ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

CHARACTERIZATION OF ARCHITECTURAL ELEMENTS IN EL TAJIN ARCHITECTURAL AREA

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DOI: 10.5281/zenodo.843983

ABSTRACT
El Tajín is an UNESCO Mesoamerican World Heritage Site, which was the most important on the north coast of the Gulf of Mexico during the epiclassic period (800 to 1150 AD). The city has pyramidal bastions, palaces with mural paintings, temples, ball courts, steles, and altars, all of them with sculptural bas-reliefs of great visual complexity.

KEYWORDS: Pyramids fractality, Mesoamerican geometry, El Tajin, complexity and durability

I. INTRODUCTION
Tajin, located on the Mexican Gulf Coast and comprising an area of 144 hectares of architectural buildings, was the prehispanic ceremonial center with the highest degree of development during the Classic period. (Soto, 1997, Wilkerson, 1994).

The great works carried out in situ by the remarkable archaeologist José García Payón (1976) for more than 40 years allowed for the identification of the architecture of El Tajín using panels with niches arranged in series finished by elaborate flared cornices, buildings on platforms or on quadrangular or rhomboid basements, steps with carvings decorated with grecas, arches of Mayan influence, 17 ball games, columns of stone drums with bas-reliefs where the 13 Rabbit ruler repeatedly appears, and the use of varied ornamental sculptural elements in all its buildings. Outwardly, they were completely covered with stucco and polychrome.
In the organization of urban planning of buildings as per Dr. Jüergen K. Brüeggemann (1991), the use of natural slopes that determine the different architectural, ceremonial, residential and administrative areas can be detected.

Formal elements of architecture-sculpture
Already from its beginnings in the Classic period, the architecture-sculpture of El Tajín stands out for the use of formal elements attached to its construction.
The most outstanding is the niche, as it is attributed to the culture of El Tajin; although they have also been found in nearby sites like Yohualichan and Cuetzalan, the influence of this unique architecture in its constructions is evident.
The niches are present in almost all the buildings of the site; Its formal variations give it dynamism and great visual attraction as metropolitan urbanism. It is a modular element, a minimal unit of formal expression that prints identity and unity of style onto the architecture of the archaeological zone.

It isn't exactly known what the function of the niche is. However, there has been speculation about a use of symbolic-religious character: the light variations projected by natural light on the niches during the different hours of the day project claroscuro, light games and analogous shades on the great Kukulcan Pyramid in Chichen Itza.
In the pyramids, the use of grechas that is visualized becomes an architectural-urbanistic resource and portends its use as a sculptural element repeated in the buildings of El Tajín Chico.

The Great Xicalcoliuhqui, monumental greca, is an example of the above because it is believed that it is also a great lunar calendar, and also because it has 260 niches along its perimeter wall in direct association with the 260 days of the Mesoamerican lunar calendar.

Another formal element is the cross and the crisscross diamonds that are part of bas-reliefs attached to the architectural façades. In El Tajín, the cross is formed with 4 stepped grechas in the Columns Building located at the highest part of the site.

Urban Areas

The main buildings of the site are distributed in urban zones distinguishable by their topographic characteristics indicating political, social and religious status.

Three phases or stages of urban development have been identified, taking into account the age of the buildings, the variations of its construction system and its sculptural-architectural elements.

In the pre-urban phase, defined by Brüggemann (1991), the first constructions were carried out with a symmetrical axis in accordance with the classic Mesoamerican tradition. These monumental buildings identified as 16, 18, 19 and 20 make up the Plaza del Arroyo or Grupo del Arroyo surrounding a spacious square.

The function of these buildings, as per Brüggemann (1991), is ceremonial, since supposedly they would celebrate lavish religious and cult activities. Associated to this set are some ball game courts identified as buildings 34-35, located in the southwest corner and 17-27, northeast corner. At the end of this phase another ball game court is built - buildings 13-14 related to the Plaza, but on its periphery.

Phase II is known as the urban phase (Brüggemann, 1991), during which the city expands to the north and changes its orientation to 45 ° Northeast. The buildings are of higher quality and technology. The zone known as Tajín Chico (buildings from A to U) was constructed as the stage of the apogee of El Tajín (600-900 A.C. Late Classic Period). It is a residential area of palatial buildings for an elite population, rulers and the priestly class, the area of highest status.

