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Original article

Multivariate study and proportion study for classification and dating of Islamic Al-Andalus' minarets: A first approach

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ABSTRACT

In this paper, we aim to continue the dimension studies of the Al-Andalus minarets that were conducted by Félix Hernández and Basilio Pavón between 1930 and 1975. Through the use of statistical methods (multivariate analysis, discriminant function analysis, neural analysis) and through the study of minarets' dimensions, we have obtained important relations and proportions from an archaeological point of view and within the context of the architecture of the old Islamic minarets in Al-Andalus. Our research is based on the prediction and classification of minarets according to their dimensions and their inner disposition; the results obtained have been highly successful, enabling archaeologist to date and/or virtually reconstruct the minarets knowing just a few of their dimensions. These dimensions are obtained during any archaeological intervention or extracted from original documentation written by scribes and travelers. Furthermore, we have found one of the first evidences of the search of the efficiency in the Islamic constructions and their correlation with political and warfare changes.

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1. Introduction

During last years, some minarets have been discovered in different excavations carried out in Andalusia, Spain [1–3]. Besides this, many authors have written different compilation works about Andalusia's minarets [4,5].

The study of these buildings is vitally important so as to know the constructive methods employed and the development of Islamic constructions during the Islamic Conquest. Despite the fact that diverse compilation works has been written around this topic, none of them employs statistical study of the minarets' dimensions, their construction era and their inner disposition to study the existence of relations between them.

In 1975, Hernández Giménez [6], architect of Cordoba's Mosque-Cathedral, took the first steps to study the existence of a canon or relation between different minarets' ground plans measures. Hernández tries to compare the minarets of Santiago's Church, San Juan de los Caballeros' Church and Santa Clara's Convent, all of them located in Cordoba, Spain. He selected these minarets because all of them have a very similar ground plan dimensions. Nonetheless, he did not achieve conclusive results with this study.

During last decade, many authors have studied the effects of earthquakes in the minarets located in the Near East [7,8]. The objective of these researchers was to analyse the stability and resistance of the minarets located in diverse sites and different eras of construction. Furthermore, some studies have analysed the geometry of various minarets [9], focusing in geometric variation among the constructions. However, these studies did not find any canon or relations that classified minarets in different historic eras making use of their geometric variations.

After the fall of the Roman Empire, the mathematical knowledge was reduced to its basics, Euclidean Geometry and Pythagorean Mathematics. At the time, few people could study Geometry and Mathematics [10]. From the IX to the XII centuries, the classical mathematical knowledge was spread along Al-Andalus. Islamic constructions were characterized by the use of integers and the incorporation of basic geometric forms on their designs and constructions. In fact, the base and height's measures of many minarets are integers, for instance, *Hishām I* minaret or *Madinat al-Zahra'* minaret, Cordoba; both of them have a base of ten cubits and a height of forty cubits [11].

Likewise, the minarets architecture is very simple; it has a square ground floor, with a circular or square inner disposition and a second sub-construction with the same design. The first study around geometric analysis and proportions at Cordoba's Mosque-Cathedral was written by Emilio Camps Cazorla [12]. His study followed an important premise, analysis and proportions must be simple. Only two sketches from the Islamic era are kept; the

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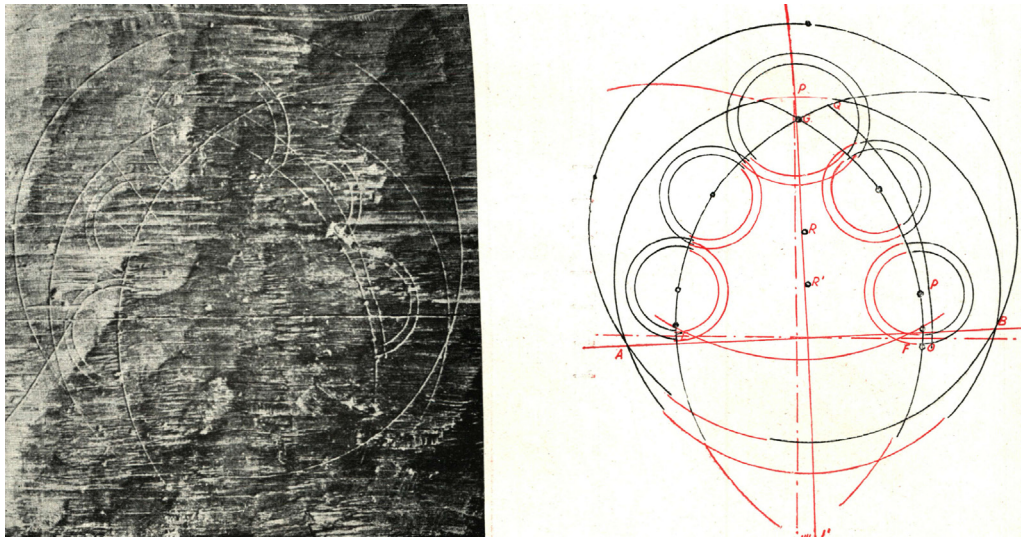


