



Article

A Deformed Muqarnas Dome at the Sala de los Reyes in the Alhambra: Graphic Analysis of Architectural Heritage

Antonio Gámiz-Gordo ^{1,*}, Ignacio Ferrer-Pérez-Blanco ² and Juan Francisco Reinoso-Gordo ³

¹ Departamento de Expresión Gráfica Arquitectónica, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, 41012 Sevilla, Spain

² Laboratoire des Cultures Numériques du Projet Architectural, Institut d'Architecture, Faculté de l'environnement naturel, architectural et construit (ENAC), École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland; ignacio.ferrer@epfl.ch

³ Departamento de Expresión Gráfica Arquitectónica y en la Ingeniería, Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos, Universidad de Granada, 18071 Granada, Spain; jreinoso@ugr.es

* Correspondence: antoniog@us.es

Abstract: The muqarnas are small pieces grouped together, adopting surprising three-dimensional forms. They are a symbol of identity of the 14th century Nasrid architecture at Alhambra in Granada. This research's aim is to graphically analyze the plaster muqarnas dome located to the south of the Sala de los Reyes, in the Palacio de los Leones. The methodology followed combines historical images analysis and modern digital graphic techniques. First, a compilation of unpublished drawings and photographs documenting architectural transformations and significant alterations in the roof structures since the 16th century is provided. Although these muqarnas were drawn by Jones and Gourey in the 19th century, the current research identifies and draws, digitally for the first time, its nearly two thousand pieces of this dome. Additionally, metric data of the current state has been collected using 3D laser scanning, revealing significant deformations. In this way, the knowledge of these fragile architectural elements is achieved to promote their heritage dissemination and to facilitate the conservation of a monumental site included in the UNESCO World Heritage List.

Keywords: heritage; architecture; Alhambra; muqarnas; drawing; deformation; conservation



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1. Introduction

1.1. A Fragile Architectural Heritage from the 14th Century

Granada was the capital of the Nasrid kingdom between the 13th and 15th centuries and therefore has an important architectural heritage, especially in the Alhambra citadel [1–8]. Its monumental site is part of a medieval urban complex included in the UNESCO World Heritage List [9].

The palatial area known as the Casa Real de la Alhambra is arranged around important patios, a traditional architectural formula that would adapt to the epoch needs and the ground topography [10]. In this palatial area, the Palacio de los Leones (Figure 1a) built by Sultan Muhammad V (1354–1359; 1362–1391), who would be its promoter and architect, is of greatest artistic interest [11]. Its elegant patio has a perimeter gallery with slender marble columns and on its shorter sides highlight two pavilions, recognized as masterpieces of Nasrid art (Figure 1b). Its architecture is characterized by fine decoration and sophisticated muqarnas compositions [12–14], which reached great complexity in the domes of the Abencerrajes and Dos Hermanas rooms, southern and northern in this palace, and in the Sala de los Reyes, located easterly.

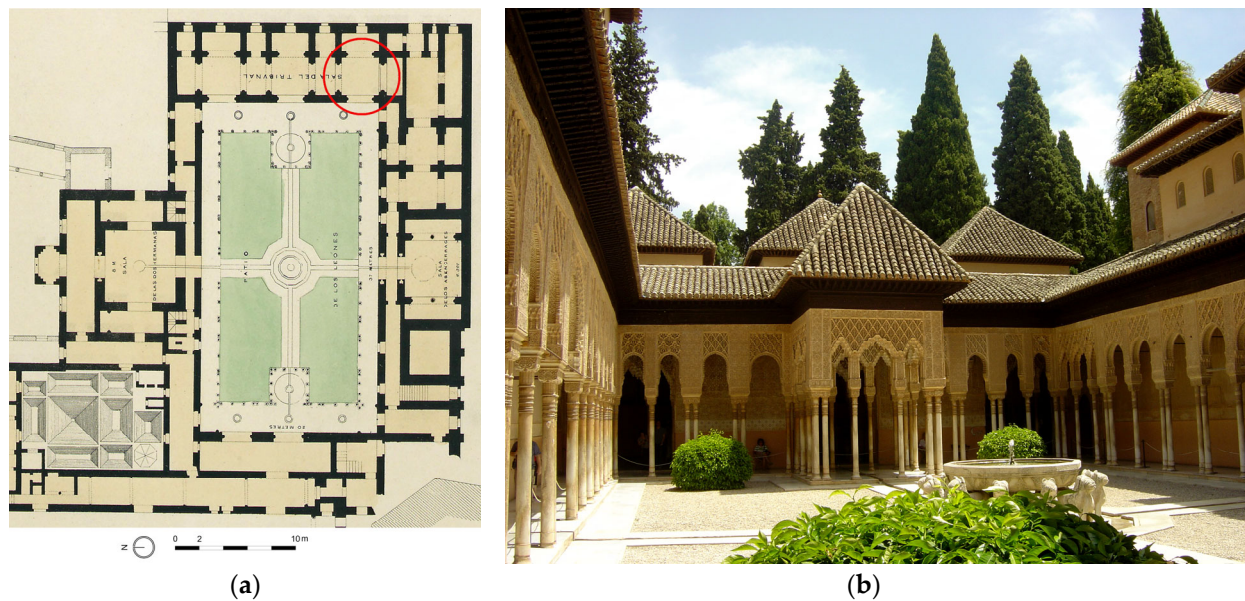


Figure 1. The Palacio de los Leones: (a) Jules Goury and Owen Jones (del.): Detail of ‘Plan of the Royal Arabian Palace in the Alhambra ancient fortress’ (Plans, elevations, sections, and details of the Alhambra Vol. 1, plate 3, 1842) (520 × 680 mm) (Red circle marks Southern muqarnas dome in Sala de los Reyes; top of the image facing East). (b) Patio de los Leones with eastern Pavilion and Sala de los Reyes (photograph taken by the authors, 2005).

The Sala de los Reyes, also called the Sala de la Justicia or the Sala del Tribunal, is named from the three unique medieval paintings on skin preserved in its vaults, which represent court life and power scenes [15,16]. Its architectural space is made up of successive muqarnas domes, vaults, and arches of great visual appeal (Figure 2a). Its main space is composed of three square muqarnas domes. Among them, there are smaller muqarnas vaults with a rectangular plan, similar to those at the ends of the room. Next to the outer wall there is another succession of smaller enclosures: three with the aforementioned medieval paintings, plus four others of smaller size with brick vaults covered with plaster. The whole set had a unitary roof, now transformed, similar to the one preserved on the west side of the patio, over the Sala de los Mocárabes, adjacent to the Palacio de Comares.

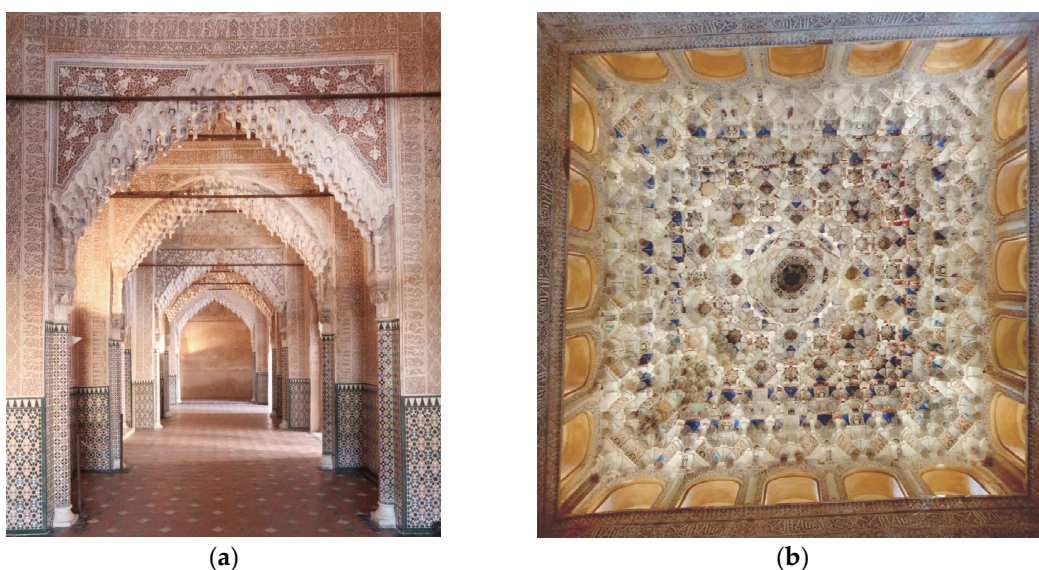


Figure 2. Sala de los Reyes (photographs taken by authors, 2018) (a) Interior view from north to south (Patio de los Leones is on the right). (b) Southern Muqarnas Dome (Image top side points East).

It should be taken into account that the Alhambra suffered ruin hazards on many occasions due to earthquakes, explosions, water leaks, or even lightning, aggravated by poor maintenance or inadequate restorations [17]. The roofs of the Sala de los Reyes underwent important restorations and its southern dome, the target of the current research, today has deformations that can be seen by the naked eye (Figure 2b).

Next, some historical data are reviewed, which show the heritage fragility of this site and the many architectural interventions in the Palacio de los Leones from Nasrid times to the present day [18].

In 1431 two important earthquakes struck Granada, with 6.5 and 6.8 approximated magnitudes, one of them with its epicenter in Atarfe, near Granada [19]. This would cause walls and towers of the Alhambra to fall a few days after which King Juan II occupied the fertile plain of Granada and the battle of Higuera [20].

However, there are no known documents about renovations in the Palacio de los Leones until the capture of Granada by the Catholic Monarchs in 1492. The monument fate would change because of important architectural transformations, such as the construction of the new palace of Carlos V. Furthermore, it was no longer the permanent seat of the Royal throne and its character as a fortress was reinforced. The repair tasks have not stopped since then.

Between 1522 and 1531, new earthquakes of 6.5 approximate magnitude [19] caused damage to the Patio de los Leones, and Muslim craftsman undertook restoration works [21]. Documents dated between 1541 and 1542 refer to the plasterwork replacement and the placement of braces to control collapsing columns in the patio. In 1555, some “specifications” were established for repairing plasters in the Patio de los Leones [22].

In 1590, a gunpowder mill exploded near the Darro River, on the northern slope of the Alhambra, causing the ceiling destruction of Sala de los Mocárabes. Emblematic architectural elements such as the Comares’ tower [23,24] or the Vela’s tower [25] were affected. Between 1691 and 1694 the pavilions roofs in the patio were modified. With the arrival of Felipe V to Granada in 1729, new repairs were undertaken, and others in 1744 and 1757 [26]. Some reports from 1784 describe the imminent ruin state, which would be aggravated by a lightning strike on 5 November 1787 [27].

Between 1804 and 1806 there were important earthquakes [19] and in 1812 and 1820 some works were carried out on the Palacio de los Leones’ roofs. Furthermore, at the beginning of the 19th century, a garden was planted in the patio and the irrigation water affected the foundations; it was removed for this reason around 1844–1846 [28]. In 1858, Rafael Contreras undertook the roofs’ transformation of the Sala de los Reyes, discussed below, and of the eastern pavilion in the Patio de los Leones [29], which was restored again by Torres Balbás around 1934 [30]. At the end of the 19th century, a fire destroyed the wooden roof in the Sala de la Barca [31], later rebuilt in the 20th century. The Sala de los Reyes’ roofs have also been repaired in the 20th century and an important restoration beginning around 2007 has been published in a monographic issue of Cuadernos de la Alhambra in 2022 [30,32–35].

1.2. Preliminary Studies on Muqarnas

Muqarnas are small pieces grouped in a variety of three-dimensional geometric shapes. In the Alhambra they adopted complex rhythms and sequences of great visual appeal in cornices, capitals, arches, pendentives, domes, and vaults. Although they were mostly built with fragile materials, such as plaster, they are one of the most remarkable artistic episodes of mediaeval Islamic art and a symbol of the 14th-century Nasrid architecture identity in Granada, especially in the Palacio de los Leones.

