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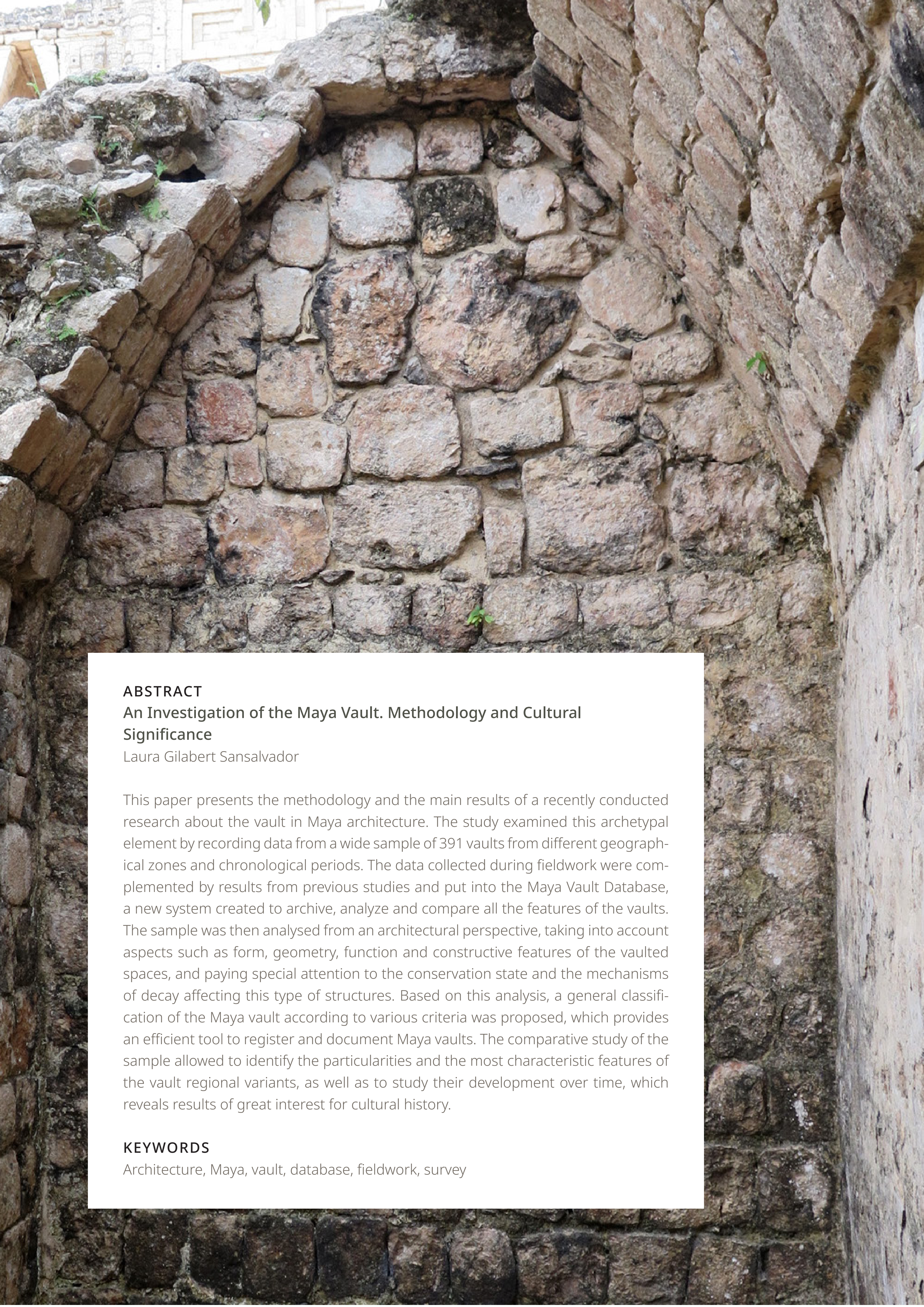


ABSTRACT

An Investigation of the Maya Vault. Methodology and Cultural Significance

Laura Gilabert Sansalvador

This paper presents the methodology and the main results of a recently conducted research about the vault in Maya architecture. The study examined this archetypal element by recording data from a wide sample of 391 vaults from different geographical zones and chronological periods. The data collected during fieldwork were complemented by results from previous studies and put into the Maya Vault Database, a new system created to archive, analyze and compare all the features of the vaults. The sample was then analysed from an architectural perspective, taking into account aspects such as form, geometry, function and constructive features of the vaulted spaces, and paying special attention to the conservation state and the mechanisms of decay affecting this type of structures. Based on this analysis, a general classification of the Maya vault according to various criteria was proposed, which provides an efficient tool to register and document Maya vaults. The comparative study of the sample allowed to identify the particularities and the most characteristic features of the vault regional variants, as well as to study their development over time, which reveals results of great interest for cultural history.

KEYWORDS

Architecture, Maya, vault, database, fieldwork, survey

LAURA GILABERT SANSALVADOR

An Investigation of the Maya Vault

Methodology and Cultural Significance

Introduction

1 The vault is one of the most hallmark elements of Maya architecture. In the period of their greatest splendor and for more than ten centuries, the Maya used the vault as the stone ceiling system for many temples and palaces. This long constructive tradition shows the continuity of building techniques employed by this ancient culture, and offers the opportunity to analyze how technological progress differs between the regions of the Maya Lowlands.

2 The vault system used by the ancient Maya is based on the structural principle of corbeling, which consists of placing stones projecting above one another. A corbeled vault is built up from opposing walls advancing in stepped-out courses that progress forward until closing the space with a final course of slabs or capstones (Fig. 1). The stability of this system is based on the correct counterbalance of each of the courses of stones, either by its own weight or by a back filling core that prevents from overturning. A common Maya vault is composed of four sides: two “half-vaults” running parallel to the long dimension of the space covered and spanning roughly half of it, and two “end-vaults” or tympanums that close the space at its ends (Loten – Pendergast 1984: 15).

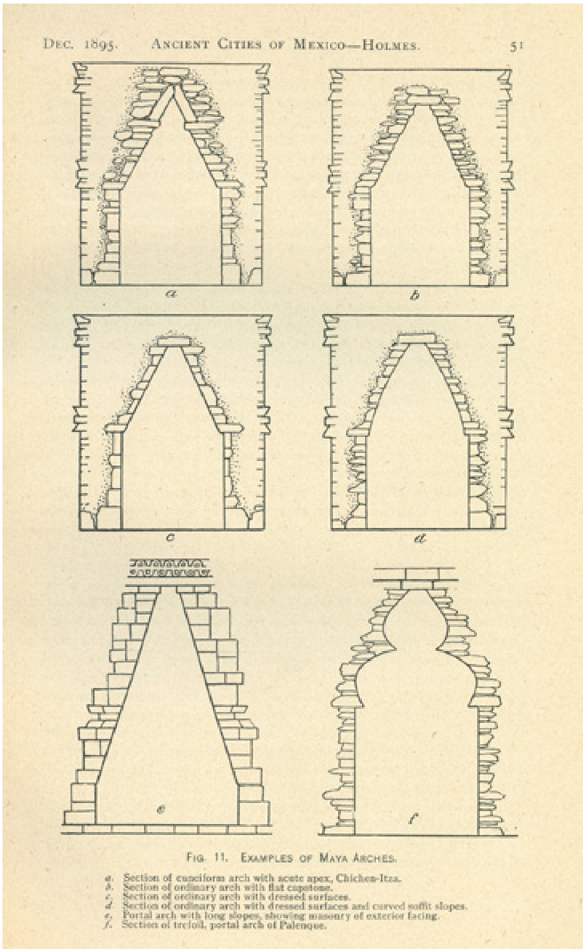
3 For being simple and intuitive, corbeled vaults and domes were used by many ancient cultures. The main advantage of this building technique is that it admits uncut stones, nevertheless, it requires thick walls and achieves limited spans. While the Maya initially used this system, eventually they developed a wide range of formal and constructive types of vaults. Over time, the development of stonemasonry and vault technology allowed the Maya builders to achieve advanced constructive solutions to cover wider spaces and to perfect the inside form.

