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Research Article

A Dual Measurement System: Standardization and Architectural Planning in Xochicalco

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Abstract

This article examines the measurement systems used in the built environment of Xochicalco, a significant Epiclassic archaeological site located in Central Mexico. Through careful analysis of the dimensions of the various structures, we identified two primary measurement units: U7 (1.47 m) and U8 (1.68 m). These units exhibit similarities to the Mayan *zapal* and Nahua *maitl*, which have been previously documented across diverse temporal contexts and other regions within Mesoamerica. The investigation revealed patterns in the application of these units related to orientation, functionality, and construction methods, indicating meticulous planning and potential symbolic importance. The frequent use of measurements that are multiples of three, four, nine, and twelve times the base units suggests the utilization of standardized measuring instruments. This study enhances our understanding of Mesoamerican measurement practices, particularly at Xochicalco, and provides insights into cultural interactions and construction traditions during the Epiclassic period.

Resumen

Este artículo examina los sistemas de medición utilizados en el entorno construido de Xochicalco, un importante sitio arqueológico del Epiclásico ubicado en el centro de México. A través del análisis cuidadoso de las dimensiones de diversas estructuras, identificamos dos unidades de medida principales: U7 (1.47 m) y U8 (1.68 m). Estas unidades exhiben similitudes con el zapal maya y el maitl nahua, que han sido previamente documentados en diversos contextos temporales y otras regiones dentro de Mesoamérica. La investigación reveló patrones en la aplicación de estas unidades relacionados con la orientación, la funcionalidad y los métodos de construcción, lo que indica una planificación meticulosa y su posible importancia simbólica. El uso frecuente de mediciones que son múltiplos de tres, cuatro, nueve y doce veces las unidades base, sugiere la utilización de instrumentos de medición estandarizados. Este estudio amplia nuestra comprensión acerca de las prácticas de medición mesoamericanas, particularmente en Xochicalco, y proporciona información sobre las interacciones culturales y las tradiciones de construcción durante el período Epiclásico.

Keywords: measurement systems; Epiclassic; Central Mexico; Xochicalco; pre-Hispanic metrology

Palabras clave: Sistemas de medición; Epiclásico; México central; Xochicalco; Metrología prehispánica

The measurement systems utilized in the construction of Mesoamerican cities have been a subject of scholarly inquiry since the nineteenth century (Almaráz 1865; Brinton 1885; Orozco y Berra 1880). Despite significant advances a century later (Castillo 1972; Drewitt 1987; Drucker 1974; Matías Alonso 1984; O'Brien and Christiansen 1986; Sugiyama 1983, 1993), this topic continues to elicit research interest (Clark 2008, 2010; Dehouve 2011, 2014; Haselbach 2003; López Corral 2023; Lucet 2015, 2020a; Matos Moctezuma and López Luján 2009; Rojas Rabiela 2011; Royall 2010; Sugiyama 2010; Valencia Rivera 2018). The diverse terminology employed to describe distances in both Mayan and Nahuatl languages suggests the existence of multiple units, many of which are derived from parts of the human body. Furthermore, both language groups contain specific lexical items for measurement tools such as sticks and ropes (Ciudad Real and Coronel 1929:408; Clark 2008:9, 11; Marcus 1982:254; Valencia Rivera 2018).

The conversion of the Nahua measurement system to the decimal system remains an ongoing endeavor. Concurrently, there is a persistent need to authenticate the existence of alternative measurement systems and to integrate these findings into archaeological research. Such integration would elucidate their construction applications, utilization, temporal evolution, cultural variations, and symbolic importance. Recent investigations in the central highlands, specifically at the Epiclassic site of Cacaxtla (Lucet 2015, 2020a), have uncovered the pervasive presence of a unit previously identified

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in the Mayan region (O'Brien and Christiansen 1986). These studies also confirmed the different application of the primary unit recognized in Central Mexico (Clark 2008, 2010; Dehouve 2011, 2014; Sugiyama 1983, 1993, 2010). To gain a more nuanced understanding of the spatial and temporal aspects of these units' employment, we directed our attention to the archaeological site of Xochicalco, which corresponds to the same Epiclassic period (A.D. 600–1000).

This investigation aims to ascertain the measurement units used in Xochicalco, analyze their correlation with other established Mesoamerican units, and offer an interpretation that considers potential cultural connections within the context of Epiclassic interregional exchange. "Measurement" in this context refers to the dimension employed by pre-Hispanic builders, comprising numerals associated with standardized units. The research postulates that the city was planned, necessitating a standardized measurement system for urban design and organization while also reflecting Xochicalco society's symbolism and cosmology. This study proposes an explanation for both practical applications—the existence of standardized measurements indicating the use of measuring instruments and the systematic relationship between construction and measurement systems—and possible symbolic significance, considering the buildings' functions and social values.

Historical background

Colonial manuscripts served as the primary source for extracting original unit names and their corresponding symbols. However, conversion of these units to the metric system has been approached using various methodologies. The initial translation of a Nahua unit to the Spanish *vara* was based on descriptions of Netzahualcoyotzin's Palace, as documented by Fernando de Alva Ixtlilxóchitl (2000) in the 1500s. In his account, Alva Ixtlilxóchitl referenced two unnamed units: one used for describing royal residences and another, referred to as "our measurement," which was one-third the size of the former. Orozco y Berra (1880:558) assumed that Ixtlilxóchitl referred to the Spanish *vara* and assigned it a value of 0.838 m, which aligns with the Burgos *vara* (Brinton 1885:203). Current academic discourse continues to explore the dimensions of the colonial *vara* that may have been used, as well as its potential variation from the Mexica *vara* (Clark 2008:7–9). Additional analyses have been conducted on other units, focusing on word etymology, bodily references, and contextual usage in writing. These investigations have resulted in the establishment of associations between units and the proposed metric equivalences (Castillo 1972; Clark 2008, 2010; Dehouve 2011, 2014; Matías Alonso 1984). While unit nomenclature initially directed research toward identifying correlations with actual human body dimensions (Castillo 1972; Matías Alonso 1984), the examination of property dispute documents has been instrumental in identifying arithmetic relationships among the most frequently utilized units (Valencia Rivera 2018).

Consequently, the standardization of units through arithmetic means transformed their designations into mnemonic associations rather than precise bodily measurements. The *maitl* emerged as the primary unit, serving as the foundation for subdivisions and corresponding to the body dimension spanning the distance between the fingertips with arms fully extended. Valued at two *varas*, it was the most frequently employed unit for describing houses and land (Clark 2008:11; López Corral and Hirth 2012:78–79; Valencia Rivera 2018:142). Analysis of empirical evidence from the Teotihuacan archaeological site indicated that the fundamental unit of measurement closely approximated the *yollotli*, a significant Nahua unit. Various scholars have proposed different values for this unit: Almaráz (1865:356–357) initially calculated 0.825 m, subsequently revising it to 0.80 m after considering additional data; Drewitt estimated 0.805 m (1987:393); and Sugiyama proposed 0.83 m (1983, 1993, 2010). Sugiyama hypothesized that this unit could be utilized in urban planning by employing multipliers that correspond to calendar cycle numerals. His research prompted investigations into potential correlations with cosmological beliefs and occasionally resulted in adjustments to unit sizes to align their multipliers with calendar numbers (i.e. Clark 2008, 2010; Haselbach 2003; López Corral 2023).

Conversely, studies on Puuc-style architecture in Uxmal, Kabah, and Chichen Itza revealed a measurement system that differed from the Nahua (O'Brien and Christiansen 1986). The identification of a 1.47 m unit in archaeological findings required its correlation with Maya linguistic terminology, considering the geographic distribution of the investigated urban centers. The term *zapal*—denoting a *brazada* (the distance between the hands when the arms are extended)—was adopted and has been documented as the fundamental unit in the Mayan system (Brinton 1885; Ciudad Real and Coronel 1929:227). The *zapal* and *maitl* represented the same anthropometric measure but differed in their metric equivalents.

The *zapal* has been observed at the Cacaxtla archaeological site, particularly in porticos and mural paintings (Lucet 2015, 2020a). Despite similar measurements across the four sites, the methods used to derive smaller units varied. O'Brien and Christiansen (1986) suggested that the *zapal* was divided by 9 and 16, while Lucet (2020a) indicated that subdivisions were achieved by repeatedly folding the reference rope into two or three parts. The identification of the *zapal* as a measurement unit in Cacaxtla might be considered to provide an additional element in the extensive list of Mayan cultural characteristics frequently observed in Epiclassic settlements throughout Central Mexico. These features encompass mural paintings, particularly in their style and the use of blue dye, iconography, ceramics, and urban planning.