Buildings and durability

Fractal geometry has been used to determine architectural features (Kawaguchi et al., 2016). In addition to rough studies (Samper, A. 2016), it has also been applied in paintings.

Lirola, J.M. Et al. 2017 has exposed various methodologies using building scales that can be studied at the microscopic level. However, fractal techniques can also be directed at the microscopic level (Shen, W. et al., 2017).

Although the architectural components of El Tajín have a centenarian antiquity, several elements remain in good condition; many of them are currently as reliable as they were in the time in which they were built. The reasons why this happens are unknown.

In this work, we intend to highlight the use of geometry from two perspectives. The first is applied to the finished buildings as they were conceived and the second to the existing surfaces from the fractal dimension by counting the boxes associated with them. This second case is carried out to the present surfaces that were originally covered with stucco. The relationship of this feature with durability is also analyzed.

II. MATERIALS AND METHODS

Line drawings were made of the façades of Buildings 5 and 3 located in the central part of the archaeological zone to highlight its geometric trace through the superposition of a mesh. This method has already been applied to other buildings in El Tajin by Valle-Chavarria et al. 2016.

The procedure followed in the trace is described according to the following terminology proposed by Sonderenger:

Rectangle Root 2: RR2. Rectangle obtained by depressing the diagonal of the square.

General Rectangle: RG. General envelope.

The Square Root 1: CR1. Geometric foundation of every rectangle. Mythical foundation, symbol of the Earth, the four cardinal points, etc.

Root Rectangle 2: RR2. Rectangle obtained by the diagonal indentation of the square.

Rectangle Root 3: RR3. Obtained by the abasement of the diagonal of RR2.

Golden Rectangle: RA. Rectangle obtained by the depression of the diagonal of the half of the square.

Gnomon GN: Point originated by the crossing of two perpendicular, oblique or curved lines used in the design of the work.

OO ': Axial axis that establishes the symmetry of the design.

The fractal dimension D is determined using the ImageJ program v1.46 through the relation (Mandelbrot B B. 1982):

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

(1)

$$D = \lim_{r \to 0} \frac{\ln N_0(r)}{\ln\left(1/r\right)} \qquad (1)$$

Where "r" is the size of the "N" sites in which the image is divided and "N0" is the number of sites in which the presence of precipitate is observed. "D" is considered to be a measure of the amount of substance "□" that is present in a plane of characteristic length "L":

(2) $\Phi \equiv L^D$ (2)

The value of D is expected to increase with the amount of precipitate formed.
Physically, images of the studied surfaces were taken. To these images the surface was determined by the fractal dimension method by box counting by the ImageJ program v1.40g in which each color image is converted into an 8 bit image, from which is obtained a binary image of the pattern to which the vertical and horizontal fractal dimensions of the images are determined, as well as their roughness. Similar methods have been reported by Ostwald, M.J. 2013 and Suarez-Dominguez et al. 2016.

III. RESULTS AND DISCUSSION

BUILDING 5.

Fractal dimension: 1.81

This building is located on a large platform of an area of 3124 m2 that rises from the floor 2.55 m. According to estimates, there were another four smaller buildings at each of the corners of the platform, of which one toward the front still survives. The platform has accesses on its eastern and western façade.
The drawing shows Building 5 without the platform and the other constructions, and is based on the copy of the plans of Project Tajín.