4 As an archetypal element of Maya architecture, the vault is mentioned in all existing literature on this topic. Vaulted roofs are already described in the chronicles of the 16th-century Spanish conquest of Yucatan[1] and also appear in the drawings, photo-

1 As an example, Friar Antonio de Ciudad Real (Ciudad Real 1872: 456) describes the Uxmal vaults in *Tratado curioso y docto de las grandezas de la Nueva España.*

Fig. 1: Early Classic corbeled vault of 5D-86 Building in Mundo Perdido in Tikal

Fig. 2: Examples of Maya arches from W.H. Holmes (Holmes 1895: 51)



graphs and descriptions of the explorers who traveled around Central America during the 19th century[2]. The topic of the vault is discussed in many of the great works from the 20th century on Maya art and architecture, although in most cases the descriptions are generic and do not deepen the vaulted buildings technique.

5 The most recurrent way of showing the great variety of vaults that exist in the Maya area is comparing cross-sections of different vaults. One of the first attempts of this type of classifications appears in the work of William Henry Holmes, *Archeological studies among the ancient cities of Mexico* (1895), who, when describing the architectural features of the monuments of Yucatan, added an illustration with drawings of six "examples of Maya arches" (Fig. 2). The author explained that this figure includes the predominant types and that most of the other vaults he had observed were merely variations of them (Holmes 1895: 49). In this spontaneous classification, Holmes established the curved and the straight sided formal types and already took into account constructive aspects such as how vault stones were dressed or the flatness of the soffits obtained. Together with four generic types of vaults, he added two very singular real cases: one of the arches of the House of the Governor of Uxmal and the trefoil arch of the Palace of Palenque (Fig. 2).

6 Later, several authors reused Holmes' graphic, extending and modifying it, but it has rarely been reviewed with

2 In *Incidents of Travel in Yucatan*, J. Stephens (Stephens 1843: 429–434) includes the appendix *System adopted by the ancient builders of Yucatan in covering their rooms with stone roofs*, which probably is the first text specifically dedicated to the Maya vault. In it, Stephens explains the differences between the corbeled vault and the "true arch", emphasizing the horizontality of the joints and the limitation on covering wide spaces of the first one.

fieldwork. Consequently, many comparative graphics of different types of vaults have been published[3], frequently with identification errors and generic typologies mixed up with very unique real cases that cannot be considered types. While these graphics may offer samples of examples of vaults, they often mix formal, functional and constructive criteria, in ways that cannot be considered methodological classifications or proposals of types of Maya vaults.

7 In certain geographical areas, especially in the Puuc, vault constructive technology has been studied through exhaustive field data collections such as those by Harry E.D. Pollock, Paul Gendrop or George F. Andrews, while in other areas the topic has barely been studied. Generally, due to the lack of specialized architectural studies, the constructive and structural knowledge of vaulted Maya buildings is scarce, in spite of the great importance of such questions for the conservation of a relevant cultural heritage as that of the Maya architecture.

Aims and objetives

8 In the light of this background, the present study – first published as a doctoral thesis (Gilabert Sansalvador 2018b) – investigated the Maya vault from an architectural perspective. Aiming both to advance our understanding of the Maya vault, in specific, and of the Maya architecture and culture, in general, as well as to provide useful results for the conservation of this architectural heritage, the following objectives were formulated:

1. Propose a general classification of the Maya vault according to several criteria, establishing formal, functional and constructive typologies that allow for a complete categorization. The geographical scope was the ancient Maya Lowlands, where masonry vault was the most predominant ceiling system for monumental architecture
2. Characterize the vaults of the ancient Maya Lowlands main regions, identifying their particularities and distinctive features, and also study their development over time.
3. Formulate criteria appropriate for the excavation, conservation and restoration of vaulted Maya buildings. In order to do this, the most common deterioration processes and forms of structural collapse were identified and analyzed.

Methodology and research procedure

9 Having formulated the objectives above, it was necessary to design an adequate methodology to achieve them. A close look at the literature revealed that no specific data collection had been carried out to date for the research of the Maya vault. Therefore, in the present study, fieldwork was established as the main methodological strategy to collect a large number of data from different types of vaults, regions and chronological periods. At the same time, it was important to design an efficient system to store all the information in an orderly manner. To this end, a Maya Vaults Database (MVD) was created, which allows to store all the features of the vaults, as well as to later extract the data for analysis and comparison.

10 The methodology used is divided into five stages described below: the design of a vaults recording form, the field data collection, the creation of the Maya Vaults Database, the data processing and entering and, finally, the design of the strategies for data exploitation.

3 e.g. Smith (Smith 1962: 208), Morley (Morley 1947: 382), Toscano (Toscano 1952: 118), Gendrop (Gendrop 1970: 67), Sharer – Traxler (Sharer – Traxler 2006: 216).

Design of a vaults recording form

11 In order to systematically collect the information at the archaeological sites, before starting fieldwork a vaults recording form was designed (Fig. 3). During the first data collection campaigns, a process of continual reviewing of this template was carried out, allowing to improve some variables or to add variables that had not been considered a priori.

12 The features and parameters to be recorded in each vault were determined from the detailed study of the vaults of La Blanca, in Peten (Guatemala). The analysis of the architecture of this site's Acropolis was conducted as an experimental phase and pilot study of this work, and it was very useful to establish the survey methodology in other sites[4]. When preparing the vaults recording form, the works of Harry E.D. Pollock (Pollock 1980) and the architectural surveys reports of George F. Andrews[5] were used as the main references, as these record numerous characteristics of the vaulted buildings. Other examples consulted were the cataloguing sheet proposed by Alfonso Muñoz Cosme (Muñoz Cosme 1991) for the architectural analysis of the Oxkintok palace rooms and the electronic file for the investigation of Maya architecture designed by Manuel May Castillo and Gaspar Muñoz Cosme (May Castillo – Muñoz Cosme 2010).

