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RESEARCH ARTICLE

The first scientific plan of the Mosque-Cathedral of Córdoba: Graphic and dimensional analysis of an oil painting from 1741

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Abstract This research analyzes the earliest located floor plan of the Mosque-Cathedral of Córdoba, an anonymous oil painting in 1741, which has not been studied so far. The objective is to know the dimensional accuracy of the most relevant architectural forms drawn, considering the elements referenced in their legend and the graphic symbols used, to assess their documentary interest. It has also been compared with two important plans of the Mosque-Cathedral drawn in 1767 and 1868. The first task was a photogrammetric survey of the oil painting has been carried out. Subsequently, some data has been measured in the monument using a 3D scanner. The orthophoto of the oil painting has been overlapped to the digital model to verify its metric accuracy in a selection of points. For the first time, the legend and labels included in the oil painting have been transcribed. This precise graphic document contains reliable abundant data for future research about the transformations and restorations of a monument that is part of the UNESCO World Heritage List. The oil painting dating from 1741 can be considered as the first scientific plan of the Mosque-Cathedral of Córdoba, and as an outstanding architectural survey of eighteenth-century Europe.

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1. Introduction

1.1. Brief historical data

The Mosque-Cathedral of Córdoba in southern Spain, a monument located in the historic downtown, next to the Guadalquivir river and the Roman bridge (Fig. 1a) has preserved both its religious use and architectural identity for more than a thousand years (Moneo-Vallés, 1985).

Its construction process began in the middle of the 7th century and was completed in the late 10th century, after several extensions to the south and east, among which the Al-Hakam II one, built between 961 and 966, is of special architectural interest (Chueca-Goitia, 1965; Nieto-Cumplido, 2007; Cantizani-Oliva et al., 2022). While other mosques in the Iberian Peninsula were demolished and replaced by churches or cathedrals, this one was consecrated as a Christian temple after the city occupation in 1236, and since then it has undergone numerous transformations.

In the 16th century a large Gothic central nave was built inside and in the 18th century some vaults and new skylights were built in its naves, while its interior perimeter was populated by Christian chapels. The current bell tower that surrounds the Islamic minaret was completed in 1663, with five superimposed bodies (Hernández-Giménez, 1975): minaret, bell tower, clock, lantern, and crown with a sculpture of St. Raphael (Fig. 1b).

Important architectural restorations began at the beginning of the 19th century and in 1882 the Mosque-Cathedral was declared National Monument. Since then, numerous architects have been in charge of its conservation and numerous interventions that have helped to recover significant fragments from different periods (Herrero-Romero, 2016). The monument was inscribed on the World Heritage List in 1984, and this site was extended to include part of the Historic Center in 1994.

1.2. Graphic documentary sources

The Mosque-Cathedral of Córdoba has a valuable legacy of historical images prior to the proliferation of photography around 1850. These images constitute an important source for heritage research that is complemented by other historical or archaeological documentary sources, both Muslim and Christian (Nieto-Cumplido, 2007).

The 1741 oil painting, object of this research, was published with poor graphic quality and without any study in the Bulletin of the Royal Academy of Sciences, Fine Arts and Noble Arts of Córdoba in 1944 (issue 51, p. 456). It was also reproduced, without any type of analysis, in a book including plans and drawings of the Mosque-Cathedral (Nieto-Cumplido and Luca-de-Tena-Alvear, 1992); and in a book which includes a partial transcription of the legend (Cosano-Moyano, 1999). It has been mentioned in a book plenty of historic documentation (Nieto-Cumplido, 2007), in another with current plans of the monument (Ruiz-Cabrero, 2009), and in a paper about graphic sources of the Mosque-Cathedral until 1850 (Gámiz-Gordo, 2019). In addition, there are plans of the bell tower—also drawn in the 1741 painting—dating from the 20th century in the aforementioned books by Nieto-Cumplido and Luca-de-Tena y Alvear, and in the one by Ruiz-Cabrero.

The first known interior perspective was included in a book by Henry Swinburne in 1779, and the first collection of views was published by Alexandre Laborde in 1812 (Gámiz-Gordo and García-Ortega, 2012). The accuracy of Laborde's interior perspectives has recently been analyzed (Gámiz-Gordo et al., 2022) plus that portrayed in Girault de Prangey's important views in 1839 (Gámiz-Gordo et al., 2021).

There is agreement that the first plans of the monument were promoted by the Royal Academy of Fine Arts of San Fernando and published in *Las Antigüedades Árabes de España* in 1787 and 1804 (Almagro-Gorbea, 2015). This work includes a Mosque-Cathedral plan drawn by Juan Pedro Arnal, which has been considered the first scientific plan of the monument: "... *Scientific criteria were followed, using geometry as the foundation of the graphic discipline to understand the composition and distribution of architecture, drawn with rigor and sensitivity* ..." (Gámiz-Gordo, 2019, pp. 149–152).

In addition, the plans published by the Royal Academy of Fine Arts of San Fernando in an important collection of plates entitled *Los Monumentos Arquitectónicos de España* (1852–1881) are of great interest (Almagro-Gorbea, 2015). Among them is included another plant of the Mosque-Cathedral of Córdoba drawn by Mariano López Sánchez in 1868.

To understand how precise drawings were obtained, at an epoch when current computer technologies did not exist, you can consult various bibliographies on architectural drawing in the Spanish XVIII century treatises (Irisarri-Martínez and Castaño-Perea, 2014; García-Morales, 1989). In the craft guilds related to architecture, the use of drawing would be common, there were manuals about measurement and also publications on geometry in the military engineers books (Gentil-Baldrich, 2021).

It must be taken into account that the Royal Academy of Fine Arts of San Fernando de Madrid, established in 1752, would try to "*promote and disseminate scientific knowledge and promote the arts and aesthetic*" (Almagro-Gorbea, 2015, p.13). In addition, the Royal Academy was involved in a new emerging scientific mentality at that time: "... *concern for incorporating technical graphic information is, without doubt, a feature that characterizes the nascent scientific spirit that impregnates the works of this century and distinguishes them from previous ones* ..." (Almagro-Gorbea, 2015, p.14).

The mentioned historic graphic documentation provides an important source for researching the architectural heritage, "... *of great importance for studying later restoration works* ..." (Gámiz-Gordo, 2019, p.174). Its analysis, in relation to other documentary sources, offers new directions for future heritage research. For that reason, the surveys promoted by the Royal Academy have been subject of an exhibition with catalog (Almagro-Gorbea, 2015).

However, there is little research on the documentary reliability of these drawings. Almagro-Gorbea compared the 1767 plan with current planimetry and concluded it to be "... *a fairly accurate drawing in its general features, both metrically and in the interpretation of the structure*

Fig. 1 a) The Mosque-Cathedral of Córdoba and its urban environment (created by Google Earth). b) Bell tower (photography by Wikipedia).

and spatial organization ...” (Almagro-Gorbea, 2015, p. 24), stating that “... *This plan constitutes an exceptional document on the state of the cathedral, former mosque, of Córdoba in 1767 ... with a very correct and accurate planimetric representation of the monument* ...” (Almagro-Gorbea, 2015, pp. 272–273). Until the present research, however, the level of accuracy had not been quantified. The plan of 1868 has also been analyzed, though not its metric accuracy.

Another matter of great interest to understand the abstraction degree of the drawn architectural reality are the elements appearing in the legend or labeled on the plan; e.g. in the 1767 plan, the shapes of altarpieces and altars were replaced by “... *small crosses identified by a number that refers to the legend* ...” (Almagro-Gorbea, 2015, pp. 272–273). The representation scale must be taken into account in order to assess the precision and documentary interest.

1.3. Research objective: graphic and dimensional analysis

The objective of this research is to analyze and quantify the graphic and dimensional accuracy of the main architectural elements drawn in the 1741 oil painting in comparison to their current state, considering as a reference two other plans commissioned in 1767 and 1868 by the Royal Academy of Fine Arts of San Fernando in Madrid. An additional objective is identifying and transcribing the labels and references included in the legend or in the drawing itself, taking into account the graphic symbols used to represent its abundant details, thus assessing its reliability and documentary interest for further research on this unique edifice and heritage.