Their employment may have been inspired by architectural models that Muhammad V knew during his exile in North Africa, such as the Almoravid vaults of the Qarawiyyin mosque in Fez [11]. However, important changes were introduced that led to amazing results, such as the muqarnas domes in the Sala de los Abencerrajes and Sala de Dos Hermanas [36]. Rectangular spaces such as the Sala de los Reyes and the Sala de los

Mocárabes were also covered with muqarnas vaults. In addition, muqarnas were integrated into some arcades of the Patio de los Leones, in the arches of the Sala de los Reyes and other architectural elements.

There are two fundamental works on the techniques or rules concerning the layout of muqarnas in the West: the treatise by Diego López de Arenas published in Seville in 1633 [37] (Figure 3a) and a manuscript by Fray Andrés de San Miguel, from the first half of the 17th century, which was not published until 1969 [38] (Figure 3b). Both drew their shapes and their grouping in ground plan from three flat geometric figures: a rectangle, an isosceles right triangle, and a 45° isosceles triangle. Theoretically, the muqarnas internal angles in plan are reduced to three 45°, 67.5°, 90°, and 135° when two 45° isosceles triangles are combined into a fourth rhomboidal figure. The pieces are grouped spatially with certain proportions, since each figure has a module side through which it is combined in ground plan with the rest. These geometric constraints allow for the pieces' identification and their possible deformations compared to their theoretical composition.

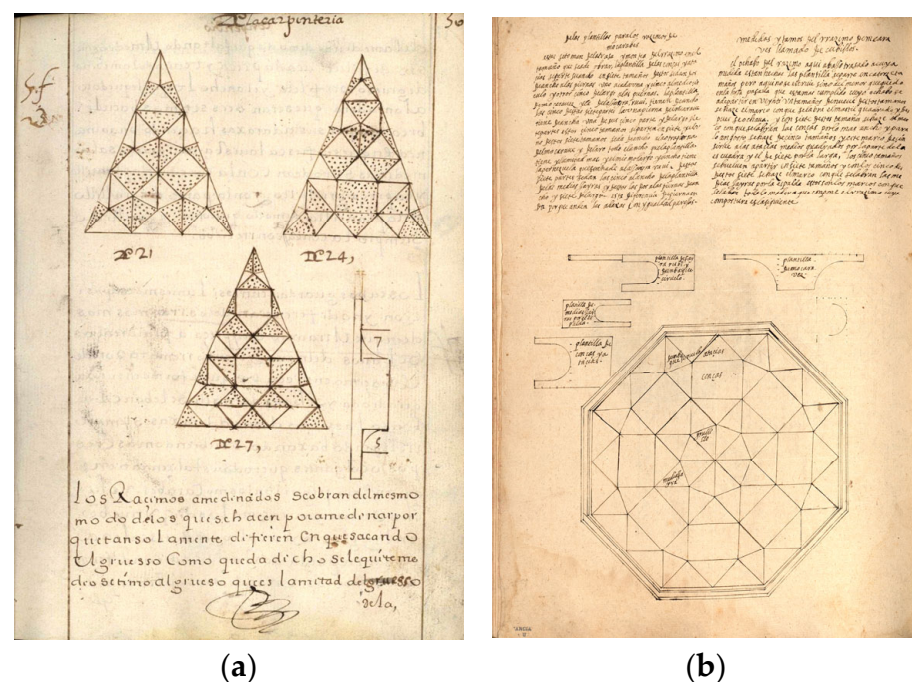


Figure 3. (a) Diego Lopez de Arenas (c. 1626–1630), Muqarnas drawings in the second manuscript preserved in the Real Academia de Bellas Artes de San Fernando in Madrid (Spain). (b) Fray Andrés de San Miguel manuscript (c. 1630) (Universidad de Texas, Librerías Generales, Colección de América Latina Benson, sig. 31775792).

In 1834 and 1837, the architects Owen Jones and Jules Goury visited the Alhambra and undertook the first documented systematic drawings of its architecture and ornamentation, which were published in two volumes in 1842 and 1845 [39,40]. Jones and Goury were well aware of the muqarnas formal complexity and in plate X of volume I they included a brief explanation of the process for grouping elementary pieces. In addition, they made a schematic drawing in ground plan and sections from three flat figures A, B, and C; two triangles; and a rectangle, from which seven pieces of muqarnas were derived, that could lead to different compositions (Figure 4a,b).

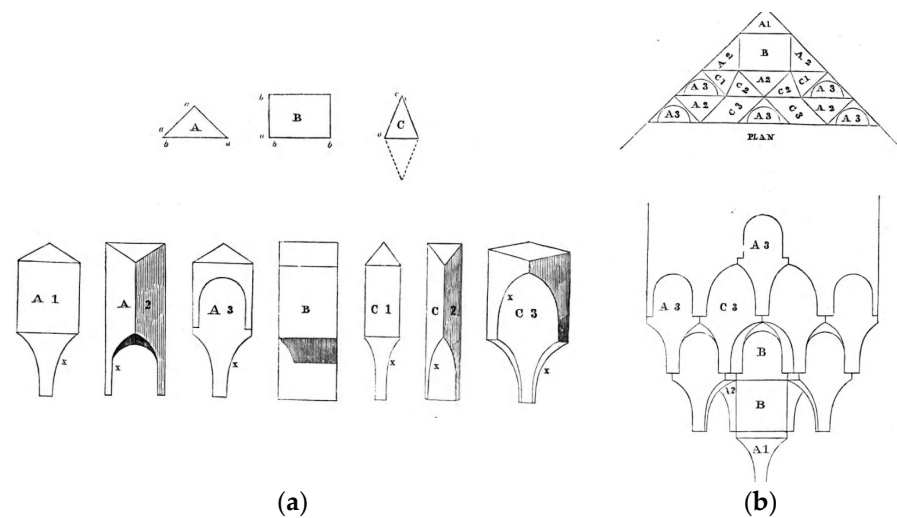


Figure 4. Jules Goury and Owen Jones (Plans, elevations, sections, and details of the Alhambra, Vol. 1, 1842, Plate 10, 520 × 680 mm) (private collection): (a) detail of seven basic muqarnas pieces derived from three basic planar figures. (b) detail of pendentive’s plan and elevation containing the seven muqarnas in combination.

Although the three flat figures proposed by Jones and Goury are interesting as a theoretical principle, they are insufficient to produce the great diversity of muqarnas groupings that exist in the Alhambra. The compositions were often enriched with auxiliary geometries, such as small triangles or squares. For this reason, subsequent authors have proposed a different number of basic pieces or have considered that some of them are divided into new ones. For example, Nicomedes de Mendivil drew muqarnas pieces in the Patio de los Leones in 1862 that were published on plate 27 of “Los Monumentos Arquitectónicos de España” around 1865 [41,42].

On the other hand, there are many studies on muqarnas compositions in the Iberian Peninsula [43–45], Morocco [46], the Mediterranean basin [47–49], Persia [50], and elsewhere [51,52]. Among the earliest examples of muqarnas from the West is the wooden ceiling of the Palatine Chapel of the Royal Palace of Ruggero II in Palermo (ca. 1130–1140). Later examples, also in Palermo, can be found in the Zisa Palace and the Quba Palace [53–55].

The earliest known representations of muqarnas, located in Iran, were built on stone around the 13th century [56]. In small constructions, no elevations or sections would be necessary, and could be deduced from the ground plan itself, although in more complex cases additional notations with various graphic codes would be necessary. For example, some muqarnas drawings on paper rolls, preserved in the Topkapi Museum in Istanbul, include several colors to distinguish different parts or levels [57].

At the end of the 20th century, the architect Enrique Nuere was a precursor studying and analyzing the muqarnas pieces and their nomenclature, following the aforementioned treatises on carpentry by López de Arenas and Fray Andrés [58,59]. Furthermore, the Alhambra muqarnas were deeply studied in the recent PhD thesis by Ignacio Ferrer [60] who, using digital graphic techniques, has analyzed their formal language, their geometric layout, their representation, and their settings, taking into account different themes and their location.

Another important issue is their construction execution. André Paccard’s book illustrates the craft process to build on wood or plaster materials that was still practiced in Morocco in the 20th century [61]. Although the muqarnas vaults and domes were self-supporting, they were always covered by a roof structure that protected them. In the Alhambra, plaster muqarnas predominate, although there are others made of wood or stone. A recent article by Ignacio Ferrer deals with muqarnas capitals that were not built by grouping small pieces but sculpted from single stone blocks [62].

The Alhambra builders' ability to conceive compositions of great geometric complexity is amazing; using a fragile material such as plaster, has helped its restoration over the centuries [63]. The aforementioned two earthquakes, explosions, and many roofs restorations affected the south dome of the Sala de los Reyes. Today, it shows important deformations, as well as the muqarnas in the Sala de la Barca [64] or in the Patio de los Leones pavilions [65].

1.3. General Objectives

The objective of this research is to document and graphically analyze the 14th century muqarnas dome in the south of the Sala de los Reyes, in the Palacio de los Leones. The aim is knowing and making this fragile architectural heritage known, so as to help its future conservation and suitable communication.

The methodology proposed to obtain that objective combines the analysis of historical images with current digital graphic techniques. Plans, drawings, and photographs from the 16th to the 20th centuries were compiled and analyzed as an essential reference that documents and illustrates the transformations on the Sala de los Reyes, its roofs, and near surroundings. Digital drawings were produced to test the real geometry versus the geometric principles of muqarnas grouping. Finally, metric data from the current state of the building were captured using 3D laser scanners to quantify meaningful deformations in ground plan. None of these three graphic analyses of the muqarnas dome studied had been early undertaken.

2. Three Methods for a Graphic Analysis

2.1. Placement and Analysis of Historical Images

It is worth highlighting how the analysis of ancient images important is, which some authors have called the "graphic life of architectural heritage" [66]. Although no image provides a completely objective view of reality, its graphic codes give information about what their authors perceived and their interests, skills, or sensitivity, depending on the graphic technique used. The location and analysis of historical images is essential to understanding heritage transformations along the time. Sometimes, these images have an artistic value independent of the represented object and are a graphic heritage by themselves.

The Alhambra and, especially, the Patio de los Leones has a rich legacy of historical images, illustrating its transformations from the 16th century to the present day. All of them are of great interest for heritage research, along with other historical or archaeological sources, always considering the current reality. For this reason, an extensive search has been carried out to find meaningful images in many archives or earlier publications. Data about each image context have also been collected: techniques, scales, and their authors. It should not be forgotten that any image is always the product of personal views with different degrees of approximation to the reality represented. Finally, the images have been arranged taking into account the area represented and its chronology.

2.2. Geometric Modeling of Muqarnas Pieces

To understand the complex geometry, proportion systems, and muqarnas composition, it is essential to draw their floor plans based on a careful observation of reality. For this purpose, the theoretical principles on the geometric layout of muqarnas from the treatise by López de Arenas in 1633 [37] and the manuscript by Fray Andrés, from the 17th century, published in 1969 [38], have been used as a reference; the interpretations of Enrique Nuere [58,59] and Ignacio Ferrer [60] have been also followed.

In this way, based on the as-built reality and the previous experience of the current research authors [40,62,64,65], the southern dome plan of the Sala de los Reyes has been drawn. Every individual muqarnas has been identified to understand its complex three-dimensional geometric grouping. The use of AUTOCAD 2021 software helped the subsequent perspective visualization.

2.3. 3D Scanner Data Capture

To document the southern dome of the Sala de los Reyes with high accuracy, a Leica BLK360 laser scanner was used; its accuracy is 6 mm at 10 m range and 8 mm at 20 m. Each scan station captured data from the whole 360° panoramic surroundings. To help model and identify the elements of interest, HDR photographs were taken with the inner camera into the scanner. The scanner allows for different density settings to capture the point cloud: low, medium, and high, which refer to 20 mm, 10 mm, and 5 mm, respectively. Medium quality was set for all scans.

The point cloud registration from the different scans requires placing them all in the same reference system and matching the homologous points in scans with common areas. Several software allow for preregistration on the field, so that the registration is performed automatically when the overlap conditions are favorable. If the automatic mode fails, the manual mode then allows for the identification of a few homologous points, and then tries to solve the registration.

To collect data in the Sala de los Reyes, the scans were made from the locations represented by gray spheres in Figure 5. A common problem in touristic sites is the appearance of moving people in consecutive scans. For this reason, one of the subsequent editing tasks was the cleaning of unwanted elements in the point cloud.

