Nexus Network Journal
https://doi.org/10.1007/s00004-022-00630-y

NEXUS NETWORK JOURNAL
Architecture and Mathematics

RESEARCH

A Hexagonal Pattern in the *Paraninfo* at the Universidad de Alcalá

Manuel De-Miguel-Sanchez[1] · **Carlos Gonzalez Duque**[1] · **Pilar Chías Navarro**[1] · **Tomas Abad Balboa**[1]

Accepted: 3 August 2022

Abstract
In the sixteenth century, the assembly hall, or *Paraninfo,* at the recently inaugurated Universidad de Alcalá was known as the *pieça del theatro*. This study focuses on the layouts and proportions designed for this hall, which could be the key to understanding the whole project as a Renaissance theater that was singularly inspired by Roman models. Specifically, the hexagonal pattern of the coffered ceiling represents a genuine formal exploration in comparison with other wooden ceilings having similar geometric bases. All this led us to study this uncommon masterpiece as a proposal for a new model toward an intellectual and architectural recovery of the Antiquity, in the core of the *Universidad*, conceived for the representation of academic ceremonies and humanistic theater.

Keywords Hexagonal pattern · Renaissance · Theater · Paraninfo · Coffered ceiling

The *Theatro* at the Universidad de Alcalá

The *Universidad de Alcalá*, initially known as *Universidad Complutense*, was founded in 1499 by Cardinal Cisneros. Since its inception, public ceremonies and the fitness of the architecture for hosting such ceremonies have lent it great prestige. They were aimed at showcasing the prestige of the university and its purposes.

✉ Manuel De-Miguel-Sanchez
manuel.miguel@uah.es

Carlos Gonzalez Duque
c.gonzalezd@edu.uah.es

Pilar Chías Navarro
pilar.chias@uah.es

Tomas Abad Balboa
tomas.abad@uah.es

[1] Escuela de Arquitectura, Universidad de Alcalá, Santa Úrsula, 8, 28801 Alcalá de Henares, Madrid, Spain

Published online: 01 September 2022

Birkhäuser

Initially, these public ceremonies took place in the main chapel of the Universidad de Alcalá, dedicated to San Ildefonso. There, it was possible to exhibit the institutional hierarchy and the ecclesiastical power that were present in the religious ceremonies. Nevertheless, academic events would need a new and unique space to express the excellence of the university. This space, which was built between 1516 and 1525, must have been the *Paranifo*, as it is called today, instead of its original designation, *pieça del theatro.*[1] The events held in this space seemed to transcend the university sphere, since it is known that prominent personalities, such as Japanese ambassadors or Francis I of France, among others, attended some events there (Cámara Munoz and Gómez López 1995: 97–98). This reveals the significance of the assembly hall and leads us to study one of the first Renaissance buildings in the Iberian Peninsula.

The purpose of the auditorium has unavoidably evolved over time, distorting our perception. Despite this, we can approximate the original use for which this space was conceived through contemporary sources, most of which were written by travelers. According to Gaspar Barreiros (1561: 57–58), Cardinal Francisco de Cisneros founded "a very well-built theatrical building to hold public events and perform comedies inside. There are seats divided into two orders for PhD, Masters, graduates and scholars." Evidence from Alvar Gomez de Castro, written in 1569, also highlighted this idea: the theater, which even has a place for musicians in the middle of the hall (Fig. 1), was not only used to deliver speeches and hold conferences but also perform plays. Thanks to this account, it is possible to understand how the space was used in that time. It is noteworthy that all the historical documents consulted referred to this space as a *theater* (Convenio de Alcalá-MOPU 1990) and affirmed that comedies were performed in it.[2]

In this context, we must conclude that the university played a powerful role in spreading Greco-Latin knowledge in the Hispanic world (Alvar Ezquerra 1999: 515). Close to *Paraninfo*, the Trilingual *Colegio* was built a few years later. This center was assigned to the recovery and study of Latin, Greek, and Hebrew. Once a year, Latin scholars had to perform an ancient or expressly written comedy or a tragedy. Meanwhile, students of Greek recited texts in this language twice a year (Alvar Ezquerra 1999: 521). The *Paraninfo* would therefore be the most appropriate place for performing plays of the Hispanic humanistic theater.

A Renaissance Space

In our opinion, it is plausible to think that there was a determination to design a new type of building based in Roman architecture to introduce both new and traditional ceremonies. The *Paraninfo* was not only an assembly hall for university events but also the ideal context for the recovery of the classical plays. We wonder if this new space was deliberately built to recover Antiquity, academically and architecturally speaking. The study of the proportions of this assembly hall

[1] From Greek, Theater: A place for viewing.

[2] This term referred virtually to any play, not specifically a comedy.

Fig. 1 *Paraninfo* at the Universidad de Alcalá The imposing presence of the coffered ceiling is appreciable. The design of the ceiling and the rest of the hall seem totally diverse; however, they are directly connected at the level of their proportions. Photograph by the authors

offers clues about the existing concept in Castile from the early sixteenth century regarding the new Renaissance ideas. They were introduced from Italy a few decades before thanks to the cultural activity of the Mendoza family and placed in the city of Guadalajara, close to Alcalá de Henares (Nader 1986: 31–32). Their influence as patrons of the arts is essential to understanding most contemporary works. One of the most prominent members of that family was Cardinal Pedro González de Mendoza, who was well known for supporting the first Renaissance works in Castile and for being the mentor of Cardinal Cisneros.

Since the end of the fifteenth century, some wealthy family members had traveled to Italy and encountered Renaissance trends, as did Diego de Sagredo (1490–1528) and Juan Bautista de Toledo (1515–1567) some decades later. Regarding the sources of classical architecture that could be used in the conception of the hall, it should be noted that its construction was completed before the publication of the text by Diego de Sagredo (1526), which was the first treatise written in Spain. Although architectural treatises, which did not have images, arrived at the university library prior to 1523 (Marías Franco 1995: 128), we cannot assert that there were copies made so early so as to have been used in the construction of the *Paraninfo*. However, the Mendoza family owned several architectural treatises (Salgado Olmeda 1995: 131) and repertoires of drawings, such as the Codex Escurialensis, which was perhaps brought by the Marquis del Cenete after his stay in Rome in 1506 (Scaglia 2004). The possible influence of the Codex in the decoration of the coffered ceiling and plasterworks of the *Paraninfo* has already been pointed out (Toajas Roger 1995: 84–85), even if we are not able to recognize the specific transmission of the source. If one of these references were used, it is easy to think that all of them could be known to the intellectual author.

We believe that the *theatro* project could have been influenced by other drawings that are lost today but are fundamental to defining the geometric pattern of the ceiling with a hexagonal base. The wooden ceilings of the Mendoza family, which are preserved on the noble floor of the Palace of Antonio de Mendoza (Guadalajara) or in the chapel of the Calahorra Castle (Granada), also used the same pattern. We will see later that this combination of polygons and stars was used in Antiquity, as well as in Islamic architecture and in Modern Age treatises (Redondo Buitrago 2022). Most likely, this graphic source could be one of the drawings that Diego de Sagredo (1526) mentioned in his treatise when he wrote about the repertories that circulated in Castile and that he would have known as a student at this university.