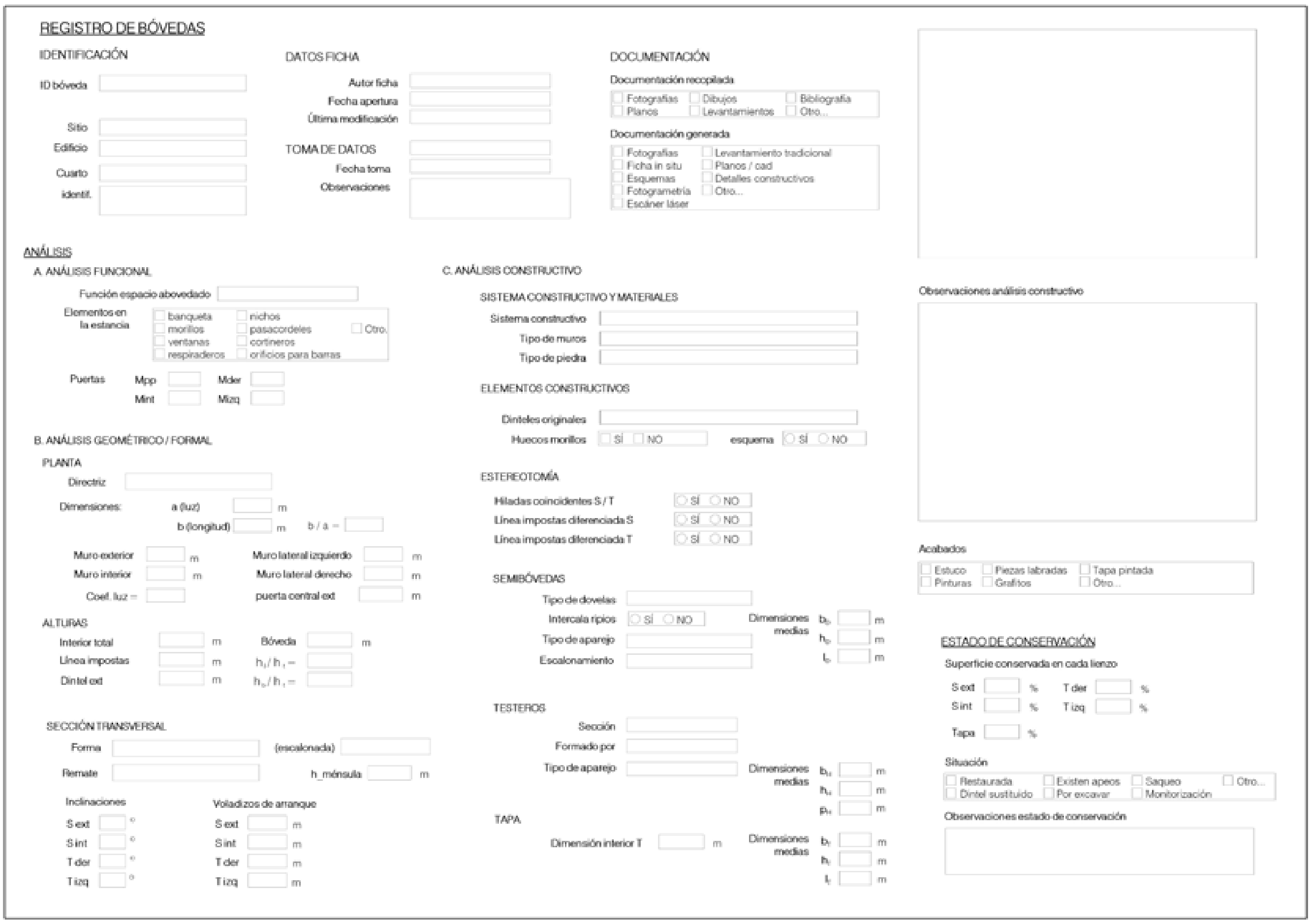

REGISTRO DE BÓVEDAS
IDENTIFICACIÓN
ID bóveda
Sitio
Edificio
Cuarto
identif.
DATOS FICHA
Autor ficha
Fecha apertura
Última modificación
TOMA DE DATOS
Fecha toma
Observaciones
DOCUMENTACIÓN
Documentación recopilada
Fotografías, Dibujos, Bibliografía, Planos, Levantamientos, Otro...
Documentación generada
Fotografías, Ficha in situ, Esquemas, Fotogrametría, Escáner láser, Levantamiento tradicional, Planos / cad, Detalles constructivos, Otro...
ANÁLISIS
A. ANÁLISIS FUNCIONAL
Función espacio abovedado
Elementos en la estancia: banqueta, morillos, ventanas, respiraderos, nichos, pasacordeles, cortineros, orificios para barras, Otro
Puertas Mpp Mder Mint Mizq
B. ANÁLISIS GEOMÉTRICO / FORMAL
PLANTA
Directriz
Dimensiones: a (luz) m, b (longitud) m, b / a =
Muro exterior m, Muro interior m, Coef. luz =, Muro lateral izquierdo m, Muro lateral derecho m, puerta central ext m
ALTURAS
Interior total m, Línea impostas m, Dintel ext m, Bóveda m, h_i / h_t =, h_v / h_t =
SECCIÓN TRANSVERSAL
Forma, (escalonada), Remate, h_ménsula m
Inclinaciones: S ext °, S int °, T der °, T izq °
Voladizos de arranque: S ext m, S int m, T der m, T izq m
C. ANÁLISIS CONSTRUCTIVO
SISTEMA CONSTRUCTIVO Y MATERIALES
Sistema constructivo, Tipo de muros, Tipo de piedra
ELEMENTOS CONSTRUCTIVOS
Dinteles originales, Huecos morillos SÍ NO, esquema SÍ NO
ESTEREOTOMÍA
Hiladas coincidentes S / T SÍ NO
Línea impostas diferenciada S SÍ NO
Línea impostas diferenciada T SÍ NO
SEMIBÓVEDAS
Tipo de dovelas, Intercala ripios SÍ NO, Tipo de aparejo, Escalonamiento, Dimensiones medias b_b m, h_b m, l_b m
TESTEROS
Sección, Formado por, Tipo de aparejo, Dimensiones medias b_t m, h_t m, p_t m
TAPA
Dimensión interior T m, Dimensiones medias b_T m, h_T m, l_T m
Observaciones análisis constructivo
Acabados: Estuco, Pinturas, Piezas labradas, Grafitos, Tapa pintada, Otro...
ESTADO DE CONSERVACIÓN
Superficie conservada en cada lienzo
S ext %, S int %, T der %, T izq %, Tapa %
Situación: Restaurada, Dintel sustituido, Existen apeos, Por excavar, Saqueo, Monitorización, Otro...
Observaciones estado de conservación

Fig. 3: Vaults recording form

13 The vaults recording form, created ad hoc in order to characterize in detail a Maya vault (Fig. 3), is structured in eight sections that allow its identification, registration of its formal, geometric, constructive and functional features, and to approach the conservation state of the vault:

4 See Gilabert Sansalvador and Muñoz Cosme (Gilabert Sansalvador – Muñoz Cosme 2015) and Gilabert Sansalvador (Gilabert Sansalvador 2018a).

5 *George F. and Geraldine D. Andrews papers*, Alexander Architectural Archive of The University of Texas at Austin.

1. Vault identification
2. Recording form information
3. Field data collection information
4. Existing and collected documentation about the vault
5. Functional aspects
6. Geometrical and formal aspects
7. Constructive aspects
8. Conservation state

14 The data in this template are recorded as qualitative and quantitative variables, complemented with different types of graphical documentation such as photographs, surveys, drawings and sketches made in situ, as described in the following paragraph. Based on this form, the Maya Vault Database was created, with its structure and variables detailed below.

Field data collection

15 The fieldwork carried out for this study was organized into five data collection campaigns performed between 2015 and 2017. Having made a plan for the sites and buildings to be visited, a first extensive campaign to collect a large number of data in several regions allowed to obtain partial results. Second, four subsequent intensive campaigns in specific geographical areas allowed to complement the previously collected data by considering further aspects that revealed themselves to be of great importance based on partial analyses from the first campaign. As discussed below, these data were collected from 200 buildings at 48 Maya Lowlands archaeological sites (Fig. 4), providing a substantial base for a thorough study of the Maya vault.

16 During the field visits to the sites, an exhaustive photographic documentation of the buildings was carried out, as well as the register of the data of each vault in the recording form. In addition, when possible, the author performed manual and digital surveys in order to dispose of more detailed information of part of the sample. After each field campaign, the data were processed and entered into the database. The partial results obtained allowed to improve the recording and data management systems for the following campaigns.

17 The tools used during fieldwork were: a set of blank recording forms (Fig. 3), printed plans of the sites and buildings, some drawing tools such as sketch paper and pencils, common measuring instruments such as a laser distance meter, a tape, an angle meter and a level; and a camera and some photography accessories such as a tripod, a LED panel light, a colorchecker or some targets.

18 In each site, the author first went on a preliminary site inspection to identify the buildings whose vaults were to be recorded. The first criterion for selection was the possibility of access to the vaulted spaces[6]. Second, each case study was selected based on level of preservation of the structure, relevance of the building and features of the vault.

19 The first step in recording a vault was to identify it by writing down the building it belongs to and the room it covers, either on an existing building plan or on a floor plan sketched ad hoc with the numbering of the rooms. The level of detail recorded for each specific vault was restricted by the level of preservation of the building and the available time in each case. As seen in Fig. 5, four levels of information were established

6 Prior to starting fieldwork the author requested authorization to the competent administration in each case: Instituto de Antropología e Historia (IDAEH) in Guatemala, Instituto Hondureño de Antropología e Historia (IHAH) in Honduras, National Institute of Culture and History (NICH) in Belice and Instituto Nacional de Antropología e Historia (INAH) in the mexican states of Yucatan, Campeche and Quinatana Roo.

Fig. 4: Maya archaeological sites with recorded vaults

for the data collected directly in the field[7]: the lowest one (level 4) is that of the vaults with identification data and photographs, from which information about some formal and constructive features was obtained. In addition to the photographs, in vaults with the 3rd level of information the main measurements (wide, lenght and heights) were registered on drawings made in situ. Level 2 is that of the vaults with also the recording form filled in, so that formal, geometrical, functional and constructive features are