2. Materials and method. Graphic representation and current state

2.1. Brief description of the 1741 oil painting and the plans of 1767 and 1868

This anonymous oil painting is the first known plan representation of the monument. It is kept in the Archive of the Mosque-Cathedral of Córdoba and it is dated 1741, according to the legend itself. The legend also states that it was commissioned by the Bishop of Córdoba Pedro Salazar Góngora, who held this position between 1738 and 1742. The painting measures 1030 mm × 1650 mm and includes a plan of the monument on the right, an elevation of the bell tower on the left, a long legend, and some flower garlands as decoration. It displays two graphic scales, both in varas: one for the floor plan and one for the tower, using a careful symbology discussed later. Its initial layout was probably made with barely perceptible auxiliary lines and arcs, on which the oil was superimposed.

To assess its accuracy, this research also analyzes two other important original plans published in 1767 and 1868. Both originals are kept in the archives of the Royal Academy of Fine Arts of San Fernando [sig. MA-0536; MA-0163], whose website contains digital reproductions of excellent quality. The first one was drawn by Juan Pedro Arnal in black ink and grey wash drawing on light-yellow laid paper measuring 523 mm × 726 mm and includes graphic scale in *pies castellanos* measurement unit. The second plan was drawn by Mariano López Sánchez with black ink and grey, ochre, blue and green wash on paper, measuring 469 mm × 616 mm, and its graphic scale is indicated in meters. Below, all three have been reproduced with their

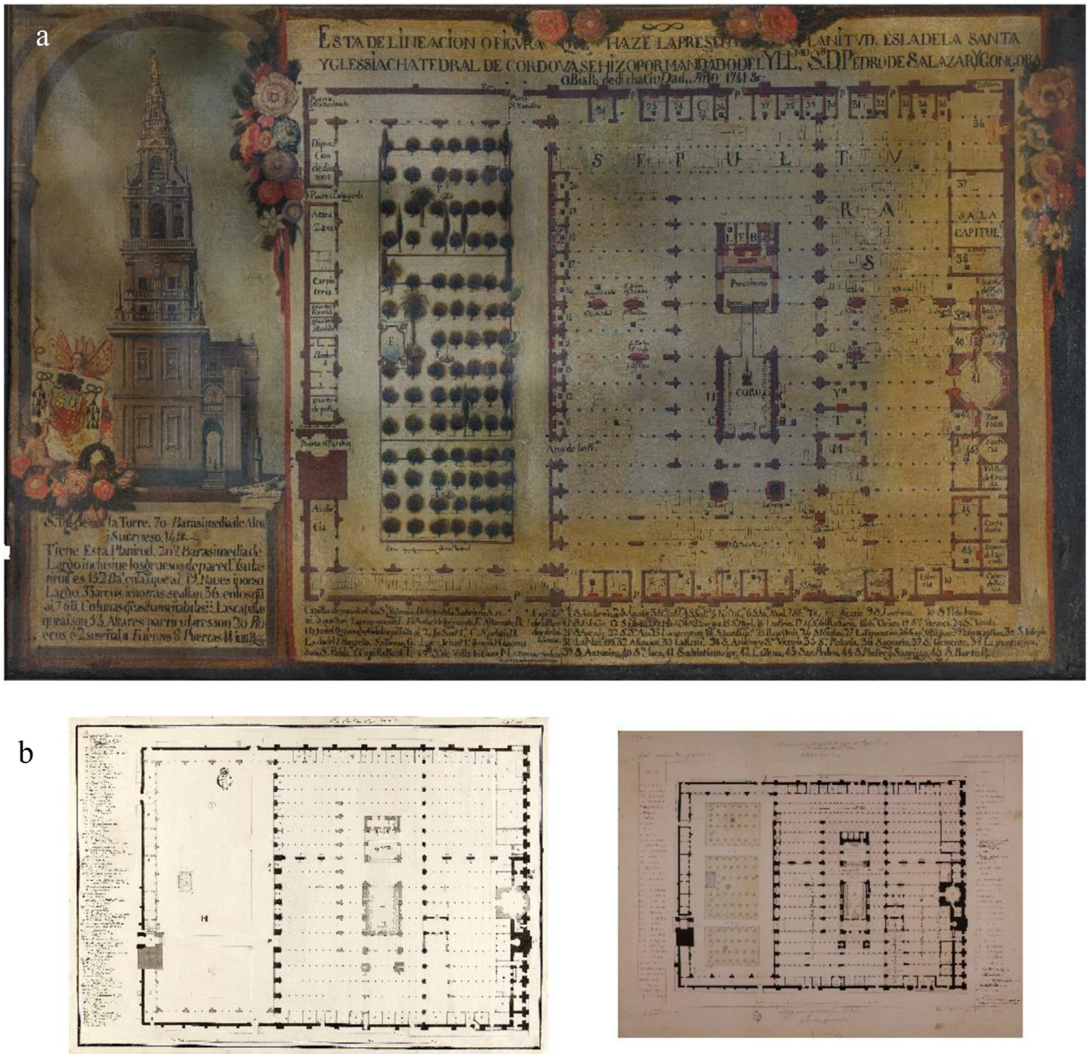


Fig. 2 Three plans of the Mosque-Cathedral of Córdoba reproduced at the same scale: a) oil painting from 1741 (Archive of the Cathedral of Córdoba); b) plans from 1767 and 1868 (Royal Academy of Fine Arts of San Fernando in Madrid).

actual size on the same scale, to clearly appreciate the larger size of the 1741 oil painting (Fig. 2).

2.2. Graphic analysis methodology

In recent years, many research works have focused on dimensional accuracy of historical maps, especially in the field of territory and urban cartography (Aguilar-Camacho, 2017; Algarín-Vélez, 1998; De-Cea-García, 2017; Gómez-Blanco-Pontes et al., 2019; Ortega-Vidal, 2000). A frequently used methodology consists in the graphic overlay of a precise digitization of the historical plan and a representation of its current state. Sometimes, a mesh stressing the main deformations has been derived from that superimposition. In other cases, the positional accuracy between homologous points has been assessed using numerical indexes which indicate the average or global error. Finally, some recent research works have applied MapAnalyst software to assess the accuracy of historical maps.

The reliability assessment of historical drawings of buildings is often based on overlapping accurate current drawings. In the case of the Mosque-Cathedral of Córdoba, other previous works already mentioned have overlayed digital surveys with the plan of 1767 (Almagro-Gorbea, 2015), and even with interior perspectives (Gámiz-Gordo et al. 2021, 2022). To assess the 1741 oil painting accuracy, this research has used very precise current planimetry and compared the two substantial plans dating from 1767 and 1868, as additional references.

First of all, a photogrammetric survey of the 1741 oil painting has been made. Afterwards, a geometric model of the current state of the monument was built from the point cloud obtained by a 3D laser scanner in four areas: the outer perimeter, the patio, the surroundings of mihrab and the interior elevation of the tower. Next, the validity of the graphic scales and measurement units used in the oil painting has been tested by means of dimensional checks of the represented elements.