The spatial, constructive, and ornamental differences that we can see between the chapel of the Colegio de San Ildefonso and the *Paraninfo* are significant. However, both works were directed by the master mason Pedro Gumiel and Francisco de Carabaña. In addition, the two works were commissioned by Cardinal Cisneros and were built almost at the same time. It is therefore surprising that while the chapel has al-Andalus spatiality and its representative elements, the theater breaks from traditional architecture to achieve a new space that would be inspired by a classical ideal involving all the constructive elements, even without claiming a complete formal integration. This is evidenced by the design disparity between the plasterwork, carpentry, and tilework. The peculiarity of this work is explained only by a deliberately groundbreaking intellectual conception, which would represent the functional and ideological purposes of the university, inspired by the recovery of Classical Antiquity.

The Layout of the *Paraninfo* Floor Plan and the Vitruvian Theater

Our research is based on a survey of the *Paraninfo* that we made by combining a laser scanner and digital photogrammetry. The Laser Scanner is a Leica BLK360, featuring 360,000 laser scan pts/sec. Its range accuracy is 4 mm/10 m (0.04%). Twenty-seven different scan positions were needed to define the space, nine on the ground floor, eight from the upper balconies, and ten in the attic. The software used to build the point cloud is Cyclone Register 360 by Leica. The plans and sections made for this study used the point cloud, comparing the measurements in different cuts. Agisoft Metashape software was used to make a photogrammetric model of the wooden ceiling. A total of 109 photographs make up the digital photogrammetric model. It was scaled and oriented using points from the laser scanner. This model was used mainly to make orthoimages of the coffered ceiling.

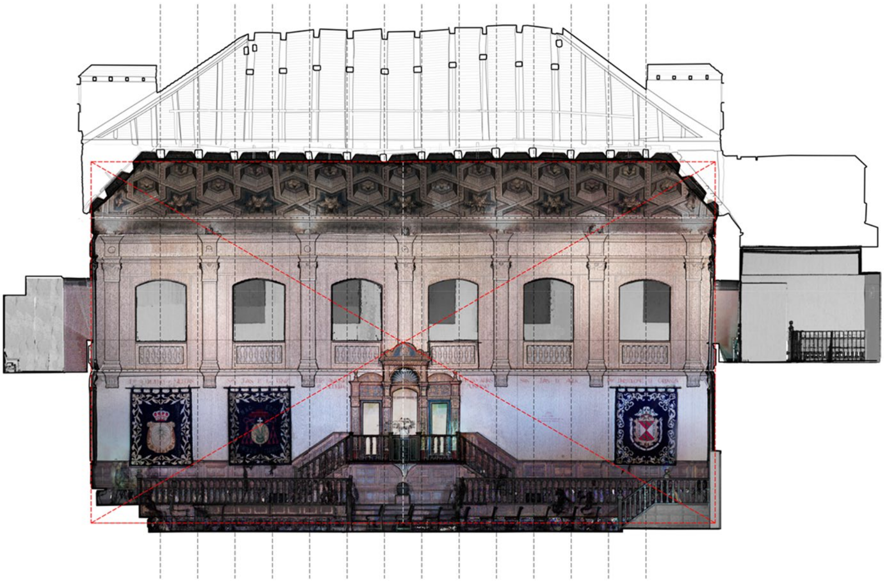


Fig. 2 Longitudinal section of the *Paraninfo* at the Universidad de Alcalá. Orthoimage from point cloud. By the authors. The center of the composition is the quadrant of the upper semicircle of the podium, which coincides with the upper line of the balustrade. Square root of 3 rectangle highlighted in red dashed lines

This work focuses on the study of the interior characteristics of the theater, its geometry and that of its extraordinary coffered ceiling. The floor plan of the theater is a rectangle measuring 19.30×11.15 m and has a free height of 11.45 m. If we take the Castilian foot (27.86 cm) as a reference, it can be deduced that the room has a width of 40 feet, while its length would be 69 feet and three inches, and the height ranges from 33 feet at the top of the wall to 41 feet at the lower side of the beams. Naturally, these are average measurements, since both the rammed earth walls and the wooden beams have irregular geometries. For example, in the center of the room, the distances between opposite planes are shorter than in the corners. However, the proximity of each measure to the mean is less than 1%.

The proportion of the hall on its floor plan is 1.73 : 1, which is very close to the square root of 3 (less than 0.1% off the ideal $\sqrt{3} \approx 1.732$). The most interesting thing is that this rectangle fits inside a regular hexagon (Fig. 5). The ratio of the short diagonal (d) to the side length of the hexagon (t) is $\sqrt{3}$: 1. Another characteristic of this rectangle is that its diagonal (D) is exactly twice the side of the rectangle and form angles of 30° and 60° with the sides of the same polygon. These angles are known to match a tool called *cartabon*, which was commonly used by carpenters and builders and is still useful today. It is plausible that these instruments were used in the Paraninfo project. We are not claiming that the designers from Alcalá de Henares consciously used root rectangles. Nevertheless, choosing the root of 3 as the main ratio, other square root lengths will appear (see Fletcher 2007). That is why we have included them in the compositional analysis (Figs. 2, 3 and 4).

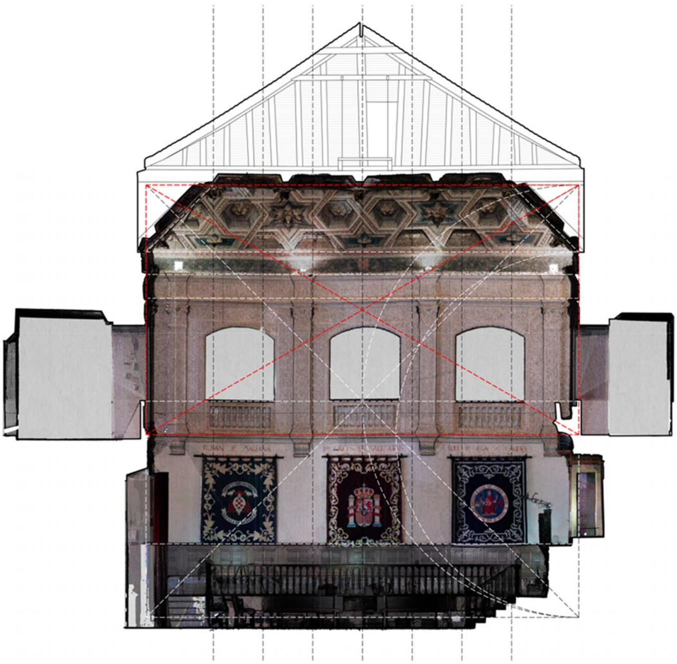


Fig. 3 Cross section of the *Paraninfo* at the Universidad de Alcalá. Orthoimage from point cloud. By the authors. Square root of 3 rectangle highlighted in red dashed lines