A substantial challenge persists in elucidating the geographical origins of *zapal* and *maitl* units, tracing their spread throughout Mesoamerica, and comprehending their multifaceted utilization. If the existence of multiple measurement systems associated with different cultures were to be established, anthropologists would acquire a valuable tool for discerning cultural affiliations through archaeological research (Lucet 2015).

Xochicalco

Located approximately 110 km in a direct line from Teotihuacan, the archaeological site is situated in the western

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region of present-day Morelos state. The construction of Xochicalco's principal structures coincided with the decline of influence and authority of the Teotihuacan metropolis around A.D. 550–650. This period, which extended until A.D. 1000, witnessed numerous transformations across Central Mexico, including demographic shifts, changes in political systems, the establishment of new urban centers with novel settlement patterns, and the restructuring of trade networks. These transformations were instrumental in shaping the postclassic states that would subsequently emerge (A.D. 1000–1521).

One of the defining characteristics of Xochicalco and other central Mexican city-states during the Epiclassic period has been the incorporation of stylistic elements from various cultures, including Mayan, the Gulf Coast, Oaxaca, and Guerrero (Berlo 1989; Hirth 2000:246; Kubler 1980; Nagao 1989; Testard 2014, 2018, 2023). The recognition of these diverse elements, particularly in the Pyramid of the Feathered Serpents at Xochicalco (PFS on Figure 1) and in the mural paintings at Cacaxtla, as well as in other cultural artifacts such as figurines, iconography, and ceramics, has resulted in the characterization of its artistic style as eclectic (Diehl and Berlo 1989; Foncerrada 1976; Hirth 2000:264–265; Kubler 1980; Nagao 1989:83; Parsons 1969:164; Pasztory 1978:16; Smith 2000:64; Testard 2021, 2023).

An examination of Xochicalco's built environments and their distribution at an elevation above the surrounding terrain of approximately 130 m (Alvarado 2022, 2023) demonstrates the exploitation of challenging terrain, which influenced the arrangement of structures based on their function, significance, and association with various social groups inhabiting the city (Hirth 2000; Lucet 2023). The central and highest areas were identified as the most exclusive zones, accommodating buildings of political, administrative, and ceremonial importance. The Pyramid of the Feathered Serpents, Xochicalco's most prominent structure, is situated in this location within the center of the Plaza Principal (PP), aligned with the Acropolis' palatial architectural complex.

The architectural modifications observed in the Acropolis (Acr), along with the construction of a pyramid corresponding to the Feathered Serpents Pyramid in characteristics and dimensions on its northern side, have been interpreted as evidence of a transformation in social space values, suggesting a governmental structure led by dual authorities (Alvarado 2015; Garza 2005:43).

Methodology

Data and margin of tolerance

The compilation of the data encompassed a significant portion of the excavated structures including buildings, open spaces, staircases, and courtyards. The dataset excluded built environments that were considered unreliable, whether due to archaeological reconstruction processes or multiple alterations during their period of occupation. Consequently, structures unearthed in the 1960s, primarily located in sectors E and H (Figure 1), as well as the Pyramid of the Stelae (G8) and the Great Pyramid (GP), were not incorporated. Furthermore, constructions attached to the walls of other buildings or situated on terrace slopes were omitted, given the ambiguity in defining the dimensional boundaries. Adhering to these principles, the heights of the structures were disregarded, whereas their widths and lengths were preserved in the dataset. Spatial parameters of the constructed environments were determined using two discrete surveys, each employing distinct methodologies at different dates. As part of the Xochicalco Special Project, the Instituto Nacional de Antropología e Historia (INAH) conducted a preliminary topographic survey in 1993–1994. A subsequent photogrammetric recording with a ground sampling distance (GSD) of 1 cm was performed by the Mecate Laboratory in 2014. The measurements obtained from these two sources generally exhibited high concordance with only minor variations. In cases in which discrepancies were identified, on-site verification using a total station was implemented to establish definitive dimensions.

The difference between historical and contemporary measurement methods necessitates a comprehensive approach for analyzing the collected data. This investigation incorporates error margins stemming from construction processes, systemic contexts, formation processes, and archaeological contexts (Schiffer 1972). The factors considered include disparities between initial conceptualization, ground layout, and actual execution; cultural alterations such as expansions and modifications; non-cultural influences such as natural structural degradation, excavation, and preservation interventions; and potential inaccuracies in documentation. Furthermore, builders' reliance on rudimentary tools, such as ropes and sticks for measurement, likely introduced inherent variability in the unit standard. It is hypothesized that the applied unit may deviate from the ideal value by approximately ± 1 cm, with variance compounding as the unit is repeated. For instance, employing a 0.76 m unit over a span of 10 units could reasonably result in a ± 0.076 m discrepancy when translated to the metric system. Consequently, the error percentages were calculated in relation to the unit used, taking into account these historical measurement intricacies.

Measurement systems typically incorporate a hierarchical structure of units, wherein larger units enable more precise quantification compared with the repeated application of smaller units (e.g., centimeters, meters, and kilometers). This approach enhances the accuracy and efficiency of the measurement process. The utilization of smaller units can result in substantial uncertainty as the margin of error compounds for each unit. Given the considerable scale of Xochicalco's built environment, it was hypothesized that builders employed measurement units exceeding one meter. These larger units were likely utilized as whole numbers for primary structures, half-units being applied to smaller constructions.

The corpus

This investigation examined 13 staircases and 45 structures encompassing ballcourts, porticos, impluvia, and architectural complexes. These complexes comprise multiple patios encircled by rooms, such as Structure G8

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Figure 1. Map of Xochicalco with the areas and buildings cited in the text. INAH modified by Iraís Hernández. *Note:* Acr = Acropolis ;AP = Acropolis Plaza; EBC = East Ballcourt; G8 = Pyramid of the Stelae; GP = Great Pyramid; NBC = North Ballcourt; PEDG = Plaza de la Estela de los Dos Glifos; PFS = Pyramid of the Feathered Serpents; PP = Plaza Principal; SBC = South Ballcourt; others are numbered elements within sectors F, G, H, I, K.

and the Acropolis room sets. The Pyramid of the Feathered Serpents was evaluated as a unique case.

Given that the rectangle serves as the primary architectural element at Xochicalco, our investigation focused exclusively on the structural outlines. We utilized mean measurements of the lengths and their corresponding widths for each structure, yielding two data points representing the dimensions of a rectangular building, distinguishing between the measurements of the perpendicular sides.

For porticoes and architectural complexes, only internal and external measurements of the perimeter wall were considered, disregarding subdivisions of units. Under the assumption that units larger than one meter were employed and that walls are expected to measure less than one unit, whole units were applied to only one side of the wall. Upon analysis, a single measurement of the width and length was maintained for each structure, based on whether it constituted an internal or external dimension.

In contrast, the three ballcourts exhibit an "I" configuration, classified—in Taladoire's system (1981:122)—as a Type VI enclosed court lacking a bench. When establishing reference points for measurements, it was considered that the design was founded on the intersection of two perpendicular axes of symmetry indicating the center, a characteristic frequently depicted in codices such as the Vindobonensis (Anders et al. 1992), the Borgia (Anders et al. 1993), the Bodley (Caso 1960), the Colombino (Hermann 2011), and the Nuttall (Nuttall 1975) (Figure 2). It was hypothesized that each of the three courts comprised two rectangles: an exterior rectangle, designated as the ballcourt, extending to the corners of the heads, and an interior rectangle, or playing field, aligned with the corners of the central section. These