Figure 1: Building 5, Central Tajin

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Impact Factor: 4.116
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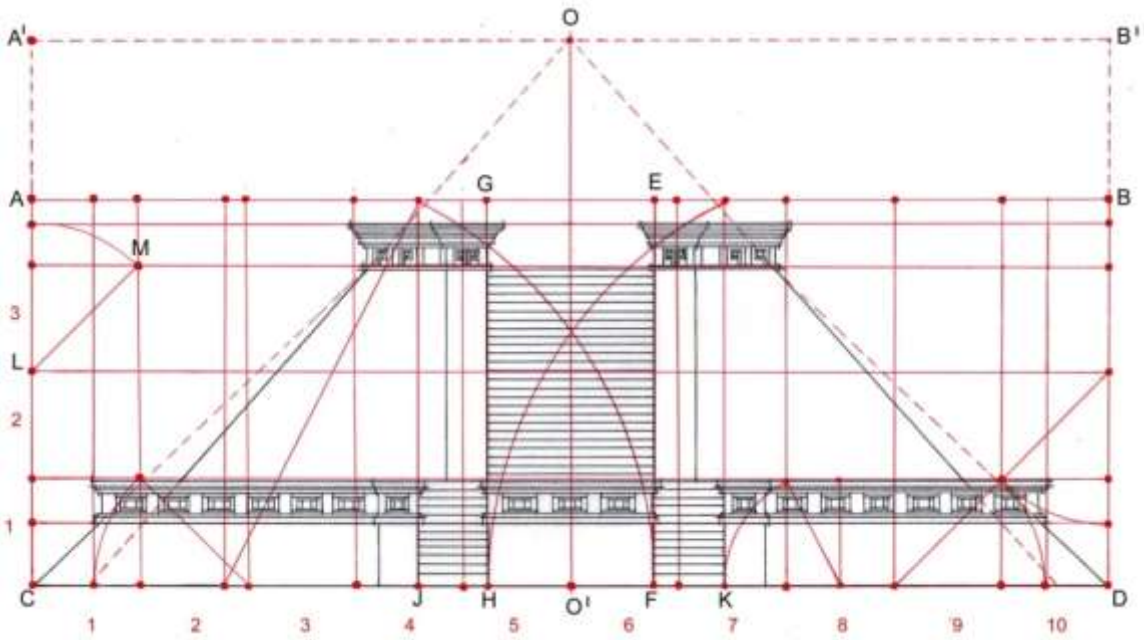

Figure 2: Geometric trace of Buiding 5

Description of the route:
ABCD: RG composed of two overlapping RA: AECF and GBHD where HF corresponds to the width of the central staircase and JH / FK width of the two lower staircases. Discharge RR2: LMA maximum height of the building. The base is divided into 10 parts: one part establishes the height of the lower basement and three parts establish the height of the main staircase and large slope that forms the body of the pyramid.

BUILDING 3.

Fractal dimension: 1.79

Located in front of Pyramid of the Niches and closing the space of the square of the same name, its main façade faces south. Bordering very closely with this building is Building 23 which also has a square floor and proportions similar to Building 3, resembling twin buildings. There are on the surface turquoise or Mayan blue leftovers, so it was presumed it was originally polychrome.
The top right of the building is missing. The following drawing of the façade is a copy of the plan to be made during the Tajin Proyect. Their characteristics are: square floor of 34 m per side. It consists of 7 staggered bodies with rectangular formal elements called squares of 40 cm long. Central staircase with side rails finished in a mass of a niche. The staircase has in its central part 6 masses interspersed with 3 niches.

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Impact Factor: 4.116
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Figure 3: Buiding 3 at Central Tajin

