20 percent, 20 percent, and 40 percent of *I* measurements, respectively. In the

Table 2. Summary of Measurement Ranges of Pillars (P) and Spaces between Them (I).

	P		
	Range (m)	#	#P
P1	.827–.842	1	2
P2	.93–1.0	2	4
P3	1.146–1.152	1	1
P4	1.175–1.226	11	30
P5	1.437–1.505	10	28
	I		
	Range (m)	#	#I
I1	1.171–1.211	5	9
I2	1.431–1.494	5	12
I3	1.600–1.605	1	3
I4	1.747–1.798	1	2
I5	1.895–2.02	10	35
I6	2.041–2.078	2	5
I7	2.114–2.176	1	5
	P and I		
	Median (m)	Average (m)	σ
P1	.835	.835	.011
P2	.962	.964	.03
P3	1.149	1.149	.004
P4 & I1	1.198	1.198	.014
P5 & I2	1.464	1.465	.017
I3	1.604	1.603	.003
I4	1.773	1.773	.036
I5	1.953	1.953	.03
I6	2.056	2.057	.014
I7	2.134	2.14	.023

Note: # = number of porticos; #P = number of pillars; #I = number of spaces between pillars; σ = standard deviation of measurements.

following sections these ranges of values are referred to by these means.

Arithmetic Relationship between Values

The means of 1.465 m and 1.953 m (both minus one millimeter) exhibit an arithmetic relationship with a common denominator of .488 cm:

$$1.464/3 = 1.952/4 = .488$$

Such a simple and precise mathematical relationship between the main dimensions of the pillars and the spaces separating them indicates the use of said denominator as the modulus (*M*) for the dimensions of architecture at Cacaxtla. These were the only dimensional relationships determined between the values of *P* and *I*.

Table 3. Measurements of Widest Central Spaces (C).

Building	C	#M	dif
Portico A	1.915	4	-.037
Building C	2.876	6	-.052
Building A	2.888	6	-.040
Building E	3.386	7	-.030

Note: All dimensions in m; C = measurement of space between central pillars, when different from lateral spaces; #M = number of modules; dif = difference between measured value and multiple of M.

Validation of the Modulus with Other Measurements

To verify whether *M* is effectively an important modulus at Cacaxtla, its relationship with other measurements at the site was sought. Two porticos have pillar widths *P* in the range .93–1 m, close to twice the value of *M* (.976). The central spaces (*C*) of the porticos of four buildings measure slightly less than 4, 6, and 7 times *M*, with a difference between 3 and 5.2 cm (Table 3). Of the 21 doorways (*D*) sampled (Table 4), 11 correspond to multiples of *M* with a difference of less than 3 cm, and three more to multiples of half *M*. Of the 9 measurable staircases (Table 5), five exhibit an application of *M* and one more seems to use a multiple of one-third of *M*. Of the 45 internal room widths (*W*), 25 vary less than 5 cm with respect to multiples of *M*, and eight more vary up to 7.5 cm. Four of these correspond to seven and nine times *M* (Figure 2). In three more cases, half of the modulus was used.

Of the 15 bays that exceed the tolerable error margin, 14 are multiples of *M* once the thickness of a wall (57 cm) is added. The only remaining case is solved when two wall thicknesses are added. Only two porticos have *W* values close to 1.198 m, and they exceed the corresponding values of *P*, *I*, and *D* by 5 cm. Six bays are within 15 cm of the 1.465 m modulus, and 13 are close to 1.953 m.

Exterior spaces also exhibit the modular scheme (Figure 2). The North Plaza followed it in its two constructive phases, first when it was at the same level as the surrounding buildings and then when it became a sunken plaza (Lucet 1999, 2007, 2013). In the Plaza of the Altars, one particular 40-modulus measurement stands out. The distance between Building F and Portico F, between the South Pyramid and the porticos surrounding it to the east and north, the length of the

Table 4. Measurements of Doorways (D).

Building	D	#M	dif
Portico B	.860	2	-.116
Patio of the Rhumbuses, South	.887	2	-.089
The Palace, room b	.907	2	-.069
Building D	.950	2	-.026
Venus Complex	.950	2	-.026
The Palace, room g	.950	2	-.026
Portico B	.970	2	-.006
Room of the Stairs	.971	2	-.005
Building F	.977	2	.001
Venus Room	1.000	2	.024
The Palace, room fc	1.000	2	.024
Building D	1.175	2.5	-.045
Building D	1.184	2.5	-.036
Patio of the Rhumboses, East	1.396	3	-.068
Building A	1.410	3	-.054
Building C	1.426	3	-.038
Building E	1.441	3	-.023
Patio of the Rhumbuses, West	1.445	3	-.019
The Palace, eastern portico	1.680	3.5	-.028
Venus Complex	1.920	4	-.032
Building B	1.932	4	-.020

Note: All dimensions in m; D = measurement of the doorway; #M = number of modules; dif = difference between measured value and multiple of M.

Table 5. Measurements of Staircases (S).

Building	S	#M	dif
Room of the Stairs	.98	2	.004
West Slope	1.435	3	-.029
North Plaza, south stairs	3.27	7	-.146
Sunken Patio S	4.07	8.3	.020
Sunken Patio E	4.76	10	-.120
Sunken Patio W	4.78	10	-.100
Sunken Patio N	6.83	14	-.002
Building E, superstructure	6.87	14	.038
South Pyramid	8.35	17	.054

Note: All dimensions in m; S = measurement of the stairs; #M = number of modules; dif = difference between measured value and multiple of M.

Sunken Patio and one of the façades surrounding the Patio of the Rhombuses correspond to the modularity.

