

Article

Digital Graphic Documentation and Architectural Heritage: Deformations in a 16th-Century Ceiling of the Pinelo Palace in Seville (Spain)

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Abstract: Suitable graphic documentation is essential to ascertain and conserve architectural heritage. For the first time, accurate digital images are provided of a 16th-century wooden ceiling, composed of geometric interlacing patterns, in the Pinelo Palace in Seville. Today, this ceiling suffers from significant deformation. Although there are many publications on the digital documentation of architectural heritage, no graphic studies on this type of deformed ceilings have been presented. This study starts by providing data on the palace history concerning the design of geometric interlacing patterns in carpentry according to the 1633 book by López de Arenas, and on the ceiling consolidation in the 20th century. Images were then obtained using two complementary procedures: from a 3D laser scanner, which offers metric data on deformations; and from photogrammetry, which facilitates the visualisation of details. In this way, this type of heritage is documented in an innovative graphic approach, which is essential for its conservation and/or restoration with scientific foundations and also to disseminate a reliable digital image of the most beautiful ceiling of this Renaissance palace in southern Europe.

Keywords: ceiling; 16th century; Pinelo; palace; Seville; deformation; scanner; photogrammetry



Citation: Reinoso-Gordo, J.F.; Gámiz-Gordo, A.; Barrero-Ortega, P. Digital Graphic Documentation and Architectural Heritage: Deformations in a 16th-Century Ceiling of the Pinelo Palace in Seville (Spain). *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 85. <https://doi.org/10.3390/ijgi10020085>

Academic Editors: Sara Gonizzi Barsanti, Mario Santana Quintero and Wolfgang Kainz

Received: 9 January 2021

Accepted: 17 February 2021

Published: 19 February 2021

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1. Introduction

1.1. Short History of the Pinelo Palace in Seville (Spain)

The Renaissance palace of the Pinelo family is located in an urban framework of medieval origin, on a corner where Abades and Segovias streets intersect, near the Cathedral of Seville and the popular neighbourhood of Santa Cruz (Figure 1a). It was built in around 1500 by a family of prosperous merchants from Genoa who played a prominent role in the *Casa de la Contratación* in Seville and the commercial relationships between Spain and the Americas [1–3].

In 1523, the Pinelo family sold the palace to the Cabildo Catedralicio. Nothing is known about the subsequent transformations of the palace until it changed its usage in around 1885, when it became Guest House Don Marcos [4]. In 1954 it was declared a historical-artistic monument and in 1964 it was expropriated by the Seville City Council. Between 1967 and 1971, some consolidation work was carried out by the municipal architect Jesús Gómez-Millán, and between 1969 and 1981 major restoration was directed by the architect Rafael Manzano Martos [5]. Since then, the building has been the headquarters of the *Real Academia de Buenas Letras* and the *Real Academia de Bellas Artes de Santa Isabel de Hungría* in Seville. Inside, the building is organised into three large courtyards in accordance with the typical layout in Spanish medieval architecture [6] (Figure 1b): an entrance courtyard, where the stables were located; a main courtyard, with a large staircase located in one corner, from which the mezzanine can be accessed where the ceiling studied in the present research is located; and a third courtyard/garden.