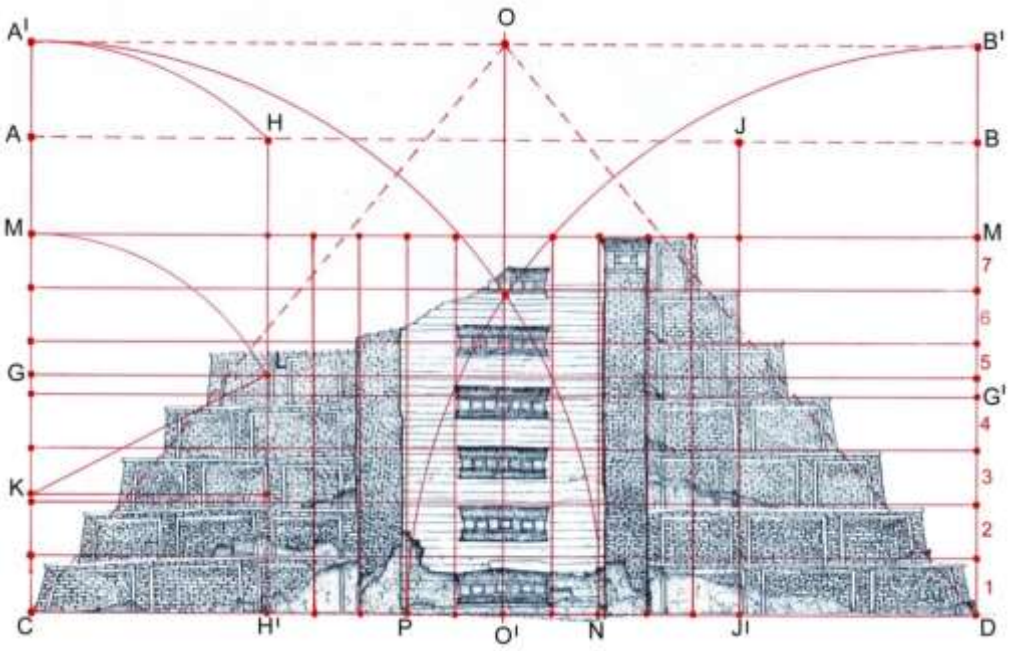

Figure 4: Geometric trace of Buiding 3

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Impact Factor: 4.116
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Description of the route.

ABCD: RG composed of two ***CR1***. Discharge ***RR2***: GHE sets the rectangle A'B'CD and virtual diagonals CO and DO: Fault ***RA***: KLM establishes the height of the 7 basements of the building.

In general, the Pyramid of the Niches is the best-known building for having 365 niches in its six basements and an upper temple alluding to the current 365 day solar calendar.
Another formal element used in the architecture of Tajin is the stepped greca known in the nahuatl language as "*xicalcoliuhqui"*. It had great symbolic importance and visual relevance because the most important buildings used it in their main façades or architectural details.
The studies in the field of iconography coincide in that the stepped greca is, in its primitive naturalistic form, the "spiral" related in Mesoamerica with the cut snail, - "ehecacozcatl" - or "joyel del viento". The cut snail represents the Wind God Ehécatl-Quetzalcoatl within the symbolic iconography of the Mesoamerican gods and the various manifestations of the supreme and maximum principal deity Quetzalcoatl. (Piña Chan, R. and Castillo Peña, P. (1999) Tajín, the city of the God Hurricane. Economic Culture Fund Mexico).
One can also consider the case of the swastika type cross or cross in motion that is formed with two grades stepped in radial symmetry; such sculptural-architectural details are featured in several buildings of the archaeological zone including the Building to Tajín Chico and Building of the Columns.
There is another case of using the cross in Buildings 13-14 - a ball court; the cross is built inside each of the niches in horizontal succession on the top cornice of both buildings.
Particularly, the geometric figure of the rhombus, was used in the basement of Building D in El Tajín Chico. A succession of rhombuses of smaller and greater shape are interlaced and repeated in horizontal sequence occupying all the space of the slope-basement on which rose two other basements with niches and stepped greca, according to hypothetical reconstruction carried out by the Architect García Payón. (Marquina, I. (1951)) Prehispanic architecture, Memoirs, INAH, Mexico.
When the rhombuses, whose height is delimited by the width of the basement, are intertwined, the smaller ones are divided into four parts. This rhombus fractioned into four minor rhombuses is repeated 12 times in the façade of the building, only interrupted by a buttress decorated with stepped grechas on the right part. Visually, a reticular system is observed based on diagonal lines that cross mathematically in two directions giving thus rhomboidal forms of great strength and dynamism. Another building with this figure is Building H, Tajín Chico, placed upwards vertically in the carvings of its staircase.
The rhombuses were a graphic motif used also in the few remains of mural painting that are conserved in Building I or of the Paintings and in the Site Museum.
The value of the fractal dimension in a system can vary depending on the dynamic processes that take place and its random nature, so a system can be described from its morphology. In this work, the morphologies correspond to the images obtained as per the experimental part described above; the dynamic processes are referred to the interactions between the particles that make up the land occupied, as well as the characteristics of the same, mainly their size.
In this sense, we will correlate the experimental results observed from the roughness and fissures with respect to the fractal dimension.