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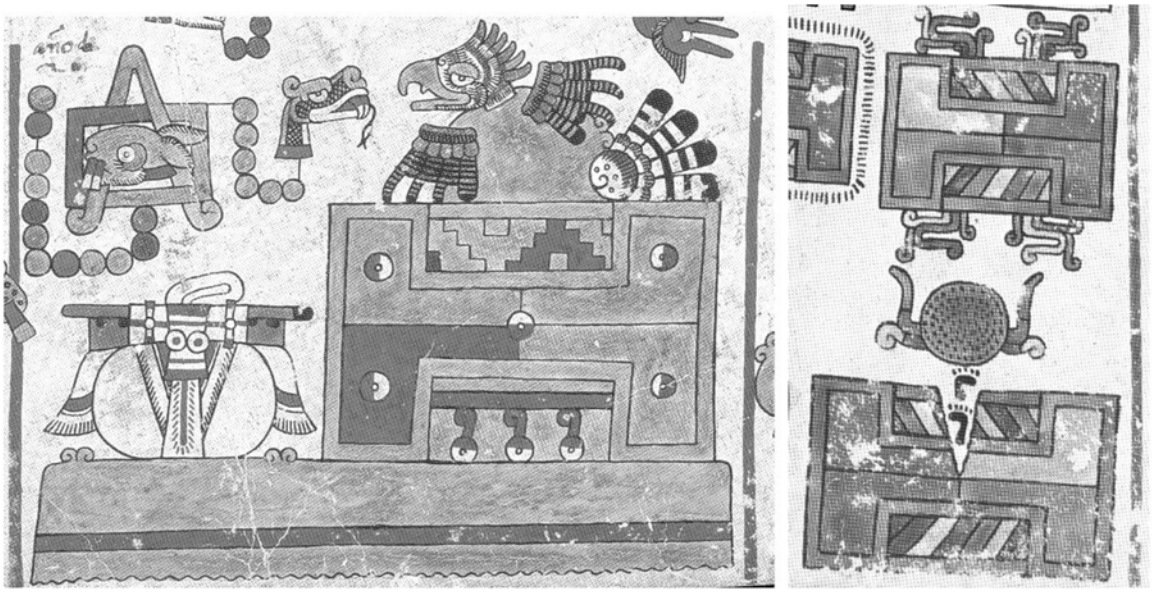

Figure 2. Depictions of ballcourts in codices: (a) Nuttall; (b) Borgia. Photography from *La Pintura Mural Prehispánica en México*.

two spaces share a common center, with their lengths and widths serving as essential components for ballcourts layouts and measurement applications.

In our analysis of the staircases, we focused exclusively on their width, which incorporated both *alfardas* (outer dimensions) and step runs (inner dimensions). This approach yielded two one-dimensional datasets for each staircase.

Segments that were unmeasurable due to environmental deterioration were denoted as X. We applied this notation to the width of one structure, the inner dimension of two staircases, and the outer dimension for the other two.

Units and numerals

In this study, measurement is defined as the correlation between a primary unit (U), which serves as a benchmark, and a numerical value (#). This relationship quantifies an element's dimension within the examined structure by indicating the number of times (#) the unit (U) is replicated. The structural measurements were characterized using four data, differentiating between the numerical values (#) and units (U) based on the orientation of the faces of the structures. The designation "H" was utilized for surfaces facing north or south, while "V" represented those facing east or west. This classification resulted in four variables: H#, HU, V#, and VU.

To ensure the accuracy of the outcome, it was established that measurements must be presented in their original format, encompassing both numerical values and units. This approach enables practical applications and facilitates the recognition of recurring patterns and solutions employed by builders. Despite the fact that measurements were not consistently exact multiples of whole units, only full units or their halves were taken into account, considering that most structures in Xochicalco are freestanding and not constrained by spatial restrictions.

Traditionally, studies of Mesoamerican measurement systems have focused on individual units and their subdivisions. This approach has neglected the possibility of non-isotropic spatial conceptualization by early builders in Mesoamerica. Studies conducted in Cacaxtla have identified the two distinct measurement units: *zapal* and *maitl*, which were commonly utilized in specific locations such as the Battle Mural and the Temple of Venus (Lucet 2020b). In fact, the integration of multiple units is feasible within a single edifice (Cauty 2011:10) or settlement, as no constraints preclude such an arrangement.

The preliminary stage of our research focused on the identification of the measurement units employed, utilizing a restricted sample set initiated with the Pyramid of the Feathered Serpents. The investigation began with the premise that the construction of the monument was subject to rigorous oversight and meticulous planning, potentially incorporating complete units and numerically significant values. This hypothesis was founded on the pyramid's location within an area associated with influential groups responsible for urban development and maintenance as well as exemplary craftsmanship and aesthetic merit.

The Pyramid of the Feathered Serpents revealed two distinct measurement units: 1.68 m and 1.47 m, as detailed below. The former, approximately twice the size of those documented in Teotihuacan, is equivalent to a *maitl* (Calnek 1974:27–28; Clark 2008:15, 2010; Dehouve 2011, 2014; Valencia Rivera 2018). In contrast, the 1.47 m unit corresponds to a *zapal*, which has been observed in both the Puuc region (O'Brien and Christiansen 1986) and Cacaxtla (Lucet 2015, 2020a).

The absence of definitive evidence regarding the geographical provenance of the system units necessitates a cautious approach when employing terms such as *maitl* and *zapal*, which carry implicit cultural associations. To avoid potential

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misattribution of the culture(s) responsible for the city's development, it is advisable to forbear these terms. As an alternative, the proposed units were designated U8 and U7, corresponding to measurements of approximately 1.68 m and 1.47 m, respectively. Both units share a common factor of 0.21 m, which is a dimension traditionally referred in Spanish to as a *palmo*, a quarter of a *vara* or *cuarta*. It corresponds to the distance between the tips of the thumb and the little finger. Its equivalent in Nahuatl measurements, according to Dehouve (2014:153), would be *ixtetl*, and its role would have been primordial between the different units of measurement. The Maya used three measurements with an open hand: *nab* to refer to the distance between the tip of the thumb and the middle finger, little *nab* to the index finger and *chi nab* to the little finger (Brinton 1885:197). The presence of a common denominator allows for the conceptualization of distances equal to seven times U8 as eight times U7; in such cases, these units are designated U7-8 (1 U7-8 = 8 U7 = 7 U8).

An analysis of the measurements of each structure was conducted to evaluate how the associated numerical value corresponded to the acceptable range when comparing the U7 and U8 units. Results that did not correspond to unit multiples were designated as "other unit" (marked as D), acknowledging their potential origin from an alternative unit, a geometric line, or a length adjusted for the thickness of a structural component.

This investigation not only identified the unit sizes utilized in Xochicalco but also examined the numerals that multiplied these units. The numerical system in Mesoamerica is characterized by its symbolic significance, demanding meticulous selection of numbers. This is particularly evident in solar and ritual calendars, where numbers were conceptualized as daily changing deities linked to other names. This concept has been extended to urban spaces in Teotihuacan, where specific numerals were employed to enhance distances, connecting the terrestrial realm, time, and celestial cycles (Dehouve 2011, 2014; Sugiyama 1983, 1993, 2010).

Results: Xochicalco Units of Measurement

This study revealed two normative units that enabled the recognition of structure measurements when multiplied by various numerals. Both units were evident in the Pyramid of the Feathered Serpents, prompting an exploration of the underlying principles governing their application. To elucidate this conceptual mechanism, additional structures were examined considering their typologies, locations, and wall orientations. Notably, measurements distinguished by multiples of U7-8 were prevalent, and standardized dimensions were found to be particularly crucial in roofed structures, potentially facilitating the procurement of timber for their roofs. The study also examined whether the numerical values corresponded to the instruments used by builders for dimensional standardization and whether those numbers were significant within the cultural worldview, particularly in relation to cosmogony.

The Pyramid of the Feathered Serpents: Main units and their numerals

Located on one of the uppermost terraces of the hill, the Pyramid of the Feathered Serpents incorporates two earlier constructions beneath its renowned carved *taluds*. Archaeological excavations led by González in 1993 and 1994 shed light on these previously undiscovered structures. The original façades of the building's earliest construction stages are now visible to visitors from the monument highest point. As noted by Alvarado (2015), the last constructive stage was likely built between A.D. 700 and A.D. 900, a moment marking the settlement's peak of economic success and prosperity.