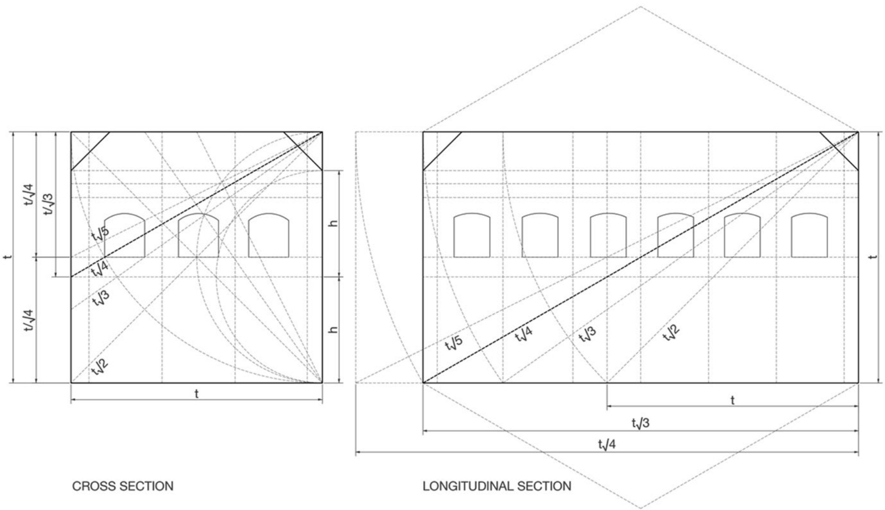
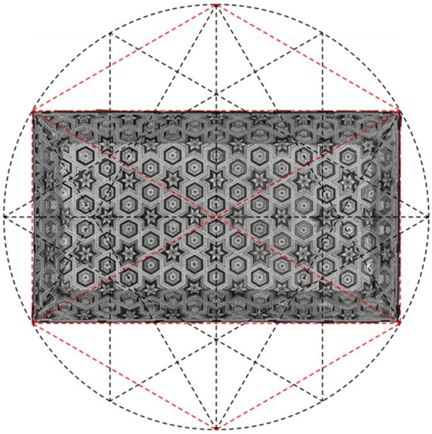


Fig. 4 Analysis of the composition of the interior elevations of the hall. By the authors



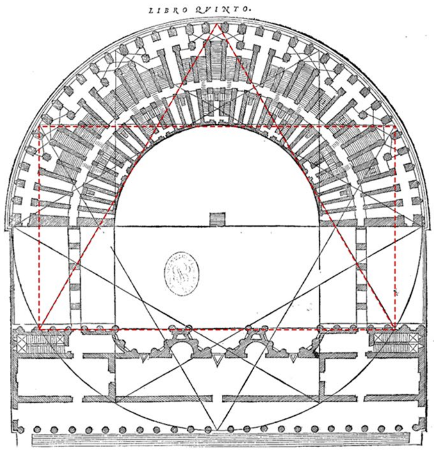


Fig. 5 Left: Floor plan of the *Paraninfo* inscribed in a hexagon according to Vitruvius's description. By the authors. Right: Illustration by Andrea Palladio of the Latin theater for Daniele Barbaro (1567: 250)

The cross section of the hall is nearly square, 40 feet wide by 41 feet high (from floor to the flat ceiling). However, if we consider that the ground level has been lowered and all ratios are related to the upper line of the section, we can assume that it could have meant to be a 1:1 ratio. Additionally, a square root of 3 rectangle forms the second floor, limited by its impost and the flat ceiling (Figs. 3 and 4).

The longitudinal section fits the square root of 3 as well (Figs. 2 and 4). Its composition shows three horizontal strips that divide the elevations of the ground floor, second floor, and wooden ceiling. The central point of the composition is the quadrant of the decorative semicircle of the upper part of the *cátedra*. It coincides with the middle line, the top of the balustrade. The distances from this line to the floor and ceiling are the same (t/2) (They measure between 5.55 and 5.63 m, within an error range of 1.5%). The distance from the ground to the impost of the second floor and from this line to the beginning of the coffered ceiling are also equal (h) (Between 4.7 and 4.8 m, less than 2% error) (Fig. 4).

The ground floor has blind walls except for the access from *Patio Trilingüe*. The upper space shows three and six windows along the short and long sides of the hall, respectively. These openings communicate with a perimeter gallery that allows the spectator to attend theater events in a more discreet way. The decoration on the upper floor consists of plasterwork in the form of cornices and bas-relief pilasters that frame the windows.

The mentioned ratios seem to indicate that there was a clear intention to introduce the hexagonal pattern in the design of the *Paraninfo*. The archiepiscopal master mason was initially Gumiel, and then Carabaña, a graduate on humanities (Marías Franco 1995: 125–128). Both had to coordinate the different units of the work so that it could bring the set back to an idealized Antiquity. Above all, the most interesting issue about this geometric pattern is the possible influence of the Vitruvian treatise on the decisions of the ideologues of the work. In Book V of *De Architectura*, the layout of the geometry of the floor plan of a Latin theater is textually described as the superposition of four equilateral triangles, forming a twelve-pointed star framed by a hexagon that determines the size and position of the *scena* (Barbaro 1567). This scheme corresponds to the hexagonal pattern (Fig. 5).

In this regard, it should be noted that the first Renaissance theatres built in Italy, which were generally ephemeral, all had a rectangular plan (Mazzucato 2009). This evidence shows that at the time, the Vitruvian text was not interpreted as it is today. This would not change until some decades later with the arrival of the first graphic interpretations of the Italian Renaissance: the illustrations of Cesariano and those of Palladio for the translation of Daniele Barbaro. Palladio developed his model by an accurate direct observation of Roman theatres, which were used for the construction of the Olympic Theater in 1580.

The Importance of the Coffered Ceiling in the Construction of the *Paraninfo*

The meticulous accounts of the university allow us to know in detail the cost and the craftsmen who worked in this space. The ceiling accounted for almost a fifth of the total budget. Among the different artisans directly hired by the university, there are no names that point to Moorish workers or from origins distant from Alcalá. The wood for the coffered ceiling was brought from the town of Pastrana (Guadalajara), and its assembly was contracted in the spring of 1518 to Andrés de Zamora, a carpenter from Ocaña (Toledo), who was helped by Lorenzo de Roa, Pedro de Trixueque, and Pedro Izquierdo, who carved the panels of the ceiling. The plasterwork was done by workers from Toledo, and many of the tiles came from Guadalajara. To achieve a high specialization, the university independently requested the rosettes to be done by Bartolomé Aguilar and Hernando de Sahagún, the colors to Alonso Sánchez from Toledo, and to Diego López, who painted and gilded the coffered ceiling, along with Juan Dávila, Gaspar Morales, and Pedro de Braxales, all of whom were from Guadalajara (Castillo Oreja 1980: 130–131).

The ceiling is shaped like a truncated pyramid, which is formed by horizontal beams with braces, called *jabalcones* in Spanish, which form 45° panels on its four sides (Figs. 6 and 14). The folding of the planes is due to a structural need, given the long span of the room, but it could also be a design condition, influenced by the taste of the time. The vaulting of Spanish wooden ceilings appears associated with images of monumentality, thanks to the feeling of depth that they produce. The geometric pattern is a combination of hexagons that meet at their vertices, leaving equilateral triangles between them. Visually, there are six-pointed stars, which are actually the sum of the hexagon and the triangles around it. That way, the simple pattern generates a dynamic and varied impression (Fig. 13).