Analysis

Images of the surfaces of the constructions were taken. To these images a treatment was carried out to bring them to a binary image where the outer edges of the surfaces are shown. From this image the fractal dimension was calculated. Figure 2 shows a photo of the construction, the original image of its surface, the conversion of the surface image, and a binary image of the contours of the engraving shown. This last image is the one that is determined by the fractal dimension.

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Figure 2. Structure image in "Plaza del Arroyo"

Figure 3. Surface image of staircase obtained from the Figure 2

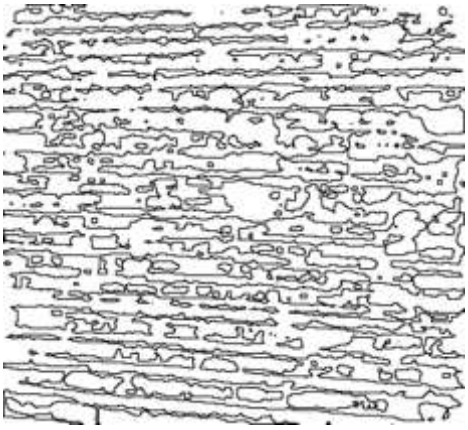

Figure 4. Image of the binary surface, corresponding to the image shown in Figure 3, by which the fractal dimension was determined

The values of the calculated dimension are shown in Table n. The images whose results are not reported in this table correspond to those in which, due to the photos taken, were not appropriate to perform the analysis, mainly because they were obtained from the surfaces and appear to present a high degree of degradation. Figures 1 and 2 correspond to the image of engravings shown in the constructions.

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Table 1. Values of the fractal dimension calculated for the surfaces of the analyzed constructions. The results showed a standard deviation of 0.0025.

Structure image	Fractal dimension of the surface
Simple grechas	1.2580
composite grechas	1.4103
Walls	1.7151
Composite elements	1.7464
Staircase	1.8005

Subsequently, the surface analysis was performed, to which the fractal dimension was also determined. These results are presented below:

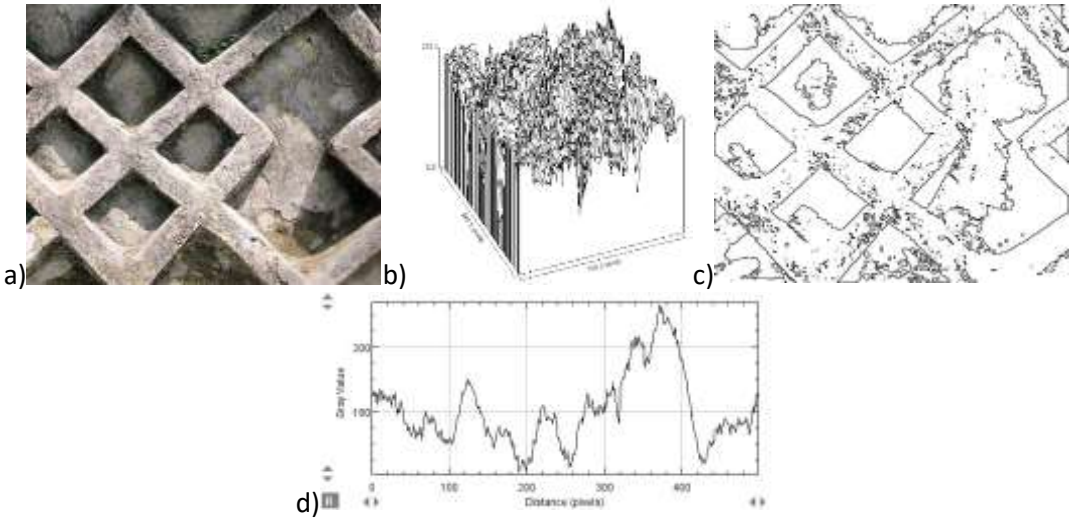
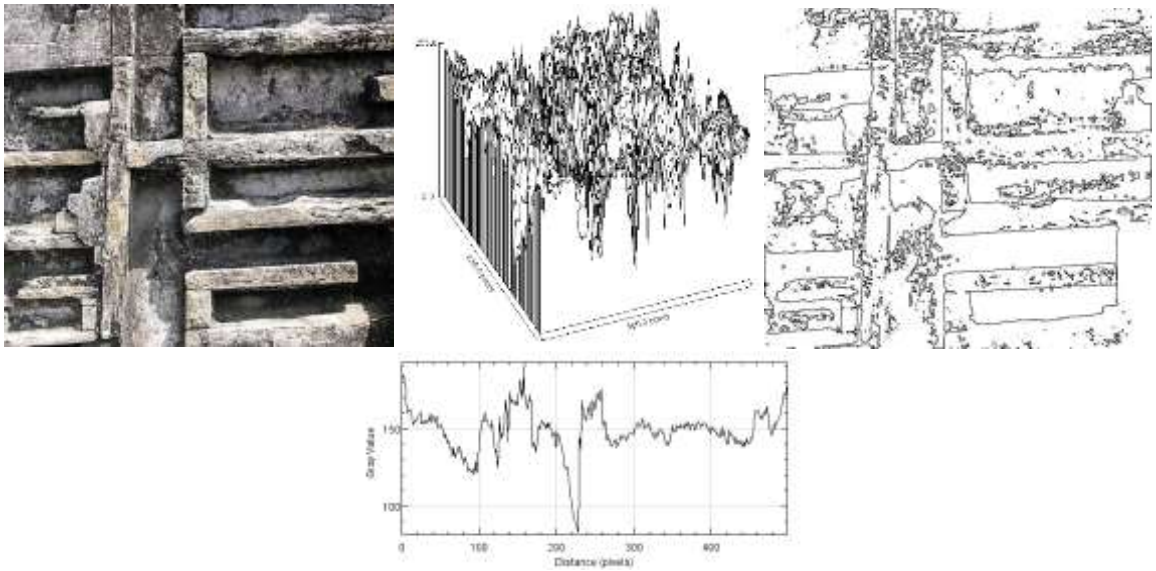