The measurements of Building B (Figure 3) are an example of the conceptual framework followed in the application of M: its southern façade has six pillars measuring 3 M and the spaces separating them are 4 M wide, as are the doorway located in the north wall and the inner ends of the western corner of the façade. In spite of having a rhomboidal deformation, the two long opposing walls of the building have the same measurements, and the internal rooms measure 9 M minus 4 and 8 cm, respectively. The doorway is not centered; the walls on either side are 12.174 m and 12.083 m long; that is, the first measurement corresponds to 25 M with an error of only 2.6 cm, and the other is not modular. In summary, the P, I, and D dimensions correspond to exact modulus multiples, as does W if measured before the application of plaster. The inside length of the building should be 54 M, but it falls short by 12.7 cm. To place the doorway, an integer modulus multiple was used from the inner western corner, and hence the wall on the eastern side is shorter.

Discussion

Comparison with Known Measurement Systems

The three recurring measurements at Cacaxtla (1.198, 1.465 and 1.953 m) are different from anthropometric measures reported for the Nahua culture. The shortest differs by 5.6 cm from the *mitl*, arrow, a measure that goes from the elbow to the opposite hand and to which a value of 1.254 m has been assigned (Clark 2008; Dehouve 2011). This difference is too large to take it as a correspondence. In one of the porticos, however, the I values coincide with the 1.60 m *cenequeztzalli*, and in two porticos they measure, on average, 2.056 m, which is close to the 2.09 m *niquizantli*. The first portico is located in an initial stage of the Palace and the others correspond to the North Portico and the buildings surrounding the North Plaza on its eastern and southern sides. They are highly visible places, which leads to the assumption that a different pattern based on anthropometric measures was used occasionally.

The two inner pillars of the Venus Room are .835 m wide, a measurement that corresponds to the constructional modulus that has been reported in Teotihuacan and also to the Nahua *yollotli* (Castillo 1972; Clark 2008, 2010; Dehouve 2011; Drewitt 1987; Sugiyama 1983, 1993, 2010). These pillars were originally wider and were part of a large portico with 12 pillars in ranging from 1.183 to 1.21 m in width that bounded the western side of a great plaza (Lucet 1999, 2013). When this portico was divided in the middle to build a new space, two pillars were left inside. The builders reduced their width and covered them with artistic

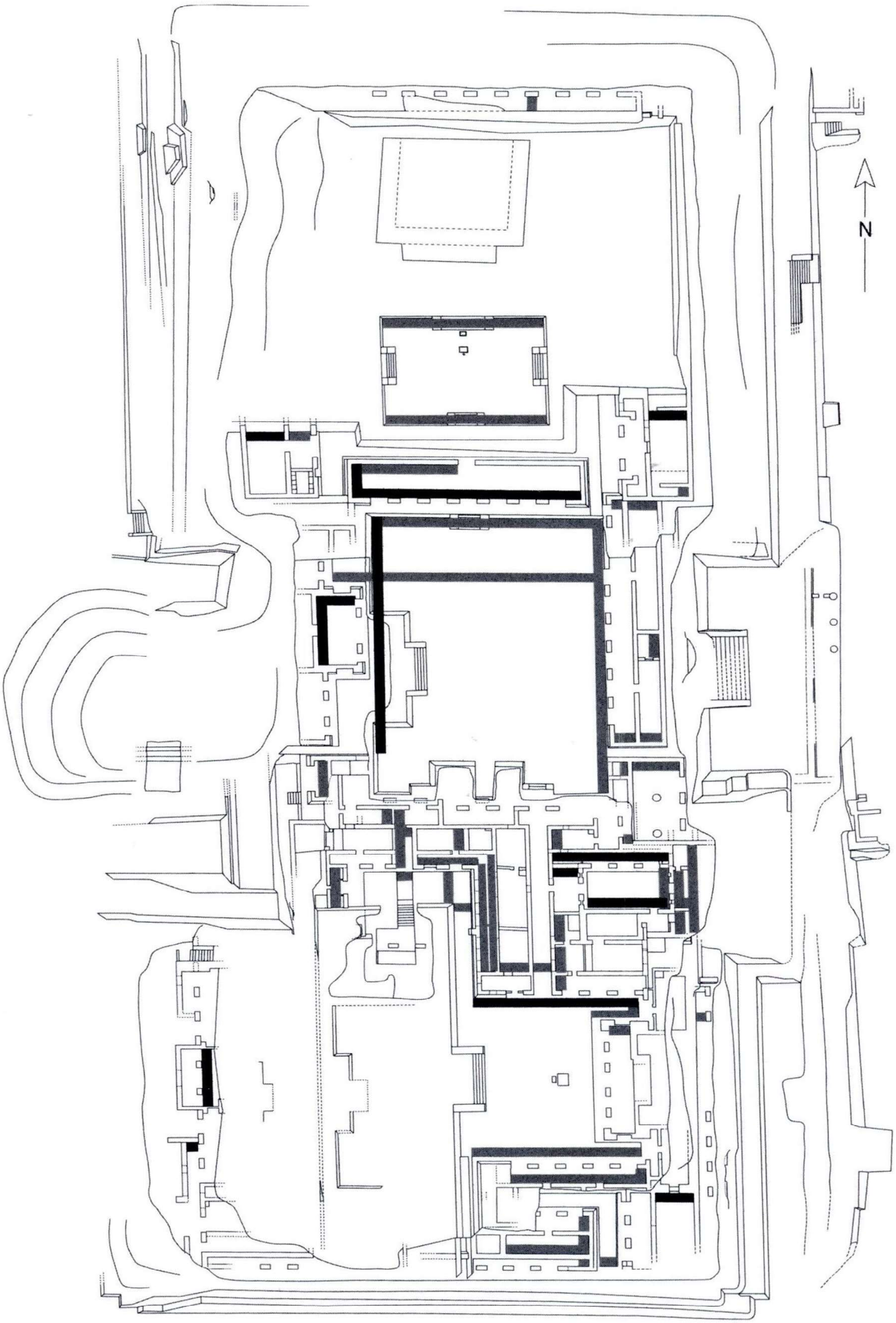

Figure 2. Summary of modular measurements in rooms and open spaces. Light gray: multiple of M; dark gray: multiple of 3 times M.