The hexagonal coffers are concave, using the gap between the beams, while the stars are flat designs, since the structure passes over the lateral points. The beams, which cover the space in the short span of the room, provide one of the three directions of the grid that form the hexagons. At the upper surface, there are 14 beams, with an axial spacing of approximately 1.15 m. This indicates that

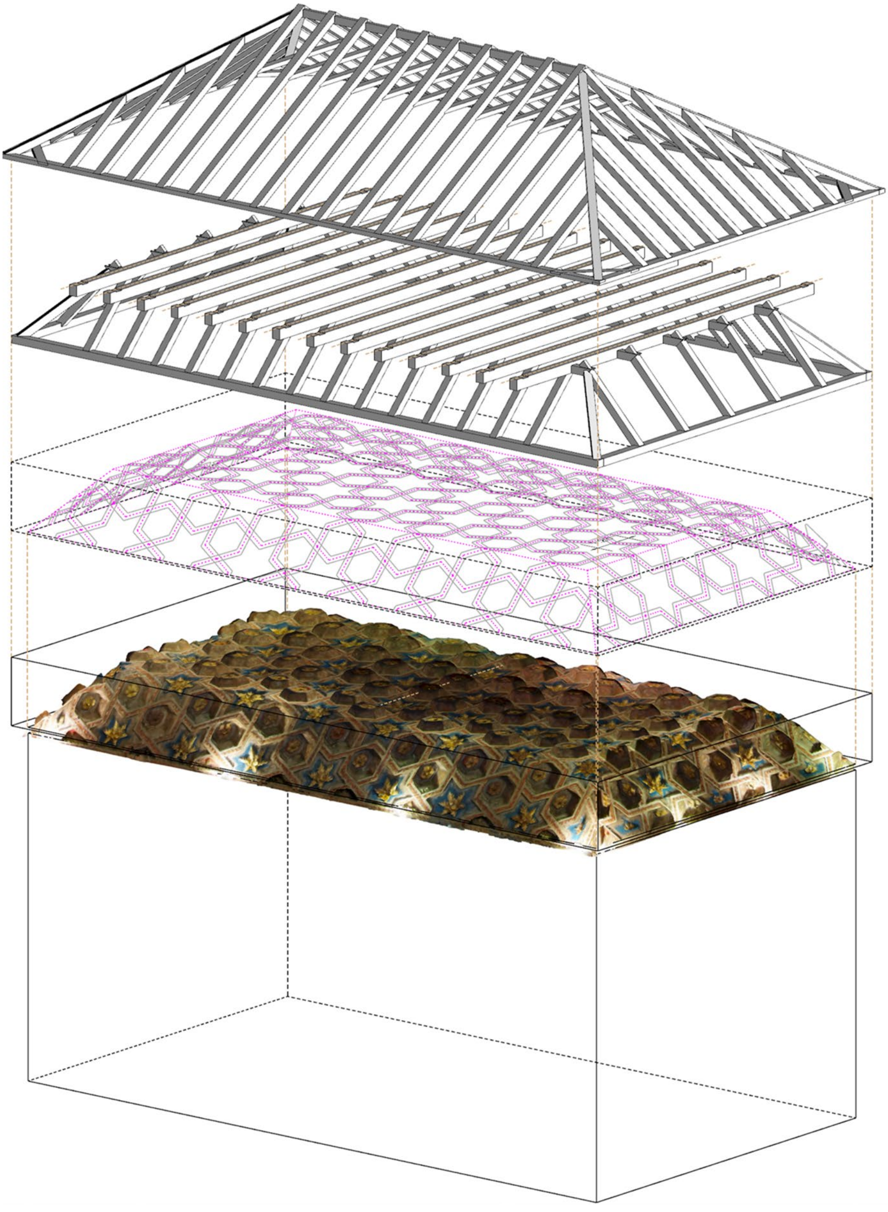


Fig. 6 Exploded axonometric of the *Paraninfo*. By the authors. The structure is made up of two levels, the rafter and collar tie that form the roof and tie beams and braces that support the coffered ceiling. By the authors

each module should be four feet wide. This hypothesis would indicate that for the manufacture of the carpentry, a unit (28.75 cm) slightly larger than the usual Castilian foot (27.86 cm) could be used.

The number of hexagons that would form the roof if it were flat would be 17 × 8 (Fig. 10). This makes us think that the coffered ceiling could have been originally conceived as a flat structure. There is evidence that a rectification of the project was introduced at approximately the end of 1517 due to a possible collapse (Castillo Oreja 1980: 55). Either for structural reasons or geometrical correction, they decided to fold the lateral panels. Consequently, the number of polygons that form the ceiling is increased slightly (18 × 8.5 hexagons). The long side of the horizontal plane adjusts to 14 modules whose measure is the width of the hexagon (d), while the short side measures six times the diagonal (D) of the hexagon. The proportion between both modules is $\sqrt{3}/2 \approx 0.866$. Therefore, as the width of the hexagon is 1.15 cm, the diagonal should measure 1.33 cm. This is the theoretical configuration, but we have verified that the dimension of the diagonal (D) of the hexagon is smaller (1.28 cm). There could be two explanations for this reduction of 4% of the pattern in the direction of the beams. It could have been an adjustment of the entire roof to better fit with the folded configuration or a subsequent deformation of the structure.

Thus, there is a slight variation in the pattern of hexagons according to its ideal trace of 4% in the short span. As said, this could be due to the deformation of the wood, but we verified that it is homogeneous throughout the length of the ceiling and is continued by the side panels. If it were a simple contraction, due to deformation of the main structure, then the side panels would not follow the same path. However, we checked that the measurements of the hexagons in all planes are the same. It is more likely that this is an intentional correction that makes better adjustments on all four sides. Specifically, the reason for this rectification in the *Paraninfo* could be to accommodate the whole decorative rosettes on the long sides of the hall, which, if adjusted to the pattern, would be cut in half. This deformation of grids is an accredited and studied practice in Renaissance coffered ceilings (González Uriel et al. 2019). Oblique polygons offer some flexibility to adjust the ceiling design. It is an unknown peculiarity in medieval ceilings. The stars of Hispanic-Muslim ceilings layouts have a much stiffer geometry, forcing the design to keep the same range of angles in all directions.

References of the Hexagonal Pattern in Contemporary Works

The pattern of hexagons and stars appears in very few Spanish Renaissance coffered ceilings, and apart from the *Paraninfo* at Alcalá de Henares, they are always associated with flat ceilings. Serlio included a very similar pattern in Book IV of his treatise (Serlio 1552) (Fig. 7a). In that text, several ceilings are shown together, some on a square grid, formed by octagons and crosses, and others on a triangular grid made up of hexagons and triangles, which indicates that the author considered this design among the best of Antiquity.