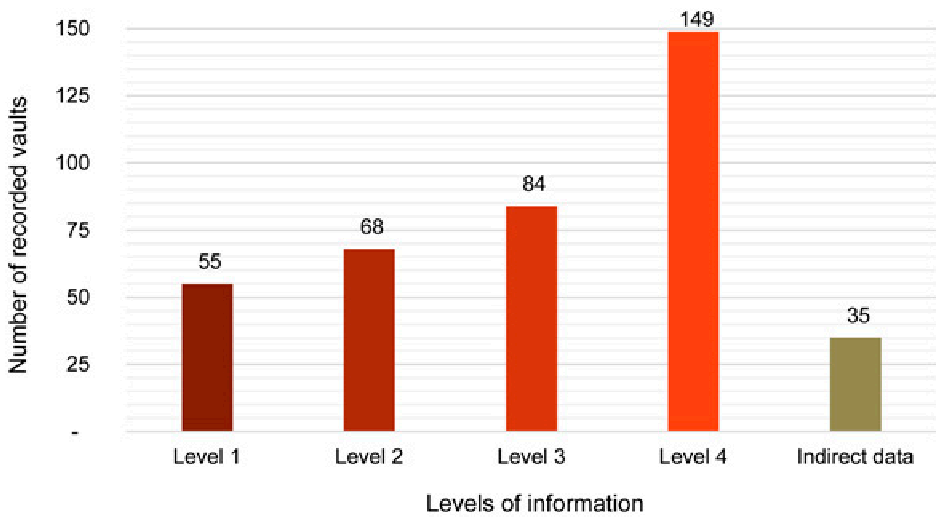


Fig. 5: Number of recorded vaults by level of information

7 The sample includes three types of data collection: “Direct” when the data were collected in the field; “Indirect” when the data come from the literature or from a person or institution; “Mixed” when the data were collected directly in the field and complemented with indirect data.

defined. Finally, vaults recorded with the most detail are those of Level 1, in which also an architectural survey was performed, either manually, by hand measurement and dimensioned sketches (Fig. 6), or digitally, by a photogrammetric survey, according to the method explained below. In 35 of the cases the data collection was indirect, i.e. the identification, a few constructive features and the available measurements were obtained from previous studies and surveys that were cited in the database (Fig. 5).

20 In addition to the above-mentioned documentation and data, and regardless of the level of information reached in each case, extra data related to specific topics were also recorded. The first topic regarded the preservation state of the vaults. In those vaults partially fallen, the author drew plans indicating which parts of the vault were preserved (Fig. 7). Subsequently, these schemes allowed to identify and study the most common decay processes of these structures.

21 Another topic of interest concerned vault beams – wooden logs that crossed the rooms transversely in several rows placed at different heights, and whose function has been debated since the first studies on Maya architecture. Being of a perishable material, most vault beams have disappeared, and nowadays there remains only the holes where they were embedded. Vault beams vary widely in number, shape and arrangement, so during fieldwork data collection, and when the conservation state of the vault allowed it, a longitudinal section of the room was sketched to document the shape and distribution of the vault beam holes (Fig. 8).

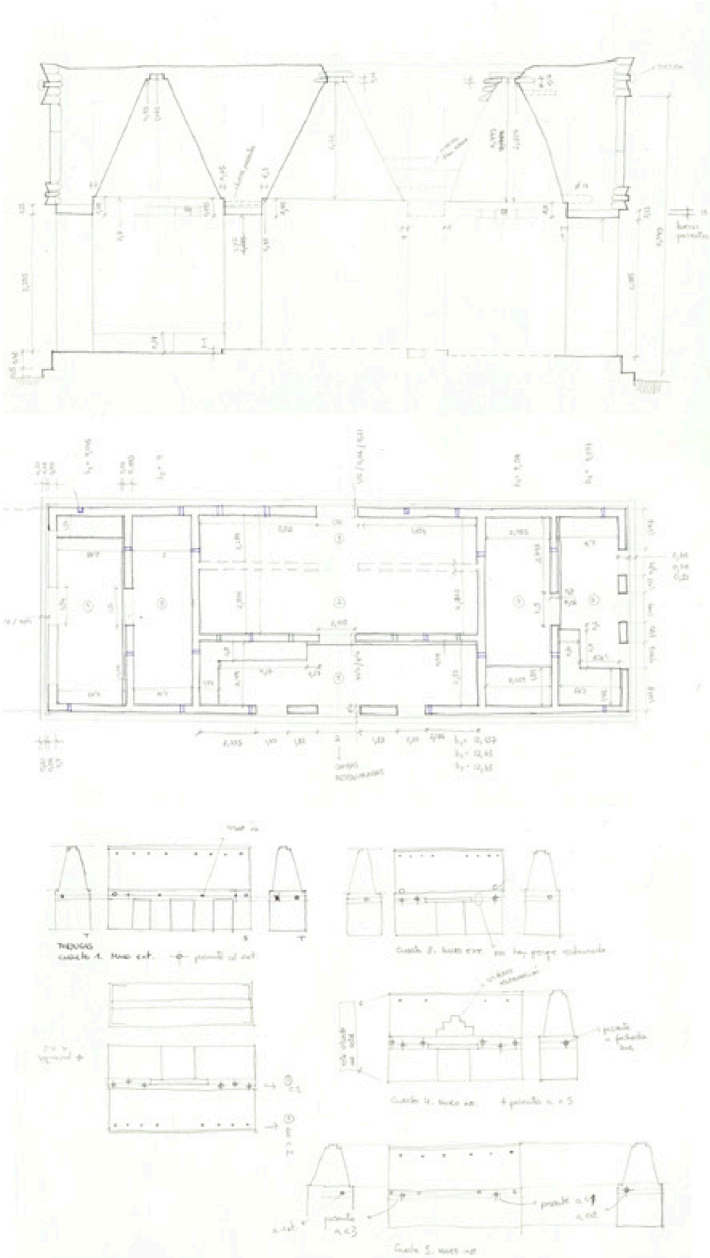


Fig. 6: Sketches from the manual survey conducted for the House of the Turtles of Uxmal

22 Surveying a part of the vaults of the sample by digital photogrammetry allowed to obtain geometrically accurate models with a high quality photographic texture, used to measure, analyze and compare their characteristics in detail. The main advantage of this technique is that it permits to obtain a high level of information from a data collection that is less time-consuming and that can be performed with low cost

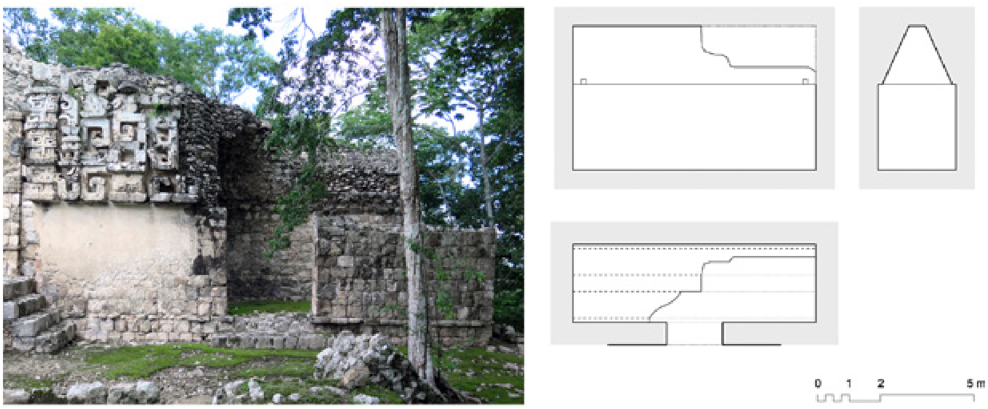


Fig. 7: Preservation graphic of a vault from the Structure 2 of Hochob

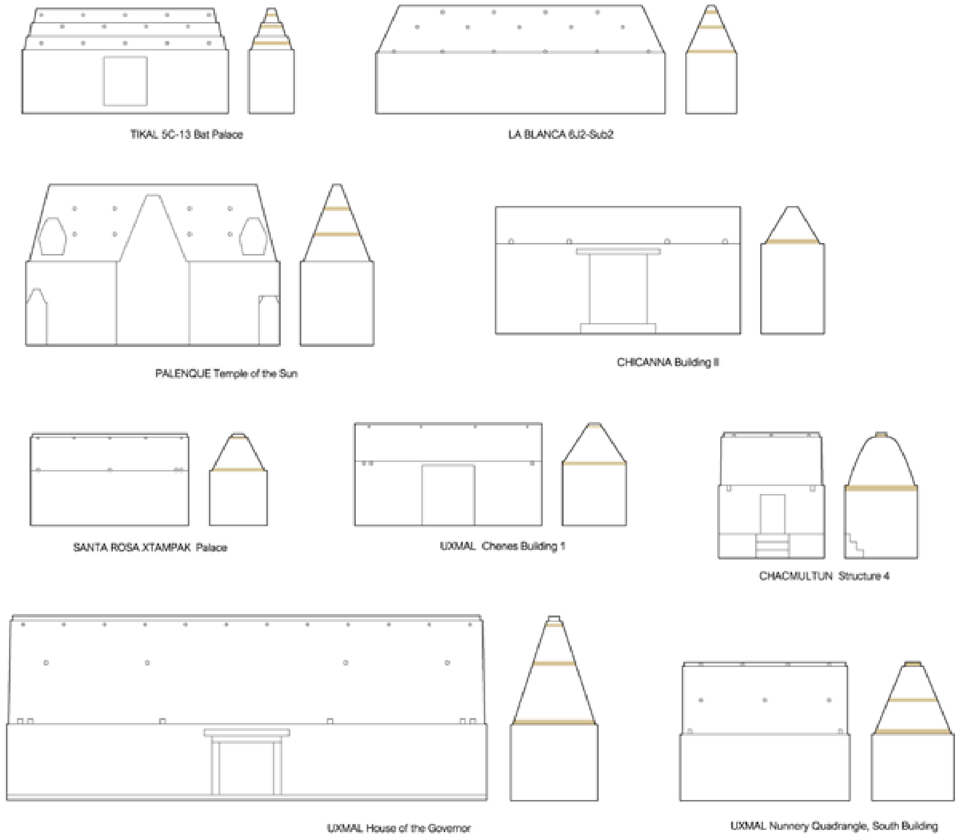


Fig. 8: Examples of different vault beam arrangements recorded in the field

instruments that are easy to carry: a digital camera, a colorchecker, a tripod, a LED panel light, a level and a laser distance meter.