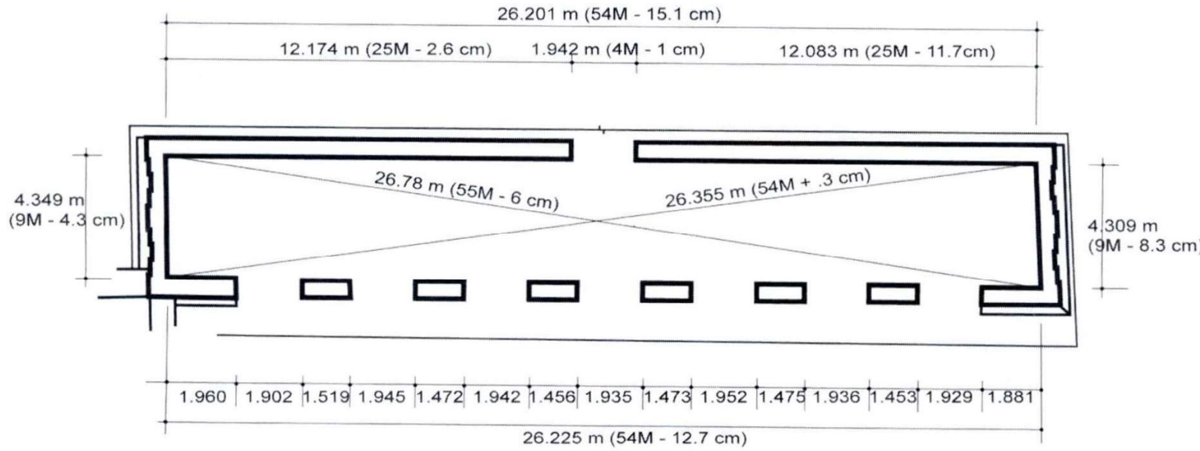

Figure 3. Building B.

representations; on the north pillar they painted a blue character with a scorpion tail and on the south pillar a woman with a jaguar skirt, both surrounded by Venus Stars. These pillars lost their constructional character; they remained as two stelae within the room and became symbol-laden objects. This is the only place in Cacaxtla where we find this measurement, and we may assume the conscious use of the *yollotli* on these pillars to complete their symbolic message and establish references to cultural elements from Teotihuacan, to Venus or to elements of the Mesoamerican worldview.

Only two of the three recurrent measurements (1.465 m and 1.953 m) correspond to multiples of the modulus .488 m. The value of 1.465 m is very close to the measurement of 1.47 m reported by Patricia O'Brien and Hanne Christiansen (1986) for the Maya area. Thus, the Cacaxtla modulus is one-third of a *zapal* and corresponds to 3 *oc*, the subunit obtained by dividing 1.47 m by 9; following this logic, the third measurement, 1.198 m, would correspond to 13 *kab* (1.194 m), one-sixteenth of 1.47 m. This correspondence is too precise to be considered a simple coincidence. The correspondence between the Cacaxtla and Maya moduli confirms O'Brien and Christiansen's findings and proves the existence of a measurement system encompassing widely separate regions.

The unit of 1.465 m, the Cacaxtla *zapal*, served as the basis for determining the modulus, and appears recurrently also as a single unit (Figure 2). The central room of Building E measures 3 times 6 *zapal*. Building B would ideally have measured 3 times 18 *zapal*. The rooms of Building A, Building C, and of the Room of the Stairs are 3 *zapal* wide. The north portico of the Patio of the Rhombuses is 9 *zapal* long, and the eastern side of the North Plaza in its second constructive phase measures 24 *zapal*. All are multiples of 3, a preferred number in ancient Mayan texts (O'Brien and Christiansen 1986), as well as of 4, 9, and 12. According to Dehouve (2011), the number 3 is related to fire, and additional study is needed to determine the significance of its use in construction. The dimension of the Venus Room is no longer a multiple of 3, but measures 5 *zapal*. Flora Clancy (1994) reports the frequent use of 1.92 m at Tikal and Naranjo. This is a measure close to 4 *M*, which strengthens the series of coincidences with the Maya area at Cacaxtla.

We may ask ourselves whether the main modulus is .488 m or 1.465 m. Both were used as units and both may be considered as moduli even if there is an arithmetic relationship between them. The *zapal* is useful for measuring the main elements, such as large rooms and plazas, and a smaller unit is needed to measure smaller elements.

The Cacaxtla modulus also appears at Teotihuacan, as deduced from the measurements reported by Jorge Acosta (1964) during excavations he carried out at the Quetzalpapalotl Palace (Table 6). Acosta concluded that the walls were 2.88 m high, 6 *M* minus 4.8 cm. The variations in the modular framework are insignificant in comparison with the dimensions of the components and in view of the construction technique used. The repeated use of 10 and 20 and the scarcity of 3 as multipliers are noteworthy. Not knowing how

Table 6. Measurements of the Quetzalpapalotl Palace, Teotihuacan.

Building	Measurement	#M	dif
Stair, building 5	9.80	20	.040
Antesala Width	9.74	20	-.020
Antesala Length	12.65	26	-.038
Tumb Width	1.44	3	-.024
Tumb Length	4.75	10	-.130
Battlement	.94	2	-.036
North Door	1.95	4	-.002
Corridor	7.3	15	-.020
Corridor Width	.96	2	-.016
Parapet	.48	1	-.008
Room Length	8.8	18	.016
Patio Width	8.24	17	-.056
Patio Length	9.75	20	-.010

Note: All dimensions in m; #M = number of modules; dif = difference between measured value and multiple of M.

Acosta measured these elements, it is impossible to generalize from such few data and to categorically state that .488 cm was the modulus used at Teotihuacan at the building scale; these coincidences would have to be confirmed through a detailed study.