As said before, it is possible that during the construction of the *Paraninfo* (1516–1525), there were graphic sources in which triangles and hexagons were joined to form stars. There are other formal references of the time, although as flat ceilings and directly connected with the ideologues of the *Paraninfo*. One of the ceilings of the Palace of Antonio de Mendoza, in Guadalajara, is associated with

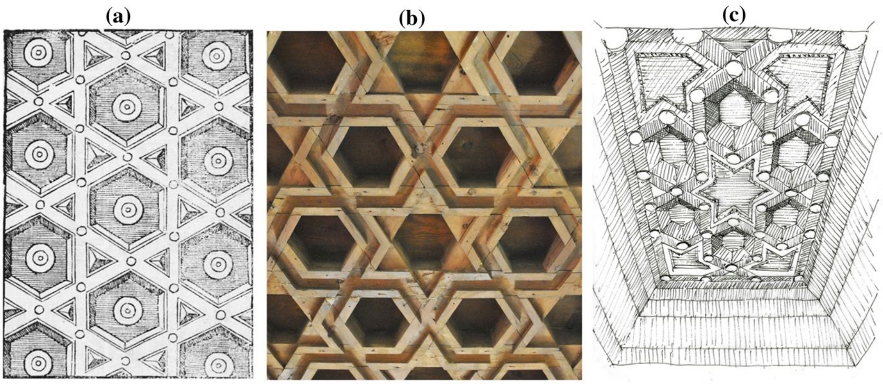


Fig. 7 Examples of hexagonal layout. **a** Serlio (1552); **b** ceiling in the Palace of Antonio de Mendoza. Photography by the authors; **c** ceiling in the Castle of *La Calahorra* (Granada). Drawing by the authors

Fig. 8 Hexagon and star patterns. **a** Photograph of plasterwork of the Alhambra by the authors. **b** mosaic in Nishapur (Fukushima 2004)

the abovementioned family of art patrons (Rodríguez Rebollo 2002). This building is considered one of the first Renaissance palaces outside of Italy, commissioned to Lorenzo Vázquez de Segovia after intervening in the Palace of Cardinal Mendoza. The pattern coincides with the one in question, although the stars include flat triangular points around the inner hexagonal coffer (Fig. 7b). The decorative simplicity allows us to see the beams and struts, on which strips are nailed to form the figures. Compared to the ceiling of the *Paraninfo,* the impression is more monotonous since the difference between stars and hexagons is barely noticeable.

We also find a similar design in the small ceiling of the Chapel located in the Castle of *La Calahorra* (Granada), which was built between 1509 and 1512 by the first Marquis del Cenete, son of Cardinal Mendoza and pioneer in the introduction of the Renaissance in Spain. The works were initially commissioned also to Lorenzo Vázquez after his works in Guadalajara and later to the Genoese Michele Cardone for the stonework. This case shares with the others the combination of hexagons and stars, although it does not introduce the Hispanic-Muslim *lazo*, loop of interlacing strips; instead, the polygons are joined with simple medallions (Fig. 7c). The points

Fig. 9 Details of the corner solution of the wooden ceiling. Photography by the authors

of the stars cover the upper beams, while the hexagons rise, fitting into the inter-beam spaces.

The design of hexagons connected by their vertices (Cromwell 2016) is not limited to wooden ceilings. In the Palace of *La Alhambra* (Granada), the same pattern is used in plasterwork at the access to the court of *Los Arrayanes* (Fig. 8a). Although the hall of the Universidad de Alcalá is profusely decorated with plasterwork, this type of pattern does not appear there. At the time, the repertories used for plasterwork were mainly Renaissance drawings, such as those collected in the *Codex Escurialensis*. This seems to corroborate that the references of the design of the ceiling and those of the walls could be independent, although all of them were the result of an interpretation of Antiquity. There are also antecedents in Islamic works, such as the one in a mosaic from Nishapur, Iran, from the fourteenth century, which is currently preserved in the Metropolitan Museum in New York (Fukushima 2004) (Fig. 8b).

The Polyhedral Solution of the Pattern

The pyramid-shaped layout of the ceiling causes significant design difficulties. The polygons fit differently depending on the side of the room. On the short side, the pattern adjusts to the edges, fitting the stars completely, while on the long sides, the pattern is cut somewhat abruptly (Figs. 9 and 10). The diagonal edges concentrate the geometric problems of the hexagonal pattern. The designer did not seem to be interested in solving the encounters of the polyhedral surface. In the medieval Hispano-Muslim wooden ceilings tradition, it was inconceivable to leave the corners unsolved, and there were established solutions for each polyhedric ceiling

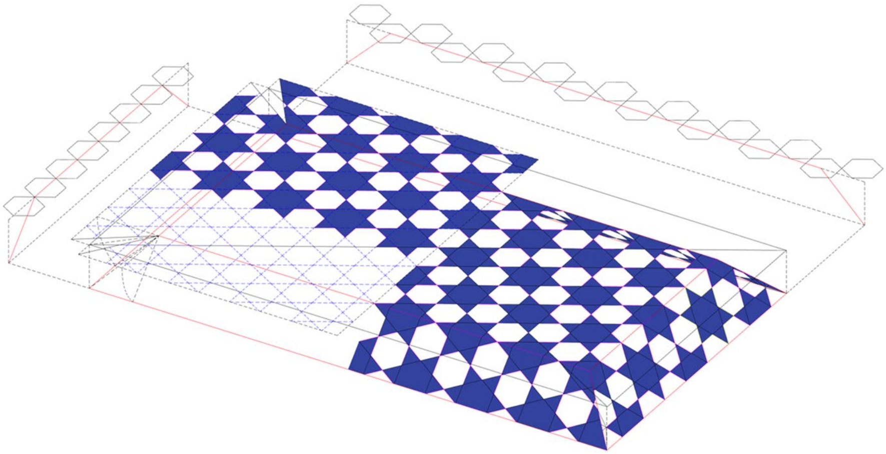


Fig. 10 Hexagonal pattern and its polyhedral adaptation to the rectangle of the *Paraninfo*. Theoretical model of the coffered ceiling. By the authors

using Islamic star-shaped lattices. Other Renaissance works also struggle with the combination of different polygons in the corners of the ceilings, trying to obtain a smooth transition between the panels.

Similar patterns to those of Alcalá can be observed in later polyhedral ceilings, such as those of the main halls of the palaces of Peñaranda de Duero (c. 1531) and Pastrana (c. 1550), both linked to the Mendoza family. Nevertheless, in these ceilings, the hexagons are placed in parallel, joined by their sides instead of their vertices, generating diamonds between them (González Uriel et al. 2019). This design allows even solutions in both the X and Y directions, facilitating the carpenter's work in folding the planes. Despite a masterful fit of the pattern made in the rectangle at Alcalá, the solution achieved at the diagonals is far from exemplary. This may be one of the reasons why there are no other Renaissance ceilings following this solution.

As explained above, the pattern of hexagons and triangles was known in carpentry, mosaics, and plasterworks before the *Paraninfo* was built. This pattern has always been associated with flat elements. There are no other polyhedral ceilings that use it, probably because of the difficult-to-solve encounters. In this regard, the illustration by Genaro Pérez Villaamil (Escosura and Pérez Villaamil 1842) is striking (Fig. 12) because he "corrects" the edges, representing a slightly different solution. He usually deformed his perspectives to make them more sublime and picturesque, even if they did not adjust to the actual monuments. It is interesting to observe how an expert artist and draftsman attempted to avoid representing geometric imperfections, "improving" the design, according to his criteria. To do this, he placed a five-pointed star at the vertex where the horizontal and lateral panels meet. Nevertheless, the perspective by Villaamil is a trompe l'oeil. It is not possible to connect the last hexagon of the lateral side with the corresponding hexagon of the front panel. To achieve this, Villaamil twisted the angles of the basic pattern, which results in a total mismatch of the overall design (Fig. 11b).