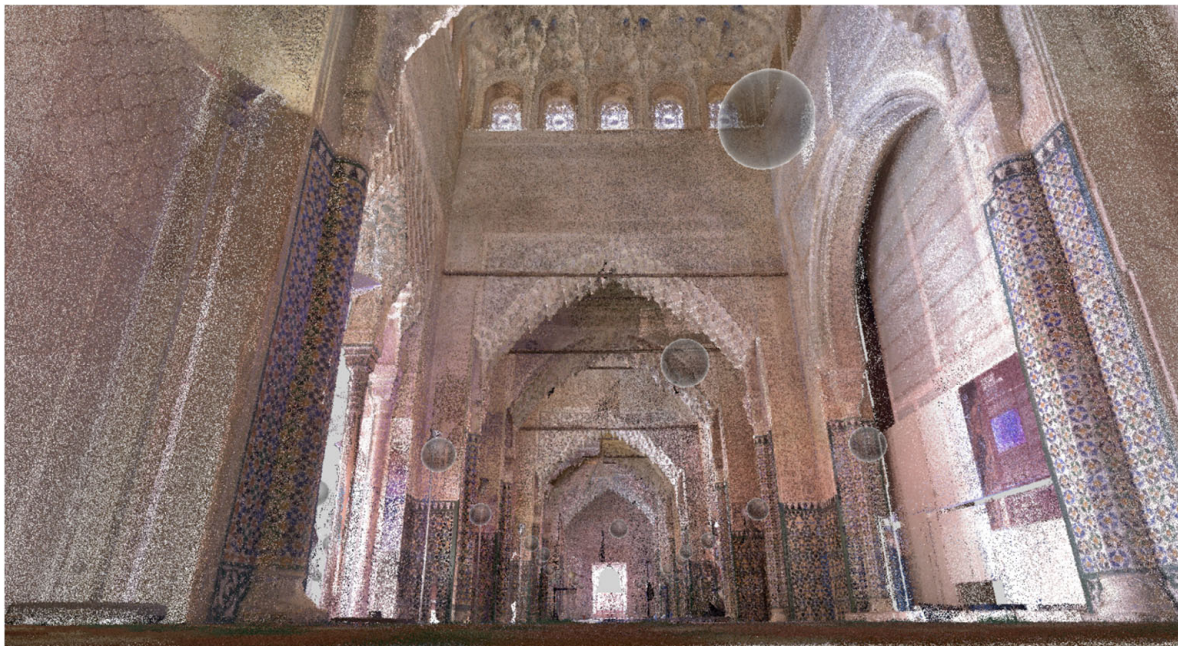


Figure 5. Sala de los Reyes; spheres mark the scan station locations (Own production, 2023).

Subsequently, the parts under study were selected, using AutoDesk Recap 2021 software, to optimize the task with lighter files. Afterwards, planar projections of the point cloud (plans, elevations, and sections) were obtained by importing the point cloud into the Cloudcompare 2.12.4 software.

On these projections, the starting and finishing points of the muqarnas were identified at different levels to prepare schematic drawings of their contours and internal axes. These lines were subsequently used as a reference to measure distances or angles, and to quantify deformations in the muqarnas set, by comparison with the theoretical geometric model drawn.

3. Results and Discussion

3.1. About the Historical Images Analyzed

Among the most interesting graphic documents of European architecture from the 16th century is the first known plan containing a part of the citadel of the Alhambra, currently preserved in the Library of the Royal Palace in Madrid (signature IX_M_242_2 (1)). It has been dated to around 1532 and its author is unknown. It includes the designed proposal for the new Renaissance Palacio de Carlos V next to the Alcazaba and the Nasrid palaces [67,68]. Its considerable size allowed for abundant details to be included.

The arrangement in the Sala de los Reyes area matches the current state (Figure 6) and the word “Capilla” is labeled, which identifies the use it had back then. No openings were drawn towards the outside of the palace (later plans will do) except for a southern entrance into a patio, where there was a staircase that does not exist currently.

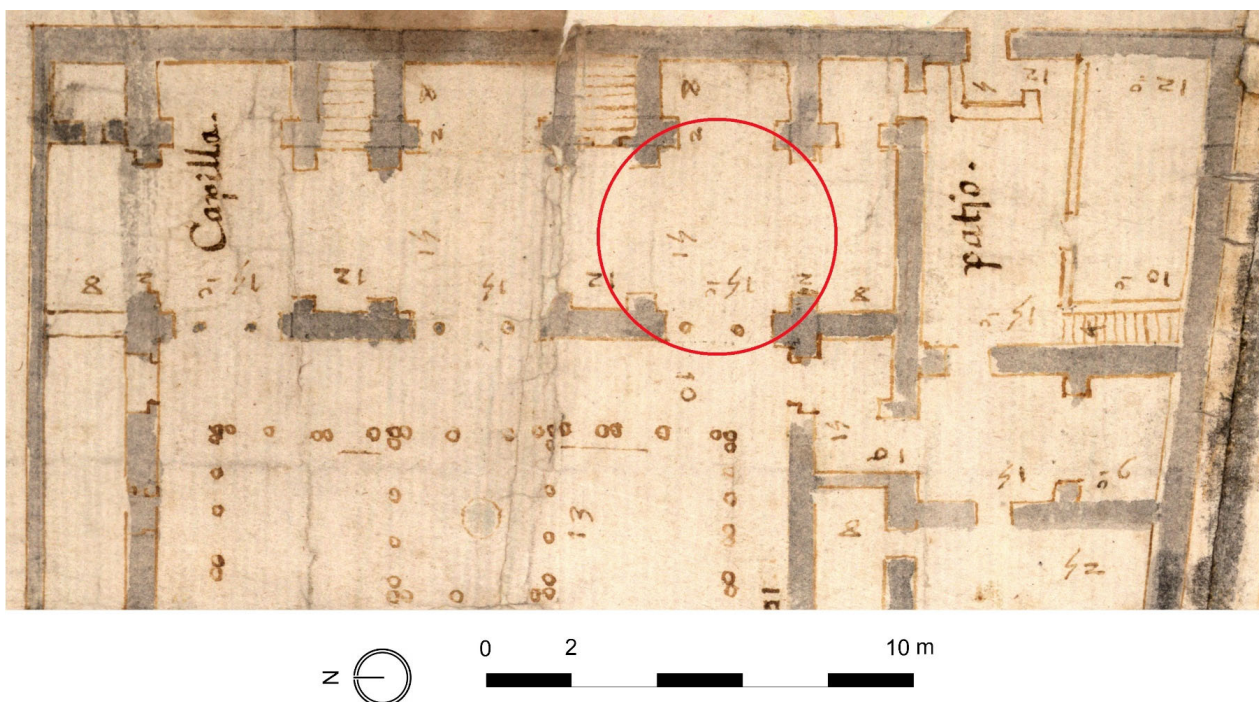


Figure 6. Detail of general ground plan of the Sala de los Reyes in the Alhambra, c. 1532 (red circle marks Southern muqarnas dome) (1307 × 669 mm). Palacio Real library in Madrid, sig. IX_M_242_2 (1).

The patio columns were carefully drawn and general measurements were annotated, which are analyzed in this research for the first time. Sometimes, it was necessary to annotate half a foot, which was written as a small superscript “o”. This abbreviation was frequently used in architectural plans in the Iberian Peninsula at that time; for example, in the church of Aranzueque in Guadalajara around 1495–1530 or in the monastery of Guadalupe around 1528 [69].

It is of special interest to note the square sides of the central muqarnas dome have different numerical annotations on the plan: where annotations of 15 feet are marked, while sides of the northern and southern domes have, respectively, 15 feet and 15 and a half feet. That is, there would have already been some geometric deformations in the floor plans of the northern and southern domes. Furthermore, it is remarkable that the patio located to the south of the Sala de los Reyes is 15 and a half feet long; and that next to it the patio of the Rauda vault base is 15 feet long, a prior construction to the Patio de los Leones [70].

On the other hand, in the intermediate muqarnas vaults in the Sala de los Reyes, the annotations are 12 feet long (including 2 feet of each wall) and the end vaults annotations are 8 feet, just like the rooms containing the mediaeval paintings. A 2 feet thickness is also annotated in longitudinal and transverse walls.

Around 1576, due to the ruin and demolition of the old Aljama Mosque in the Alhambra, consecrated as the Santa María Church, the parish service was moved to the nearby Sala de los Reyes. At that time, a gallery would be built on it, as a residence for the Alhambra priests and its roofs were transformed. According to Gallego Burín, the parish was there until 1618, when the new church construction was finished [3]. Later, the Sala de los Reyes once again became the private chapel of the Alhambra Royal House and during the stay of Felipe IV in the Alhambra, religious events for Easter were held there in 1624 [32].

The worsening conservation state of the Alhambra in the middle 18th century would cause the Real Academia de Bellas Artes in Madrid to commission the preparation of drawings and stamps to understand and publicize its architecture. This work was entrusted to José de Hermosilla, together with the students Juan de Villanueva and Juan Pedro Arnal, who later became distinguished architects. The drawings were undertaken in 1766–1767 and were published in “Las Antigüedades Arabes de España” in two volumes in 1787 and 1804 [42,71]. The plan representing the Royal House shows a large gap in the exterior wall near the southern dome studied here, which was not included in the plan of 1532; perhaps this opening was created as an access when the parish church was there. The section (Figure 7) originally includes graphic scale in Castilian feet, and shows the upper floor built on the next side of the Sala de los Reyes, which does not exist nowadays and would correspond to the aforementioned residence of the priests. The drawn roofs only allowed for zenithal lighting and ventilation on the side overlooking the Patio de los Leones.

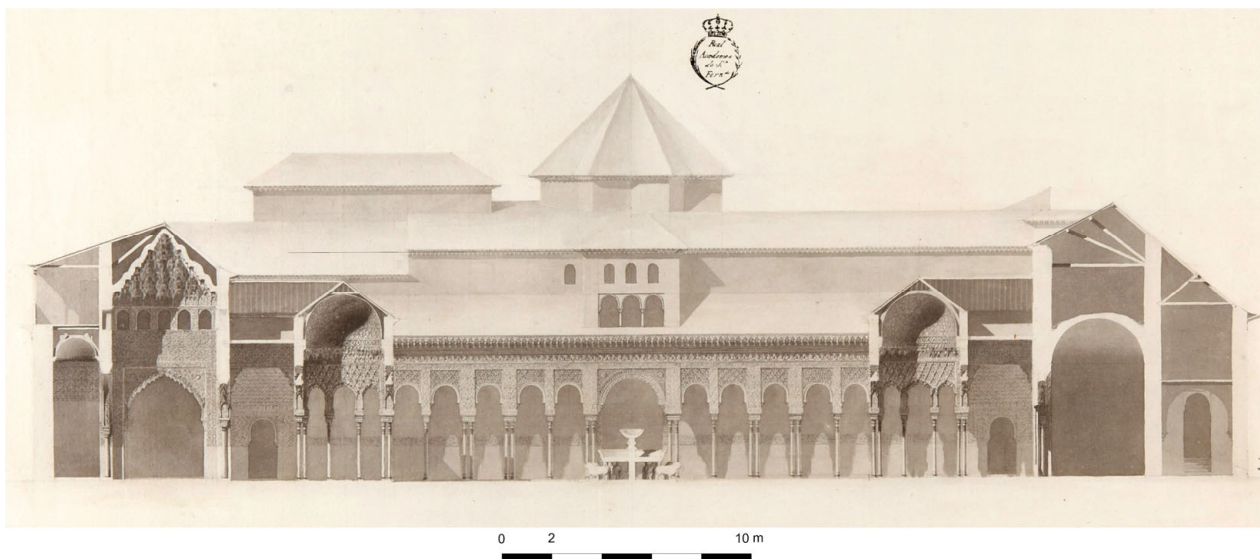


Figure 7. Detail of Patio de los Leones longitudinal section by Juan de Villanueva, 1766–1767 (765 × 540 mm) (Real Academia de Bellas Artes de San Fernando, Madrid, MA-0540).