23 The data collection for the digital documentation of the vaults was organized in two phases: the photogrammetric survey and a direct survey to record the distances between several targets located in an horizontal reference plane, which later allowed to scale and orientate the 3D model obtained. For each vault, several photographic sets were taken from different angles, using a colorchecker to later balance and homogenize the chromatic data (Fig. 9). In cases where the vaulted ceiling was entirely preserved, interior rooms were usually dark spaces, which made it necessary to use a tripod or a light panel that is placed on the camera and works with batteries.

24 In a later stage of laboratory work, all the photographic sets were processed with the *Agisoft Photoscan* digital photogrammetry software to obtain a highly detailed polygon mesh with photographic texture. Then the data from the direct survey were added: each reference point was individualized in the 3D model by placing a marker, and measurements taken in situ were introduced in the digital model to orientate and scale it. As a result, a real-scale and chromatically true-to-reality model for each of the vaults was obtained (Fig. 10). These 3D models were very useful to documentate the vaults and allowed to obtain scaled ortophotos to thoroughly analyze the geometry, form and constructive features of the vaults (Fig. 11). From the examination of the model, slopes or deformations that otherwise were invisible to the eye could be detected, quantified and measured. Moreover, these high-quality

Fig. 9: Use of a colorchecker when performing a digital photogrammetric survey

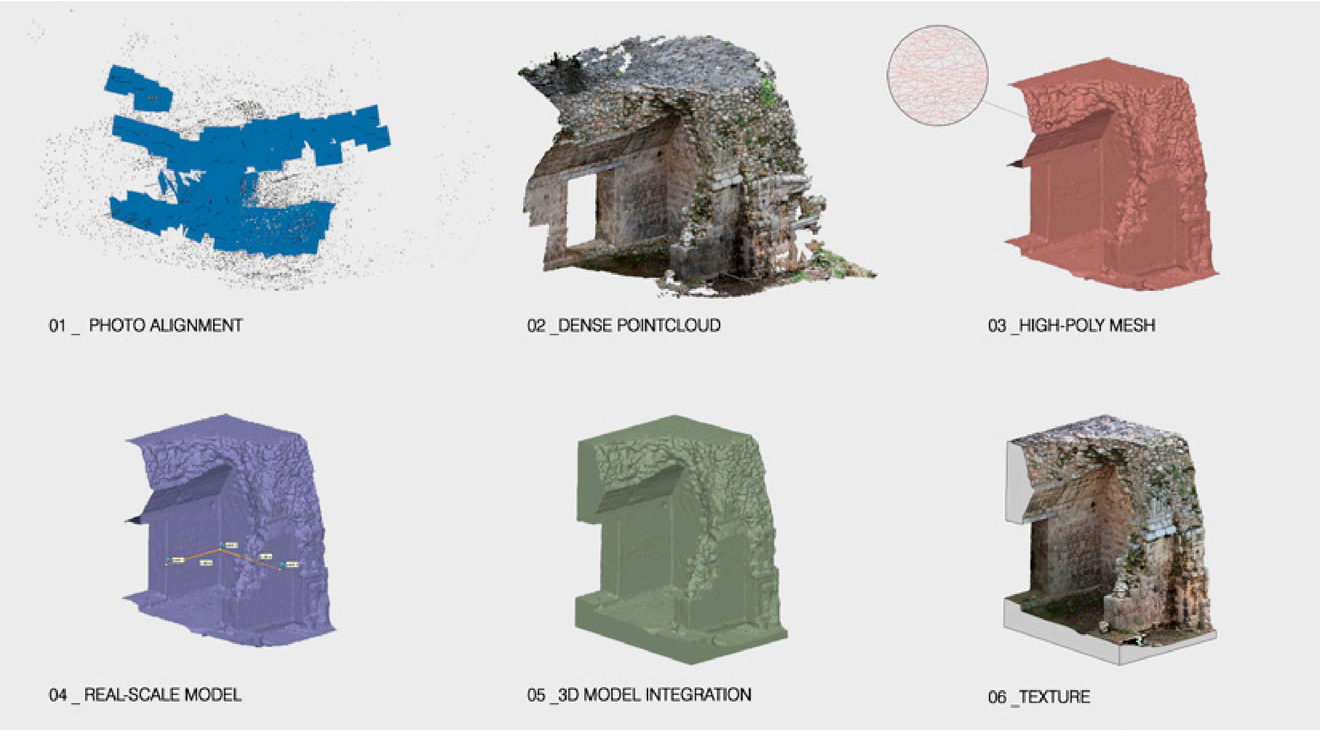


Fig. 10: Processing of the photogrammetric model of a vault from the Chenes Building 1 of Uxmal

3D models can have many other applications in terms of heritage dissemination through virtual reality applications[8].

Creating a Maya Vault Database

25 Based on the structure and variables included in the field registration form (Fig. 3), the Maya Vaults Database (MVB) was created as an easily accessible system to archive and compare all the features of the vaults. MVB is a relational database created with the database management system *Filemaker Pro* and consists of three related data tables:

1. *Sites table* stores the general information of each recorded archaeological site, such as the geographical area it belongs to.
2. *Buildings table* contains data of the buildings the vaults belong to. It is related to the previous table in the sense that in order to enter a building it is necessary to choose an existing site previously recorded in *Sites table*.
3. *Vaults table* contains the information of case study vaults. As in the previous relationship, in order to enter a new vault it is necessary to select the building it belongs to among those recorded in *Buildings table*.

26 Each table contains several fields[9] to be filled in when entering the data of each record. *Vaults table* contains 77 fields and is the most complex one, as it is designed to meticulously characterize the vaults. *Buildings table* stores information about the buildings in 18 fields, permitting, for example, to compare between vaults that belong to a certain architectural typology or to a specific chronological period buildings. *Sites table* is the most general one and contains 7 fields to place the studied buildings and vaults, so that comparisons can be made between vaults of different sites or geographical areas.

8 See Montuori and Gilabert Sansalvador (Montuori – Gilabert Sansalvador 2018).

9 Depending on the nature of each field the values to enter can be: a free text, a numerical value, an option from a drop-down list of values or a date from a drop-down calendar. In addition, the software can insert the result of a calculation according to a previously set formula.

Fig. 11: Comparative orthophotos and sections obtained from the photogrammetric models of three of the vaults studied

27 These tables are related through a match field: *Sites table* is related with *Buildings table* through the field “Name of the site” to which the building belongs, and, in turn, *Buildings table* is related to *Vaults table* through the field “Name of the building” to which the vault belongs. The database allows to easily extract the information by doing searches with one or several criteria, such as “vaulted rooms narrower than 2 meters” (one search criterion) or “concave shaped vaults with wedge-type vault stones” (two search criteria). The advantage of having related tables is that data can be exploited by searching through these relationships. To do this, one or various search criteria[10] are given in the desired fields and the software finds the records that match those entered criteria, e.g.: “vaults wider than 3 m from Usumacinta area” (data from Vaults and Sites tables); “vaults from Early Classic buildings” (data from Vaults and Buildings tables); or “vaults wider than 2 m from temples of Peten” (data from Vaults, Buildings and Sites tables).