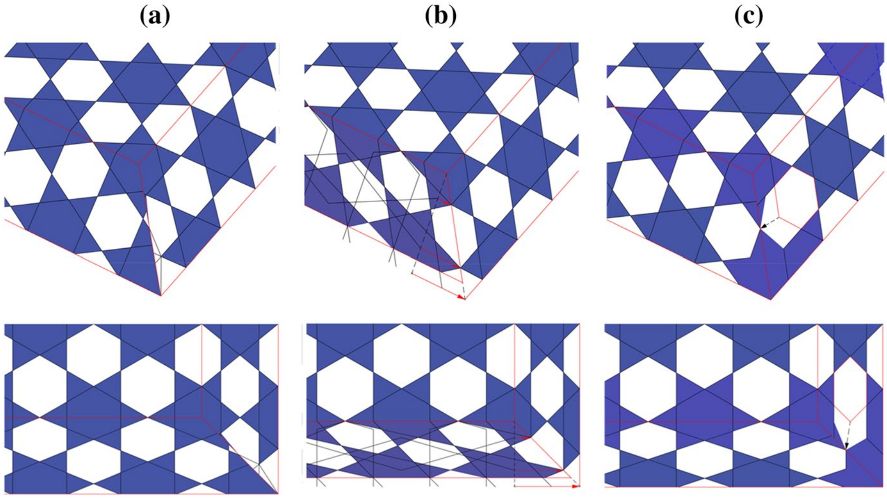


Fig. 11 Possible designs for the corner of the coffered ceiling, **a** Theoretical model of the built solution; **b** axonometric representing the interpretation by Genaro Perez Villaamil where the pattern is twisted at the lateral panel to match the corner; **c** authors' proposal lengthening the last hexagon of the front panel. By the authors

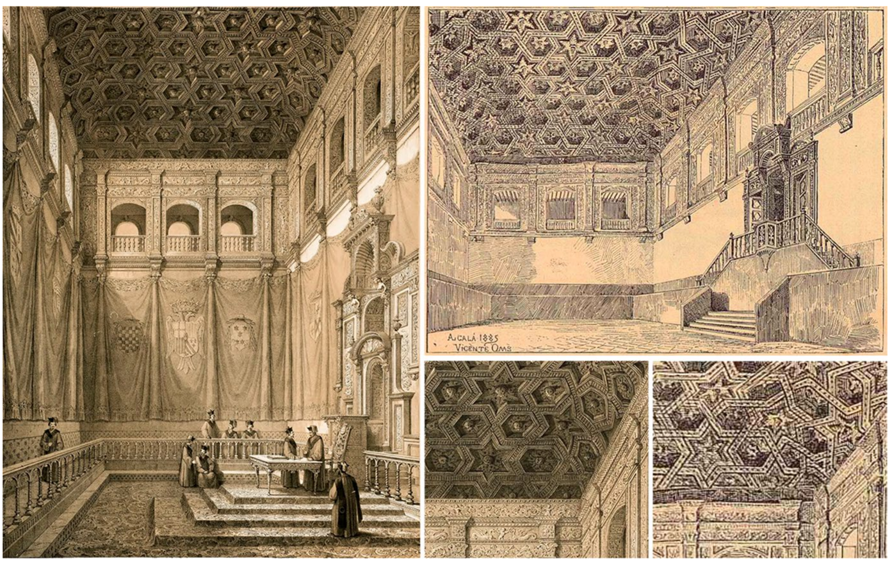


Fig. 12 Representations of the Auditorium of the University of Alcalá. Left, Villaamil (1842), right, Vicente Oms (1885)

In our view, a possible alternative to the corner cut would have been to extend a hexagon from the short side panel to the edge (Fig. 11c); however, this would have forced the extrados structure to be modified, eliminating the last rafter of the row (Fig. 14). The Alcalá carpenters decided to maintain the structural rhythm and reduce one of the hexagons to a quadrilateral, although they tried to simulate the shape of a pentagon slightly crossing the decoration strips. Another illustration, also from the nineteenth century, in this case made by Vicente Oms (Quadrado and Fuente 1885) shows the space as well. However, this representation is quite faithful to reality, both in the shapes of the ceiling and in the proportions of the room (Fig. 12).

Transition from Medieval to Renaissance Ceilings

Renaissance ceilings are distinguished by fitting coffers between the beams and using decorated strips to cover the joints. These wooden moldings incorporate the characteristic Renaissance carving decoration of Roman origin. In our case, those ornaments are small carved cylinders. However, in the *Paraninfo's* ceiling, the use of another decorative technique that produces the effect of interlaced bands is remarkable. This motif is called *lazo* and is characteristic of the stars of the Hispano-Muslim ceilings (Nuere Matauco 2008). This element generates a visual effect that emphasizes the continuity of the lines along the surface. The strips cross the room from end to end, following the three directions in the basic triangular pattern (Fig. 13). The presence of the *lazo* on this ceiling indicates that the carpenters had knowledge of the medieval tradition and, at the same time, were able to assimilate Renaissance designs into their structures.

As we said earlier, medieval wooden ceiling designs in the Iberian Peninsula had established suitable solutions for the intersections between panels, according to the different types of al-Andalus stars. A wide range of potential solutions was possible. For triangular patterns, 9- and 12-pointed stars were used, 8- and 16-pointed stars were suitable for square lattices, and 10-pointed stars were suitable for rhombuses. During the transition to Renaissance structures, artisans used traditional geometric bases, substituting al-Andalus stars for polygons of the same number of sides. At the *Paraninfo,* a new pattern emerges for the carpenters (Fernández-Cabo et al. 2020).

At the beginning of the sixteenth century, the choice of the hexagonal pattern in the *theatro* of Alcalá de Henares must have been a difficult decision for the carpenter. Faced with the impossibility of matching vertices or edges, the designer chose to continue the pattern down to the walls, connecting the side panels as well as possible (Fig. 14). With these decisions, the designer seems to convey that the pattern could have been an imposition of the patron and that it does not belong to the carpenter tradition.