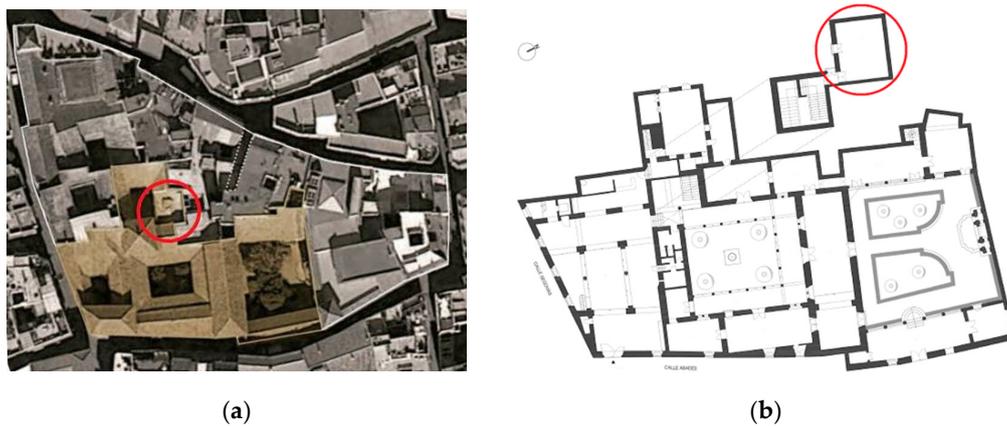


Figure 1. (a) Modern aerial photograph of the Pinelo Palace and its surroundings (overview through Google Earth). (b) Ground floor and mezzanine (indicated by the red circle). Authors' own drawing, 2020.

The lookout tower built in the corner between the two exterior façades of the building would be the first such tower built in Seville under the influence of the villas of the Italian Renaissance. Under the lookout tower is the entrance (Figure 2a). The main courtyard constitutes a prime example of Sevillian Renaissance architecture and contains three galleries on the ground floor and four on the first floor. The arches on the ground floor include original decoration with plasterwork and are supported by columns of imported Genoese marble (Figure 2b). These arches form part of an interesting evolutionary sequence of the courtyards in the main palaces of Seville, and combine influences from Mudejar and Gothic art [7], ranging from the *Palacio del Rey Don Pedro* in the *Real Alcázar*, through the *Casa de Pilatos*, and the *Palacio de las Dueñas* [3]. The first-floor gallery of the courtyard was recovered and decorated in the second half of the 20th century, after being partitioned to create rooms when the building was Guest House Don Marcos [4].

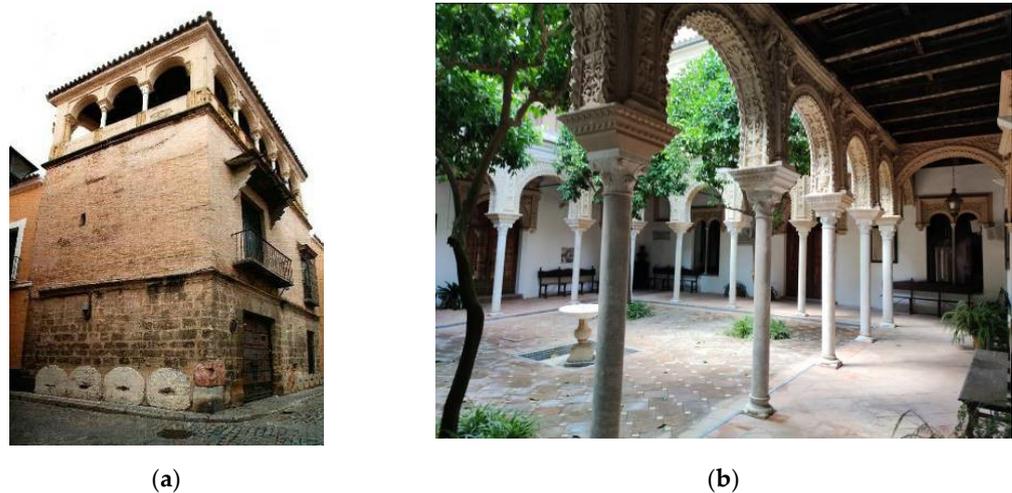


Figure 2. (a) Lookout tower on the façade. (b) Main courtyard view. Authors' own photographs, 2020.

In the ground-floor rooms, the ceilings with painted Renaissance decoration are preserved, as are the ceilings of the courtyard galleries. On the first floor, however, a large part of the 16th-century ceilings has disappeared [8]. The garden in the third courtyard has another gallery with two floors without decorative plasterwork.

From the landing of the main staircase there is access to a mezzanine room that is currently used as the plenary hall for the *Real Academia de Bellas Artes* of Seville, where the ceiling with a geometric decoration that is studied in this research is located (Figure 3).