Among the travelers of the late 18th century who left testimony of their passage through the Alhambra, a view of the Patio de los Leones that Henry Swinburne published in 1779 in his book “Travels through Spain in the years 1775 and 1776...” (1779) [72] is of great interest. Through this research, the original view drawing—unknown in the scientific bibliography—was found in the Yale Center for British Art (Paul Mellon Collection) (Figure 8a). The east pavilion and the roof of the Sala de los Reyes are represented, with three small windows for lighting and ventilation.

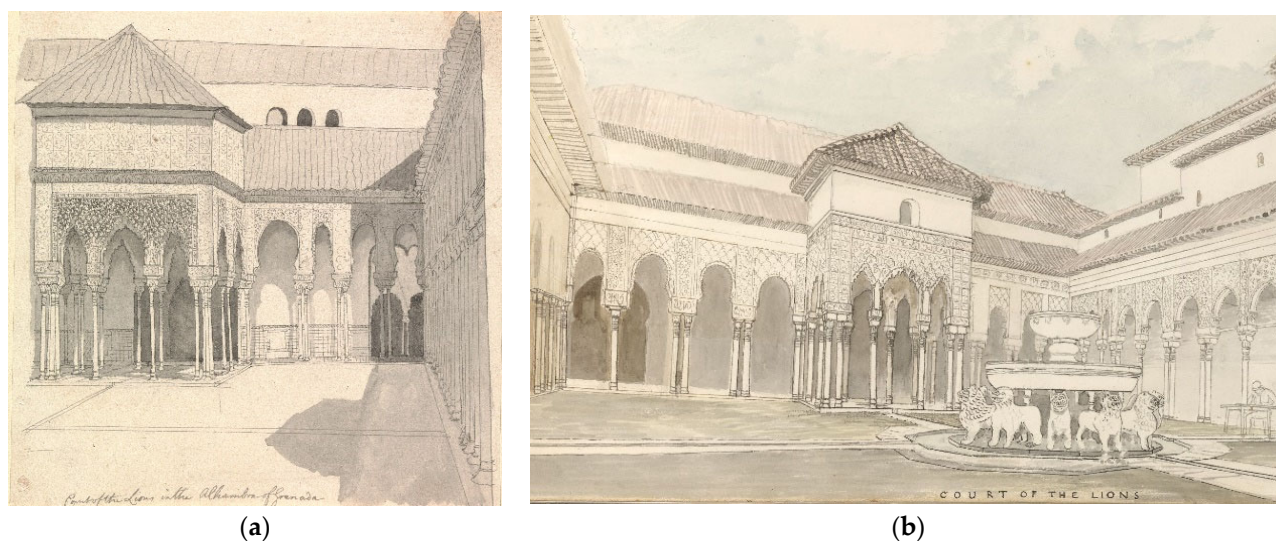


Figure 8. Patio de los Leones and Sala de los Reyes: (a) Detail of drawing by Henry Swinburne, 1775–76 (414 × 284 mm) (Yale Center for British Art, Paul Mellon Collection, B1977.14.3851). (b) Detail of drawing by William Gell (detail), 1808 (475 × 240 mm) (British Museum, 1853,0307.666; asset number 1173203001).

Other drawings of great documentary interest, available on the British Museum website, were made by William Gell [73] at the beginning of the 19th century using a camera lucida, deeming them quite reliable. Among them, a Patio de los Leones' view shows the east pavilion and the Sala de los Reyes' roof (Figure 8b), although the small ventilation and lighting windows that Swinburne drew were not represented, possibly due to carelessness, since they appear in later images.

In 1812, volume II of the remarkable work led by Alexandre Laborde was published and developed by excellent artists, and “Voyage Pittoresque et Historique de l’Espagne” [74] was published, which includes some forty-five plates about the Alhambra. The interior views of the monument are very detailed and realistic. Among them is the first known interior view of the Sala de los Reyes (Figure 9a), where piled bricks appear, perhaps due to construction works being undertaken at that time.

In 1837, Philibert Girault de Prangey published a similar interior view of the Sala de los Reyes in “Souvenirs de Grenade et de l’Alhambra” [75,76], also with materials remains in the foreground (Figure 9b). On his Patio de los Leones floor plan, a gap appears in the exterior wall of the Sala de los Reyes, which the academics drew in 1766. In the Patio de los Leones view that crosses the west pavilion, the Sala de los Reyes' roof can be seen.

Based on the drawings made by the painter David Roberts on his trip through Spain in 1832–1833, engravings were published in four volumes titled “The Tourist in Spain” between 1835 and 1838. The Granada volume [77] includes an interior view of the Sala de los Reyes, which was widely spread, although the proportions seem manipulated.

On the other hand, the artist John Frederick Lewis published “Sketches and drawings of the Alhambra” (1835) with beautiful and precise views of the Patio de los Leones [78]. A drawing shows the Sala de los Reyes' roof in a similar setting to the one drawn by Swinburne and Gell, without the small windows for lighting and ventilation.

In a similar view by Prangey published in 1842 in “Choix d’ornements moresques de L’Alhambra” [79], five small windows can be seen under the roof studied here.

The drawings by Owen Jones and Jules Goury, published in “Plans, Elevations, Sections, and Details of the Alhambra” (2 vol., 1842–1845), deserve special attention [39]. As mentioned above, these architects analyzed the Alhambra ornamentation with a scientific approach and astonishing detail, taking into account the geometric rules for grouping muqarnas in order to draw them rigorously.

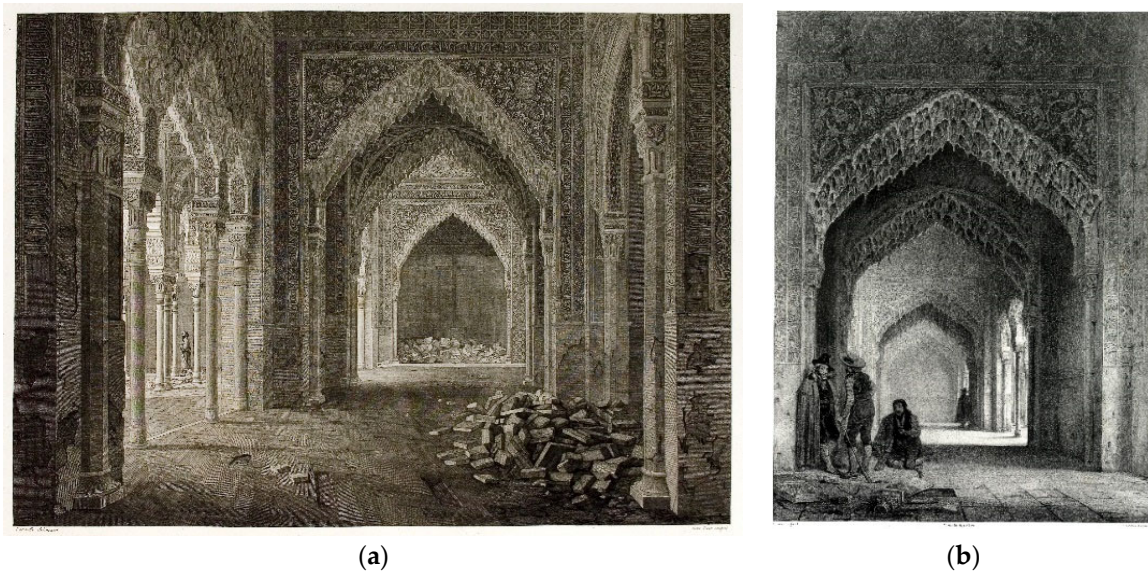


Figure 9. Sala de los Reyes: (a) Jean Lubin Vauzelle (drawing) Victor Texier (engraved); published by Alexandre Laborde, 1812 (572 × 431 mm) (private collection). (b) Girault de Prangey (drawing), Villemin (lithography) Bayot (figures); published by Girault de Prangey, plate 28, 1836 (311 × 489 mm) (private collection).

In a detailed section that includes the Sala de Dos Hermanas, the Patio de los Leones, and the Sala de los Abencerrajes, the eastern pavilion's elevation and the Sala de los Reyes' roof are drawn, with its ventilation and lighting openings for each inner dome (Figure 10a). In the longitudinal section of the patio overlooking Sala de Dos Hermanas (Figure 10b), the upper floor built on the external area of the Sala de los Reyes is detailed, which the Academics had also drawn, with its ventilation openings above.

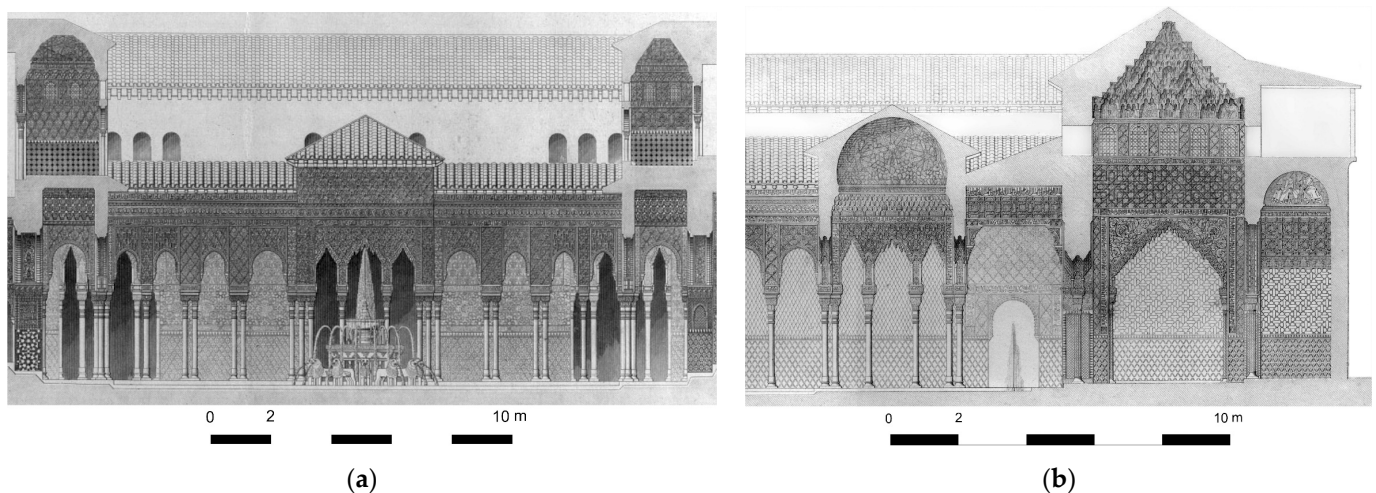


Figure 10. Plans, elevations, sections and details of the Alhambra, Vol. 1, 1842, J. Goury and O. Jones (del.), I. Kennion (sculp.) (680 × 520 mm) (private collection E. Páez). (a) Detail of 'Section of the Sala de Dos Hermanas, Patio de los Leones, and Sala de Abencerrajes' [detail]. (b) Detail of 'Longitudinal section of the Patio de los Leones' [detail] published by Owen Jones, 1838.

Furthermore, Jones and Goury drew some muqarnas on cornices, arches, pendentives, or domes, proving their ability to represent them [40]. Among them, two longitudinal sections into the Sala de la Barca stand out without their roofs, one overlooking the patio and the other towards the exterior wall, showing some subtle differences between the different domes (Figures 11 and 12).

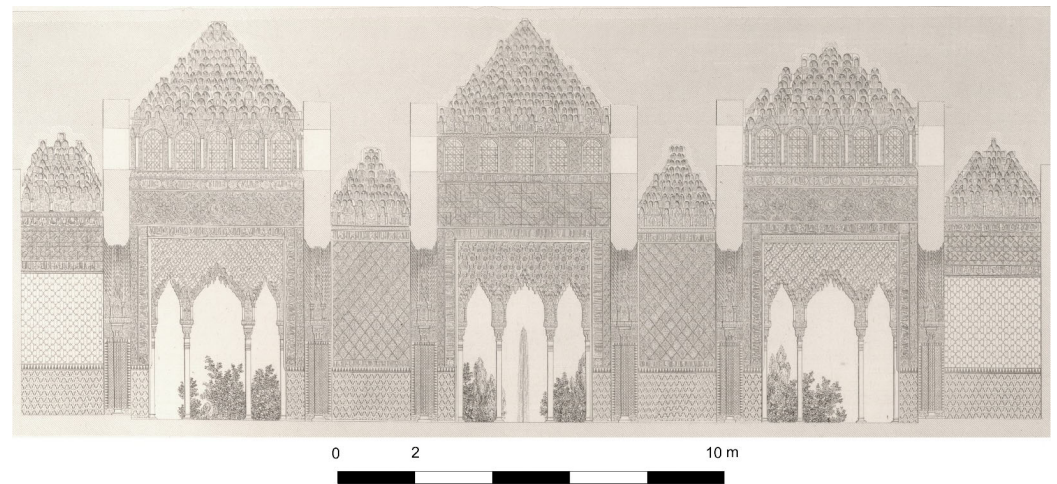


Figure 11. Detail of ‘Section of the Sala de la Justicia [Sala de los Reyes] looking towards the Patio de los Leones. Owen Jones (del.), W.S. Wilkinson (s.c.); published by Owen Jones, 1838. Plans, elevations, sections, and details of the Alhambra Vol. 1, 1842 (680 × 520 mm) (private collection E. Páez).