The final stage of the structure incorporated a platform with slanted walls (*talud*), a panel (*tablero*), and a decorative cornice (Figures 3–5). Atop sits a temple with perimeter walls reconstructed during Leopoldo Batres' 1910 intervention (1912). The platform's *talud* is adorned with eight feathered serpents, with two on each side. On three sides—north, south, and east—these serpents have sinuous bodies, with their tails pointing toward the center of the structure and heads toward the edges. The vertical bands between each serpent feature crisscrossing lines that form diamond patterns bordered by vertical lines terminating in spirals. Interspersed among the serpents' undulations are human figures and calendar dates, possibly alluding to a New Fire ritual. The western façade, split by the stairs, exhibits feathered serpents

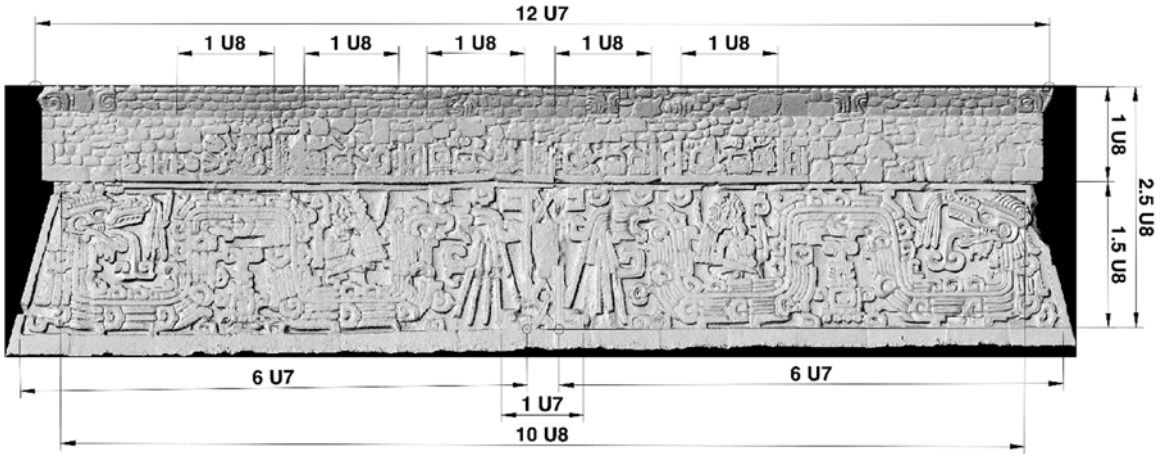

Figure 3. The east side of the Pyramid of the Feathered Serpents and its measures. Image by Geneviève Lucet.

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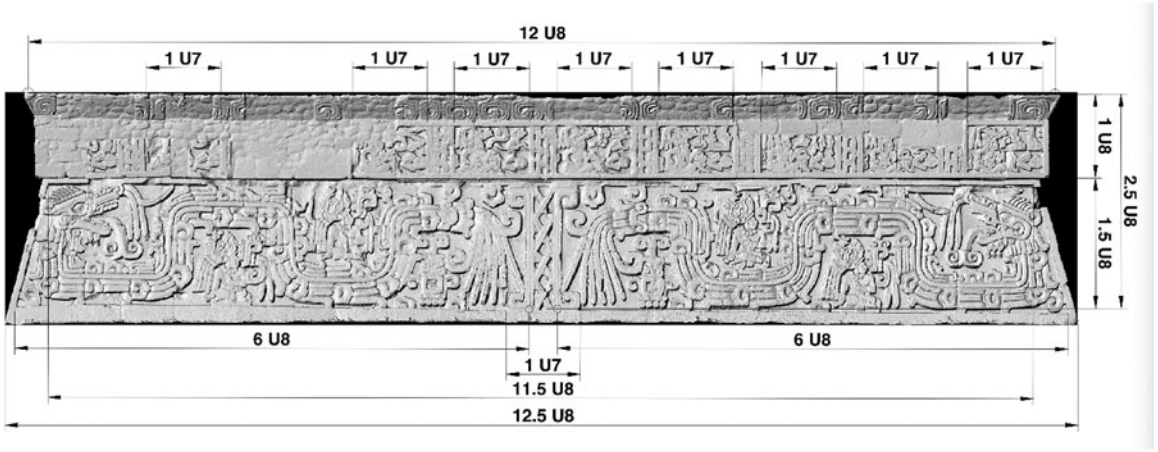

Figure 4. The north side of the Pyramid of the Feathered Serpents and its measures. Image by Geneviève Lucet.

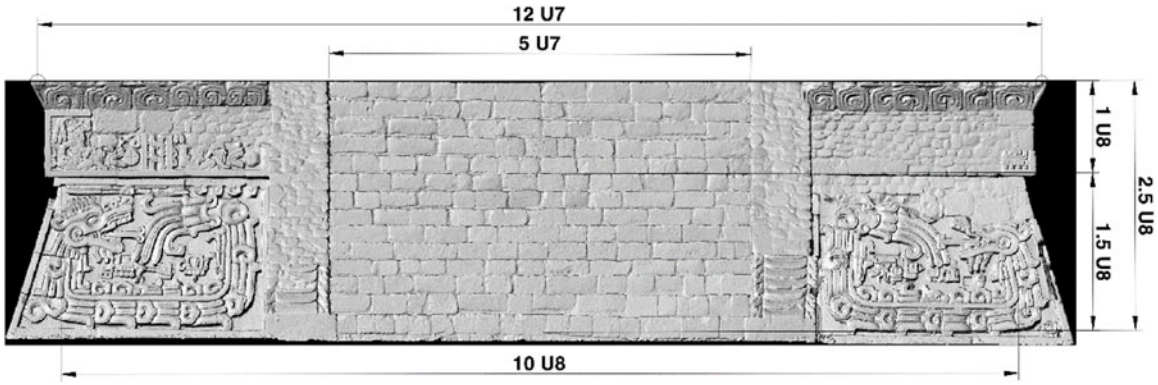

Figure 5. The west side of the Pyramid of the Feathered Serpents and its measures. Image by Geneviève Lucet.

encircling a series of glyphic elements. The *tablero* is decorated with square-shaped reliefs demarcating human figures holding vessels or copal pouches, accompanied by various identifier glyphs (Nielsen and Helmke 2023).

The iconography of this monument has been recognized as exhibiting Mayan influences since its earliest references (see Alvarado 2018; Helmke et al. 2025), primarily in relation to the seated human figures on the *talud*. At the same time, other decorative features, notably those adorning the *tableros*, demonstrate characteristics derived from a more Teotihuacan-based tradition (Nielsen and Helmke 2023). Contemporary analyses posit that the structure presents a visual narrative focused on establishing the legitimacy of the ruling group's authority (Nielsen and Helmke 2023; Smith 2000).

The structure exhibits a rectangular configuration with equivalent dimensions for its southern and northern façades (H) as well as its eastern and western sides (V). A staircase with *alfardas* was constructed on the central portion of the western façade (Figure 5).

Measurable components were classified into three architectural elements: *tableros*, stairways, and *taluds* (Table 1). The surface of each of the three sections features unique bas-reliefs: these were taken into account due to their deliberate and organized arrangement. The study began with the analysis of the bas-reliefs of the *tableros.*

Significant deterioration occurred prior to Batres' 1910 intervention, particularly on the eastern and southern sides. The fragmented components presented reassembly challenges, requiring Batres to employ reconstruction techniques. This process led to the identification of 28 square-shapes (Garza 2017; Smith 2000) framed by vertical bands featuring interlaced patterns. However, our calculations suggest that 32 square-shapes were initially present.

The seven square-shapes on the northern and southern *tableros* measured between 1.46 m and 1.49 m (U7), indicating the presence of ten square-shapes along these sides (Figure 4). Only five of the original eight square-shapes remained on the eastern façade, with dimensions ranging from 1.64 m to 1.69 m (U8) (Figure 3). The western façade contains two square-shapes on each side of the staircase (Figure 5), with only those on the northern side preserved, measuring between 1.57 m and 1.59 m. This dimension represents the mean of the two lengths used for the square-shapes on the other façades. The selection of this intermediate size may be attributed to spatial constraints imposed by the central staircase, preventing alignment with the length of the eastern square-shapes, or to maintain neutrality by avoiding the assignment of greater significance to any particular façade unit.

A comprehensive analysis of the *tableros* revealed the implementation of the two distinct units that were

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Table 1. Measurements and numerical values of the Pyramid of the Feathered Serpents' primary components, which are categorized according to their directional orientations

	H#	HU	V#	VU
Length				
Tablero and cornices	12	U8	12	U7
Tablero's square-shapes	1	U7	1	U8
Talud's edge to diamond shapes	6	U8	6	U7
Talud upper segment	11.5	U8	10	U8
Talud lower segment	12.5	U8	-	-
Width				
Diamond-shape band	1	U7	1	U7
Staircase	-	-	5	U7
Height				
Total	2.5		U8	
Tablero	1		U8	
Talud	1.5		U8	

Note: H = surfaces facing north or south; V = surfaces facing east or west; # = count; U = unit (U7 or U8).

consistently replicated throughout the structure. These units were corroborated by the accompanying numerals and consistent measurements across all four façades. Notably, the same numeral 12 was used for the dimensions of the cornices and *tableros* in H and V, while numeral 6 was used for the length of the bas-reliefs on the *talud*, from the edge to the central diamonds, in H and V. Consequently, the rectangular configuration resulted from the utilization of different units on the V and H sides. On V sides, the U7 unit is replicated 12 times on both the cornice and *tablero*, and 6 times on the bas-reliefs of the *talud*. Conversely, the H sides employ the same numerals, 12 and 6, but in conjunction with the U8 unit. This orientation-based unit application was extended to the total length of each building side, which constitutes the base length of the *talud*. The unit utilization is inverted for square-shapes lengths, *talud* elements, and their bas-reliefs based on the façade orientation. For example, U8 was employed for the V-side square-shapes, whereas U7 was utilized for the H-side squares. The slopes and bas-reliefs exhibited more diverse numerals in both the H and V orientations. However, this rigorous model cannot be universally applied, making it impractical to dimension both architectural elements and bas-reliefs when combining different units for each structural orientation with identical numerals.