Figure 3. Mezzanine ceiling. Authors' own photograph, 2020.

The first known historical document that refers to this room is a text written in 1542, which is located in the Archive of the Seville Cathedral (sección IV, Fábrica, Libro nº 377, fol. CCXCV-CCCII vto) and provides essential information regarding the state of the palace in the 16th century [9,10]. This document describes the room, and confirms that the remarkable ceiling already existed: “*E tiene un saquiçami de nueve y doze con sus deçendidas . . .*”. A “*saquiçami*” is a ceiling that hides its structural elements under the geometric decoration. The term “*deçendidas*” refers to the sloping sides. There is a mistake in the description however, since it speaks of a ceiling with interlocking patterns of nine-point and 12-point stars, although there are only interlocking patterns of eight-point and 12-point stars, as explained later.

1.2. General Objectives

The present research is the first to be carried out on the most important ceiling of this outstanding Renaissance palace. Its current situation seems fragile due to the existence of major deformations that can be observed with the naked eye and that form the object of this study.

In order to conserve the architectural heritage, it is essential to possess up-to-date and accurate graphic documentation. A well-documented monument has a better chance of surviving over time and through unpredictable adversity. Even in the case of its destruction, its intangible values would be safeguarded if there were graphic documents that allowed its reconstruction and virtual recreation or diffusion.

For this reason, the main objective of this research is to provide a new and precise graphic documentation on a fragile architectural element, to be better known, suitably conserved, or restored on a scientific basis, and for its digital dissemination. For the first time, this ceiling is represented by two complementary digital graphic technologies: a 3D laser scanner that quantifies the existing deformations, and photogrammetry, which accurately visualises its details.

The bibliography regarding Pinelo Palace and its history has been reviewed, as mentioned in the introduction, as well as the design of this type of wooden ceiling in the 16th century, especially regarding the treatise by Diego López de Arenas of 1633. In addition,

the documentation of several major architectural interventions of the 20th century that affected the ceiling has been uncovered in the Municipal Archives of Seville.

The importance of graphic representation in architectural documentation is shown in the numerous manuscripts published in the proceedings of the latest “Graphical Heritage” International Congress held in 2020 [11]. Heritage documentation techniques must avoid damaging it during data collection tasks and this objective is achieved using digital techniques such as photogrammetry and laser scanning [12]. The importance of these techniques, included in the field of geomatics, in the sustainable conservation of heritage has been proved [13]; and they are also especially useful in the reconstruction of architectural heritage when it is damaged by natural disasters such as earthquakes [14].

Documenting heritage by means of laser scanners can be considered as one of the best techniques to reliably represent architectural assets [15–17], and the cloud of points derived from these scanners provides a useful tool for the evaluation of the measured objects [18]. Photogrammetry is a technique complementary to scanning when used in heritage documentation [19,20], and it is able to give images with accurate details thanks to the textural resolution. Scanning has been particularly useful in the detection of deformations, for example, in the muqarnas of the Alhambra [21,22] and as a basis for generating BIM (Building Information Modelling) models [23], as well as in architectural parametric modelling [24] and engineering [25]. This suggests that combining laser scanning and photogrammetry can provide accurate documentation of this 16th-century ceiling and its deformations, thereby developing a graphic methodology with no precedents in the literature on this type of architectural element.

The application of photogrammetry to wooden ceilings has been used in [26], although possible deformations were not a reason for study. In order to understand and interpret the data obtained through geomatics, it is necessary to review the studies of Renaissance wooden ceilings: the layout and modulation of ceilings similar to the one we analyse in this manuscript [27,28], the historical evolution concerning the way of building the wooden ceilings [29] and a relevant example [30].