Then, some control points have been defined and their vector coordinates computed. The graphical analysis undertaken is based on the overlay and representation of the deformation based on the same origin of coordinates and

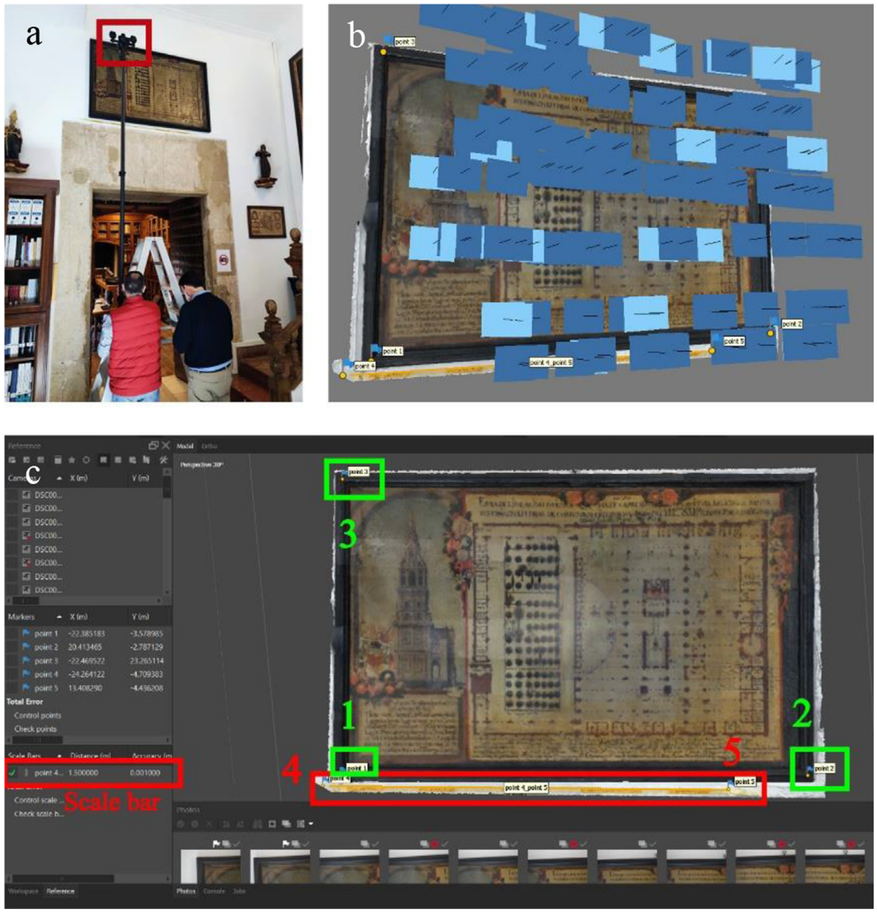


Fig. 3 a) Camera mounted on a pole 4 m high to take the 130 photographs. The painting is hanged on the wall. b) Photographs relative position reconstruction taking the painting as the reference. c) Scaling and setting coordinate reference system for the orthoimage projection plane. Authors' own elaboration.

rotation angle. The following variables have been quantified: outer perimeter area, inner courtyard area, displacements according to x and y, displacement vector (module and angle), as well as percentage error as a ratio between the module of the displacement vector and the length from origin, and the Root Mean Squared Error (RMSE).

The expression $\sqrt{\frac{\sum_{i=1}^{n}(P_i-O_i)^2}{n}}$ allows the RMSE computation, a measure frequently used to assess cartographic accuracy (Aguilar-Camacho, 2017). It allows to obtain a single analytical index that quantifies the error between two data sets, using the same unit. In this way, the mapping from points location in the historical planes (Oi) to the current state ones (Pi) is analyzed, where *n* is the number of points considered in the study area.

Finally, to offer a broader assessment of the information represented in the different plans, the labels included in the legend and plan area have been analyzed, also identifying the main symbols or graphic codes used in the architectural representation.

2.3. Photogrammetry process applied to the 1741 oil painting

A photogrammetry survey of the 1741 oil painting has been performed to obtain an orthoimage on which to take precise measurements of the drawn elements. Considering the state of conservation of the painting and its current location in the Archive of the Mosque-Cathedral of Córdoba, hanging on the wall at a certain height, it was advisable not to move it to avoid any possible deterioration. For this reason, photographs were taken at a short distance using a camera pole that reached a height of up to 4 m (Fig. 3a), with a combination of natural and artificial light (mini spotlights with integrated battery). The camera used was a Sony Alpha ILCE-7K Full Frame and 24Mpixels.

The software used to get the painting orthoimage was Metashape and the needed workflow to produce the point cloud, mesh and texture was as follow.

- Alignment. At this stage the parameters values were *accuracy* (high), *key point limit* (40,000) and *tie point limit* (4,000).
- Dense cloud building. The setting for this step was as follow: *quality* (high) and *depth filtering* (mild).
- Mesh building. The parameters configurations got as follow: *source data* (dense cloud), *surface type* (arbitrary (3D)), *face count* (high), *interpolation* (enabled).
- Texture building parameters: *type* (diffuse map), *source data* (images), *mapping mode* (keep uv), *blending mode* (mosaic), *texture size/count* (8192).

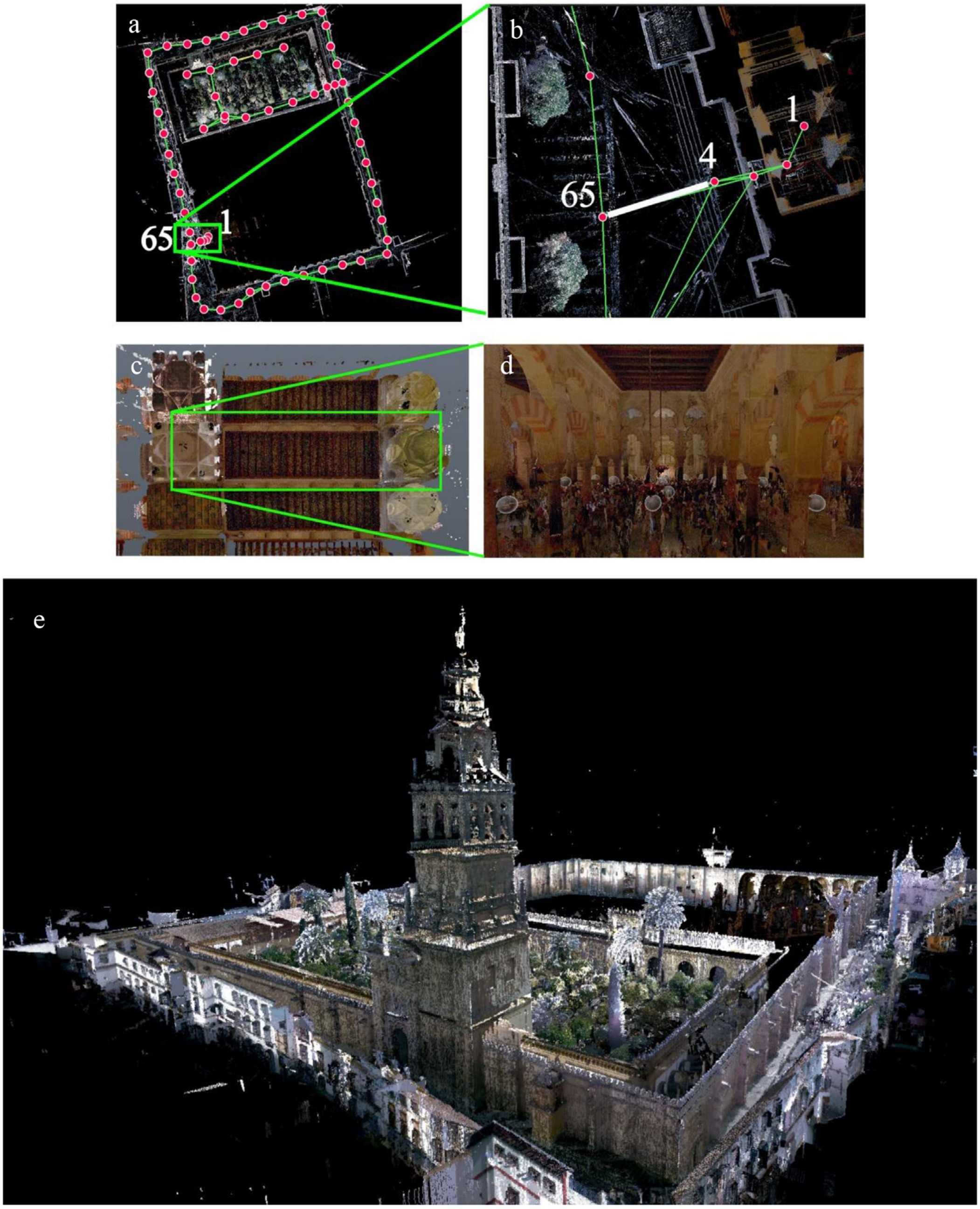


Fig. 4 a) Scan stations location around the Mosque perimeter. b) Detail of the traverse closing carried out between the 4th and 65th scan station. c) Mihrab plant point cloud view. d) Mihrab perspective point cloud view. e) Point cloud perspective outside the monument. Authors' own elaboration.