The mean units calculated for each range were determined to be 1.47 m and 1.68 m, designated as U7 and U8 respectively. These dimensions were incorporated into various architectural elements: U7 was applied to determine the width of staircases, the height of cornices, and overall height, while U8 was utilized to establish the cornice height including *tablero* and the vertical measurements of the *talud*'s bas-reliefs. Builders employed vertical measurements (the eight) as a reference to define the size of inclined surfaces, such as *taluds* and their associated bas-reliefs, rather than the size of the sloping surface itself.

The combined analysis of the cornice and *tablero* dimensions revealed an average that aligns with Xochicalco's standardized units. This quantitative approach facilitates the resolution of formal aspects, while maintaining the coherence of the platform structure. Through the application of mathematical principles, architectural elements can exhibit consistency within the overall design.

Due to their demolition during the final phase of construction, the substructures provide limited opportunities for obtaining measurable distances. Nevertheless, the standardized units identified in the last stage were evident in the *talud* heights of both substructures, each measuring one unit: the first being U7 and the second U8. In the earliest façade, the entrance opening measured 4.5 times U7 (+0.06 m) or 4 times U8 (-0.06 m), whereas in the second expansion, the corresponding space measured 5.5 times U7. Although data are scarce, it is significant that both units were utilized throughout all three construction stages, suggesting a persistent and long-lasting application.

Corroboration of units and numerals in other architectural elements

To validate the units, we compared the two standardized units obtained from the Pyramid of the Feathered Serpents study against the dimensions found in all the examined structures within the settlement. After refining the data, the final corpus provided 111 data, including structures and stairs. Because of their deviation from the acceptable tolerance range, in some cases by centimeters, 14 data of this set were labeled as D. Therefore, 88 percent of the data supported the hypothesis that standardized units U7 and U8 were used in Xochicalco. Discrepancies in the measurements of some structures adhering to this pattern can frequently be attributed to deterioration, alterations, or subdivisions of the original structures. Examples include the altar at the Plaza de la Estela de los Dos Glifos (PEDG) and its substructure, exterior of Ac8 and K4 stairs, impluvia of Ac10 and Ac7, and H4 and H5 complexes. Moreover, modifications were necessary when structures had to be adapted to fit into existing spaces between earlier or irregularly shaped buildings (for example, Ac7 in V and the two impluvia of G6).

Interpretations

Use of units according to orientation and typology

The Pyramid of the Feathered Serpents exhibited a unique architectural feature: the employment of two distinct units, U8 on the H sides and U7 on the V sides. This finding prompted a comprehensive examination of the relationship between these units and façade orientation. Within the corpus of 33 structures measured in whole units on both sides, 10 exemplified this specific configuration, constituting the most frequent arrangement (Table 2). The structures exhibiting this pattern are characterized by features that enhance their importance, whether due to their strategic location within

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Table 2. Unit allocation based on the purpose and directional alignment of the structure's sides

H			D			U7-8			U7				U8			X	Total
V	D	U7	U8	U7	U7-8	U8	D	U7	U7-8	U8	D	U7	U7-8	U8	U7-8		
Altars			2					1		1		1					5
Complexes				1			1	2				2	1				7
Impluvia	1	1	2			1	1			1	1	1	1	3			13
Ballcourt												2		1			3
BC fields					1							2					3
Porticos				1		1	1	2	1	1	1	2		3	1		14
Total	1	1	4	1	2	2	3	5	1	3	2	10	2	7	1		45

Note: H = surfaces facing north or south; V = surfaces facing east or west; U= unit (U7, U8, U7–8); D = other unit; X = unmeasurable; BC = Ballcourt; NA = not applicable.

the Acropolis or Plaza Principal or their functions as ballgame courts or porticos serving as terrace access points (Figure 6).

In contrast, we observed three structures in which the units were used in opposite orientations, with U7 in H and U8 in V (Table 2). This indicates that the use of these units is not strictly dictated by the building orientation. The observed differences may not be deliberate deviations from the established pattern but rather adjustments to accommodate terrain features or for specific structural needs.

The second most common configuration involves the use of identical units on all sides of the building. Among the structures featuring U8, four out of seven were located in the Acropolis, whereas U7 was employed as the base on all four sides in five constructions (Table 2). Of particular significance is the F2 portico and its position next to the Great Pyramid. Its strategic placement indicates that its function was intimately connected to the pyramid, and that it served high-ranking individuals involved in ceremonial practices.

Measurements incorporating multiples of U7-8 were observed in nine structures. The South Ballcourt (SBC) stands out as the most notable example, utilizing these dimensions on both field sides to create a proportion equivalent to a double square (Figure 7). The deliberate use of these measurements in exceptional buildings and prominent locations suggests an intentional effort to highlight the importance of the construction.

Use of units according to functionality

An analysis of the units in relation to the functions of the structures revealed specific patterns. The U8 unit was notably common in structures associated with water management, such as impluvia, indicating a possible link between this unit and water-related facilities in Xochicalco. In contrast, the U7 unit was consistently found in V orientation across various architectural complexes. The consistent presence of U7 suggests its connection to residential quarters or administrative spaces (Table 2).

Ballcourt's and playing fields employed U8 in H and predominantly U7 in V. One field exhibited both orientations measured with U7-8, while one court utilized U8 for both H and V orientations.

Examination of the staircases indicated that the majority used consistent units for both the external and internal measurements (Table 3). Specifically, U7 was employed in both the Pyramid of the Feathered Serpents staircase and the stairway of the altar in the Plaza de la Estela de los Dos Glifos. Conversely, U8 was observed in three sets of stairs that connect significant changes in elevation between different terrace levels.

Use of numerals according to construction systems

Standardized measurement systems facilitate effective communication among diverse parties involved in construction projects, ensuring a consistent reference to the measurement of elements in the built environment across various stakeholders. In this context, cylindrical wooden beams, known as *morillos*, are essential components of construction projects. To create roofs, *morillos* functioned as support structures for the *tezontle, tepetate*, and stucco layers, which served as thermal insulators and prevented water from infiltrating into the structure.

At Teotihuacan, the *morillos* measured approximately 7 cm across (Margáin 1966:175) and were supported on walls running parallel to each other along the building's shortest dimension, which is its width. The *morillos* spanned between the side walls without extending over them, as these walls continued upward and served as a barrier to keep the roofing material in place (Figure 8).

The dimensions of 11 porticoed structures were determined using the U7 and U8 units with an approach that aligns with the construction logic in five cases: externally for width measurements and internally for length measurements.

The measurement method for porticos I4, I9, and G3 was inverted: exterior dimensions were used to determine length, whereas interior measurements were employed for width calculations. These structures are notable for their prominent location on elevated terrain along the route connecting the Plaza de la Estela de los Dos Glifos and the Plaza Principal (Figure 1). The application of specific measurements (15 U8, 20 U8, and 3 U7-8) on the façades of these buildings indicates that aesthetic considerations were prioritized over functional aspects.