At Tenochtitlan, the state of the structures makes a similar study difficult; nevertheless, in 1902 Leopoldo Batres (1990) reported the finding of a sculpted altar upon a pedestal; the measurements 1.45, 1.96, 2.44 and 2.96 m corresponded to 3, 4, 5 and 6 *M*, and only one (.885 m) does not correspond to the modulus.

Xochicalco should likewise be compared to Cacaxtla. It was a great city of the high plateau in the Epiclassic period; in both places shared elements are found, such as the distinctive slope-and-panel structures. These coincidences invite a comparison of their measurement systems, although a preliminary review of plans of the Acropolis and the Pyramid of the Serpent does not appear to confirm the use of the *zapal* or of the modulus *M*.

On the Manner of Architectural Measurement

The modulus of .488 m and the unit of 1.198 m appear in various architectural categories and point to the use of a unifying system, in contrast to the three anthropometric measures (.835 m, 1.60 m, and 2.056 m) used only for pillars and spaces that separate them. Walls at Cacaxtla run north-south or east-west; walls along a given orientation are parallel, but walls oriented on a different axis exhibit a deviation close to one degree from the right angle. Building B (Figure 3) has a more marked rhomboidal form than the rest of the buildings; one of its diagonals is 54 *M* long and the other is 55 *M* long, a difference that increased the deformation of the building. It seems as though these diagonals were measured and laid out differently on purpose so as to maintain the pattern marking the general orientation of the site.

In five porticos, pillars and the spaces between them have the same dimensions, which shows that measurements were made computing the thickness of plaster layers that would cover the pillars. In contrast, in the majority of the central wider spaces of porticos, bay widths, and doorways, the dimension is slightly less than a multiple of *M*. The opposite is the case for stair widths. These irregularities indicate that the builder defined the layout of these elements without including the thickness of plaster. This difference in criteria shows the importance of the regular visual appearance of porticos. Conversely, for rooms and staircases, a practical criterion prevailed. The structural part was built following modularity and then finishes were applied, reducing or increasing its dimensions. The importance of the visual appearance of porticos is corroborated by the regular measurements of the pilaster widths, the small range of variation in their values, and the small variation within a group of measurements.

The most frequent measurement for the pillars is 1.198 m and the next is 1.465 m, whereas most spaces between pillars are 1.953 m wide. Bay widths are close to the latter, and for the doorways, one-half of the modulus was used.

Plazas are multiples of the *zapal* or of *M*, taking the measurements from the peripheral sidewalks; this shows that the plaza is an exterior space designed carefully and a primary element in the spatial concept.

Space-time Relationship

It is pertinent to ask what the criteria were for choosing a specific measure and whether they changed in the various constructive phases.

Cacaxtla is clearly divided into three zones. Access to the north zone is restricted by a small staircase located at the center of the Slope of the Battle. The central zone is a plaza that is completely enclosed on its four sides by buildings, located at a lower level than the north zone; outside entrances are through small passageways between buildings on the southern corners. The southern zone is completely isolated from the preceding ones. To reach it, two long passageways must be used, arriving at the Plaza of the Altars. In this zone we can distinguish two levels: the lower one corresponds to the Venus Complex and the Red Temple; the higher one to the Palace, the Plaza of the Altars, and the South Pyramid, which progressively covered the structures of the lower level over different constructive episodes (Lucet 1999, 2007, 2013).

There is a clear difference in the use of measurements in the pillars for the three zones. The north and south zones each exhibit their own dimensional schemes, and the buildings separating them use a mixture of both schemes (Figure 4). In the south zone, *P*s cluster around 1.198 m, as happens in Building E in the central zone. The rest of the pillars, including all of those in the north zone, approximate the 1.465 m modulus. The pillars of the peripheral porticos surrounding the Great Platform that face outwards have measurements in accordance with the zone to which they belong. On the north, they measure 1.465 m and on the south, 1.198 m; in the central part of the east side, they measure 1.465 m, and toward the south, 1.198 m (the west side was destroyed). A clear spatial differentiation is thus observed. The *I* values are mixed, and it seems that the builders aimed to preserve the symmetry and harmony of the plazas, using the same measure all around or on opposite sides.

The distinctive use of pillar measurements could be related to the spatial significance of the zone where they are located. Numerous studies have sought to decipher the significance of paintings with iconographic and epigraphic readings, finding meanings related to rituals, in particular to actual or mystical sacrificial rituals, or to wars, conquests, or proclamations of ethnic provenance (Carlson 1991; Domínguez and Urcid 2013; Foncerrada de Molina 1980, 1993; Piña 1998; Urcid and Domínguez 2013; Uriarte 2013; Uriarte and Velázquez 2013). None of these has linked its interpretations with a spatial division of meanings. Depending on the location of the mural, its degree of visibility, and its context (within a room or in front of a plaza), the rituals of the Great Platform served various purposes and were seen by groups of different sizes. Spatial analysis has shown that the southern part of the site was separated from the northern part through form and access (Lucet 2013). We now see that this separation is also expressed in the measurements of pillars, and that it may be the result of the expression of a duality reflected in the architecture. This duality may have been rooted in the articulation that Cacaxtla establishes with its natural environment and the two important gods that personify the volcanoes that frame it, since the site is equidistant from the summits of two active volcanoes, the Iztaccihuatl and the Matlalcueye or Malinche (Lucet 2013).

Alternatively, if the builders were Olmeca-Xicalanca people, the distinction may be associated with their origin, given that this group was the result of the cultural mixing of two separate ethnic groups. It may also be linked to a "two-headed government and its ideology" that Michel Graulich (2001:21; translation by author) infers from the pairing of plumed serpent and serpent-jaguar imagery, possibly related to the opposition between "Maya conqueror in charge of the external government of the city" and "indigenous character of the Mexican high plateau."