The locations of the photographic shots were arranged in horizontal alignments, you can see their relative positions in (Fig. 3b) (blue rectangles). Before producing the true orthoimage, two task should be carried out.

- Scaling the model: A metric reference was used to scale the model between the point 4 and point 5 markers (red rectangles in Fig. 3c). Points 4 and 5 have been marked on the 3D model separated each other 1.5 m as it is shown on the scale bar in Fig. 3c. The exact dimension 1.5 m has been achieved pasting a metric tape under the painting (yellow tape in Fig. 3c) that is divided in millimetric marks.
- Setting the coordinate reference system (CRS) for the projection plane. The CRS was established in 3 corners over the painting frame 3D model (points 1, 2 and 3 inside the green rectangle in Fig. 3c). The axis 1-2 (*x* axis) and 1-3 (*y* axis) are perpendicular and make up the plane for projecting the 3D model that produce the orthoimage shown in Fig. 3c.

130 photographs were used to generate the digital mosaic of the final orthoimage (Fig. 2a) for a visible canvas of dimensions 1030 mm × 1650 mm. The orthophoto pixel size was 50 μm. This value was selected after several tests in which a smaller pixel size produced a low-quality image, and a larger value did not improve the visual resolution of the image obtained.

2.4. Current state survey obtained from 3D laser scanner and point cloud

A 3D laser scanner has been used to get an accurate survey of the exterior walls perimeter of the Mosque-Cathedral, the perimeter of the patio, the bell tower, and the Mihrab nave. The first scan was registered to a previous one that had been leveled with a Leica C10 scanner. The monument perimeter was surveyed using 65 new scans performed with a Leica BLK360 scanner and processed with the Cyclone 360 software. The BLK360 has three different density options to capture data (high, medium and low). The selected option in this study was the medium one which take points separated by 5 cm if the object was a plane placed 10 m away.

The scan station (numbered 1 in Fig. 4a and b) was performed by C10 scanner and is the starting point for the traverse that fit the 65 scans used in the perimeter survey of the Mosque (Fig. 4a). In order to get a suitable accuracy, the traverse was closed by the 65th scan on the 4th scan getting a 4 mm fitting error (Fig. 4b). The traverse scan stations fitting guarantees that the accumulated errors are minimized (the error is 5 mm, both the whole and the cloud-to-cloud measurement).

The registration for every scan station was carried out one by one inside Cyclone Register 360 software and it was used a cloud to cloud methodology. The registration is performed translating and rotating manually the one to be registered until it approximately be coincident to the reference and then order the software to optimize the registration. After the optimization task, an error distribution is shown by the software and the user has the option to accept or reject the result.

The Mihrab survey is in the same coordinate system that the exterior walls, but it was processed by the Recap software. Fig. 4c and d represent the point cloud plant and a perspective view respectively for the Mihrab central nave. The spheres shown in Fig. 4d are the scan stations locations.

The geometric model of the current state of the monument—on the outer perimeter of the courtyard, Mihrab surroundings, and interior elevation of the bell tower—has been elaborated by importing as reference the point cloud to CAD. Next, some sections have been performed on the point cloud, which have been then orthogonally projected to obtain the corresponding orthoimages. To define the geometry, certain commands have been used to obtain lines and edges, as well as planes and intersections. Each of the elements has been defined according to the degree of precision and definition of the model analyzed in each scale used. Fig. 4e shows a perspective for the whole point cloud of the capture data.

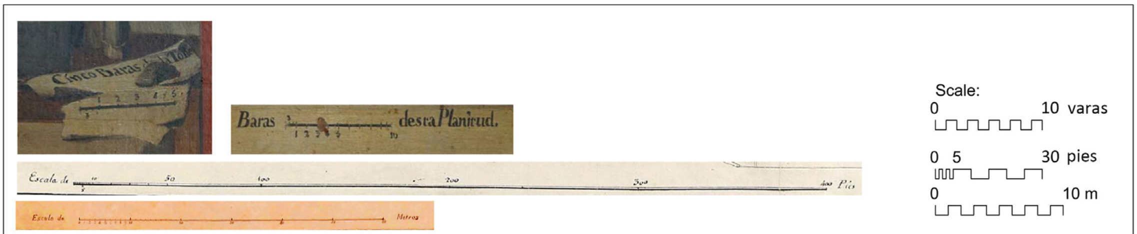
3. Results and discussion: dimensional analysis, legend and symbols

3.1. Quantification of scales and variables

In order to know the equivalence of the measurement units used in the 1741 oil painting, it must be considered that the perimeter of the monument's floor plan measures 175.34 m × 128.52 m, according to our own survey carried out with a laser scanner. The legend included in the oil painting indicates that the floor plan measures 207.5 varas × 152 varas, therefore it is deduced that 1 vara is equivalent to 0.84 m.

On the other hand, the tower measures 11.71 m wide × 59.65 m high and according to legend it measures 14 varas × 70.5 varas, that is, 0.83 m in width and 0.84 m in height. These values are quite similar to 0.835905 m, which is the equivalence of 1 vara according to the Geographic and Statistical Institute of Spain (Dirección, 1886; Escalona-Molina, 2009). Thus, considering that 1 vara is equal to 0.836 m and 1 pie to 0.279 m, the three planes scale is revealed.

The dimensions of each plane along with their measurement units allow to obtain the numerical scale, computing it as a ratio between the distance on paper (*d*) and the real distance (*D*); the length of the graphic scale itself has been considered (Fig. 5).



VARIABLES	Dimensions (mm^2)	Unit of measure	Equivalence (m)	Number of units in graphic scale	(*D*) Real distance (m)	(*d*) Distance on paper (m)	(1/*U*=*d*/*D*) Numerical scale
1741 OIL PAINTING	1030 x 1650	vara	0.836	10.00	8.36	0.052	1/160
			0.836	5.00	4.18	0.047	1/90
1767 PLAN	523 x 726	pie	0.279	400.00	111.47	0.372	1/300
1868 PLAN	469 x 616	m	1.000	60.00	60.00	0.149	1/400

Fig. 5 Scales analysis. Authors' own elaboration.

Table 1 Control points and variables quantification. Authors' own production.