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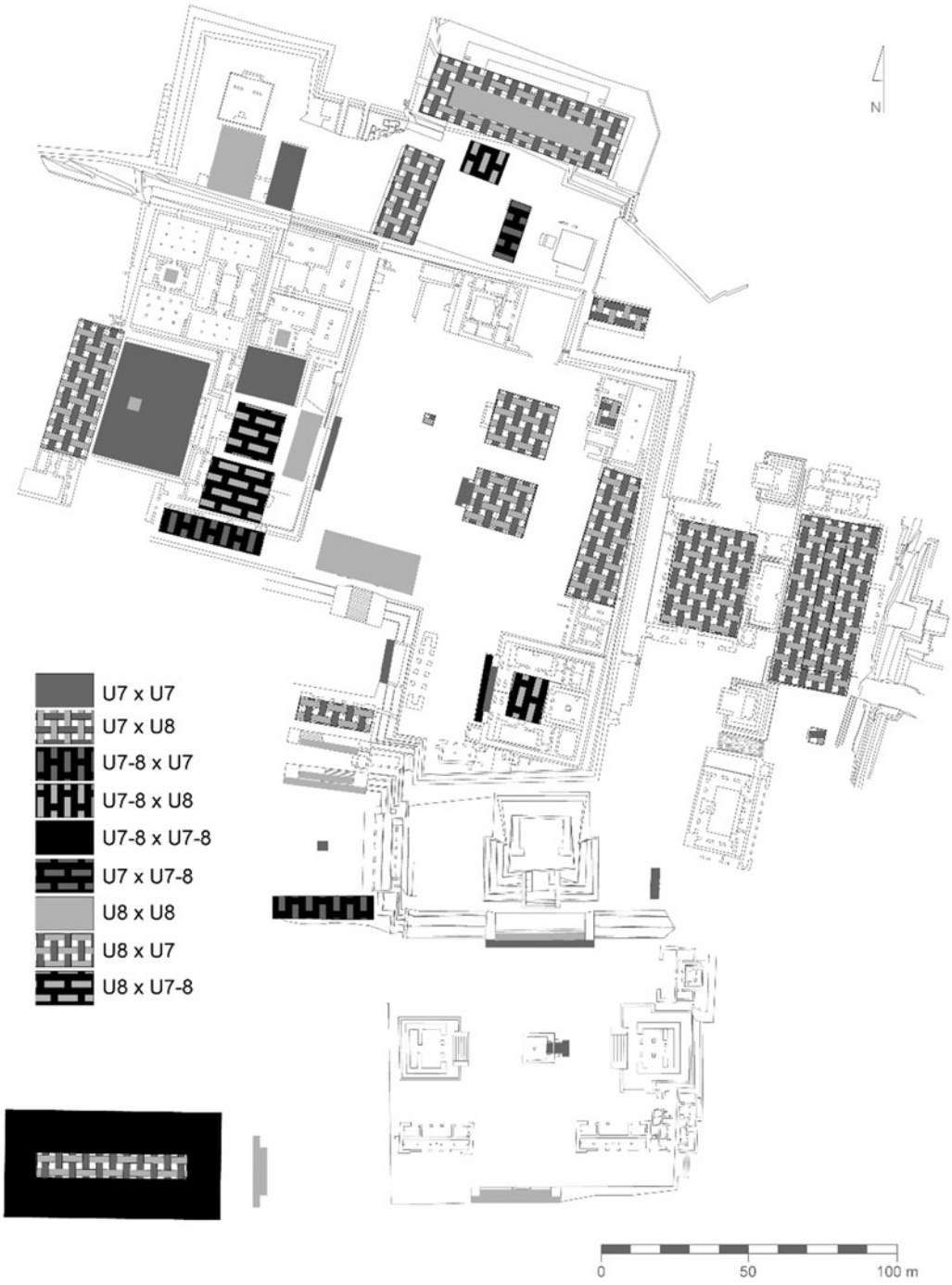

Figure 6. Indication of the relationship between buildings and the units identified. Iraís Hernández after Claudia I. Alvarado 2022.

The units remained consistent across both orientations, and the dimensions of the *morillos* were calculated as multiples of three units, except for the F2 portico, where the value doubled the U7.

Numerals and measuring instruments

In both Nahuatl and Mayan societies, standardized units were used to measure land boundaries. Historical Mayan records reveal that land area perimeters were quantified using units of 36 or 48 *zapal* (Brinton 1885; Ciudad Real and Coronel 1929:408, 602, 109). Moreover, a standardized land parcel, termed *vinic* or *winik* (meaning "man"), was established as an area encompassing 20 squared *k'aan*. This particular plot dimension was considered adequate for sustaining a family unit (Ciudad Real and Coronel 1929:408). The instruments used in Mayan territories, such as ropes or sticks, were based on fundamental units defined as three and four times the *zapal* (Ciudad Real and Coronel 1929:494). Land measurement practices involved tripling these units, resulting in two distinct *k'aan* measurements: the short *k'aan*, encompassing 9 *zapal* (*hun k'aan tii ox zapalchee*), and the long *k'aan*, comprising 12 *zapal* (*hun k'aan tah can zapalche*) (Brinton 1885; Ciudad Real and Coronel 1929:408). On the

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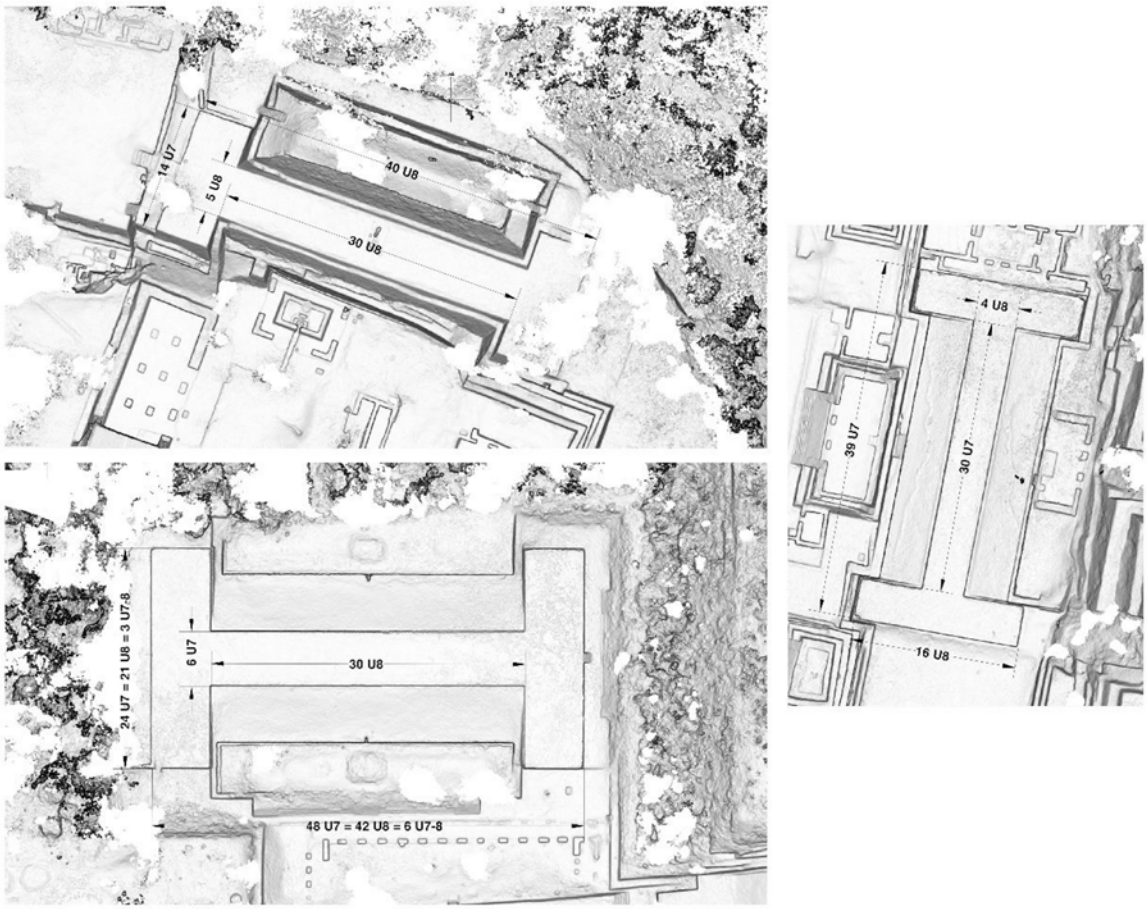

Figure 7. Ballcourtsmeasurements. (top) North Ballcourt (NBC); (bottom) South Ballcourt (SBC); (right) East Ballcourt (EBC). Image by Geneviève Lucet and Iraís Hernández.

Table 3. Unit allocation according to the directional alignment of the staircases.

H			NA		U7	U8	Total
V	D	U7	U7-8	U8	NA	NA	
Staircases	2	8	1	5	1	5	22

Note: H = surfaces facing north or south; V = surfaces facing east or west; U = unit (U7, U8, U7-8); D = other unit; NA = not applicable.