Conclusion

Based on its hexagonal grid, the general proportions of the *Universidad Complutense theatro* hall are directly related to its coffered ceiling pattern. The design of the walls also responds to the same proportions, although the architectural grids of the walls

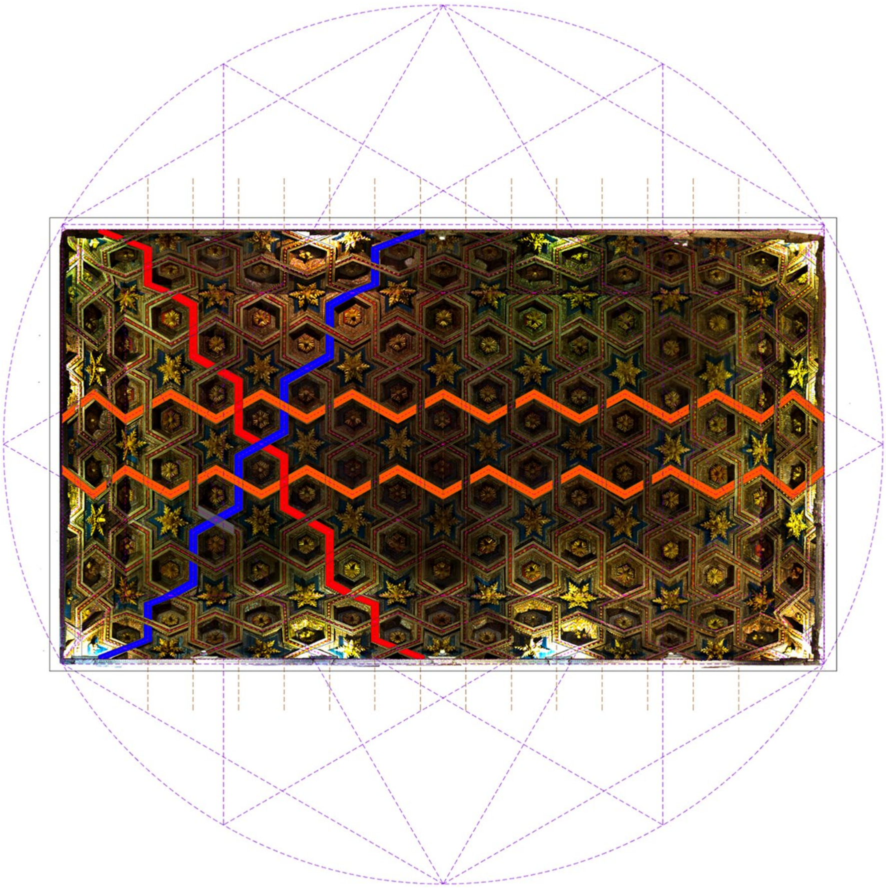


Fig. 13 Orthoimage from automated photogrammetry of the coffered ceiling of the *Paraninfo* of Alcalá de Henares. Drawing of the strips representing the *lazo* decoration. The three colors correspond to the three directions of the hexagonal pattern. Drawing and orthoimage by the authors

and ceilings do not correspond. It is likely that the pattern of hexagons and triangles was a proposal based on descriptions associated with the idea of Antiquity recovery. Designed with the symbolic authority of Roman Architecture, the new space was made for a new use. The intellectual elite of the university environment, specifically the Mendoza family, allow this design to be put into context with the beginning of the Renaissance in the Iberian Peninsula.

The wooden ceiling of the *Paraninfo* of the Universidad de Alcalá is spectacular for its geometry, polychromatism, and *lazo* decoration. It dominates the entire design of the hall, from the proportions of the volume to the theatrical atmosphere that it conveys. This structure is also an exceptional object within the Renaissance scene and within the Castilian carpentry tradition that would not be repeated among the Spanish ceilings, probably due to its difficulty in forming concave surfaces. This idea reinforces the hypothesis that this work represents the search for a unique model

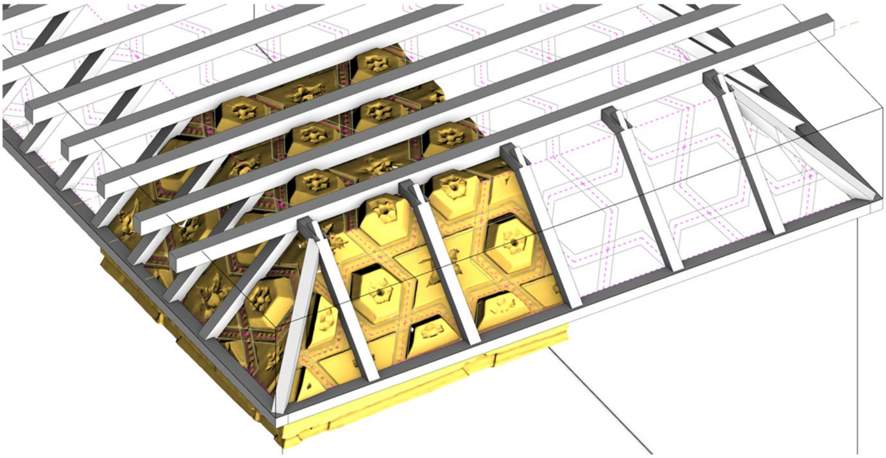


Fig. 14 Axonometric analysis of the coffered ceiling corner solution. Mesh from point cloud. It shows the relationships between the beams, the hexagonal coffers and the 6-pointed stars. Digital model by the authors

that was based on possible graphic and textual references from Antiquity, now lost, and was circulating at the time among art patrons, such as the cultural elites who introduced the Renaissance in Spain.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. Research funded by Comunidad de Madrid/Universidad de Alcalá, Project CM/JIN/2019-041, IP: Manuel De Miguel Sánchez.

References

Alvar Ezquerra, Antonio. 1999. El Colegio Trilingüe De La Universidad De Alcalá De Henares (Notas Para Su Estudio). In *Contemporaneidad De Los Clásicos En El Umbral Del Tercer Milenio: Actas Del Congreso Internacional Contemporaneidad De Los Clásicos* (La Habana, 1 a 5 De Diciembre De 1998), 515–523. Murcia: Servicio de Publicaciones, Universidad de Murcia.

Barbaro, Daniele. 1567. I Dieci Libri Dell'Architettura Di M. Vitruuio. Tradotti & Commentati Da Mons. Daniel Barbaro Eletto Patriarca D'Aquileia, Da Lui Riueduti & Ampliati; & Hora in Piu Commoda Forma Ridotti. Venice: Francesco de' Franceschi senese

Barreiros, Gaspar. 1561. *Chorographia De Alguns Lugares Que Stam Em Hum Caminho Que Fez Gaspar Barreiros*. Coimbra: Ioan Aluarez

Cámara Muñoz, Alicia and Gómez López, Consuelo. 1995. "Ceremonias Y Fiestas De La Universidad De Alcalá De Henares." In *La Universidad Complutense Y Las Artes /Congreso Nacional, Celebrado En La Facultad De Geografía E Historia, Los Días 30 De Noviembre, 1, 2 Y 3 De Diciembre De 1993,* 97–114. Madrid: Universidad Complutense, Servicios de Publicaciones

Castillo Oreja, Miguel Ángel. 1980. *Colegio Mayor De San Ildefonso De Alcalá De Henares: génesis y desarrollo de su construcción, siglos XV-XVIII*. Madrid: Algar.

Convenio de Alcalá-MOPU. 1990. *Primitiva Construcción Del Teatro O Paraninfo De La Alcalá De Henares*. Madrid

Cromwell, Peter R. 2016. Modularity and Hierarchy in Persian Geometric Ornament. *Nexus Network Journal* 18 (1): 7-54. https://doi.org/10.1007/s00004-015-0280-6.

Escosura, Patricio and Pérez Villaamil, Genaro. 1842. *España Artística Y Monumental: Vistas Y Descripción De Los Sitios Y Monumentos Más Notables De España*. Fac. Ed. Paris: Albert Hauser.