Figure 5. Results of the analysis Building D Tajín Chico, in detail. A) original figure b) plotting the surface, c) 8bits image of the contours, d) plotting cross-section. The results of surface analysis are: 1.4633. For the contour analysis: 1.2363



ISSN: 2277-9655
Impact Factor: 4.116
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Figure 6. Results of the analysis fig 2 DETAIL GRECAS Edif. D Tajín Chico. A) original figure b) plotting the surface, c) 8bit image of the contours, d) plotting cross-section. The results of surface analysis are: 1.5570. For the contour analysis: 1.2644

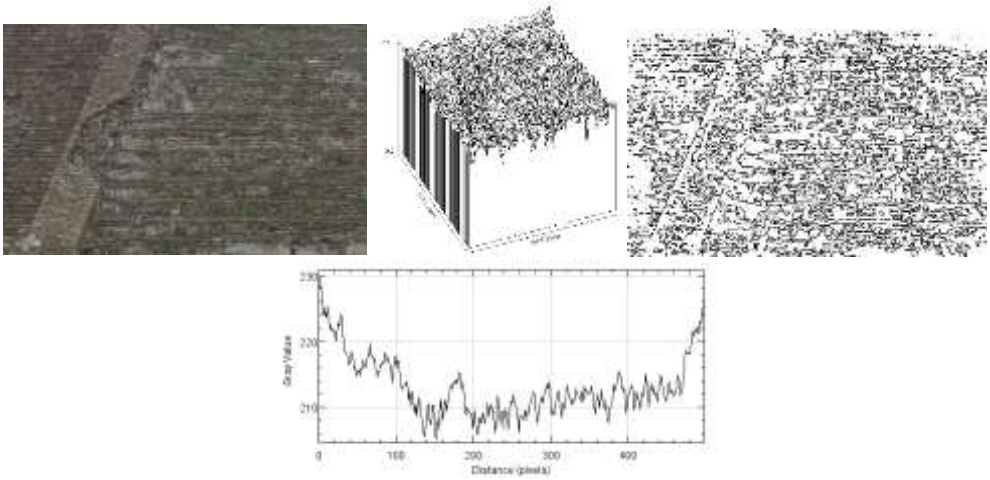

Figure 7. Results of the staircase analysis Edif. 19. A) original figure b) plotting the surface, c) 8bit image of the contours, d) plotting cross-section. The results of surface analysis are: 1.7902. For the contour analysis: 1.2924