Yucatan Peninsula, the *mecate* denotes square areas of approximately 20 m on each side (Rojas Rabiela 2011:41). Nevertheless, Steggerda (1941:94) documented the continued utilization of ropes with an average length of 21.5 m in Pisé, Yucatan, a practice that persisted into the twentieth century.

On the other hand, Nahuas employed a measurement tool known as *mecatl* or *tlalmecatl*. The rope length was equivalent to 25 *varas*, corresponding to either 20 m (Cabrera 1974:90) or 20.90 m (Clark 2008:10), depending on the specific *vara* length used. Some studies have equated this measurement to 20 *varas* (Guerra 1960:344). It is worth noting that the long *k'aan* was equivalent to the *mecate*, a unit of measurement later incorporated by Spanish colonial authorities (Ciudad Real and Coronel 1929:408).

A significant portion of the numerical values obtained in this study was related to the dimensions of the measuring devices (Table 4). In this context, the units identified at Xochicalco enabled us to determine the sizes of these instruments with high accuracy. Based on U7 and U8, standardized measurement tools were established in the form of sticks representing three and four units: U7(3), U7(4), U8(3), and U8(4), corresponding to 4.41 m, 5.88 m, 5.04 m, and 6.72 m, respectively. Subsequently, ropes were manufactured with lengths three times that of the original sticks: U7(9), U7(12), U8(9), and U8(12), with equivalents of 13.23 m, 17.64 m, 15.12 m, and 20.16 m. The latter measurement closely approximated the *mecate* length used in Yucatan.

The study found that 29.9 percent ($n = 29$) of the 97 measurements could be evenly divided by three, and 13.4 percent ($n = 13$) by four. Moreover, 12.4 percent ($n = 12$) were divisible by both three and four, whereas 18.6 percent ($n = 18$) could be divided into five without a remainder. More than half (55.7 percent) of these instances were associated with the identified measuring instruments. Despite the importance of multiples of five in the pre-Hispanic vigesimal numerical system, no specific tool has been identified for this measurement. It is worth noting that the measurements recorded in the South Ballcourt correspond to multiples of ropes U7(12) on both sides, which is equivalent to eight long *k'aan*.

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Figure 8. Collocation of *morillos* on the structure's roofs in Cacaxtla. The *morillos* rested on the side walls, while the front wall (the west wall of Building B) is higher and prevented their movement. Photography from *La Pintura Mural Prehispánica en México*.

Table 4. Instrument frequency

	Ropes				Sticks			
#	12		9		4		3	
U	U8	U7	U8	U7	U8	U7	U8	U7
Altar							2	
Complexes		2	1	2	1			4
Staircases	3		2		2	2		2
Impluvia		1	1			1	1	1
Ballcourts					1		2	2
BC playing fields		2			2			1
Porticos	2	2	1		1	3	4	3
Total	5	7	5	2	7	6	9	13

Note: U = unit (U7 or U8); # = numeral; BC = Ballcourt

Calendar numerals

In Mesoamerican culture, time transcends the physical realm and has spiritual significance. The various cycles of the Mayan calendar, including solar, ritual, and long-count, function as markers of numerous rhythms that define the temporal dimension of existence. As previously noted, in Teotihuacan, terrestrial space was integrated with temporal space to convey the worldview (Sugiyama 1983, 1993, 2010). The same concept of the time-space-worldview relationship was implemented in Xochicalco's most symbolic structure, the Pyramid of the Feathered Serpents. The building's upper perimeter measures 12 U7 along its eastern and western edges, whereas the northern and southern sides extend 12 U8. The total circumference at the superior level is 360 *palmos*, calculated as ((12U7 + 12U8) × 2). The dimension of the ceremonial space in which the ritual participants positioned themselves reflects the *tun* of the Mayan calendar. In the Mayan long-count time system, a *tun* consists of 360 days divided into 18 months of 20 days each; 20 *tuns* form a *k'atun*, and 20 *k'atuns* form a *b'aktun*. Although the long-count system fell out of use around the tenth century, the solar calendar continued to be utilized and spread throughout Mesoamerica.

The integration of a worldview value into perimeter measurements aligns with Mesoamerican land measurement practices. As previously noted, square plots measuring 9 or 12

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zapal per side were referred to as 36 and 48 *zapal*, respectively, in terms of their perimeter.

Additionally, the Pyramid of the Feathered Serpents staircase spans five U7, which, when combined with the perimeter of 360 *palmos*, represents the 365-day solar cycle. This design encapsulates two fundamental cycles in the Mesoamerican worldview.

Vigesimal numerical system

Ancient Mesoamerican cultures utilized a vigesimal numerical system, likely stemming from counting digits on the hands and feet. Researchers applying Western methodologies have consistently used 20 and its multiples as divisors when analyzing measurement systems in these cultures (Drucker 1974:129–149). Employing this method, Tichy (1989) identified a fundamental unit of 0.26 m in his investigation on the Pyramid of the Feathered Serpents at Xochicalco. The number five, representing one hand, held significance as a factor of 20. Although not the most prevalent multiplier at Xochicalco, it appears 18 times at crucial locations, with multiples of 5, 10, 15, 20, 25, 30, and 40 observed.

The incorporation of these numerical values in ballcourts is noteworthy. The number 30 is commonly employed in playing fields, and its combination with U7 and U8 results in varying structural lengths. A ballcourt length was measured at 40 units, while the playing field width spanned 5 units. As a result, 5 out of the 12 numbers used in ballcourts were derived from the vigesimal system. The prevalence of vigesimal-based numerals in ballcourts indicates a potential relationship between their symbolic importance and functional roles.

The frequent occurrence of multiples of five underscores their significance in structuring terrestrial spaces, particularly within the context of the ballcourt, even in the absence of dedicated measuring instruments. In alternative locations, standardized measurement devices were employed to maintain the symbolic importance of these numerical values.

Measurement systems and numerical patterns

The strategic positioning of the U7 and U8 units in specific orientations, coupled with the use of measurements that were multiples of both these units and the number 12 for U7, was consistently implemented in relevant contexts. The importance of integrating multiples of 12 with the U7-8 unit is emphasized, as evidenced in the South Ballcourt, where this numerical pattern is manifested on all four sides of the playing field. This measurement was also observed in complexes Ac4 and G12, Acropolis Plaza, as well as in porticos I9 and B2-3.

The Pyramid of the Feathered Serpents exhibits the same numeral and units, albeit in a distinct configuration. Number 12 was present on all four cornice sides and was associated with U7 in V and U8 in H. This pattern of utilizing identical numerals with different units in each orientation is replicated exclusively on the Plaza Principal altar but employs the number 2. Both combinations are confined to specific instances and are potentially correlated with their significant roles and importance in Xochicalco's social space. Conversely, multiples of 12 U8 are observed on the stairs at the I2 terrace, east of the South Ballcourt, between sectors M and H, on the portico to access the Acropolis, and in B1-2-C1. This combination was primarily associated with steep staircases, in contrast to the 12 U7 measurements that were related to the two most prominent structures of the city.

The data analysis supported the notion that ballcourtswere conceptualized as dual rectangular structures: an exterior court encompassing an interior field. The variability in multiple values of 4, 5, or 6, contingent upon the unit employed (U7 or U8) for field width, suggests adaptability to terrain conditions or practical considerations, rather than symbolic ones.

In summary, the H walls exhibited a wider range of number and unit combinations, indicating greater dimensional flexibility in these orientations. The most common configuration was 6 U8, which occurred four times for V walls. Measurements of 12-10.5 U7-8, 30 U7, 6.5 U7, 6 U7, 12 U8, 4.5 U8, and 2.5 U8 were recorded three times (Table 5). This frequency may indicate standardization in the measurements for these walls, potentially related to the sunrise and sunset positions.

Final comments

The analysis of Xochicalco's architectural complexity has yielded insights into the primary units employed in its construction, associated numerical systems, the application of measurements for symbolic purposes, and their practical implications. This investigation encompasses a comprehension of the dimensions of standardized measuring tools and their implementation in the building process.