	SURFACES	3D GEOMETRIC MODEL			OIL PAINTING FROM 1741					PLAN OF 1767					PLAN OF 1868				
	Perimeter surface	21983.508 m^2			21462.67 (2.37%)					22401.48 (−1.90%)					22180.44 (−0.90%)				
	Courtyard surface	5781.685 m^2			5439.53 (5.92%)					5911.87 (−2.25%)					5597.98 (3.18%)				
	VARIABLES	*X*	*Y*	Vector modulus	Error *X*	Error *Y*	Error vector modulus	Error vector angle	Error	Error *X*	Error *Y*	Error vector modulus	Error vector angle	Error	Error *X*	Error *Y*	Error vector modulus	Error vector angle	Error
PLAN	P1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00%	0.00	0.00	0.00	0.00	0.00%	0.00	0.00	0.00	0.00	0.00%
	P2	175.35	−0.84	175.35	2.07	−0.01	2.07	−0.28	1.18%	−0.28	0.00	0.28	179.59	0.16%	−1.06	0.01	1.06	179.73	0.61%
	P3	174.43	127.68	216.17	2.67	1.48	3.05	28.95	1.41%	−0.93	−0.75	1.19	−140.96	0.55%	−1.03	0.31	1.08	163.08	0.50%
	P4	−0.96	124.41	124.41	−0.56	0.43	0.71	142.37	0.57%	0.39	−1.75	1.80	−77.56	1.44%	−0.85	−1.09	1.38	−127.82	1.11%
	P5	8.25	7.86	11.40	−0.59	−0.62	0.85	−133.48	7.50%	0.40	−0.18	0.44	−24.35	3.85%	−0.14	−0.72	0.73	−100.83	6.40%
	P6	59.82	7.53	60.29	0.55	−0.26	0.61	−25.72	1.01%	−0.03	0.17	0.17	100.28	0.29%	1.13	0.17	1.15	8.48	1.90%
	P7	58.91	117.47	131.41	−0.11	2.43	2.43	92.53	1.85%	−0.07	−1.93	1.93	−92.11	1.47%	0.39	−0.23	0.45	−30.86	0.35%
	P8	6.67	116.62	116.81	−1.53	2.25	2.71	124.18	2.32%	−0.05	−1.25	1.25	−92.15	1.07%	−0.99	−1.53	1.82	−122.79	1.56%
	RMSE (perimeter)				1.71	0.77	1.88			0.52	0.95	1.09			0.85	0.57	1.02		
	RMSE (courtyard)				0.86	1.69	1.89			0.21	1.16	1.18			0.78	0.86	1.16		
NAVE OF MIHRAB	M1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00%	0.00	0.00	0.00	0.00	0.00%	0.00	0.00	0.00	0.00	0.00%
	M2	3.16	0.00	3.16	0.36	0.03	0.36	4.76	11.42%	0.09	0.02	0.09	13.28	2.89%	−0.18	0.02	0.18	172.87	5.61%
	M3	6.32	0.01	6.32	0.45	0.07	0.45	9.05	7.14%	0.01	−0.02	0.02	−67.17	0.33%	0.00	0.07	0.07	89.12	1.03%
	M4	9.45	0.01	9.45	0.48	0.10	0.49	11.49	5.15%	0.15	0.07	0.16	25.14	1.72%	−0.04	0.08	0.09	116.28	0.96%
	M5	12.63	0.00	12.63	0.53	0.05	0.54	5.56	4.25%	0.16	0.04	0.16	14.12	1.30%	0.04	0.06	0.07	54.94	0.55%
	M6	15.76	0.00	15.76	0.63	0.06	0.64	5.78	4.03%	0.18	0.01	0.18	4.11	1.15%	−0.01	0.04	0.04	100.54	0.28%
	M7	18.91	−0.03	18.91	0.54	0.02	0.54	1.90	2.87%	−0.08	0.11	0.14	125.63	0.74%	0.09	0.09	0.13	43.75	0.69%
	M8	19.32	−0.02	19.32	0.34	0.03	0.34	4.42	1.74%	0.04	0.10	0.11	69.00	0.55%	0.21	0.10	0.23	24.59	1.21%
	M9	22.21	−0.10	22.21	0.38	−0.02	0.38	−3.01	1.71%	0.00	0.15	0.15	89.21	0.65%	0.11	0.20	0.22	60.92	1.01%
	M10	25.19	0.00	25.19	0.57	0.00	0.57	0.00	2.27%	0.21	0.00	0.21	0.00	0.84%	0.05	0.00	0.05	0.00	0.20%
	M11	18.86	2.58	19.04						−0.02	0.25	0.25	95.59	1.29%					
	M12	18.88	5.20	19.58						−0.10	0.20	0.23	117.24	1.16%					
	M13	0.01	7.81	7.81	−0.03	0.55	0.55	93.21	7.08%	0.09	0.22	0.24	67.75	3.04%	−0.02	−0.08	0.08	−104.36	1.08%
	M14	3.16	7.79	8.41	0.06	0.57	0.57	84.24	6.75%	0.08	0.23	0.24	71.49	2.88%	−0.05	−0.10	0.11	−116.11	1.35%
	M15	6.33	7.78	10.03	0.21	0.55	0.59	69.57	5.88%	0.03	0.22	0.22	81.54	2.24%	0.03	−0.05	0.06	−57.68	0.58%
	M16	9.48	7.79	12.27	0.32	0.64	0.71	63.15	5.81%	0.19	0.18	0.26	43.92	2.15%	0.05	−0.04	0.07	−41.99	0.55%
	M17	12.65	7.80	14.86	0.45	0.62	0.77	53.98	5.18%	0.12	0.14	0.19	50.19	1.26%	0.12	−0.02	0.12	−11.40	0.82%
	M18	15.78	7.81	17.61	0.52	0.66	0.83	51.87	4.74%	0.23	0.12	0.26	28.43	1.48%	0.11	−0.06	0.12	−31.36	0.70%
	M19	18.92	7.82	20.47	0.47	0.73	0.87	56.93	4.23%	−0.13	0.09	0.16	146.02	0.80%	0.09	−0.01	0.09	−5.77	0.44%
	M20	19.34	7.82	20.87						−0.04	0.09	0.10	113.85	0.50%	0.22	−0.05	0.22	−12.86	1.08%
	M21	22.26	7.82	23.59	0.59	0.89	1.07	56.27	4.54%	−0.07	0.02	0.07	161.05	0.30%	0.29	−0.08	0.30	−14.40	1.28%
	M22	25.17	7.81	26.36	0.56	0.96	1.11	59.84	4.22%	0.20	0.10	0.22	26.79	0.85%	0.00	−0.08	0.08	−87.95	0.32%
	RMSE				0.44	0.48	0.65			0.12	0.13	0.18			0.12	0.08	0.14		

BELL TOWER	T1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00%
	T2	11.72	0.00	11.72	−0.13	0.00	0.13	0.00	1.07%
	T3	17.09	0.00	17.09	−0.09	0.00	0.09	0.00	0.55%
	T4	17.09	15.95	23.38	−0.09	−0.05	0.11	−152.95	0.45%
	T5	0.45	21.68	31.68	0.35	−0.56	0.66	−57.62	2.07%
	T6	11.42	21.70	24.52	−0.25	−0.53	0.59	−115.13	2.40%
	T7	1.67	31.52	31.56	0.26	−0.74	0.78	−70.89	2.47%
	T8	10.08	31.58	33.15	−0.05	−0.71	0.72	−94.33	2.16%
	T9	1.86	38.60	38.64	−0.25	−0.68	0.73	−110.41	1.88%
	T10	9.77	38.64	39.85	0.31	−0.73	0.79	−66.76	1.99%
	T11	3.56	47.23	47.37	−0.03	0.22	0.22	98.02	0.47%
	T12	7.97	47.23	47.90	0.38	0.12	0.40	16.95	0.84%
	T13	5.68	54.62	54.91	0.16	0.17	0.23	47.12	0.42%
	T14	5.42	59.65	59.90	0.45	0.49	0.67	47.67	1.12%
	RMSE				0.24	0.46	0.52		

Table 1 includes the 44 control points and some variables and statistics: 8 at the corners of the building perimeter and at the corners of the patio, 22 at the axes of the columns in the Mihrab nave, and 14 at the tower. It should be noted that two columns were not drawn on the plans of 1741 and 1868; and that the tower is not represented in the plans of 1767 and 1868.

3.2. The outer perimeter of the floor plan and the patio

After defining 4 control points at the corners of the outer perimeter of the monument and another 4 at the corners of the patio, the survey itself has been overlayed to the 1741 oil painting and both plans of 1767 and 1868, matching the vertex lower left and the direction of the lower facade (Fig. 6). All this has been scaled in meters, considering that 1 vara is equivalent to 0.836 m, 1 vara to 3 pies and 1 pie to 0.279 m (Dirección, 1886; Escalona-Molina, 2009).

The RMSE of the module of the displacement vector in the outer perimeter shows a deviation respect to the scanned survey of 1.88 m in the 1741 oil painting, 1.09 m in the 1767 plan, and 1.02 m in the 1868 plan. The same occurs in the perimeter of the patio, although the differences are smaller (1.89 m, 1.18 m, and 1.16 m, respectively).

From the analysis of the variable surface enclosed by the outer perimeter, the greatest difference respect to the survey corresponds to the oil painting of 1741 (2.37%), and the minimum to the plan of 1868 (0.90%). The same occurs with the surface of the patio, corresponding the largest deviation to the oil painting of 1741 (5.92%) and the smallest to the plan of 1767 (2.25%). All this allows to conclude that the 1741 oil painting is somewhat less exact, considering the surface, than the 1767 and 1868 plans.

3.3. The Mihrab central nave

The survey of the Mihrab nave has been overlayed to the vectorial transcription of the oil painting of 1741 and the plans from 1767 and 1868 (Fig. 7). 22 control points have been selected, corresponding to the columns axes of the main nave, matching the center of column M1 and the direction that joins the center of columns M1—M10. It must be noticed that columns M11 and M12 are not represented neither in the 1741 oil painting nor in the 1868 plan.