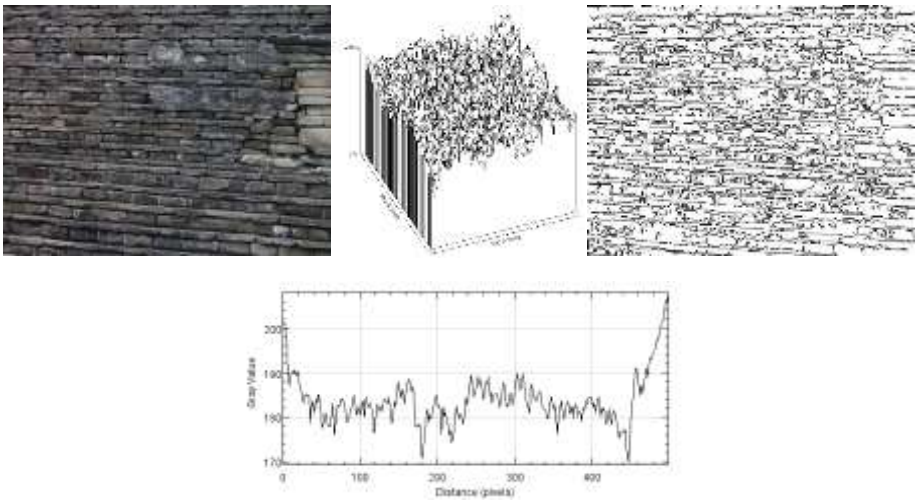

Figure 8. Results of the wall analysis Edif. 18. A) original figure b) plotting the surface, c) 8bit image of the contours, d) plotting cross-section. The results of surface analysis are: 1.7502. For the contour analysis: 1.2754

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

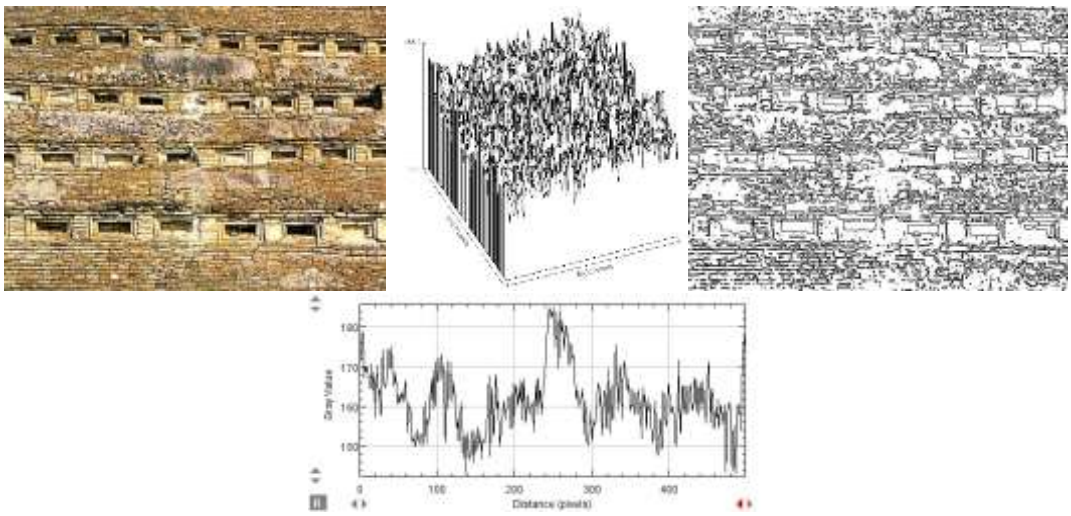

Figure 9. Results of the wall analysis Edif. 16 Arroyo Group. A) original figure b) plotting the surface, c) 8bit image of the contours, d) plotting cross-section. The results of surface analysis are: 1.8118. For the contour analysis: 1,430