The two identified units were used in approximately equal proportions. These units, *maitl* and *zapal*, have been previously documented; however, their consistent usage and combined application within the same structure has not been recognized prior to this study. The unit documented in Teotihuacan is half the size of the U8, which corresponds to the *maitl* in the Nahua system, the fundamental unit of the Mexicas. This unit, measuring 1.68 m, or its half, has been identified through historical and ethnological studies, as well as recent archaeological research. The 0.02 m discrepancy between U8 and twice the Teotihuacan unit may be attributed to construction variability or an intentional effort to standardize the units for easier combinations. Studies on the Nahuas' main unit have suggested a conversion range of 1.66 m to 1.68 m, with most analyses based on historical document interpretations. However, at Xochicalco, the results were derived from built environment analysis. Conversely, U7 is equivalent to the *zapal* unit identified in the Puuc region. While this unit has been recently observed at Cacaxtla, no further research has demonstrated its utilization at other sites. Despite the references and approximations to the Teotihuacan measurement, at no time do we suggest that this is the result of any kind of relations established between Xochicalco and Teotihuacan. Rather, we believe that it may be a measure of long tradition or a cultural constant shared by several Mesoamerican cultures.

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Table 5. Measurement frequencies according to numerals

#		1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7.5	8	9	9.5	10	10.5	11	12	12.5	13.5	14	14.5	15	16	17	18	20	21	24	24.5	25	27	30	39	40	12–10.5	16–14	24–21	48–42	8–7	Total
U7	H	1	1		1	3					1										1			1	1					1			1	1									13
	V	1	1		2		1		1	1	3	3	1			1	1	1					2						1			1		1	3	1							26
Total		2	2		3	3	1		1	1	4	3	1			1	1	1			1		2	1	1				1	1		1	1	2	3	1							39
U7-U8	H																																							2	1	2	5
	V																																					3	2	1			6
Total																																						3	2	3	1	2	11
U8	H		1	2			1	1	2		1			1	2		1		1	1	1	1			1	1	1	2	2		1				2		1						27
	V	1	1	3	1			3	1	1	4			1	1					3																							20
Total		1	2	5	1		1	4	3	1	5			2	3		1		1	4	1	1			1	1	1	2	2		1				2		1						47
Total		3	4	5	4	3	2	4	4	2	9	3	1	2	3	1	2	1	1	4	2	1	2	1	2	1	1	2	3	1	1	1	1	2	5	1	1	3	2	3	1	2	97

Note: # = numeral; H = surfaces facing north or south; V = surfaces facing east or west; U = unit (U7 or U8).

Analysis of the measurement systems used at Xochicalco revealed that the implementation of units and their multiplication by specific numerical values extends beyond the fundamental requirements of structural sizing or spatial design. This observation suggests a level of complexity that would have necessitated comprehensive knowledge and meticulous planning on the part of the site architects and builders.

In this regard, it is noteworthy that U7 and U8 share a common factor of 0.21 m, which corresponds to a *palmo* or a span, a measurement with equivalent terms in both the Mayan and Nahua languages. The mathematical relationships between the units facilitated the use of measurements that could be interpreted using either system in locations of high symbolic significance, indicating an intentional design approach aimed at conveying deeper meaning through the dimensions of these spaces. The incorporation of measurements interpretable across both unit systems, coupled with the presence of the number 12, suggests a potential correlation to the Mesoamerican worldview, wherein time, space, and numerical values are deeply intertwined.

This combination was used to measure the South Ballcourt, which is notable for its dimensions, accessibility, configuration, and visibility, with the units and their associated numerical values emphasizing the concept of optimal design. The U7-8 unit is not present in the other two ballcourts, but U7 and U8 were incorporated consistently into the northern and eastern ballcourt and the playing fields of all three ballcourts, either in their length or width. This arrangement typically adheres to the same relational pattern of units and façade orientation observed in the Pyramid of the Feathered Serpents.

This monument's prominent location within the city's urban design, in conjunction with its alignment to the spatial and landscape axes, accentuates its significance. Our analysis confirmed the meticulous consideration given to incorporating its distinctive reliefs, which were appropriately dimensioned to convey symbolic meaning, further reinforcing its urban importance. The numeral 12 was observed on each side, with its H orientation multiplication by U8 and V orientation multiplication by U7, resulting in a perimeter corresponding to a Mayan *tun* (360 days). The construction plan demonstrated the precise implementation of measurement units through the incorporation of a staircase to complete the 365-day solar year.

This research revealed the novel use of arithmetic calculations in architectural design at Xochicalco, a practice not previously documented at other sites. This innovative approach, likely originated by Xochicalco's architects and builders, was evident in the dimensions of the square-shapes on the *tablero* at the monument's western face and in the measurements of its upper base, which corresponded to the U7 and U8 unit averages. The employment of units, numerical values, and averages as design solutions indicates sophisticated cognitive processes that integrate measurements into the structure's symbolic elements.

Specific numerical values and measurement units were consistently employed for particular types of constructions. For instance, the number 30 was frequently utilized to establish the length of playing fields in the three ballcourts, while the U8 unit was prominently featured in the measurements of the impluvia.

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Although the measurements held symbolic significance, they did not preclude the use of practical building standards. To facilitate the provision of instructions to stoneworkers and those supplying roof materials, appropriate dimensions were specified for areas covered by *morillos*. These dimensions employed identical units for both length and width, as well as numbers that were multiples of three. The prevalent use of these multiples, and to a lesser extent, multiples of four, corroborates the findings of various researchers regarding standardized cane measurements in the Maya region.

By examining the measurement system employed at Xochicalco, it was possible to ascertain the characteristics of the instruments used, particularly sticks and ropes. Our study demonstrated that the rope length used in Xochicalco, derived by multiplying U8 by 12, was slightly longer than the standard metric equivalent of approximately 20 m, which was assigned to the *mecate* currently used in Yucatan. The ongoing utilization of the *mecate* in contemporary times indicates that certain practices persisted and were adapted to the colonial measurement system based on *vara* and meter.

To ensure the validity of our conclusions, we deliberately avoided post hoc reasoning. Our methodological approach prioritized the examination of empirical data gathered throughout the investigation, and we subsequently juxtaposed our findings with those of related research. This approach allowed us to identify units, numerals, connections to construction systems, and instrument dimensions, without bias from preconceived notions. Although measurements found in Xochicalco correspond to *maitl* and *zapal*, it is important to approach these terms cautiously in the absence of a thorough comprehensive understanding of their cultural background. Otherwise, doing so might result in inadequate assumptions about the impact or presence of different cultural groups in Xochicalco.

Empirical evidence supports the identification of consistent patterns in unit dimensions and measurement applications, which exhibit variations based on orientation, function, and importance. Furthermore, the investigation confirmed hypotheses regarding the determinants of ballcourt dimensions and revealed that the measurement protocol for enclosed spaces is based on the roof constructive system. It is noteworthy that while some measurements did not exactly correspond to multiples of U7 and U8, these minor deviations can be attributed to initial construction measurement inaccuracies, site-specific adjustments to terrain or other architectural elements, and gradual deterioration. Importantly, these nonstandard measurements do not invalidate the measurement system identified at Xochicalco. In certain instances, units were likely employed with a degree of flexibility, demonstrating builders' capacity to adapt to the unique requirements of individual projects. This indicates a pragmatic approach to construction wherein mathematical precision coexists with contextual adaptability.

The Epiclassic period city-states of Xochicalco and Cacaxtla share a notable characteristic: their use of two units derived from the *palmo* and the implementation of standardized measuring devices. Interestingly, while Cacaxtla favored the U7 unit, with U8 appearing sporadically in measurements interpretable in both units (typically in areas of political or ceremonial significance, such as the Battle mural), Xochicalco employed both units with equal frequency. A common feature in both locations was the extensive use of multiples of three to determine the dimensions of courtyards and rooms. Specifically, in Cacaxtla, a 0.49 m unit was tripled to create 1.47 m, which was then tripled again for larger distances.

Although this study provides valuable insights, it was hindered by the limited dataset available. Broadening the scope of data collection and exploring other variables could deepen our understanding of additional patterns, correlations, building techniques, and the symbolic relevance of measurements within the Xochicalco measurement system. Despite some limitations, these findings contribute to a more nuanced understanding of the measurement and construction methods used in the intricate spatial layout of Xochicalco. Additionally, they shed light on cultural interactions and architectural traditions during the Epiclassic period in Mesoamerica. Furthermore, these findings highlight the enduring and widespread nature of certain measurement techniques, such as the *mecate*, which continues to be used even in modern times.

Our research seeks to stimulate future scholarly investigations that focus on elucidating and validating the diverse measurement systems employed throughout different chronological and geographical contexts in Mesoamerica.

Data availability statement. The data supporting this study are not publicly available, but they can be accessed upon reasonable request to the corresponding author. The recorded archaeological structures can be remeasured using the provided methodology and available datasets.

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Competing interests. The author(s) declare none.

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