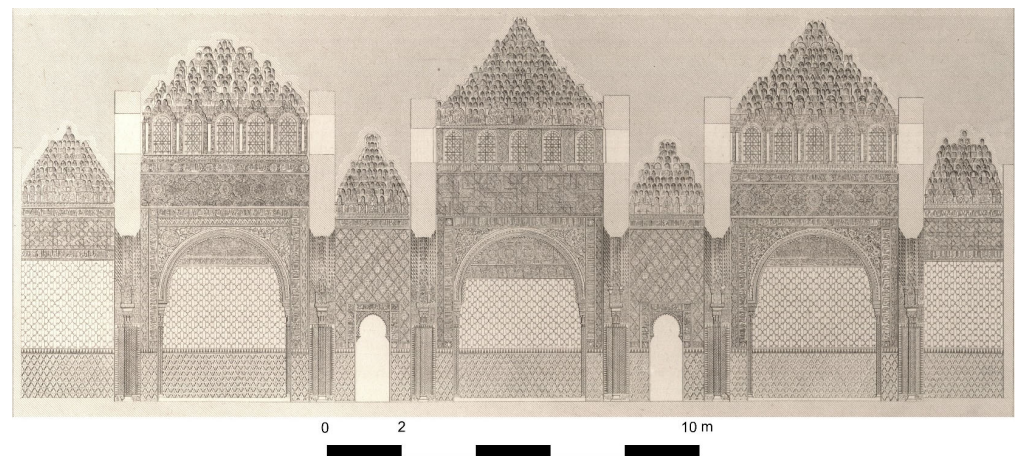


Figure 12. Detail of ‘Section of the Sala de la Justicia [Sala de los Reyes] looking East. Owen Jones (del.), W.S. Wilkinson (s.c.), published by Owen Jones, 1838. Plans, elevations, sections, and details of the Alhambra Vol. 1, 1842 (680 × 520 mm) (private collection E. Páez).

A drawing view of great beauty and documentary interest of the Patio de los Leones is dated to 1849, after the garden planted in Napoleonic times had been eliminated (Figure 13a). It was drawn by the German painter Eduard Gerhardt, companion of the Dukes of Montpensier during his stay in Granada [80]. In this view appears the fountain of the Lions, the east pavilion, and the Sala de los Reyes’ roof with its small windows. These openings were very important to illuminate and ventilate the interior, and for an appropriate conservation of the muqarnas’ vaults, avoiding humidity due to condensation.

This view is essential to understanding the state prior to the important alterations promoted by Rafael Contreras, Alhambra curator, with Juan Pugnare being the architect who led the works [16]. Gerhardt’s image corresponds with the details appearing in a stereoscopic photograph by Joseph Carpentier around 1856 [81] (Figure 13b)

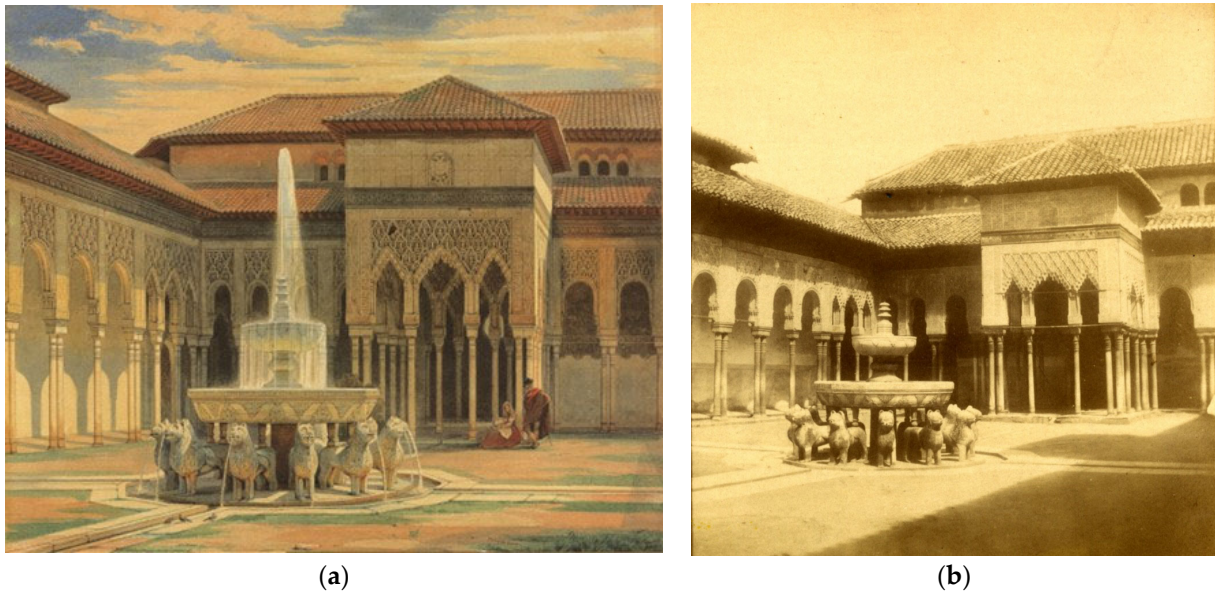


Figure 13. Patio de los Leones and Sala de los Reyes' roofs (a) View by Eduard Gerhardt, towards 1849 (365 × 304 mm) (published by V. González Barberán, 2000. Fundación de los Infantes—Duques de Montpensier, Spain). (b) Detail of stereoscopic photograph, by Joseph Carpentier, 1856 (180 × 90 mm) (private collection author).

The spreading of photographic technique around 1850 brought about some images of Palacio de los Leones which are of great documentary interest [82]. In a photograph by Joaquín Pedrosa taken in 1857 (Archivo de Planos de la Alhambra, F-05689), the Sala de los Reyes' roof can be seen as a unit, similarly to the images by Gerhardt, Carpentier, and some earlier drawings already mentioned. The upper ventilation openings can also be seen in both photos attributed to Eduardo García Guerra and Jules Falan-pin-Dufresne [83].

The photo by Gustave de Beaucorps, dated in 1858 (Figure 14a), shows the east pavilion braced to reinforce its foundations and fix its columns collapse. Above is the radical transformation of the roofs, now with turrets, also shown in another photograph by Jacob August Lorent of 1858. These photographs show the pavilion's condition prior to the Rafael Contreras' intervention, who between 1858 and 1859 [16] removed the roof to install a glazed ceramic dome that appears in many photographs, some of them being taken by Jean Laurent [84] (Figure 14b). Many interventions by Contreras in the Alhambra failed because he tried to beautify the monument by replacing original elements lacking a solid scientific basis, clashing the current principles of architectural restoration [85].

Later, in 1934, the architect Leopoldo Torres Balbás decided to remove the whimsical dome in the pavilion [17] and placed the tile roof that currently exists (Figure 1b). This had to be built with a great inclination, since Contreras had removed the upper panels of plasterwork. That is why the roofs in the east and west pavilions are different today.

Around 1858–1860, further work was undertaken inside the Sala de los Reyes, under the direction of architect Baltasar Romero [85]. A photograph of great interest by Pedrosa from 1857 (Figure 15a) shows construction materials piled up, as in the engravings by Laborde and Prangey, as well as the one by Jakob August Lorent from 1858, when tiled plinths had not yet been repaired [86]. The result of this restoration can be seen in some photographs, such as the one by Laurent (Figure 15b).

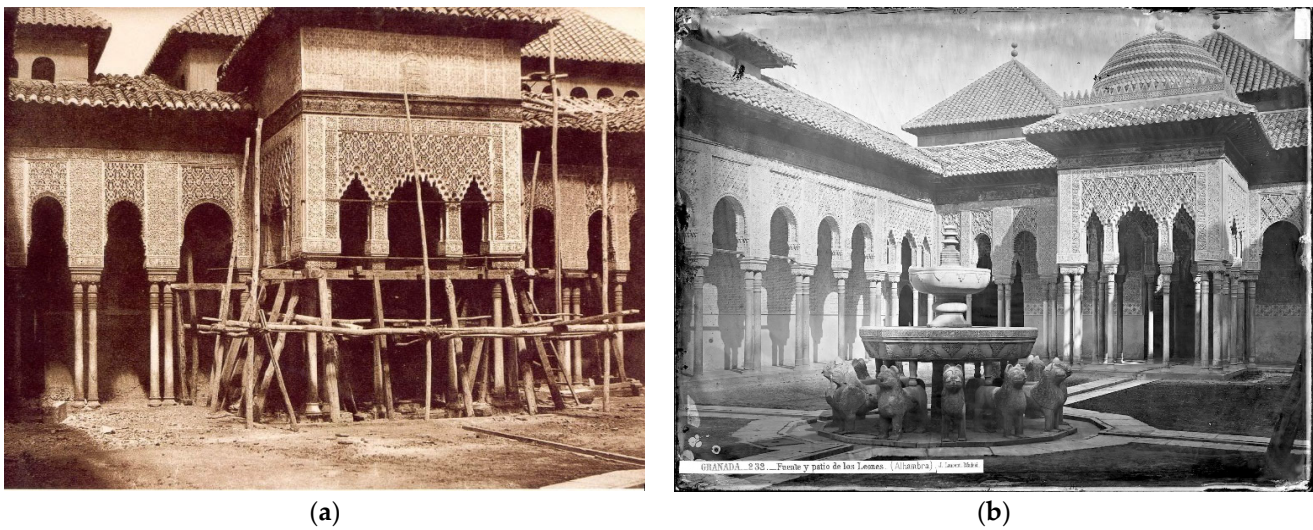


Figure 14. Patio de los Leones Eastern before and after the Rafael Contreras restoration. (a) Detail of picture taken by Gustave de Beaucorps, 1858 (395 × 286 mm) (University of Navarra). (b) Picture taken by J. Laurent, around 1860–1886 (354 × 268 mm) (VN-05011, Archivo Ruiz Vernacci, Ministerio de Cultura y Deporte, Spain).