2. Materials and Methods

2.1. The Design of the Ceiling According to the Book by López de Arenas (1633)

There are numerous studies on ceilings with wooden interlocking patterns in Spain and the Americas that present interesting examples [31,32]. One of the most extensive and well-known documents on the geometric layout of interlocking patterns is that of Prieto Vives [33], which brought together an uneven set of previously written articles, although it focused on mathematical speculations that failed to agree on the craft origins of these designs and therefore failed to formulate a coherent theory.

Another outstanding study on interlocking patterns appeared in a short article by Fernández-Puertas [34] concerning the eight-point stars and was developed in another article by Donaire-Rodríguez [35]. Both stated that these designs were undertaken taking as a reference a unit of measurement that relates all the magnitudes, without the need to employ a compass, with simple geometric lines that give rise to various designs obtained solely using bevels.

These ideas are now well-known and accepted thanks to the studies of Nuere-Matauco [36–38], and based on the book by Diego López de Arenas that included different rules on interlocking patterns that the carpenters used in Hispano-Muslim and Mudejar art. After a first manuscript in around 1619, it was published in 1633 with the title *Breve compendio de la carpintería de lo blanco y Tratado de Alarifes* [39] (Figure 4a). Interlocking patterns were also dealt with in another contemporary document by Fray Andrés de San Miguel that remained unpublished until the 20th century [40]: folios 72 to 92 include a section on carpentry based on documents that are now missing but have nothing to do with the book by López de Arenas.

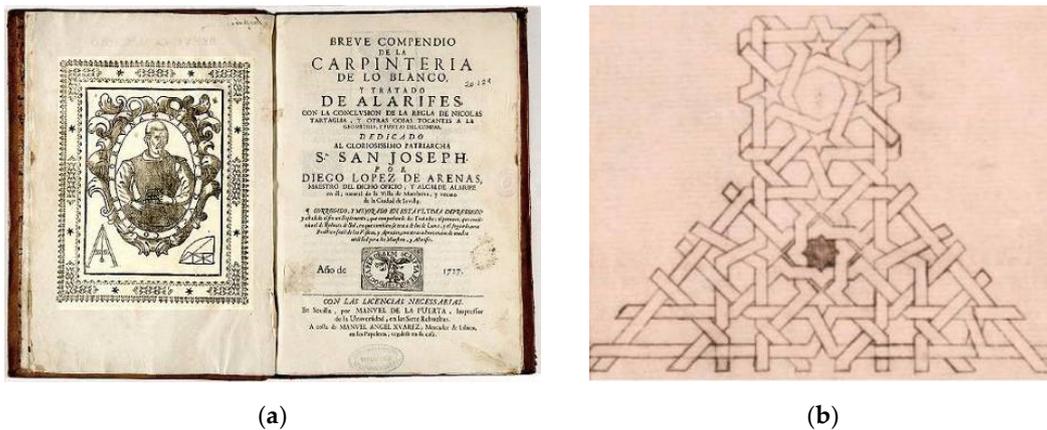


Figure 4. (a) Cover of the book by Diego López de Arenas (1633; reissue 1727). (b) Plate 15r.

According to López de Arenas, the design was made using only bevels, first drawing a pattern of lines as the basis for the type of interlocking pattern chosen. The thickness of the linear elements was then determined and repeated at intervals. After drawing these elementary modules, the set is obtained by its juxtaposition, with common units of measurement and proportion.

The ceiling studied in the current research has no structural function in the building as a whole. It has two well-differentiated parts: the load-bearing elements, and the geometric decorative elements. The load-bearing elements, “girders” and “braces”, are hidden in its upper part, and perpendicular to these are the smaller load-bearing elements, called “belts” or “battens”. These smaller elements support the flat wooden surface upon which the geometric ornamentation modules are arranged.

This ceiling belongs to a type of mixed interlocking pattern of eight-point and 12-point stars. In other words, the 12-point star is a variation of the modules generated by the eight-point star, as encountered in other examples in the Iberian Peninsula, such as the ceiling of the central nave of the Church of Santa Catalina in Seville. The drawing of the aforementioned modules called “cuartillejos”, appears in the book by Diego López de Arenas (Figure 4b) and also in that of Fray Andrés de San Miguel.