The RMSE variable of the displacement vector module has been quantified. The maximum displacements in the oil painting from 1741 correspond to the M22 column (1.11 m), in the 1767 plan to the M11 (0.25 m), and in the 1868 plan to the M21 (0.30 m). The accuracy of the 1767 and 1868 plans (RMSE equal to 0.18 m and 0.14 m, respectively) is greater than the oil from 1741 (0.65 m). Therefore, the accuracy of the 1741 oil painting in the central nave of the Mihrab is slightly inferior than that of the outer perimeter of the monument and its patio.

3.4. The bell tower elevation

The survey from the scanner has also been overlayed to the interior elevation of the tower represented in the 1741 oil painting, making the lower left end coincide with the

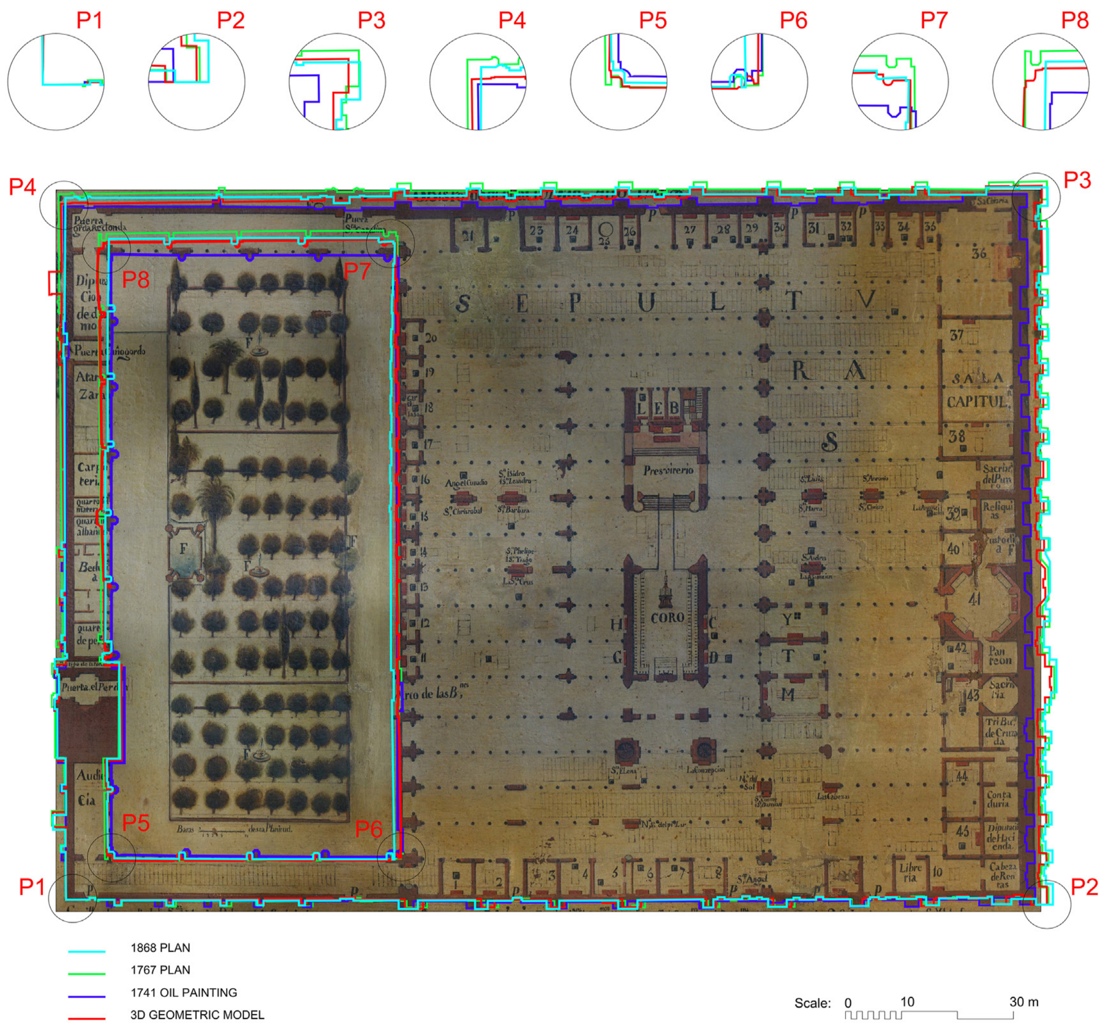


Fig. 6 Geometric model overlay: 1741 oil painting and 1787 and 1868 plans. Deviation details of control points. Authors' own elaboration.

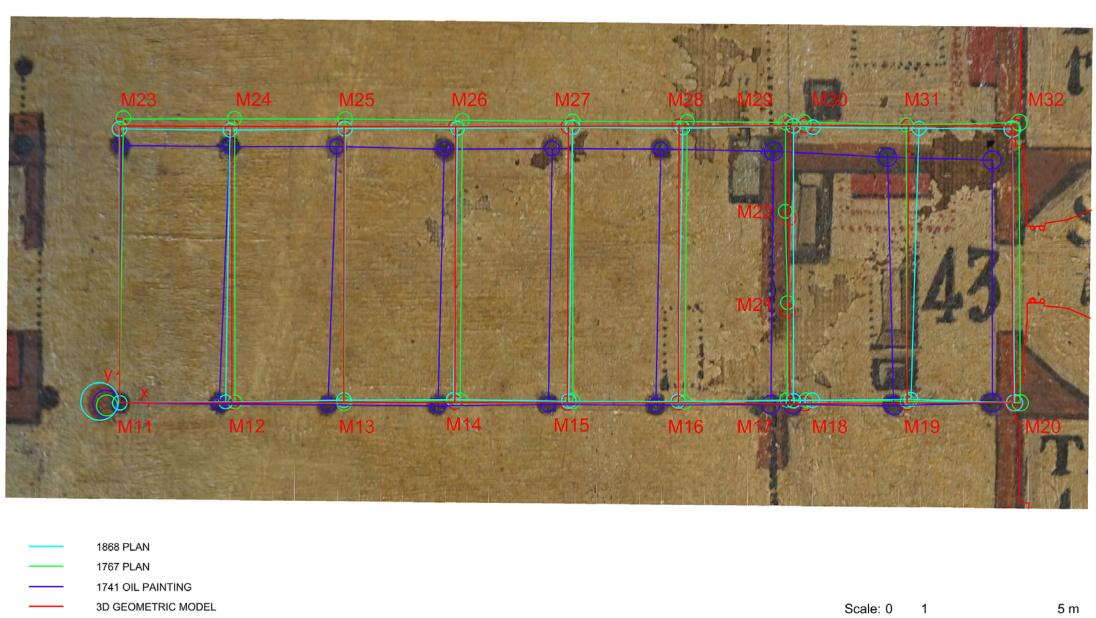


Fig. 7 Digital geometric model overlay for the floor plan of the Mihrab nave: the oil painting from 1741 and the plans from 1767 and 1868. Authors' own production.

center of local coordinates—control point T1—and the x-axis to the direction defined by the control points T1—T3. The scales defined in the previous section were maintained (Fig. 8).

The total height of the tower from the level of the patio according to the scanner survey is 59.65 m. The maximum deviation through this direction corresponds to the second section (control points T7 and T8) of 0.74 m and 0.71 m. The width of the tower at its base has differences of 0.13 m, and in the section containing the bells (points T9 and T10); the differences are 0.25 m smaller and 0.31 m larger, respectively. The RMSE variable on the x axis is reduced to 0.24 m and on the y axis to 0.46 m.

All this allows to conclude that the agreement between the oil painting and the survey obtained with the scanner is quite precise, showing only an error of 0.49 m in relation to the total height of 59.65 m (global RMSE equal to 0.52 m).

3.5. Legend and graphic symbology used in the representation

The oil painting from 1741 includes an extensive legend distributed in four areas (Fig. 9) which is transcribed below. The first, located in the upper area, indicates the title, the promoter—Bishop D. Pedro de Salazar y Góngora—and the date, 1741. The second area is located under the tower, indicating the dimensions of the tower and the floor plan, plus the number of naves (19), arches (33 and 36), columns (768), chapels (55), private altars (20), *buecos* [crypts] (52), fountains (8), doors (14) and shutters (1) and indicating the symbol used to identify the columns and *buecos*.