Graulich's (1988, 2001) interpretation affords an opportunity to establish a direct parallel between spatial occupation and meaning of two different dimensional systems. Each of his two governing groups would have used one of the defined zones and the central zone, acting as the convergence point for the complex, would have exhibited a combination of the two measures. The Mesoamerican political system is an open subject of study. Whereas in the Maya area there is evidence of dynastic systems, in the high plateau government would have been multiethnic and corporate, and its antecedent would be traced back to Teotihuacan (Blanton 1996; López and López 1999). It also must be remembered that the use of a measurement system is a deep expression of a culture and is only with difficulty replaced by another.[2]

Conclusions

The differences between the creator's vision and what is measured in the present may vary depend-

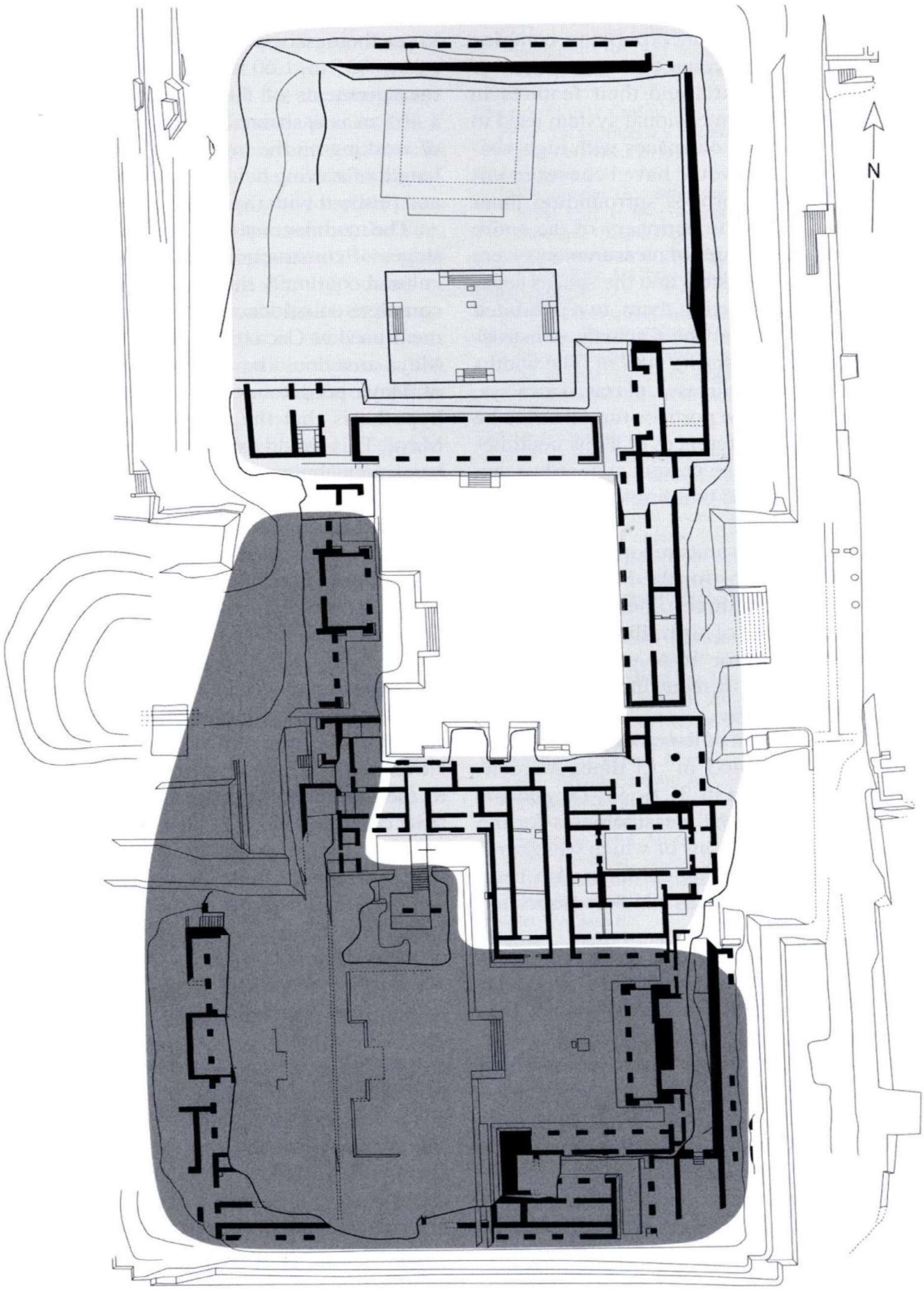

Figure 4. Distribution of *P*. Dark gray: 1.198 m; light gray: 1.465 m.

ing on the nature of the object measured. With this in mind, rather than incorporating complex statistics, I took into account the current state of the buildings at Cacaxtla and their features in order to decipher the dimensional system used to lay them out. I focused on spaces with high visibility where precision would have been more important, namely the porticos surrounding inner plazas and delimiting the periphery of the entire site. Three recurring groups of measurements were shared between the pilasters and the spaces separating them. After averaging them, two exhibited a common denominator: the Cacaxtla constructional modulus *M*, measuring .488 m. The widths and lengths of rooms, staircases, plazas, doorways, and central spaces of the porticos turned out to be multiples of *M* with differences of a few centimeters. This modulus is also present at Teotihuacan, where it was used in the building of the Quetzalpapalotl.

The result is close to units reported by O'Brien and Christiansen (1986) for the Maya area. The *zapal* corresponds to three times the Cacaxtla modulus, with an error of six millimeters. The *zapal* was divided by 9 or 16 to obtain subunits, which explains the third recurring measurement in the Cacaxtla porticos.

Additional validation of the modulus was found in multipliers. The 1.465 m (3 times *M*) constructional modulus and its 3-, 6-, 9-, 18- and 24-fold multiples provide the measurements for the main spaces, the dimensions of which were carefully planned; these multipliers have also been reported in Mayan writings as numbers associated with building activities.