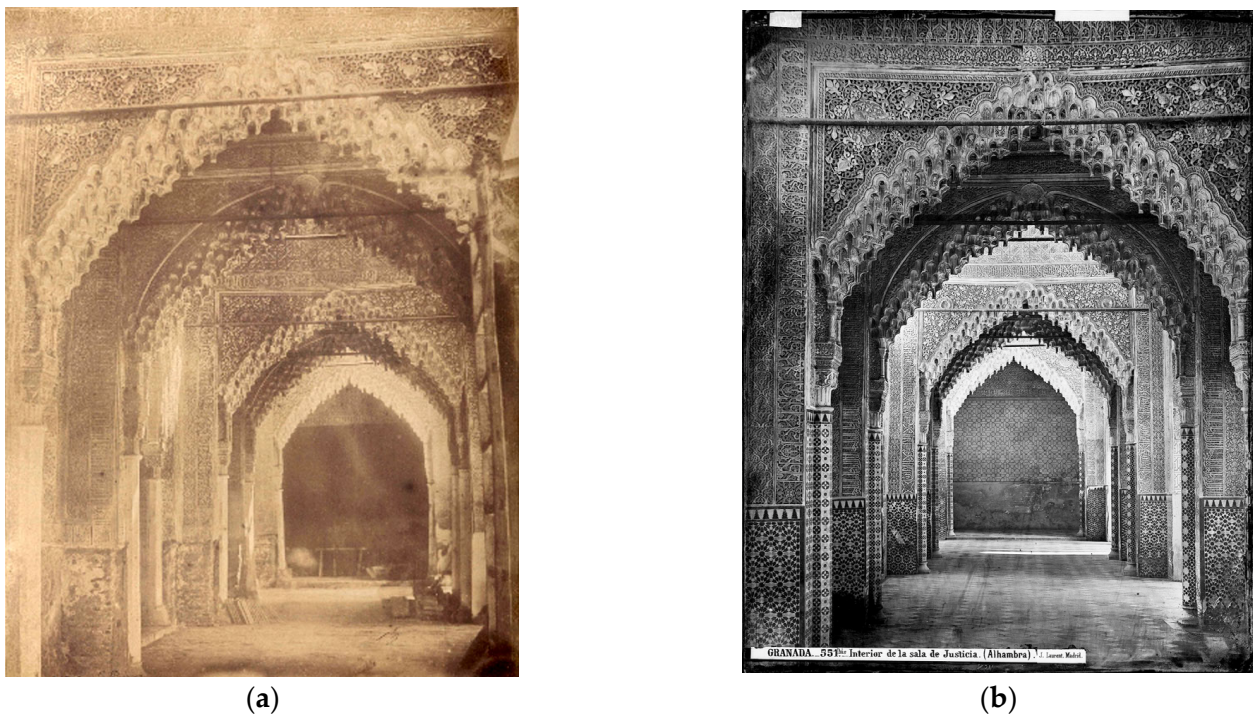


Figure 15. Sala de los Reyes before and after the Rafael Contreras restoration. (a) Picture by Joaquin Pedrosa, 1857 (290 × 355 mm) (Alhambra plans archives, F-05698). (b) Picture by J. Laurent, around 1860–1886 (268 × 354 mm) (VN-05011, Archivo Ruiz Vernacci, Ministerio de Cultura y Deporte, Spain).

The first known drawing concerning the external views of the Palacio de los Leones and its roofs was made by Richard Ford, the author of nearly five hundred views during his travels in Spain between 1830 and 1833 [87]. Although he was not a professional draughtsman, he was rigorously adapted to the reality he perceived. He produced about seventy drawings of Granada, most of which were published in 1955 together with his own texts [87,88]. In 1833, during his stay in the Alhambra, he stayed in the so called “Casa de

Doña Clara”, above the Sala de los Reyes, once the priests’ residence that he depicted in one of his drawings (Figure 16a)

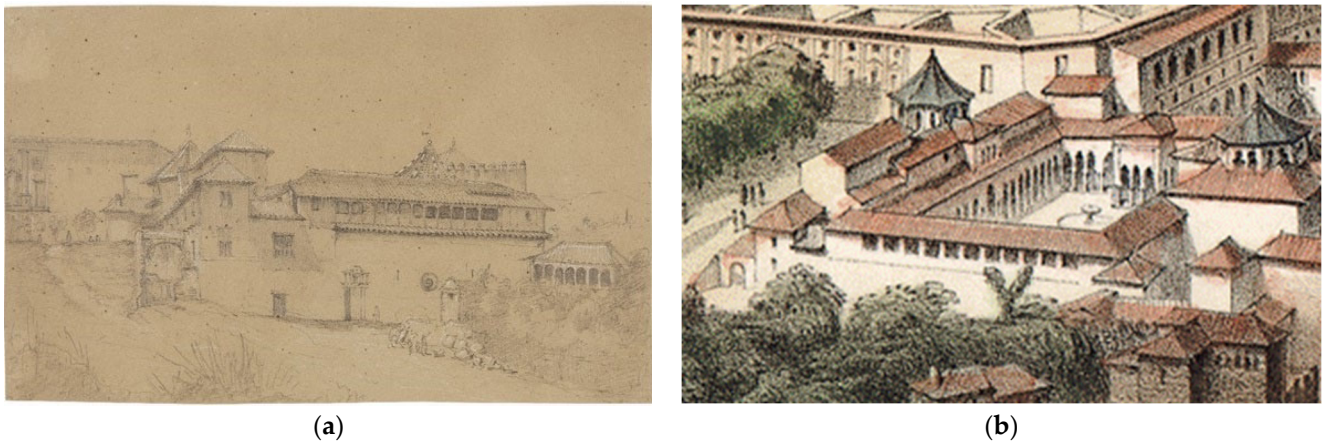


Figure 16. Palacio de los Leones exterior: (a) Partial view drawn by Richard Ford, 1833 (290 × 177 mm) (Ford Family collection). (b) View from the Cerro del Sol, details from a drawing and lithograph by Alfred Guesdon, c. 1853 (440 × 285 mm) (private collection).

The reliability of this view is confirmed by comparing it with the abovementioned sections by the Academicians, or by Jones and Goury. Moreover, the volumes represented closely match the Granada view by the architect Alfred Guesdon drawn and lithographed around 1853 [89] (Figure 16b). In this case, the level of detail is lower because the view was taken from far beyond, a point of view from the Cerro del Sol.

To understand the Rafael Contreras’ transformations introduced into the Sala de los Reyes’ roof, details from other photographs must be analyzed. The volumes from the photo by Charles Clifford, taken around 1853–54 from the Silla del Moro [90] (Figure 17a), agrees with the ones from Ford and Guesdon. They show the single roof that evacuated rainwater directly towards the Patio de los Leones and the Partial.



Figure 17. Palacio de los Leones exterior. (a) View from the Silla del Moro, photograph detail by Charles Clifford, 1854 (419 × 280 mm) (private collection). (b) View from Cerro del Sol, photograph detail published by Andrés Fabert, c. 1915 (140 × 90 mm) (private collection).

A photograph by Andrés Fabert around 1915 (Figure 17b) shows the new independent roofs over the different areas of the Sala de los Reyes. Here, the water does not drain directly towards the outside. This roof construction soon led to problems of leakage that seriously affected the mediaeval paintings and muqarnas domes.

It is remarkable that several documents concerning the works to be carried out in the Alhambra between 1845 and 1857 [91,92] indicated that the volume built in the 16th

century over the Sala de los Reyes paintings caused serious damage. For this reason, it was considered necessary to remove it and build new roofs. Rafael Contreras said that when the room became a church, the light was removed, and his proposal would try to recover the Islamic lighting. The acta session of the Granada Monuments Commission on 27 April 1876 included the architect Pugnaire's opinion, which expressed that he was convinced that in medieval times there were independent covers for each room [32].

The new roof solution, with independent towers and poor waterproofing systems, caused many problems. The new canals badly drained due to waste accumulation, since in the Alhambra surroundings there are many groves and cypresses whose leaves obstruct the rainwater downspouts. Furthermore, the lack of ventilation in the spaces under the new roofs caused humidity condensation on the muqarnas.

The conservation works report of 1870 inform of the deterioration caused by the new roofs' leaks and serious damage to the mediaeval paintings [32]. The intervention was not successful according to Gómez-Moreno González, who in 1892 informed on the incessant water leaks [2]. The report presented at the session on 11 June 1906 of the Academia de San Fernando proposed some solutions to prevent the rainwater leaks. In December of 1910, Modesto Cendoya repaired the gutters [32] and, around 1930–1933, Torres Balbás restored a deteriorated roof structure in the northern area [93].

Jesús Bermúdez Pareja, in the plenary session of 1 July 1957, exposed the worrying condition of the paintings in the Sala de los Reyes due to roofs' leaks. In 1970, Bermúdez Pareja and Maldonado Rodríguez set a report on the mediaeval paintings that included explanatory drawings addressing the different roofs solutions for the problematic interior gutters [16] (Figure 18).

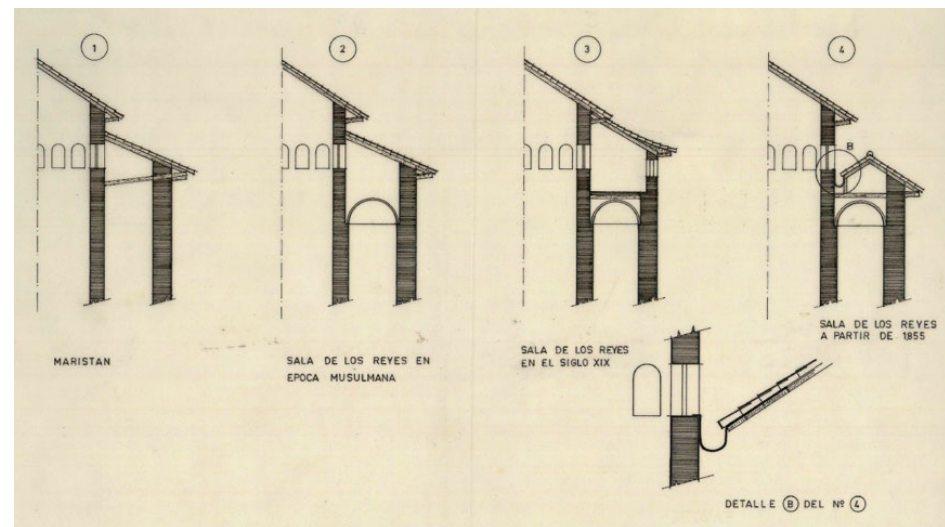


Figure 18. J. Bermúdez and M. Maldonado: detail of schematic sections show the Sala de los Reyes' roofs development. 1970 (460 × 320 mm) (Alhambra plans archives, P-007932).

Around 1973, the need to reform the roofs was raised again. Some plans preserved in the Alhambra Archives, drawn by the draughtsman Manuel López Reche with Francisco Prieto Moreno as the curator architect [94], show the 1857 solution (Figure 19a) and a proposal to build a single roof (Figure 19b). However, in the 1974 repairs, the 19th century turrets were maintained [32].

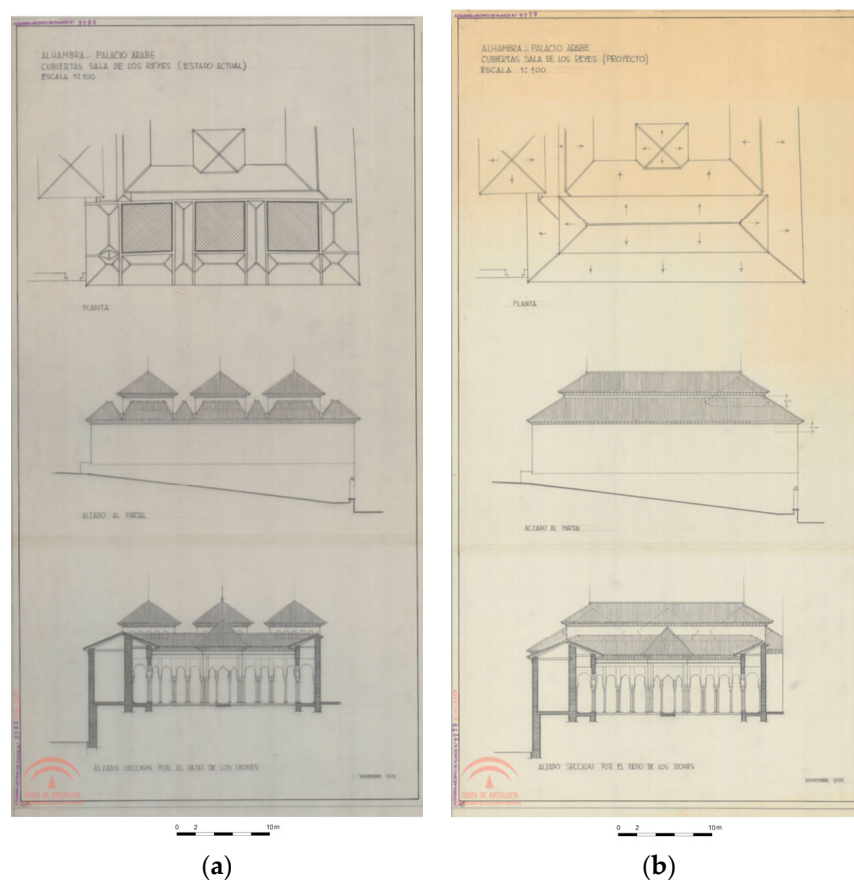


Figure 19. M. López Reche (del.): Sala de los Reyes; roofs. Ground plan, elevation towards the Partial and section from Patio de los Leones: (a) Current state, nov. 1972 (460 × 870 mm) (Alhambra plans archives, P-003071). (b) Proyecto, nov. 1972 (460 × 870 mm) (Alhambra plans archives, P-003087).