In its lower part is the third legend, indicating the chapels located 'In the middle of the Holy Church below the High Sacristy' (L, E, B), under the organ on the Epistle side (C, D), in the Gospel side (G, H), and others (Y, T, Y, M). Next, in a fourth area, the chapels located on the perimeter of the monument are listed, numbered from 1 to 45, indicating that the private altars are written in the corresponding place.

In addition, there are many other labels in the drawing, which are not included in the legend, and which have been transcribed here for the first time thanks to the high-resolution orthophoto obtained. Thus, different doors are now identified: *Puerta grda Redonda* [Grada Redonda], *Postigo de la torre, Puerta, el Perdon, Puerta Cañogordo, Arco de las B^{nes}* [Bendiciones], *Puerta Sta Catalina*. Likewise, 20 altars are identified with the following labels: *S^{t} Angel, S^{ta} Elena, La concepción, Las Cabezas, N del Sol, S^{n} Cosme y S^{n} Damian, N^{a} S. del pilar, S^{n} Christobal, Angel Cutudio, S^{ta} Barbara, S^{n} Isidro i S^{n} Leandro, S^{n} Marta, S^{n} Luis, S^{n} Charlos, S^{n} Antonio, La Anunciacion, S^{n} Phelipe y S^{n} Tiago, La S^{ta} Crus, La Asunción, S. Andres*. Signs are also included in the rooms of the courtyard gallery: *Diputación de diesmos, Atarazana, Carpinteria, Quarto del material, Quarto de albañiles, Beduria, Quarto de peros, Audiencia*. In addition, other texts appear: *CORO, Previterio* (hacia el centro de la planta); *Sacristia Sagrario, SALA CAPITUL^{R}, Sacristia del Punto, Reliquias, Custodia, Panteon, Sacristia, Tribu^{na} de Cruzada, Contaduria, Diputación de Hacienda, Cabeza de Rentas, Librería* (on the right margin); and *Garcilaso*, on the left margin, corresponding to chapel 18.

The oil painting from 1741 has 174 identified elements: 10 chapels located in the central part of the building, with capital letters; 45 numbered chapels around the perimeter; 20 altars of private and identified people; 52 *buecos* [crypts] identified with a symbol; 8 fountains marked with the letter F; 14 doors, 7 of them with the letter P and the rest, plus a shutter, are labeled on the plan; 8 outbuildings in the patio galleries and 16 labeled in other locations. 107 elements among the 174 mentioned above appear in the legend or labeled on the plan and another 67 (*buecos*, fountains and doors) are marked with generic symbols in the legend.

As a comparative reference, it should be considered that in the 1767 plan, 72 dependencies or elements are identified: 70 appear in the legend and 2 labeled in the plan; and in the 1868 plan the number of identified elements is similar, 74: 68 in the legend and 6 labeled on the plan, 5 with generic identifications.

Finally, the symbols or graphic codes used in the architectural representation have been also included in the

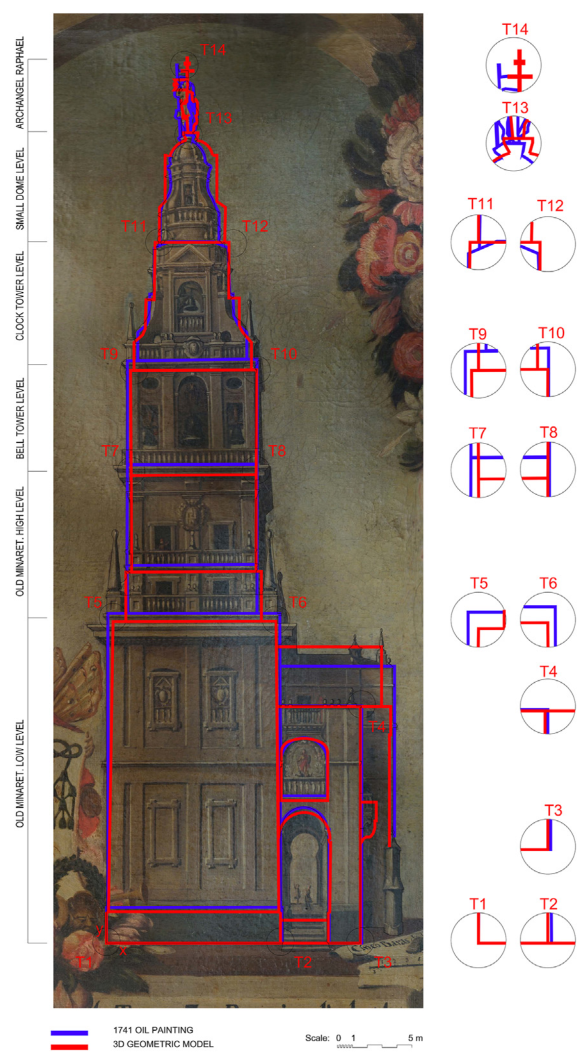


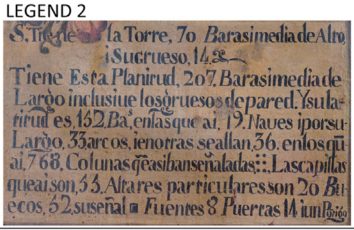
Fig. 8 Digital geometric model overlay between the survey from the scanner and the oil painting from 1741. Deviation details of control points. Author's own production.

LEGEND ON THE 1741 OIL PAINTING

LEGEND 1

ESTA DELINEACIÓN O FIGVRA QUE HAZE LA PRESENTE PLANITUD, ES LA DE LA SANTA /YGLESSIA CHATEDRAL DE CORDOVA SE HIZO POR MANDADO DEL YLL^{MO}. S^{R}. D. PEDRO DE SALAZAR Y GONGORA / OBISPO de dicha CIUDAD, Año 1741&

LEGEND 2



S, Tiene la Torre, 70 Barasimedia de Alto,/ i Su Grueso, 14&/Tiene Esta Planitud, 207.Barasimedia de/ Largo inclusive los gruesos de pared. Y su la-/titud es 152 Ba^{s}, en las que ai, 19. Naves i por su / Largo, 33 arcos, i en otras se allan, 36. En los que/ ai. 768. Columnas que asi ban señaladas, ⁘. Las capillas / que ai son 55. Altares particulares son 20 Bu- /ecos 52, su señal ▪ Fuentes 8 Puertas 14 i un Postigo

LEGEND 3

Capillas de enmedio de la S^{ta}, Yglessia. Debajo de la Sachrista Ata./ ai, 3 que Son. La presentacion L, El Angel de la guarda, E. Sn Bernabe, B./ Vajo del Organo lado de la epistola ai, 2. Jesus Ma , C. Sn pelajio, D./ Lado del EBanjelio, Sn, to Tomas, G. i la otra Jesús Ma, i Joseph, H. las otras/ Son, S^{n}, Pablo, Y. Capilla Real, T. N, S, de Villa viciosa, M

Capillas de alRee-/ dor de la i-/Glesia/ Atares particulares/ Ban anotados en/ su sitios.