Fernández-Cabo, Miguel Carlos, González Uriel, Ana and De Miguel Sánchez, Manuel. 2020. Un Artesonado Poliédrico Manierista En Castroverde De Campos (Zamora, España). *Informes De La Construcción* 72 (557): 326. https://doi.org/10.3989/ic.64238

Fletcher, Rachel. 2007. Dynamic Root Rectangles Part One: The Fundamentals. *Nexus Network Journal* 9 (2): 327-362. https://doi.org/10.1007/s00004-007-0047-9.

Fukushima, Katherine. 2004. *Islamic Art and Geometric Design: Activities for Learning*. New York: The Metropolitan Museum of Art.

González Uriel, Ana, De Miguel Sánchez, Manuel, and Fernández-Cabo, Miguel Carlos. 2019. Los Artesonados Renacentistas Del Palacio Ducal De Pastrana (Guadalajara): Análisis Geométrico. *EGA: Revista De Expresión Gráfica Arquitectónica* 24 (36): 60-71. https://doi.org/10.4995/ega.2019.10530

Marías Franco, Fernando. 1995. *El Arquitecto De La Universidad De Alcalá De Henares*. Madrid: Universidad Complutense, Servicios de Publicaciones.

Mazzucato, Tiziana. 2009. Idea Del Espacio Escénico Y Lugares Para La Representación Teatral Entre Los Siglos XV Y XVI. Modelos De Teatro a La Manera De Italia. *Studia Aurea: Revista De Literatura Española Y Teoría Literaria Del Renacimiento Y Siglo De Oro* 3: 139-172. https://raco.cat/index.php/StudiaAurea/article/view/183734. Accessed 15 May 2022

Nader, Helen. 1986. *Los Mendoza Y El Renacimiento Español*. Guadalajara: Institución Provincial de Cultura "Marqués de Santillana".

Nuere Matauco, Enrique. 2008. *La Carpintería De Armar Española*, edited by Instituto Español de Arquitectura, Universidad de Alcalá. Madrid: Munilla-Lería

Quadrado, José María and de la Fuente, Vicente. 1885. *España: Sus Monumentos Y Artes, Su Naturaleza E Historia. Castilla La Nueva. I*. Barcelona: Establecimiento Tipográfico-Editorial de Daniel Cortezo y Cia

Redondo Buitrago, Antonia. 2022. Polyhedra and Honeycombs in a Coffered Ceiling in the Picasso Museum in Malaga. *Nexus Network Journal*: 1-20. https://doi.org/10.1007/s00004-022-00607-x

Rodríguez Rebollo, Ángel. 2002. El Palacio De Don Antonio De Mendoza En Guadalajara. Aspectos Decorativos Y Formales. *Archivo Español De Arte* 75 (299): 269–281. https://doi.org/10.3989/aearte.2002.v75.i299.331

Sagredo, Diego de. 1526. *Medidas Del Romano*. Toledo: Remón de Petras

Salgado Olmeda, Félix. 1995. Humanismo Y Coleccionismo Librario En El Siglo XV: Las Bibliotecas Renacentistas De Santillana, Infantado Y El Cardenal Mendoza. *Wad-Al-Hayara: Revista De Estudios De Guadalajara* (22): 123–135

Scaglia, Gustina. 2004. "El Codex Escurialensis" Llevado Por El Artista a La Calahorra En El Otoño De 1509. *Archivo Español De Arte* 77 (308): 375-383. https://archivoespanoldearte.revistas.csic.es/index.php/aea/article/view/219/216. Accessed 15 May 2022

Serlio, Sebastiano. 1552. *Tercero y Cuarto Libro de Architectura de SebastiaSerlio Boloñes*, Toledo: Casa de Iván de Ayala.

Toajas Roger, María Ángeles. 1995. "En Torno Al Llamado "Estilo Cisneros": La Techumbre Del Paraninfo De Alcalá De Henares." In *La Universidad Complutense Y Las Artes: Congreso Nacional, Celebrado En La Facultad De Geografía E Historia, Los Días 30 De Noviembre, 1, 2 Y 3 De Diciembre De 1993*. 1st ed., 75–96: Universidad Complutense de Madrid, Servicio de Publicaciones.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Manuel de Miguel Sánchez has a Ph.D.in Architecture, and is Professor and Secretary of the School of Architecture at the University of Alcala. He received his degree in architecture from the Polytechnic University of Madrid in 1996 and a Master of Architectural Restoration from the same university in 2001. His research is related to analytical studies of historical and contemporary architecture, architectural heritage, architectural geometry, construction and sustainability. He also works on the relationship between mathematics and architecture, teaching and innovation. As part of the research group "Intervention in Architectural heritage and Sustainable Architecture" (CCTE2.006/R34), Manuel has published the results of his work in numerous scientific journals and international conferences. He has taught at several Spanish universities and has been invited as visiting scholar at foreign research centers such as Berkeley (USA), the Urban Planning Institute of Paris (France) and the Politecnico di Torino (Italy).

Carlos González Duque holds a MSc in Architecture (Universidad de Alcalá) and a BA in Art History (Universidad Complutense), both with an honours thesis. In the last one, a review was made about the imbrication of the Renaissance in Late Middle Ages palatine Architecture. He is a PhD candidate in the Department of History, Representation and Restoration of Architecture at La Sapienza University in Rome. His research focuses on the relationship between Italian and Spanish restoration theory and practice. He is currently directing several architectural heritage restorations. He has received awards, both in public tenders as well as in architectural competitions. For instance, his work has been selected for the Venice Biennale, the Chamber of Architects and the Arquia Foundation, which allowed him to work for half a year in the studio of Álvaro Siza, winner of the Pritzker Prize.

Pilar Chías Navarro has a PhD in Architecture and is Full Professor and Director of the School of Architecture at the University of Alcalá. She is a member of the Spanish National Agency for Quality in Higher Education (CNEAI-ANECA); until 2018 she was responsible for architecture in the coordination team of the Area of Civil Engineering and Architecture in the National Agency for Evaluation and Prospective of the Spanish Ministry of Economy and Competitiveness (ANEP). She is a specialist in Cultural Heritage study, analysis and documentation, and is currently leading the research team "Intervention in Cultural Heritage and Sustainable Architecture" (University of Alcalá). She is a member of the Working Group on Spanish Spatial Data Infrastructures (IDEE), and the Working Group on INSPIRE for the Spanish Cultural Heritage (Instituto del Patrimonio Cultural de Espa a). In 2018 she was awarded the Golden Medal by the Unione Italiana per il Design in Milan (Italy).

Tomas Abad Balboa has a Master in Civil Engineering EQF 7 and is a researcher. He is a specialist in Cultural Heritage research and documentation, analysis and dissemination, focusing on the study of cartography as an essential tool for knowledge of territory and landscape. As an expert in the history of civil works and infrastructures, he is a speaker and member of the scientific committees of numerous international and national conferencies and journals. He has authored 23 books together with Prof. Chías (several of them award-winning) and more than 100 articles. As principal researchers, he and Prof. Chías have conducted more than 50 research projects funded by the Spanish National Research Plan and other sources. He is a member of the research team "Intervention in Cultural Heritage and Sustainable Architecture" (University of Alcalá).