The measurement system of Cacaxtla combines two logics: one with a base pattern for the modular system, and another with four stable measures. One of these measures is .835 m, used only for the width of the painted pillars of the Venus Room, which has the peculiarity of corresponding to the base modulus of the urban layout at Teotihuacan, thus establishing a relationship of the site dimensions with the most important astronomical cycles in the Mesoamerican worldview. Another dimension is 1.198 m, used mainly for the pillars and in some of the spaces between pillars; 1.60 m and 2.056 m appear specifically in spaces between pillars. These four measures are not divided or multiplied and do not participate in the modular scheme.

When working with measurements, it is usual to see their association with anthropometric measures; .835 m, 1.60 m, and 2.056 m correspond to measurements of the human body. In contrast, 1.465 m is associated with the practical manner of working on the layout and corresponds to the length of a string held taut with outstretched arms and pinched with the thumb on each hand.

The modular measures were used in the various stages of construction at Cacaxtla and point to a cultural continuity throughout the Epiclassic. The complete coincidence of the system of measurement used at Cacaxtla with that reported for the Maya area could be an indicator of the presence of Maya people in the *altiplano*, leading to the hypothesis that the builders of Cacaxtla were Maya. This would explain the similarities in style, painting techniques, and architectural configurations of the buildings. The need to adapt to a land in which a different language was spoken obliged the leaders to leave aside hieroglyphic writing. Hence, the discourse was centered on shared iconographic elements (Graulich 1988). Maya symbols were interpreted and adapted through artistic bilingualism so as to integrate elements of the written languages of the center (Martin 2013).

Until now, the modulus encountered at Cacaxtla had been recorded only in the Maya area. Nevertheless, I have shown (with reservations due to measurements that were not obtained under strict control) that it was also used at Teotihuacan, in an altar at Tenochtitlan, and in a construction built by Central Mexican or Maya groups at Ciudad Vieja, El Salvador (see Note 2). It would therefore be necessary to carry out similar analyses of measurements at other sites in order to know whether the *zapal* was a measurement of Maya origin that was adopted and used in other contexts—whether generally or in isolated cases—or whether it was part of a wide range of tools employed by the builders of Mesoamerica, without this necessarily implying a specific origin. What has impeded our ability to generalize from this kind of work is the need for dependable data that must take into account the conditions of the structure and the thickness of applied finishes.

So far as we understand it, the use of the *zapal* (or one-third of it), some anthropometric units, and units of .835 m at Teotihuacan, Cacaxtla, and in Nahua sculpted stones support the claim that these formed the basis of a dimensional scheme in continual use for centuries in a large portion of the Mesoamerican world.

The spatial distribution of the measurements employed for the pillars at Cacaxtla points to their association with the significance of the spaces; in this case, it does not appear to be related to calendrical features, as has been reported for other sites. Rather, it reflects a duality present at the site, which can correspond to an important division in the use of its different spaces. The hypothesis of a dual government in Cacaxtla leads to the assumption that these variations in measurements could reflect spaces built for each of the two ruling groups, which could have been of different ethnic origins.

The systems of measurement used in dimensioning Mesoamerican architecture are an integral part of a discourse that goes beyond simply solving a building problem. They are related to symbolic manifestations of the worldview and social organization of the people who used them.

Acknowledgments. This research paper forms part of the results of the project *La pintura mural prehispánica en México*, which received grants from the program UNAM-DGAPA-PAPIIT-IN402613; I am especially grateful to Prof. María Teresa Uriarte, coordinator of the project, who made this study possible.

References Cited

Acosta, Jorge
1964 *El Palacio del Quetzalpapalotl*. Instituto Nacional de Antropología e Historia, México, D.F.

Batres, Leopoldo
1990 Exploraciones en las calles de las Escalerillas. In *Trabajos arqueológicos en el centro de la ciudad de México*, edited by Eduardo Matos Moctezuma, pp. 111–170. Antologías. Instituto Nacional de Antropologia e Historia, Mexico, D.F.

Blanton, Richard E., Gary M. Feinman, Stephen A. Kowalewski, and Peter N. Peregrine
1996 A Dual-Processual Theory for the Evolution of Mesoamerican Civilization. *Current Anthropology* 37(1):1–14.

Brittenham, Claudia
2009 Style and Substance, or Why the Cacaxtla Paintings Were Buried. *RES: Anthropology and Aesthetics* 55/56:135–155.
2011 About Time: Problems of Narrative in the Battle Mural at Cacaxtla. *RES: Anthropology and Aesthetics* 59/60:74–92.

Carlson, John B.
1991 Venus-Regulated Warfare and Ritual Sacrifice in Mesoamerica: Teotihuacan and the Cacaxtla "Star Wars" Connection. Paper presented at the Oxford International Conference on Archaeastronomy, College Park, Maryland.

Castillo, Víctor Manuel
1972 Unidades nahuas de medida. In *Estudios de cultura náhuatl* 10:195–223. Instituto de Investigaciones Histórica, Universidad Nacional Autónoma de México, México, D.F.

Chanfon Olmos, Carlos
1979 La geometría y la piedra del sol. *Revista Churubusco*:7–29, México, D.F.

Clancy, Flora S.
1994 Spatial Geometry and Logic in the Ancient Maya Mind Part 1: Monuments. *Proceedings of the Seventh Palenque Round Table, 1989*, edited by Merle Greene Robertson and Virginia M. Fields, pp. 237–242. The Pre-Columbian Art Research Institute.

Clark, John E.
2008 Hands and Hearts. *Mesoamerican Voices* 3:5–34.
2010 Aztec Dimensions of Holiness. In *The Archaeology of Measurement. Comprehending Heaven, Earth and Time in Ancient Societies*, edited by Iain Morley and Colin Renfrew, pp. 150–169. Cambridge University Press, New York.

Dehouve, Danièle
2011 *L'imaginaire des nombres chez les anciens Mexicains*. Presses universitaires de Rennes, France.