28 Next we define the fields of each table:

Fields of ***Sites table***

– Site name
– Site identification code[11]
– Country
– State or department
– Geographic coordinates
– Region or geographical area[12]
– Site plan with identification of the buildings: author, year and source

Fields of ***Buildings table***

• Identification data
– Building name
– Building identification code[13]
– Archeological site where it is located
– Group which it belongs to

• Chronological data
Chronological information of the recorded buildings was taken from existing literature sources. Through the relationship between Buildings and Vaults tables, it was possible to compare the features of vaults from different time periods and study the development of the vault over time, both for each specific region and in general. Since the dating of Maya

10 Searches can include comparison operators such as “less than”, “greater than”, “greater than or equal to” or a numerical range. It is possible to save searches and to export the results to several formats.

11 Examples: HO (Hochob); TK (Tikal).

12 Fig. 4 shows the eight regions considered for the ancient Maya Lowlands. This division is based on the stylistic provinces proposed by Gendrop (Gendrop 1983: 16), who divides Southern Lowlands in the Peten area and the Pasion, Motagua and Usumacinta river basins. For Northern Lowlands, in addition to the regions defined by Gendrop (Puuc, Chenes, Rio Bec and Caribbean coast), Northern Plains Area was added, as proposed by Andrews (Andrews 1995: 274). This geographical division takes the name of the predominant architectural style for some areas, such as Rio Bec, Chenes and Puuc. In other cases it establishes wider divisions such as those of the river basins. In any case, these are approximate delimitations that also leave not defined intermediate areas in which there are many archaeological sites. It should be noted that this delimitation does not imply that all buildings in the same region belong to the same style and, in addition, there may be buildings of a certain style located in geographical areas assigned to another predominant style.

13 Examples: HO_2 (Building 2 of Hochob); TK_G_58 (Building 58 of Group G of Tikal).

buildings was determined through different methods[14], several fields were created to specify the most appropiate type of dating in each case:

- – Chronological period
- – Absolute dating or interval between two dates
- – Bibliographic source of dating
- – Architectural style attributed to the building
- – Substyle attributed to the building
- – Bibliographic source of stylistic classification

In order to compare all available building datings with a common criterion, it was necessary to create a table of equivalences for the periods and styles defined for each region in the existing literature. With this table it was possible to place most of the buildings under investigation in a common chronology, which allowed to examine the development of the vaults over time.

• Building descriptive data

- – Architectural typology[15]
- – Number of floor levels
- – Evidences of roofcomb
- – Distributive typology[16]
- – Number of parallel bays or rows of rooms
- – Distribution of rooms and bays[17]
- – Observations or additional information

• Collected existing documentation about the building

Types of collected documentation: photographs, plans, drawings, surveys, specific literature, a building floor plan with the numering of the rooms[18]...etc.

Fields of ***Vaults table***

• Identification data

- – Building to which the vault belongs
- – Number of the room that it covers
- – Source of the building floor plan with the numbering of the rooms
- – Vault identification code[19]

14 In the best cases, buildings are dated by Carbon-14 analysis of organic materials or by epigraphic data from lintels, wall paintings, stelae or tombs. When the building is attributed to a ruler whose period in power is known by epigraphic data, its chronology is defined by a time interval. In most cases, ceramic data allow to assigne the buildings to one of the Maya cultural periods (Preclassic, Classic, Postclassic and their subdivisions), which offers a more imprecise dating. Moreover, in some regions the established architectural styles are attributed to specific time periods and, although dating a building by its architectural and iconographic features has certain limitations, in most cases it can give a more specific time interval.

15 Based on the classification proposed by Muñoz Cosme (Muñoz Cosme 2006), the following architectural typologies for Maya architecture were considered: palaces, temples, ball courts, towers, quadrangles, astronomical buildings, labyrinths, sweatbaths, markets, aqueducts and city walls. Moreover, the “urban arches” typology (Gilabert Sansalvador – Peiró Vitoria – Martínez Vanaclocha 2017) and the “multi-purpose complexes” typology, proposed by Gendrop (Gendrop 1983: 73–78), were added.

16 Distributive type of the building’s main floor according to the typologies defined by May Castillo and Muñoz Cosme (May Castillo – Muñoz Cosme 2010).

17 Code to define the number and distribution of rooms and bays (May Castillo – Muñoz Cosme 2010).

18 For each of the buildings, the database includes a floor plan with the numbering of the rooms, either taken from the literature or elaborated *ad hoc*.

19 Examples: HO_2_1 (vault of room 1 of Building 2 of Hochob); TK_G_58_14 (vault of room 14 of building 58 of G Group of Tikal).

- Information about the vault registration form
  - – Author
  - – Date of file opening
  - – Date of file last edition

- Data collection information
  - – Data collection type: direct, indirect or mixed
  - – Date of data collection
  - – Additional information such as support received from other researchers or sources consulted

- Collected existing or generated documentation about the vault
  - – Types of existing documentation: photographs, plans, drawings, surveys, specific literature, etc.
  - – Types of generated documentation: photographs, vault registration form, manual or digital surveys, plans, construction details, sections with the vault beams distribution, preservation plans, etc.

- Vault functional aspects
  - – Vaulted space function
  - – Types of existing architectural elements inside the room such as benches or platforms, wall openings, cordholders, hangers, rod sockets, stone rings…etc.
  - – Number of doors on each side of the room

- Vault geometrical and formal aspects (Fig. 12)
  - – Vault axis form
  - – Vault span or width of the room: a (m)
  - – Lenght of the room: b (m)
  - – Thickness of the room perimetral walls (m)
  - – Width of the outer central doorway: p_{ext} (m)
  - – Interior height of the room h_t (m), from floor to bottom of capstones
  - – Vault spring height h_i (m), from floor to springline
  - – Vault height h_b (m), from springline to bottom of capstones, being $h_b = h_t - h_i$
  - – Lintel height h_d (m), from floor to bottom of lintel
  - – Cross-section shape of the vault (half-vaults shape)
  - – Steps shape (only for stepped vaults)
  - – Vault top form
  - – Capstone molding height (m)
  - – Longintudinal-section shape of the vault (end-vaults shape)
  - – Half-vaults slope, measured in degrees above the horizontal
  - – End-vaults slope, measured in degrees above the horizontal
  - – Measurements of the overhangs at vault spring, both in half-vaults and in end-vaults (m)

- Vault constructive aspects
  - – Constructive system of the building
  - – Type of stonework walls
  - – Type of stone
  - – Lintels type and materials
  - – Vault beams evidences: size, shape and ditribution of the holes
  - – Vault stones shape and dressing
  - – Vault stones dimensions: base, height and depth (m)