Starting in 1999, new works to document the roofs and painted vaults were undertaken, which would be the basis for the interventions begun in 2006. The restoration of the roofs with the painted vaults (2006–2011) was considered to be a priority; following this, an emergency intervention in the muqarnas domes (2007); and then the subsequent restoration of the leather vaults' backs (2008–2009).

The architect Pedro Salmerón designed and directed restoration works (2008–2009) where humidity, multiple cracks, and deformations in the geometry of the muqarnas vaults were found [30]. New stainless steel cables were mounted to guarantee that the dome would hang in case of a detachment. In addition, a new “U” shaped surrounding perimeter roofing was built. However, the Patronato de la Alhambra decided to keep the three turrets built in 1857 on the muqarnas domes, despite their recurrent problems, and the idea to recover a unitary roof over all of them was discarded.

3.2. About the Muqarna Pieces in the Southern Dome: The Theoretical Geometric Setting

Based on an extensive bibliography and authors' experience, a careful observation of the built reality, and the support of photographs, this research has identified every muqarnas piece in the southern dome of the Sala de los Reyes, considering the aforementioned geometric rules of Fray Andrés and López de Arenas.

It is found that it is made up of 1973 pieces. Among the 27 types of existing pieces, there are 12 generic types (sum up to 1212 pieces) that are the most frequent to all the compositions of the Alhambra, plus 8 singular types (sum up to 101 pieces), and 7 types in the medina, which limits the muqarnas groups of the vault (sum up to 660 pieces) (Figure 20).

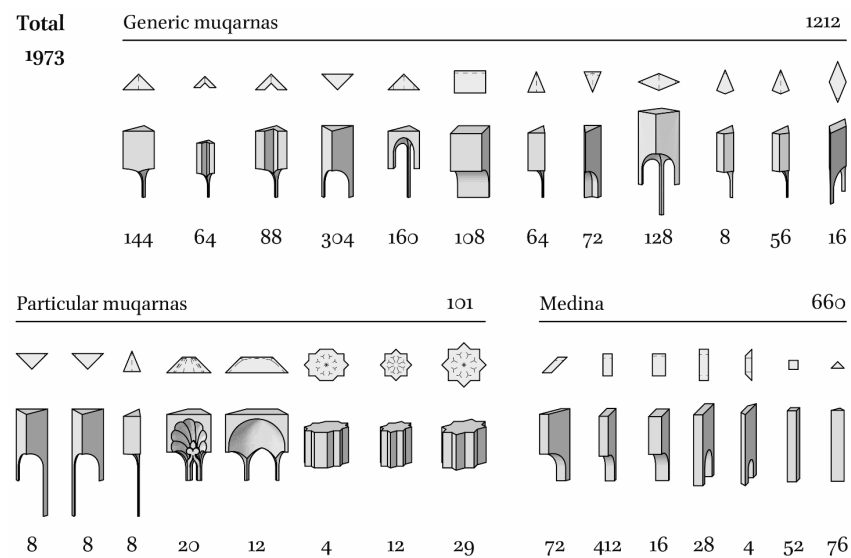


Figure 20. Types and quantities of muqarnas in southern dome, Sala de los Reyes (drawn by the authors, 2023).

To help understand the complex problem of geometric pieces' grouping, an ideal dome model of 440 cm, to the side, has been drawn, and then compared to the as-built dome. The theoretical pieces have been drawn without problems, proving that this design can be built into a square (Figure 21). To obtain this result, the internal principal axes of the dome were defined, so that they allow for the measurement and analysis of point cloud deformations after overlapping the 3D laser scan.

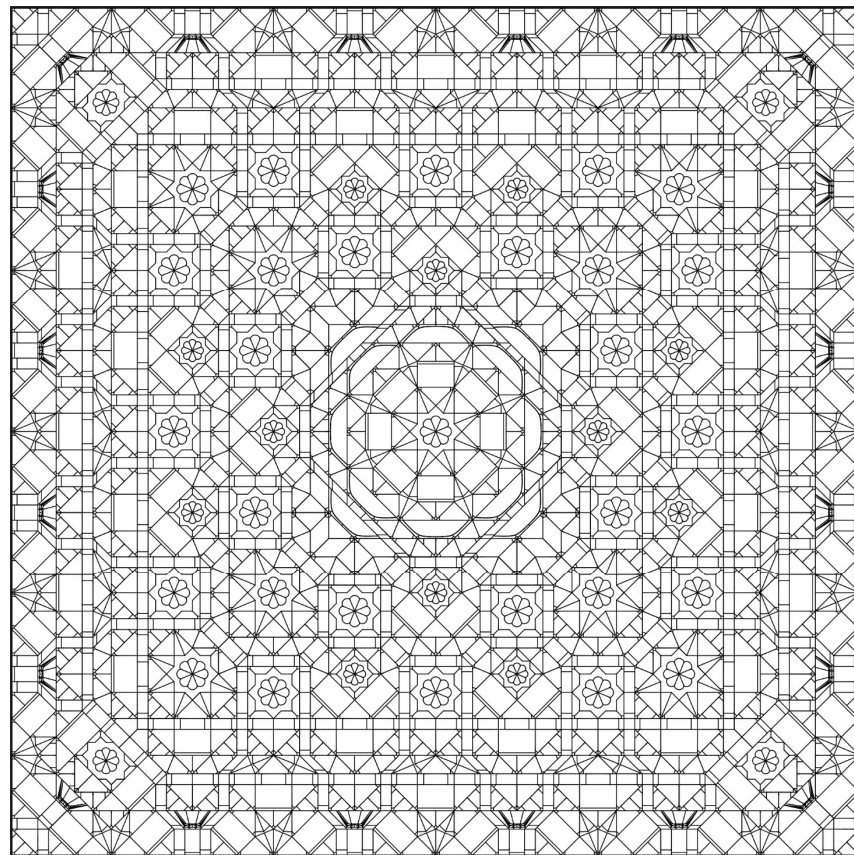


Figure 21. Hypothesis plan from the original muqarnas dome in Sala de los Reyes (drawn by the authors, 2023).

From the plan obtained using the Archicad 26.4019 software, a perspective has been drawn up showing the theoretical formal setting that groups all the muqarnas pieces of this dome. (Figure 22).

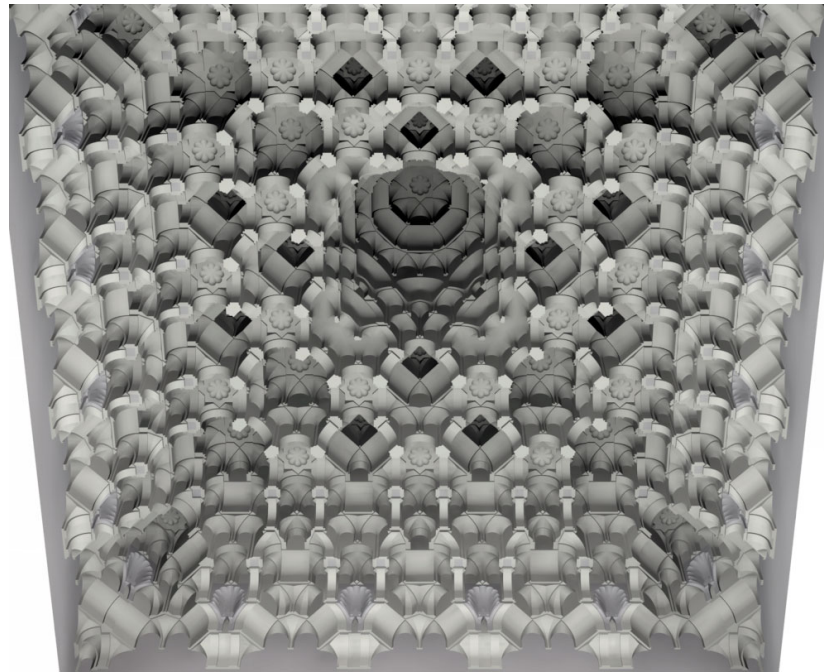


Figure 22. Hypothesis perspective from the original muqarnas dome in Sala de los Reyes (drawn by the authors, 2023).

3.3. About the Deformations on the Sala de los Reyes Ground Plan

As mentioned above, this room is made up of three square domes of about 4.40 m-side (R2, R4, and R6), two intermediate vaults between them (R5 and R3), and two other vaults at both ends (R1 and R7); all of them made up of muqarnas (Figures 23–25).

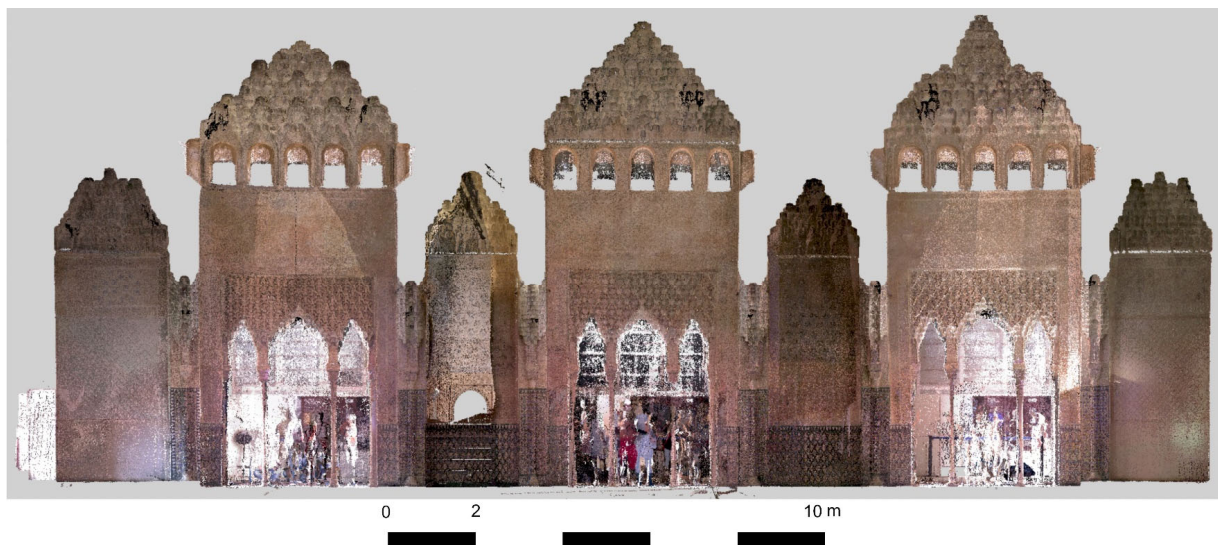


Figure 23. Sala de los Reyes: Elevation projection from the point cloud (Own production, 2023).



Figure 24. Sala de los Reyes: Ground plan projection from the point cloud (Own production, 2023).

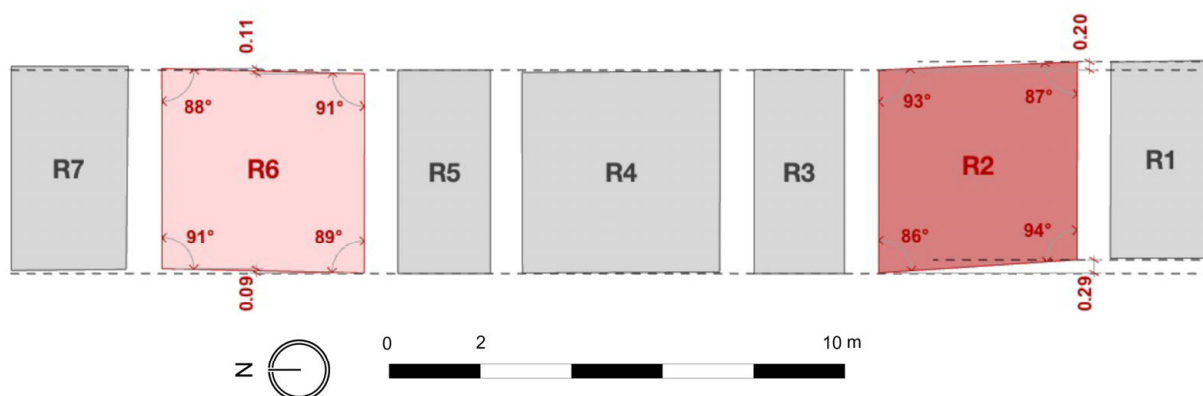


Figure 25. Layout of the domes and vaults basis in Sala de los Reyes. Lines drawn from the scanner laser point cloud.