Domínguez, Elba, and Javier Urcid
2013 El ascenso al poder del Señor 4 Perro: las pinturas murales del Conjunto 2-sub en Cacaxtla. In *La pintura mural prehispánica en México, volumen V, Cacaxtla*, edited by María Teresa Uriarte, pp. 547–607. Universidad Nacional Autónoma de México, México, D.F.

Drewitt, Bruce
1987 Measurement Units and Building Axes at Teotihuacan. In *Teotihuacan, Nuevos Datos, Nuevas Síntesis, Nuevos Problemas*, edited by Emily McClung de Tapia and Evelyn Childs Rattray, pp. 389–398. Instituto de Investigaciones Antropológicas, Serie 72. Universidad Nacional Autónoma de México, México, D.F.

Foncerrada de Molina, Marta
1980 Mural Painting in Cacaxtla and Teotihuacan Cosmopolitanism. In *Third Palenque Round Table, 1978*, edited by Merle Green Robertson, pp. 183–198. University of Texas Press, Austin.
1993 *Cacaxtla: la iconografía de los olmeca-xicalanca*. Instituto de Investigaciones Estéticas, Universidad Nacional Autónoma de México, México, D.F.

Fowler, William R.
2011 *Ciudad Vieja: excavaciones, arquitectura y paisaje cultural de la primera villa de San Salvador*. Editorial Universitaria UES, Secretaría de Cultura de la Presidencia, San Salvador, El Salvador.

Fredet, Jacques
2003 *Les maisons de Paris: types courants de l'architecture mineure parisienne de la fin de l'époque médiévale à nos jours, avec l'anatomie de leur construction*. Encyclopédie des nuisances, Paris.

Garcia Cook, Angel
1978 Tlaxcala: poblamiento prehispánico. *Comunicaciones* 15:173–179.

García Cook, Angel, Beatriz Leonor Merino Carrión, and Lorena Mirambell
1995 *Antología de Cacaxtla*. Instituto Nacional de Antropología e Historia. México, D.F.

Graulich, Michel
1988 Dualities in Cacaxtla. In *Simposio Antropología 8, 46th International Congress of Americanists*, pp. 94–117. Ultrecht.
2001 El simbolismo del Templo Mayor de México y sus

relaciones con Cacaxtla y Teotihuacan. *Anales del Instituto de Investigaciones Estéticas* 79:5–28. Universidad Autónoma de México, México, D.F.

Guerra, Francisco
1960 Weight and Measures in Pre-Columbian America. *Journal of the History of Medicine and Allied Sciences* 15(4):342–344.

Harrison, Peter D.
1994 Spatial Geometry and Logic in the Ancient Maya Mind Part 2: Architecture. In *Seventh Palenque Round Table, 1989,* edited by Merle Greene Robertson and Virginia M. Fields, pp. 243–252. The Pre-Columbian Art Research Institute, San Francisco.

Haselbach, Annemarie
2003 Juegos de pelota del período posteotihuacana: construcciones a base de medidas fundamentales y patrones matemáticos. Ph.D. dissertation, Maestría en Estudios Antropológicos de México, Universidad de las Américas-Puebla, México.

Jorge, María del Carmen, Barbara J. Williams, Clara E. Garza-Hume, and Arturo Olvera
2011 Mathematic Accuracy of Aztec Land Surveys Assessed from Records in the Codex Vergara. In *Proceedings of the National Academy of Sciences of the United States of America* pp. 15053–15057. National Gallery of Sciences.

Kubler, George
1978 Eclecticism at Cacaxtla. In *Tercera Mesa Redonda de Palenque*, Part 2, edited by Merle Greene Robertson and Donnan C. Jeffers, pp. 163–172. Pre-Columbian Art Research Center, University of Texas Press, Austin.

Lee, Vincent R.
1996 *Design by Numbers: Architectural Order among the Incas*. Sixpac Manco Publications, Berkeley, California.

López Austin, Alfredo, and Leonardo López Lujan
1999 *Mito y realidad de Zuyúa. Serpiente Emplumada y las transformaciones mesoamericanas del Clásico al Posclásico*. Fondo de Cultura Económica, El Colegio de México, México, D.F.
2001 *El pasado indígena*. 2nd ed. Colec. Fideicomiso Historia de las Américas. Fondo de Cultura Económica, El Colegio de México, México, D.F.

López Lujan, Leonardo
2010 *Tlaltecuhtli*. Centro Nacional para las Artes, Instituto Nacional de Antropología e Historia, México, D.F.

Lucet, Geneviève
1999 La computación visual aplicada a la documentación y estudio de monumentos. El sitio arqueológico de Cacaxtla y el mural O'Gorman: dos estudios de caso. Ph.D. dissertation, Posgrado en Arquitectura, Universidad Nacional Autónoma de México.
2007 Propuesta de secuencia constructiva del Gran Basamento. In *Memorias del coloquio internacional: Cacaxtla a sus XXX años de investigación*. Instituto Nacional de Antropología e Historia, Tlaxcala, México.
2013 Arquitectura de Cacaxtla: lectura del espacio. In *Cacaxtla*, edited by María Teresa Uriarte, *La pintura mural prehispánica en México, volumen V, Cacaxtla*, pp. 19–109. Universidad Nacional Autónoma de México, México, D.F.

McVicker, Donald
1985 The "Mayanized" Mexicans. *American Antiquity* 50(1):82–101.

Magaloni, Diana, Claudia Brittenham, Piero Baglioni, Rodorico Giorgi, and Lorenza Bernini
2013 Cacaxtla, la elocuencia de los colores. In *La pintura mural prehispánica en México, volumen V, Cacaxtla*, edited by María Teresa Uriarte, pp. 147–197. Universidad Nacional Autónoma de México, México, D.F.

Martin, Simon
2013 El Templo Rojo y los mayas: arte, mitología y contactos culturales en las pinturas de Cacaxtla. In *La pintura mural prehispánica en México, volumen V, Cacaxtla*, edited by María Teresa Uriarte, pp. 529–544. Universidad Nacional Autónoma de México, México, D.F.