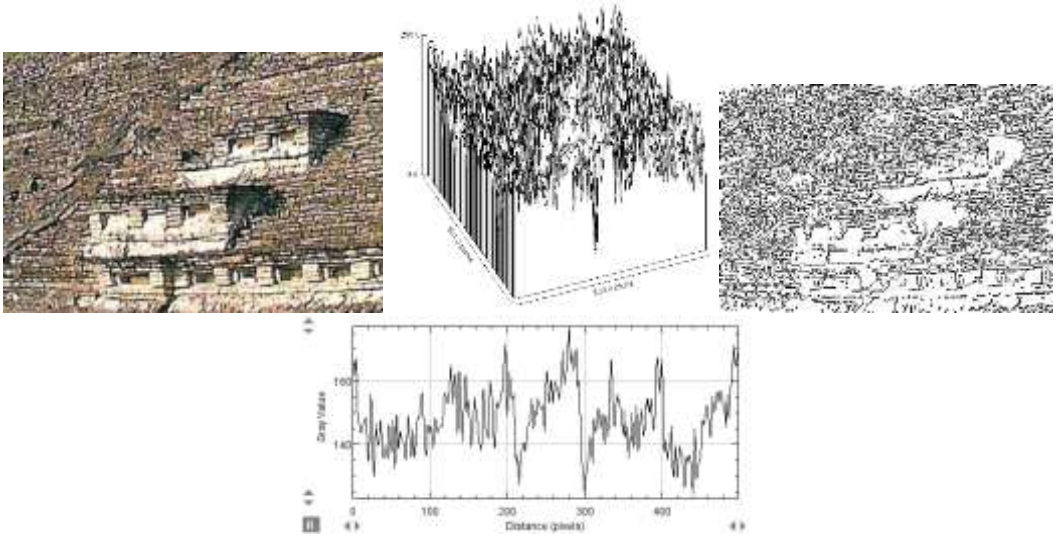

Figure 10. Results of the wall analysis Edif. 20. A) original figure b) plotting the surface, c) 8bit image of the contours, d) plotting cross-section. The results of surface analysis are: 1.77948. For the contour analysis: 1.3865

Several applications can be applied with the applied fractal dimension. Grossi, C. M., & Brimblecombe, P. (2004) have simulated various processes and it is important to note that some harmony can be had between environments, as has been pointed out by Grietēna, A. (2014) in various architectural structures mainly in churches. In addition, it has been linked to stress reduction (Taylor, R. P. 2006; Ziabakhsh, N., & Ghavami, M. 2016).
The results shown in the previous Figures show that all the images analyzed on surfaces tend to have a value close to 1.70 even though they are viewed in a global or particular way.
In this way, when the study shown in this work is performed with pre-Hispanic vestiges in the preserved elements, a fractal dimension or dimension superior to the topological one is presented. Even when these types of terms were not

known at the time, it is possible that they have been instinctively applied not only to relate to the divine sense but also to the natural use of deep logical reasoning

IV. CONCLUSION

From the results obtained, it is found that the architectural pieces developed in the pre-Hispanic period of El Tajín, even though linked to sacred numerology, present golden ratios and square root rectangles. In addition, it was found that the uncoated architectural elements present an arrangement of the elements that is complex and that is around a value of 1.70.

Gestalt perception, and synthesis images are constant in works representative of Mesoamerican art. Models such as holographic vision, space fold and unfolding, fractal geometry, astronomical numerology, implicit order, and chaos theory constitute fertile grounds for generating new theoretical frameworks, whose pertinence to study ancient art is striking.

Although the results shown in this work can't assure that the pre-Hispanic culture of Tajin was aware of complexity and of a "perfect" proportionality, its systems of harmonic proportion lead us to fractal geometry. The conjunction of space and time is constant in its architecture, and that could be the cause of these structures being able to withstand degradation and endure in time.

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CITE AN ARTICLE

Chavarria, L. V., Loredo-Cansino, R., & Suarez-Dominguez, E. (2017). CHARACTERIZATION OF ARCHITECTURAL ELEMENTS IN EL TAJIN ARCHITECTURAL AREA. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY, 6*(8), 295-306. Retrieved August 16, 2017.