It can be assumed that the Islamic designers devised the domes inside a perfect square plan but that they suffered several deformations until reaching the current parallelepiped shape (R2). If this deformation had occurred all at once it would have probably involved the fracture or collapse of the dome. The existing deformed geometry could be due to small successive misalignments in the existing walls and the accumulation of restorations that slowly adjusted the muqarnas pieces to each other.

The roof plan derived from the point cloud clearly shows something difficult to appreciate with the naked eye: the northern and southern façades are always parallel for each independent dome.

However, there are remarkable deformations north of dome R6 and south of R2. The central dome R4 keeps all its angles at 90° , it is a square in ground plan, and the vaults R3 and R5 are perfectly aligned. Dome R6 is a parallelepiped with a translation of about 10 cm from its north façade to the east. The R7 vault is again a rectangle, displaced 10 cm towards the east.

3.4. About the Deformations on Southern Dome Ground Plan of the Sala de los Reyes

To study the deformations observed in the point cloud with the theoretical model, the perimeter general dimension was taken as a reference. An attempt was made to check if the geometry is coherent and if there are internal distortions, quantifying the deformations of axes and angles on the point cloud. (Figure 26).



Figure 26. Sala de los Reyes: Southern Muqarnas Dome ground plan from the point cloud [Image top side points East] (Own production, 2023).

It was confirmed that the south dome's corners are displaced by to a large extent: 29 cm in the southwest corner and 20 cm in the southeast corner. As in the north end, the south end of the muqarnas vault R1 has an orthogonal base, and it is displaced towards the east with respect to the axis of the gallery. Thus, the south dome, R2, does not have 90° internal angles, but they are rather offset by 3° and 4°.

The west axes show a deviation of about 2° towards the south face and, therefore, would have suffered stress and probably fractures in their first levels. Deviations of 3° can also be seen on the south face, detecting deformed muqarnas in a deformed star. The angle between the east and south faces is 87°, the remaining 3° are spread among the contiguous faces, the east face axes deviated 2° and the south ranging 4° to 6°. These faces compressed each other, and suffered damage, but since they are compression forces, they were easier to absorb. Between the south and west faces, occurring simultaneously in its opposite corners, the muqarnas would have been separated and, therefore, greater deformations can be seen.

Regarding the vertical component, there is not a perceivable global misalignment in a north–south section; there is, however, a small but noticeable inclination of the whole composition towards the east. The lower base of the window openings is slightly inclined towards this direction. It is observed that the muqarnas' center slightly displaces towards the east from its theoretical position (Figure 28).

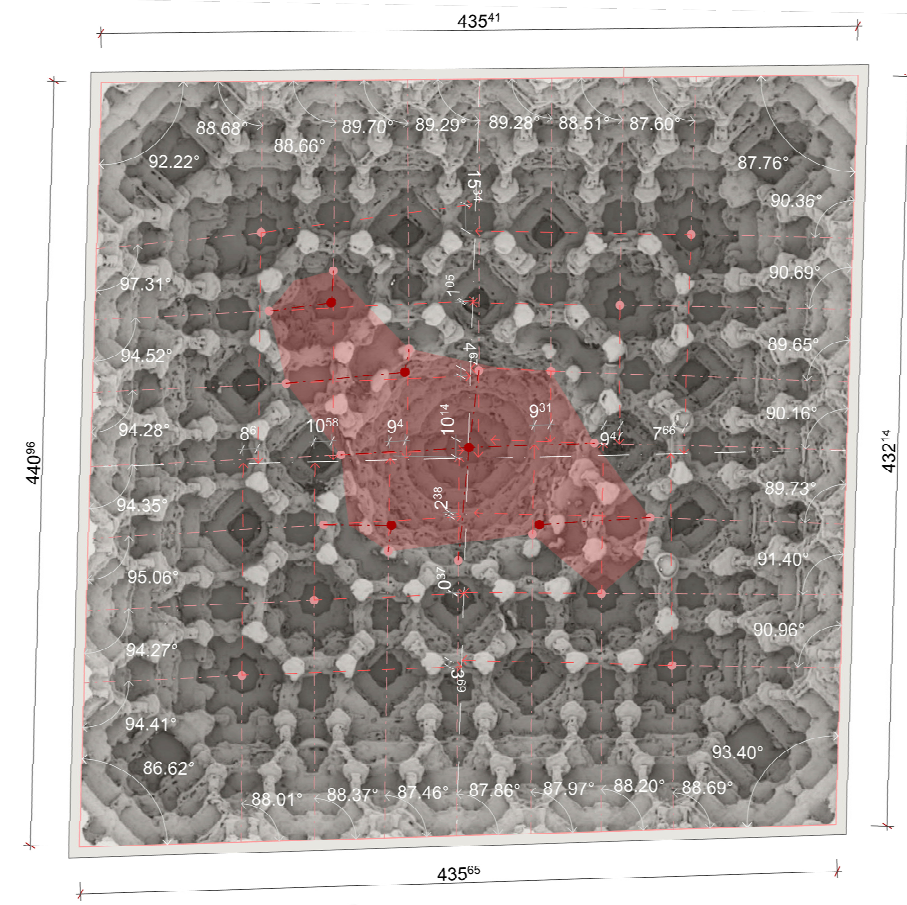


Figure 27. Top plan of southern muqarnas dome deformations in Sala de los Reyes [Image top side points East] (Own production, 2023).

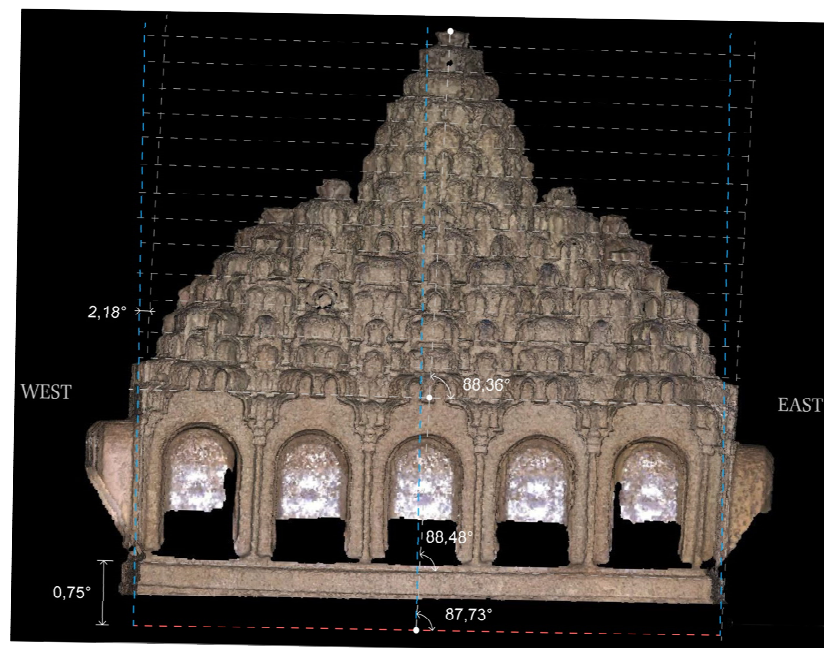


Figure 28. Elevation of southern muqarnas dome deformations in Sala de los Reyes (West–East section). Red dash line is horizontal, blue dash line is vertical, white dash lines show levels of muqarnas and top–down alignments (Own production, 2023).

4. Conclusions

Drawing is an essential research tool to understanding and preserving architectural heritage. A monument with a suitable graphic documentation has a greater chance of surviving over time in the case of catastrophes or unfortunate human interventions. If it is destroyed, its values can be preserved if there is graphic documentation that helps its virtual recreation or material reconstruction.

This research documents and graphically analyzes the southern muqarnas dome in the Sala de los Reyes of the Alhambra, a fragile architectural heritage from the 14th century. A brief historical background and data on many earthquakes, explosions, and other ruin hazards, as well as important repairs or restorations over the centuries, have been provided as an introduction. General issues surrounding muqarnas and their geometric grouping have also been reviewed. The proposed methodology combines historical image analysis and current digital graphic techniques. These studies concerning the muqarnas dome studied had not been yet undertaken, not even in the important restorations of the 21st century published in Cuadernos de la Alhambra in 2022. This article detects geometric deformations that have not been considered in the scientific panorama, in an attempt to help future heritage conservation.

An unpublished set of important plans, drawings, and photographs dated between the 16th and 20th centuries, have been provided and analyzed. These documents are fundamental to understanding and illustrating the remarkable transformations of the Sala de los Reyes, its roofs, and surrounding context. The earliest known drawing of this room, a plan dated around 1532, shows annotations with its main dimensions. This research is the first one to reveal that the base square sides of the muqarnas domes are 15 feet long, although the northern and southern domes are annotated by 15 and a half feet. That means that in the 16th century there were already geometric deformations, hitherto unknown. The “Capilla” label confirms the religious use it had, and it should be noted that in the 16th century an upper floor that transformed the roofs was built to house the residence of the Alhambra priests. The sections drawn by Academicians in 1767, and the ones by Jones and Goury in 1842, show the upper floor and a unitary roof over the room with small lateral openings for ventilation and lighting overlooking the Patio de los Leones. These also appear in a drawing by Swinburne in 1775, hitherto unknown in the scientific bibliography, and also in some later images. The drawings by Jones and Goury were especially careful; pioneers in identifying muqarnas pieces in the Alhambra, they drew two Sala de los Reyes sections detailing subtle differences between its domes and vaults. Also of great interest are the details of the beautiful view of Patio de los Leones by Gerhardt’s from 1849, matching the earliest known photographs of this place, taken shortly before its important transformation in 1857.

Some external images showing the Sala de los Reyes’ roofs have been found. The first one drawn by Ford in 1833, matches the 1853 Guesdon view and a photo by Clifford around 1854 taken from a medium distance. The Contreras restoration in 1857 replaced the unitary roof, which instantly evacuated the waters towards the outside by towers with independent roofs for each space; these multiple roofs still exist today. The multiple roofs implied the installation of interior gutters that caused many water or humidity leaks and repairs or restorations. However, neither the 20th century interventions nor the 21st century intense restoration planned to retrieve the unitary roof over the room, so the interior gutters that likely did not exist in Nasrid times, were kept. The lighting and ventilation openings created in 1857 on the four sides of each dome have been kept, although other representative Islamic spaces of the Alhambra, such as the interior of the Comares tower, are not illuminated and ventilated by its four sides. Therefore, new research or scientific explanations seem necessary to justify the complex shapes of these emblematic roofs.

This research is the first to identify nearly two thousand pieces that make up the analyzed dome according to the geometric principles of grouping of muqarnas and after a careful observation of reality. Perspective and ground plan drawings by computer

are also provided, which are the earliest ones to detail the complex geometry of its muqarnas group.

The 3D scanner point cloud allowed for us to find and document differences among the domes set of the Sala de los Reyes, which are difficult to appreciate at first glance. Remarkable deformations have been detected and quantified in the southern dome ground plan, especially its upper part. These deformations could be a consequence of earthquakes, explosions, or water leaks, worsened by poor maintenance or improper restorations. It is impressive to see how a dome built with plaster muqarnas has survived over centuries, and it must be considered that the fragility of this material facilitated successive repairs. It has been confirmed that the deformations found match the annotations in the 1532 plane analyzed. It is not easy to identify the causes that led to such significant deformations in such a unique muqarnas dome in the Alhambra. However, the point cloud used in this research provides accurate metric data to control deformations that may happen in the future.

It is not possible to appropriately protect anything without a sound knowledge about what is intended to be preserved or restored. For this reason, this research tries to promote the conservation of this important 14th century muqarnas dome over time, as well as its suitable diffusion and highlight, as an outstanding identity symbol of the Alhambra Nasrid architecture in Granada.

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