Matías Alonso, Marcos
1984 *Medidas Indígenas de Longitud (en Documentos de la Ciudad de México del Siglo XVI)*. Cuadernos de La Casa Chata, 94. Centro de Investigaciones y Estudios Superiores en Antropología Social. México, D.F.

Millon, René
1973 *The Teotihuacan Map, Vol.1, Part One: Text*. University of Texas Press, Austin and London.

Millon, René, Bruce Drewitt, and George L. Cowgill
1973 *The Teotihuacan Map, Vol.1, Part Two: Maps*. University of Texas Press, Austin and London.

Molina Feal, Daniel
1977 Consideraciones sobre la cronología de Cacaxtla. In *XV Mesa Redonda de La Sociedad Mexicana de Antropología* pp. 1–5, SMA, México, D.F.

Morley, Iain
2010 Conceptualising Quantification before Settlement: Activities and Issues Underlying the Conception and Use of Measurement. In *The Archaeology of Measurement. Comprehending Heaven, Earth and Time in Ancient Societies,* edited by Iain Morley and Colin Renfrew, pp. 7–18. Cambridge University Press.

Morley, Iain, and Colin Renfrew (editors)
2010 *The Archaeology of Measurement: Comprehending Heaven, Earth and Time in Ancient Societies*. Cambridge University Press.

Nagao, Debra
1989 Public Proclamation in the Art of Cacaxtla and Xochicalco. In *Mesoamerica after the Decline of Teotihuacan A.D. 700–900*, edited by Richard A. Diehl and Janet C. Berlo, pp. 83–104, Dumbarton Oaks Research Library and Collection, Washington, D.C.

O'Brien, Patricia J., and Hanne D. Christiansen
1986 An Ancient Maya Measurement System. *American Antiquity* 51(1):136–151.

Piña Chan, Román
1998 *Cacaxtla, Fuentes Históricas y Pinturas*. Fondo de Cultura Económica, México, D.F.

Powell, Christopher B.A.
2010 The Shapes of Sacred Space: A Proposed System of Geometry to Lay Out and Design Maya Art and Architecture and Some Implications Concerning Maya Cosmology. Ph.D. dissertation, University of Texas at Austin.

Royall, Travis J.
2010 Built to Measure: Reconstructing an Ancient Measurement System from Extant Architecture at Casas Grandes. Master's thesis, Anthropology Department, University of Missouri.

Sugiyama, Saburo
1983 Estudio preliminar sobre el sistema de medida teotihuacana. Paper presented at the XVIII Mesa Redonda de la Sociedad Mexicana de Antropología, Taxco, Guerrero, México.
1993 Worldview Materialized in Teotihuacan, Mexico. *Latin American Antiquity* 4(2):103–129.
2010 Teotihuacan City Layout as a Cosmogram: Preliminary Results of the 2007 Measurement Unit Study. In *The Ar-*

chaeology of Measurement. Comprehending Heaven, Earth and Time in Ancient Societies edited by Iain Morley and Colin Renfrew, pp. 130–149. Cambridge University Press.

Urcid, Javier, and Elba Domínguez
2013 La casa de la tierra, la casa del cielo: los murales en el Edificio A de Cacaxtla. In *La pintura mural prehispánica en México, volumen V, Cacaxtla,* edited by María Teresa Uriarte, pp. 609–675. Universidad Nacional Autónoma de México, México, D.F.

Uriarte Castañeda, María Teresa (editor)
2013 *La pintura mural prehispánica en México, volumen II y III, Cacaxtla.* Universidad Nacional Autónoma de México, México, D.F.

Uriarte, María Teresa, and Erik Velázquez García
2013 El Mural de La Batalla de Cacaxtla. Nuevas aproximaciones. In *La pintura mural prehispánica en México Cacaxtla, volumen V, Cacaxtla*, edited by María Teresa Uriarte, pp. 677–739. Universidad Nacional Autónoma de México, México, D.F.

Urton, Gary
2010 Recording Measure(ment)s in the Inka Khipu. In *The Archaeology of Measurement. Comprehending Heaven, Earth and Time in Ancient Societies*, edited by Iain Morley and Colin Renfrew, pp. 54–68. Cambridge University Press.

Vinette, Francine
1986 In Search of Mesoamerican Geometry. In *Native American Mathematics*, edited by Michael Closs, pp. 387–407. University of Texas Press, Austin.

Walling Jr., Stanley L.
1982 A Stylistic Analysis of the Cacaxtla Murals. *Estudios de Cultura Maya* 13:205–223.

Williams, Barbara J., and H. R. Harvey
1988 Content, Provenience, and Significance of the Codex Vergara and the Codice de Santa Maria Asuncion. *American Antiquity* 53(2):337–351.

Williams, Barbara J., and María del Carmen Jorge y Jorge
2008 Aztec Arithmetic Revisited: Land-Area Algoriths and Acolhua Congruence Arithmetic. *Science* 320(5872):72–77.

Notes

1. In 1790, the French Revolution established the use of the metric system, but builders were reluctant to implement the decision because they found the previous system based on the duodecimal system much more flexible with its units divisible by two, three, and four; it was only in 1840 that a decree made it obligatory (Fredet 2003).

2. This phenomenon seems to be demonstrated in the constructions of Ciudad Vieja, El Salvador. This city was founded in 1524 using a measurement system based on the Spanish *vara* (Fowler 2011). One building, however, is distinguished from the rest; it is situated on a hill outside the grid of the city, with a different orientation, and obsidian objects were found associated with it. It likely served as a lookout post—surveillance being a function entrusted to the Tlaxcaltec, Mexica, and Maya troops who accompanied the conquistadors. It has been noted that half the dimensions of the room correspond to the *zapal* with a difference of only 5 percent. This distinction in the measurements could be taken as a cultural representation and as a statement about the origin of the builders.

Submitted July 22, 2014; Revised October 31, 2014; Accepted March 2, 2015.