Fig. 1. Sketch of the Holy Ark of Oviedo [12].

first was found by Ricardo Velázquez Bosco, architect of Cordoba's Mosque-Cathedral, in *Madinat al-Zahra'*, which was found incomplete in a wall. The second sketch was found by Manuel Gómez Moreno during the restoration of the Holy Ark of Oviedo (Fig. 1). This sketch shows a lobed arch with the compass layout in the wood. It is dated back in the XI century.

During the constructions carried out in the Middle Ages, diverse units of measurement were used, such as the rod, the finger, the span, the toesa, and the cubit [13]. Arab writers wrote some texts about the dimensions of the old mosque of Cordoba and the rest of constructions built during the Islamic occupation. The architect Félix Hernández studied all the dimensions of Cordoba's Mosque-Cathedral and wrote a book about this study [14]. As it might be expected, the work of Hernández is a great help to know the design and construction of this building and other built around the same era.

Another important study of the dimensions of the minarets built in Al-Andalus was conducted by Pavón Maldonado [15]. First, the author studied the proportions in the merlons found by him and Félix Hernández in *Madinat al-Zahra'*. Maldonado classified merlons into two groups, big and small. Big merlons were used for the lower part of the minarets and small merlons were used for the top part of the minarets. In both cases, merlons have a proportion of 1/2 between the base and the height. By contrast, the merlons located in the main zones of the mosques have a proportion of 0.88, very close to 7/8 or 0.875.

Pavón obtained in his study important conclusions about the proportions between the base and the height of minarets in different zones and different construction eras. Regarding the height, the author obtained the following conclusions after the study of chronicles and other works:

- the relation between the lower part's side base and the total minaret's height: $\frac{1}{4}$;
- the relation between the base and the height of the minaret's lower part: $\frac{1}{3}$;
- the relation between the lower part's base and the upper part's base: $\frac{1}{2}$.

At present, the oldest window of the minarets is located in the minaret of Ibn Adabbas' Mosque, now Church of Salvador, Seville. This window was studied by Hernández [6]. The architect studied

the different measures and relations between the elements that are part of the window. Furthermore, he analysed the windows of the minaret of the actual Church of San Juan de los Caballeros, Córdoba, its relation between sagitta and diameter is $\frac{7}{8}$ (0,875), the same relation and dimensions of the windows of the Church of Santiago's minaret, Córdoba [16]. In his study [15], Pavón found the same relation in the merlons discovered in the Mosque of *Madinat al-Zahra'*, Córdoba.

Furthermore, significant research was conducted making use of statistical methods for dating diverse archaeological sites, some of these studies made use of multivariate studies to date the production of iron objects [17], or for dating ceramic objects discovered in an excavation [18]. By contrast, other studies made use of statistical analysis with radiocarbon analysis to know the precise time of every site [19,20]. In this paper, we use both methods, a multivariate analysis and a neural and discriminant analysis.

The objective of this paper is to determine, through statistical procedures and statistical plots, the existence of relations between different dimensions of minarets. The study of these relations or canons can help us to know the construction era of minarets regardless of time of construction.

For this purpose, we made use of a:

- multivariate study for obtaining relations between variables;
- discriminant function analysis to cluster the minarets in function of their construction era taking into consideration their dimensions;
- neural analyse to cluster minarets in function of their ground plan inner disposition: circular, rectangular or octagonal.

From these studies, we have obtained relations and proportions between different minarets, and with these parameters, we can catalogue and improve the dating of minarets discovered in the future.

To achieve this objective, we have selected various minarets located in Andalusia, Spain, because it is in this area where we find the greatest number of discovered minarets. Furthermore, we have analysed briefly different types of cubits, an Islamic measure, used during Islamic constructions.

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