The “cuartillejos” are square modules in which the eight-point stars can be traced by various methods using bevels with different angles, called “cuadrado”, “ocho” and “ataperfiles”. The first two are created by dividing 180° by the number that defines them ($180^\circ/4$ and $180^\circ/8$). The third is computed from the formula $45^\circ - 90/n$, where n is the number of points of the star in the interlocking pattern, in this case $n = 8$ (Figure 5). The complete geometric construction of the eight-point and 12-point stars (Figure 6) is well-known and explained in the aforementioned publications. Finally, the size and number of ceiling modules are fitted to the dimensions of the room to be covered.

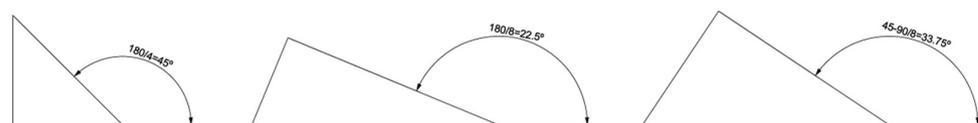


Figure 5. Bevels to trace the eight-point star, according to López de Arenas (1633). Authors’ own drawing, 2020.

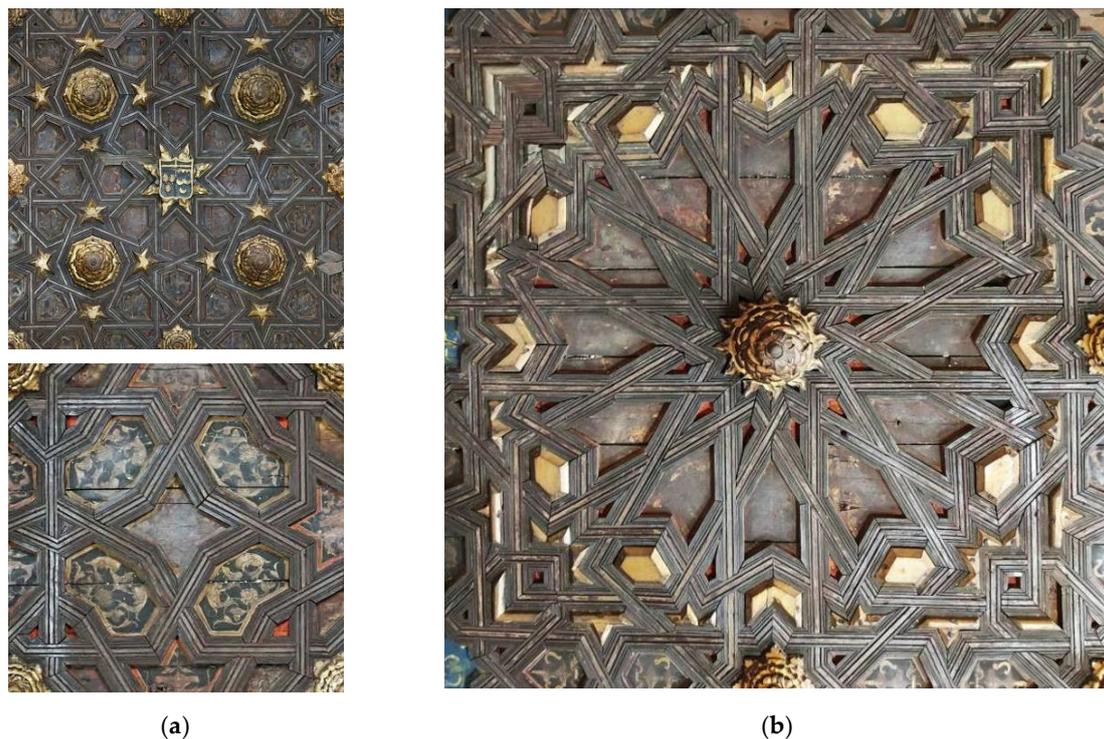


Figure 6. Ceiling details: (a) Eight-point star and “cuartillejos”. (b) “Cuartillejo” with a 12-point star. Authors’ own photographs, 2020.