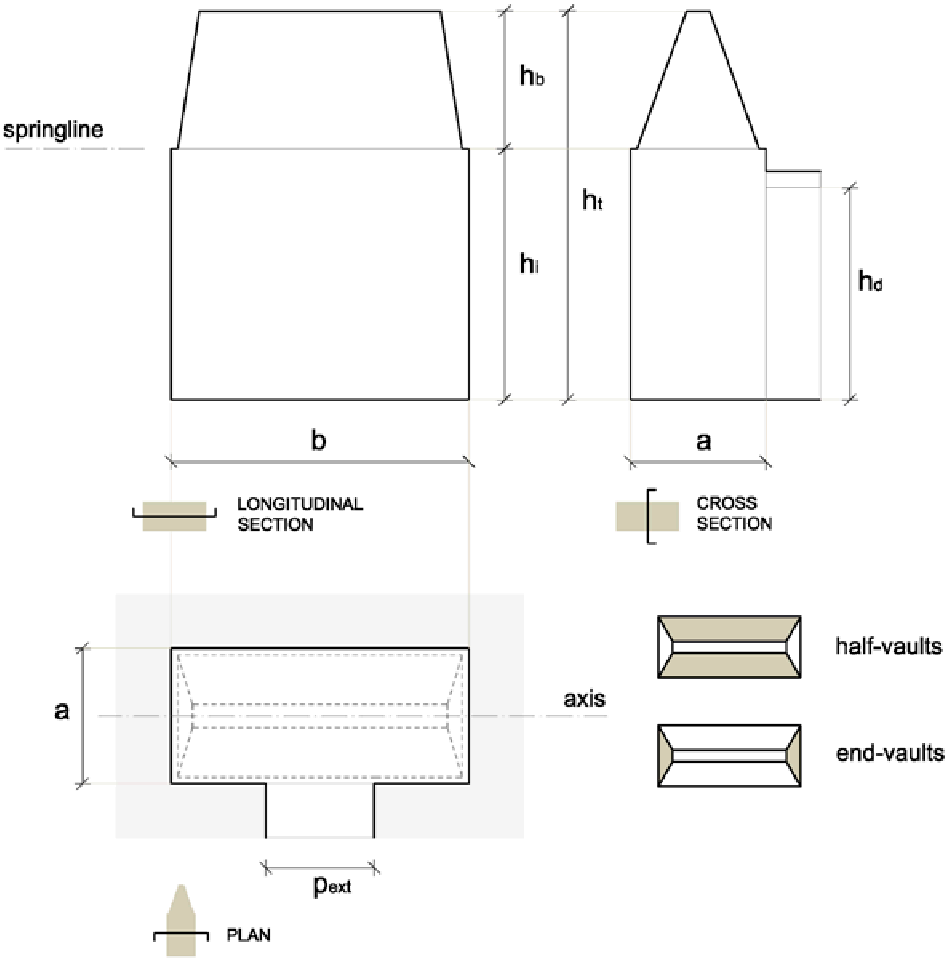


Fig. 12: Vaults geometrical variables

– Spalls in the vault stonework
– Half-vaults bond and joggle joints
– Vault spring course: shape and size
– Steps stones: number and shape (only for stepped vaults)
– End-vaults stones shape and dressing
– End-vaults stones dimensions: base, height and depth (m)
– End-vaults bond and joggle joints
– End-vaults spring course: shape and size
– Continuous courses in the four sides of the vault
– Capstones span (m)
– Capstones dimensions: base, height and depth (m)
– Additional information on constructive aspects

• Conservation state of the vault
  – Approximate percentage of preservation for each of the five surfaces of the vault
  – Stucco coatings preserved
  – State of the vault: restored, not excavated, shored, looted, monitored...etc.
  – Additional information about the building state of consevation

Processing and entering the data

29 After each of the field campaigns, the first task was to organize all the documentation obtained (photographs, recording forms, sketches and drawings) in a digital archive linked to the MVD by classifying it by sites, buildings and vaulted rooms. Once this information was organized, the next tasks were to process the digital surveys and to perform graphic restitutions of all the planimetries. Finally, from the systematically

collected data by the vaults recording forms, and together with all the graphical documentation obtained, the last task was to fill in the database with all the available data for each of the studied vaults.

30 Throughout the whole process, numerous bibliographic sources and field reports of several authors were used to complement the information taken in situ. First and foremost, this was necessary in order to record data about vaults that could not be accessed and whose characteristics were vital for the study, but it was also important in order to check, contrast and complement the direct data. Moreover, the use of these bibliographic sources and field reports was essential in order to gather general information about the buildings to which the vaults under investigation belong, such as plans, chronological data, or information about the restoration works performed or about the archaeological findings related.

Design of strategies for data exploitation

31 Entering all the above information into the MVD resulted in a complex set of interrelated data that needed to be exploited in a way that would serve the objectives of the study. Therefore, the following three strategies were designed:

1. The first strategy was to conduct a thematic analysis of the entire sample, i.e. to exploit the data by specific topic, taking into account all the geometrical, formal, functional and constructive aspects of the vaults. The results of this thematic analysis allowed not only to establish the criteria for the classification of the vaults, but also to define typologies for most of the recorded variables.
2. The second strategy was to exploit the data by geographical area and time period, in order to characterize the regional variants of the Maya vault and their different development over time.
3. The third strategy was to exploit the data related to the conservation state of the vaults in order to identify and analyze the most common deterioration processes and forms of decay of the vaulted structures.

Results

32 The final sample considered consisted of a total of 391 vaults from 200 buildings from 48 different archaeological sites of Maya Lowlands (Fig. 4). Before analyzing it, this sample was described and quantified from different perspectives in order to establish its limitations and assess what scope the results could have.
From a data collection's perspective, in 65% of the vaults the information came exclusively from fieldwork, while in 26% of the cases the direct data were complemented with information from the literature. In the remaining 9% of the cases the data collection obtained from previous studies (Fig. 5).

33 The sample provides different amounts of information for each case study depending on factors such as the vault preservation conditions, the origin of the data or the recorded level of information. Table 1 shows the number of vaults for which some of the most important aspects used in the analysis were available. These include, for example, the main vault dimensions, the vault stones type or the half-vaults and the end-vaults shape. The percentages of the preserved surfaces of the vault were quantified for almost 75% of the sample (Fig. 13), which helped assess the preservation state of the vaults and study causes and patterns of the collapse process.

34 The arrangement of the vault beams could be documented in 96 cases from different geographical areas and sites (Fig. 13), mainly in those that at least one of the half-vaults was completely preserved. This allowed the author to study the distribution patterns of these wooden beams with the aim of defining their function (Fig. 8). From

Available data	number of vaults	% of the total
Vault span (a)	233	59,6%
Interior height of the room (h_t)	162	41,4%
Vault height (h_b)	149	38,1%
Half-vaults shape	386	98,7%
End-vaults shape	304	77,7%
Lintels type and materials	228	58,3%
Vault stones type	311	79,5%
Vault beams arrangement	96	24,6%
Percentages of the preserved surfaces	291	74,4%
Chronological data	346	88,5%

Fig. 13: Number of vaults for which indicated data are available

studying these distribution patterns, it seems that their main purpose was to work as auxiliary means during the construction process of the buildings and, later, they were possibly used as furniture elements while the rooms were inhabited[20].

35 From a geographical point of view, 43% of the recorded vaults belonged to archaeological sites located in the Southern Maya Lowlands, while the remaining 57% came from the Northern Lowlands (Fig. 4). When extrapolating the results, it must be considered that the areas of Peten and Puuc could be studied more intensively than other areas, thus making the sample of vaults of these two regions considerably larger.

36 From a chronological point of view, the vast majority of the recorded vaults belonged to the Classic period and only a few anecdotal cases dated to the Postclassic period. Therefore, the results are applicable to the vaults of Maya Classic buildings: 10% of the examples date to the Early Classic period (250–600 CE), 56% to the Late Classic period (600–850 CE), and 32% to the Terminal Classic period (850–1050 CE).

37 The following sections provide an overview of the main results obtained from the exhaustive analysis and comparison of all these collected data on the vaults.

Proposal for a general classification of the Maya vault

38 Taking into account the whole sample of vaults in the MVD and the data exploited by topic, an in-depth architectural analysis of the Maya vault was conducted. This thematic analysis contemplated all functional, formal, geometric, constructive and structural aspects of the vaults.

39 The functional analysis was based on a previous theoretical study about the interior space in Maya architecture, considering concept, size, proportion, acceses, hierarchy, privacy, ambient and possible uses. From the results of this study and the examination of the data recorded, it was possible to define several functional typologies for the vaulted spaces.

40 The formal and geometrical analysis considered the solutions for both half-vaults and end-vaults, and identified the differents forms of the spring and the top of the vaults. It explored the variability of dimensions and proportions of vaulted spaces, with a special emphasis on the vaults span, which is the main limitation of this structural system, and analyzed its variation depending on the architectural typology, the geographical area and the chronology of the building.

41 The analysis also contemplated the structural system of the vaults and all their constructive features, such as the materials used, the stonemasonry technique, the stereotomy and the building process of the vaulted buildings, considering its implications for stability and conservation. A novel aspect of this study was the examination of the