LEGEND 4

Capillas de alRee- / dor de la i-/ Glesia

1 S. Ambrosio, 2 S. Agustin, 3 N.las N^{es}, 4 S.Si^{mon} yJ^{as}, 5 NªSª la C^{on}, S, An^{to},Abad , 7 SS^{ma} Tri, 8 Acazio, 9 S. Lorenzo, 10 S Yldefonso, / 11 S. Eulogio, 12 S. Esteba, 13 La Magda^{na}, 14 NSª la antigua, 15 S^{n} Miguel, 16 Los Reies, 17 N,Sª,del Rosario, 18 S ^{to} Christo, 19 S^{tas} Varones, 20 S^{ta} Vrsola, /21 S. Antonio 22 S ^{ra} S^{ta} Ana, 23 La concep ción, 24 S. Juan Bap ^{ta} , 25 Baptisterio, 26 S. Nicolas, 27 La Espectación, 28 Cap^{a} Obispos, 29 La Concepcion, 30 S. Joseph, / 31 La Nati^{dad} de NªSª, 32 Asuncion, 33 La Resu ^{n}, 34 S. Azisclos y S^{ta} Victoria, 35 S^{ta} Polonia, 36 Sagrario, 37 S^{n}, Clemente, 38 La anunciación, /39 S, Antonio. 40 S ^{ta} Ines. 41 Sachristíamaior. 42 La Zena, 43 San Pedro. 44 S. Phelipe y Santiago, 45 S. Bartolome

GRAPHIC SYMBOLS

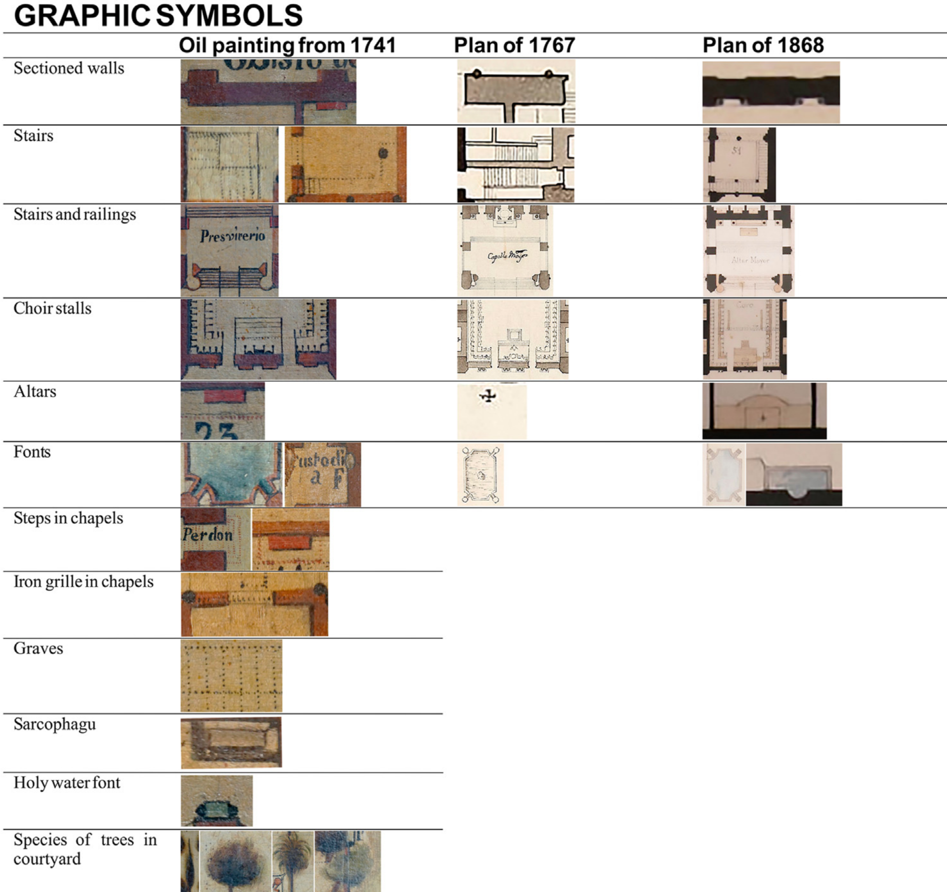


Fig. 9 Legend on the 1741 oil painting and the symbols used in relation to the 1767 and 1868 plans. Authors' own production.

analysis, creating a table with certain examples or details (Fig. 9). In the oil painting from 1741, a wide variety of symbols were used for details not included in the legend. For example, to differentiate the walls sectioned in the floor plan, black lines were used for their outline and color for their interior. The color was slightly modified to differentiate some recent works, or even to indicate projected or planned works. In the 1868 plan, a lighter shade was used to differentiate the walls from the Christian period. In the three plans, different types of continuous lines were used to represent steps in chapels, stairs, railings, altars, or choir furniture.

Many elements appearing in the oil painting from 1741 were omitted in the other two plans, and they were drawn using discontinuous lines or black dots (sometimes red) to represent tombs, sarcophagi, grids, holy water fonts, etc. In addition, the access railings to the presbytery, the choir stalls, or the patio water dispenser—also referenced in the 1767 and 1868 plans—were drawn in perspective to facilitate visual understanding. It is remarkable the representation of trees, which clearly distinguishes some species (cypress, orange, palm tree, or others).

4. Conclusions. The first scientific plan of the Mosque-Cathedral of Córdoba

The oil painting from 1741 has hardly been studied until now, despite being the first known plan of the Mosque-Cathedral of Córdoba. In order to assess its documentary importance and its reliability, this research analyzes for the first time its dimensional accuracy, including its legend and graphic symbology. In addition, two relevant plans from 1767 and 1868 endorsed by the Royal Academy of Fine Arts of San Fernando in Madrid have been taken as references.

To do this, a photogrammetric survey of the 1741 oil painting has been carried out and metric data of the current state of the monument has been taken, with a 3D laser scanner. The validity of the two graphic scales included in varas *castellanas* has been verified: one for the floor plan and the other for the elevation of the tower, validating that the floor plan measures 207.5 varas × 132 varas and the tower 70 varas × 14 varas. These dimensions agree with those indicated in the legend, which reads: "... *Tiene* [...] *la Torre, 70 Barasimedia de Alto iSuGrueso 14* £. *Tiene Esta Planitud 207 Barasimedia de Largo inclusive los gruesos de pared. Y su latitud es 132 Ba*^{s} ..." [The tower is 70 and a half varas high and 14 varas wide. The plan is 207.5 varas long and 132 varas wide, including wall thickness].

It should be noted that the oil painting from 1741 is larger (1030 mm × 1650 mm) than the 1767 plan (523 mm × 726 mm), which in turn it is larger than the 1868 plan (469 mm × 616 mm). The measurement units are vara *castellana*, *pie* and meter, respectively. Considering that 1 vara is equal to 0.836 m and 1 pie to 0.279 m, the scale used in the oil painting would be 1:90 for the tower and 1:160 for the floor; while that from the 1767 plan is 1:300 and that of 1868 is 1:400. Thus, the smallest scale and, therefore, the highest level of definition and detail corresponds to the oil painting dating from 1741.

This research has unveiled the agreement between the 1741 oil painting and the real external perimeter of the plant is slightly lower than that of the plans of 1767 and 1868 (RMSE: 1.88 m compared to 1.09 m and 1.02 m); and somewhat less accurate in the mihrab nave (RMSE: 0.65 m versus 0.18 m and 0.14 m). In addition, the interior façade of the bell tower is surprisingly precise, only a 0.49 m error compared to the total height of 59.65 m.

In addition, this research has identified for the first time, 174 elements referenced in the oil painting from 1741, 107 of them appearing in the legend or labeled on the plan and another 67 (*buecos*, fountains and doors) are marked generically with symbols in the legend. In the 1767 plan, 72 elements are identified and the 1868 plan identified a similar number, 74, simplifying the real world. Thus, although the three floor plans used similar symbols for the architectural representations, the 1741 oil painting, thanks to its larger size, included many more details (steps, grids or doors in chapels, sarcophagi, tombs, holy water fonts, fountains, types of trees ...).

It is striking that the 1868 plan omitted two columns in the Mihrab (M11 and M12), as it occurs in the 1741 plan. This suggests that the Royal Academy plan probably copied or used the oil painting as a reference, an issue that could be analyzed in future research.

In any case, scientific criteria were followed, using geometry as the foundation of the graphic discipline to understand the composition and distribution of architecture, drawn with rigor and sensitivity. The oil painting is a fairly accurate and reliable representation, and not an idealized pictorial image. It is the first scientific survey of the Mosque-Cathedral of Córdoba; it is older than the foundation of the Royal Academy of Fine Arts of San Fernando (1752) and was part of the new scientific mentality emerging at that time. The analysis of its abundant details drawn or labeled, compared to other documents and to the current state of the monument, will open up new research lines to understand its architectural transformations and restorations.

In addition, the oil painting has an exceptional heritage value as graphic document. This is the earliest scale representation of the Mosque-Cathedral of Córdoba, in which the scientific rigor of architectural drawing is combined with a pictorial method that endows it with a peculiar artistic emotion and great communicative force. On account of all this, it is necessary to highlight the importance of this architectural survey in the history of 18th century European architecture.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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