20 See Gilabert Sansalvador and Peiró Vitoria (Gilabert Sansalvador – Peiró Vitoria 2019).

CLASSIFICATION CRITERIA			TYPOLOGIES OR VARIATIONS			
FUNCTIONAL FEATURES	Vaulted space function		Room	main space		
				auxiliary space		
			Temple room			
			Tomb			
			Urban arch			
			Stairway			
			Passageway			
			Passage below stairway			
			Roofcom chamber			
			Canal or aqueduct			
FORMAL FEATURES	Plan	Axis	Straight			
			Curved			
			Broken			
		Proportion	Rectangular			
			Square			
	Half-vaults	Cross-section shape	Straight	Flat		
				Broken		
			Concave	< 90°		
				Semicircular		
			Stepped	Steps shape	Vertical	
					Inclined	
				Steps stones	One stone for step	
					Multiple	Several equal stones
						Different types of stones
					Combined	
			Bottle			
			Convex			
		Vault spring form	with overhang			
			without overhang			
			inverted overhang			
		Vault top form	Course of capstones			
			Molding below capstones			
			Vertex above molding			
			Only vertex			
	End-vaults	Longitudinal-section shape	Vertical			
			Inclined	Less sloped than half-vaults		
				Similarly sloped than half-vaults		
			Stepped	Steps shape	Vertical	
					Inclined	
				Steps stones	One stone for step	
					Multiple	
					Combined	
		End-vaults spring form	with overhang			
			without overhang			
CONSTRUCTIVE FEATURES	General	Constructive system	Loading walls and vaults			
			Loading walls and mixed ceiling (partial vault + beam-and-mortar roof)			
			Vaulted ceiling supported by columns and wooden beams			
		Stone type	Limestone			
			Sandstone			
			Rhyolite			
			Trachyte			
			Tuff			
			Basalt			
		Lintels	Wooden lintels	squared		
				natural beams		
			Stone lintels			
			Arched doorways			
	Half-vaults	Vault stones	Uncut			
			Slab			
			Faced			
			Block			
			Peten type			
			Wedge			
			Boot-shaped			
			(Brick)			
		Spring stone	Same as vault stones			
			Different size and proportions			
		Vault beams	Evidences of vault beams			
			No evidences of vault beams			
	End-vaults	End-vaults stones	Ashlars			
			Ashlars and tenons			
			Vault stones			
		Spring stone	Not differentiated			
			Different size and proportions			
		Buiding process	Gable wall that is attached to a previously built vault			
			Built in two phases: 1) from floor to springline, 2) from springline to vault top			
			Continuous courses with half-vaults bond			

Fig. 14: Classification of the Maya vault according to its functional, formal and constructive features

end-vaults formal and constructive features. These short sides of the vaults present peculiarities and specific characteristics in each architectural style, provide information on the construction process of the buildings and furthermore influence the processes of structural decay (Fig. 15).

42 In the light of the results, it was possible, on the one hand, to establish all the qualitative and quantitative variables that define a Maya vault and, on the other hand, to identify the existing variations and typologies for each of the established qualitative variables, as we can see in Fig. 14. For instance, it was posible to define functional typologies for the vaulted spaces, formal typologies for half-vaults and end-vaults, types of vault stones or typologies for the existing solutions for the spring and the top of the vaults.

43 This allowed to elaborate a general classification of the Maya vault according to several functional, formal and constructive criteria, shown in Fig. 14. This taxonomy establishes 17 classification criteria that can be divided into the seven categories or points of view below, which must be considered when describing and characterizing a maya vault:

– vaulted space function
– vault plan formal features
– half-vaults formal features
– end-vaults formal features
– general constructive features
– half-vaults construction features
– end-vaults constructive features

44 Each vault being studied belongs to one of the variations defined for each criterion in Fig. 14. It is important to note that the classification proposed above includes only the qualitative variables, to which the quantitative variables, such as the different measuremets and proportions included in the analysis, should be added in order to obtain an accurate definition of the vault under investigation. Along with a metric survey, Fig. 14 can be used as a checklist to characterize vaults in the Maya area[21].

Regional variants of Maya vault and development over time

45 The exploitation of data by geographical area allowed to identify and characterize the variants of the Maya vault in Peten, the Usumacinta river basin, Rio Bec, Chenes, the Puuc and Northern Yucatan areas. The results indicate that there are substantial differences in the construction techniques used in each region, which in many cases have determined the architectural and stylistic features of the vaulted buildings.

46 Through the analysis of the large bibliographic documentation available, it was possible to record the chronological dating of more than 88% of the vaults in the sample (Fig. 13), based on the existing data of the buildings to which the vaults belong. As we saw earlier, the elaboration of a dating table of equivalences made it possible to place most of the studied buildings in a common chronological table and, subsequently, to analyze the development of the vault throughout the Classic period, both in general and in specific regions with a long constructive tradition.

47 From the results of the temporal analysis, it can be affirmed that the development of vault technique in Maya architecture followed a path of specialization and standarization of the stonemasonry technique and aimed for the improvement of the shape and flatness of the inside surfaces (Fig. 16). The eagerness to expand the vault span

21 In some cases it would be necessary to record the singularities some vaults may present and are not included in this general taxonomy.

Fig. 15: The change in end-vaults stones bond indicates two differentiated phases of the building process in Chenes Building 1 in Uxmal

Fig. 16: Vaulted room of the House of the Governor in Uxmal

and therefore the interior spaces, both in width and height, led the Maya builders to develop very advanced vaulting techniques that involved even a change in the structural system, begining with corbeled vaults and gradually evolving into monolithic or cast vaults, in which highly specilized vault stones form the facing of a supporting core of lime concrete.

48 The analysis of the constructive peculiarities of the regional variants of the vault and the study of the chronological development of stonemasonry technique in each geographical area suggest that building knowledge may have been transferred across regions in specific time periods. This allows us to make hypotheses on the interregional relationships and influences in both directions, thus contributing to our understanding of the cultural history of the Maya civilization.

Analysis of conservation state

49 For the third objective of the study – i.e. to formulate criteria appropriate for the excavation and conservation of vaulted Maya buildings – a statistical analysis of the preservation state of the vaults was performed. From the data collected in the field, the most frequent deterioration processes were examined, considering both intrinsic and extrinsic factors to the building constructive system, as well as the various forms of collapse of the vaulted structures (Fig. 17).

50 This analysis indicated that in most cases the deterioration processes that affect vaulted buildings depend directly on the constructive and stereotomic features of the vaults. Again, this shows the crucial importance that investigating Maya architecture from a constructive perspective has for the preservation of this heritage.

Conclusions

51 As Hasso Hohmann (Hohmann 1979: 35) expressed at the end of the seventies, in order to define different types of Maya vaults and to categorize them, it was necessary to perform extensive architectural recordings and analyzes as a preliminary work. The study reported in this article has presented the methodological bases to document a Maya vault and to systematically record all its features. Furthermore, it has presented a system to store information about vaults in an orderly manner, one that may be published online as an open Maya vault repository for other researchers to use in order to progressively extend the collected sample and continue researching the vaulted Maya architecture.

52 Establishing fieldwork as the main strategy, the present study collected a large number of data from 391 vaults from different regions and chronological periods, thus providing a substantial base for in-depth analyses of the Maya vault. After carefully processing and entering the information, a large dataset was obtained, from which the

Fig. 17: Collapsed vault in the Palace of Palenque

vaults were analyzed from different points of view. One of the most important results is the proposed classification for the Maya vault, which is a new contribution to the study of this architectural element and serves as a complete tool for accurately recording vaults.

53 The study, which has taken into account both geographical and temporal dimensions, also demonstrates the importance of constructive analysis of Maya architecture in advancing knowledge of the cultural history of this civilization. Through constructive analysis of the buildings, transfers of technical knowledge between different geographical regions can be detected, thus facilitating the formulation of hypotheses on the historical relations between those same regions. In-depth knowledge of the vaulted Maya structures is, moreover, a key factor in assessing the current conservation state of buildings and in developing strategies for the excavation and conservation of this heritage.

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RESUMEN

An Investigation of the Maya Vault: Methodology and Cultural Significance

Laura Gilabert Sansalvador

Este trabajo presenta la metodología empleada y los principales resultados obtenidos en una investigación realizada recientemente sobre la bóveda en la arquitectura maya. Para abordar esta investigación se registró una amplia muestra de 391 bóvedas de diferentes áreas geográficas y períodos cronológicos. Los datos tomados en campo se complementaron con la información de la bibliografía existente y se introdujeron en una Base de Datos de Bóvedas Mayas, un sistema creado ex profeso para archivar, analizar y comparar todas las características de las bóvedas. A partir de la muestra registrada se realizó un estudio arquitectónico en profundidad sobre la bóveda maya, que contempla los aspectos formales, geométricos, funcionales y constructivos, con especial atención al estado de conservación actual de los edificios y a los mecanismos de deterioro que les afectan. Como resultado, se propone una novedosa clasificación de la bóveda maya que atiende a diferentes criterios y que se establece como una herramienta muy útil para el registro de las bóvedas mayas. El análisis comparativo realizado entre las características de las bóvedas de diferentes áreas geográficas permitió caracterizar las variantes regionales de la bóveda maya y analizar su desarrollo temporal, revelando importantes resultados para la historia cultural de la civilización maya.

PALABRAS CLAVE

Arquitectura, maya, bóveda, base de datos, trabajo de campo, levantamiento

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