The ceiling also includes heraldic coats of arms and other decorative elements, “florones” or “piñas”, which refer to the names of the Pinelo and De la Torre families who commissioned the construction of the building (Figure 7).



Figure 7. Details of the heraldic coat of arms (Pinelo and De la Torre families). Authors’ own photographs, 2020.

2.2. The Ceiling Consolidation in the 20th Century

As the municipal architect, Jesús Gómez-Millán directed the consolidation work funded by the Seville City Council in the Pinelo palace between 1967 and 1971. Until 1981, other major restorations were carried out in the same building, directed by the architect Rafael Manzano Martos and promoted by the *Dirección General de Bellas Artes*.

Documentation concerning the nine phases of the work directed by Gómez-Millán is preserved in the Municipal Archive of Seville, two of which, performed on the mezzanine, are the files titled “Comisión Administradora del Impuesto para la Prevención del Paro Obrero, nº 19/1967. D/1368; 32/1968. D/1371”.

The first-phase report (August 1967–November 1967) describes the interventions projected on the mezzanine ceilings. Disassembly of the two roof skirts on the wooden ceiling was planned, together with the removal of the old wooden beams that made up its slopes and their replacement with new metal girders, to later complete the gabled tile roof.

However, the third-phase report (May 1968–September 1968) changed the projected proposal and the gabled roofs were replaced by a flat roof. According to this document, it was planned to reinforce the heads of the old ceiling beams. In addition, two new metal girders supported by the perimeter walls were introduced, arranged as two perpendicular axes of the room, that is, parallel to the two lateral walls. The shorter transverse girder was placed at a lower elevation and the longer longitudinal girder placed above it.

These new girders served as anchors for metal tensioners, fixed to the old wooden beams that support the weight of the older ceiling. From these beams, also supported on the side walls, other wires were hung to tighten the wooden boards (Figure 8).



Figure 8. Hidden structural elements. (a) Anchorages of the 16th-century wooden beams on the wall/new metal girders and roof tie rods. Photographs by Ramón Queiro Quijada, 2016. (b) Schematic sections (hand drawn): hypothesis inclined roof of disappeared wood (left)/current state with new concrete slab and metal beams (right).

A report on the Technical Inspection of the Building (ITE), drawn up in June 2016 by the architect Ramón Queiro Quijada for the Urban Planning Management of the Seville City Council, warned about the possible imminent danger of collapse of the ceiling. It detected a deflection of approximately 0.15 m, which far exceeds that which is allowed for this type of material, and also uncovered cracks and small fissures in the wood. It was stated that this could be due to the deterioration of the upper anchors to the ceiling and together was seen as an indication that a collapse could occur with fatal consequences.

The artworks housed in the room were transferred to other units of the building itself and the state of conservation of the fastening elements was evaluated, with a precautionary shoring of the ceiling being planned. After reviewing the metal girders placed by the architect Gómez-Millán and the cables from which the old wooden beams hang, it was estimated that the risk of detachment seemed limited.

Taking all these considerations into account, and in order to ensure suitable conservation and monitoring in the future, it was decided to utilise digital graphic technologies to quantify the current deformations: a first for this type of ceiling.

2.3. Graphic Survey: Material and Method

Two graphic surveys of the ceiling have been carried out, based on 3D laser scanners and photogrammetry, respectively, which have both proven to be effective [21,24,25].

The first method aimed to quantify the deformations, with an approach similar to that in previous work [22,23]. Vertical deformations are better observed if the walls, window, and floor of the room are also included in the survey. The scans carried out allow us to ascertain the whole room with homogeneous precision.

On the other hand, the photogrammetric method has been used to achieve a textured three-dimensional model with a higher image resolution, in such a way that orthophotos can be derived and material details can be visualised.

The material used to obtain these surveys included the following:

Leica C10 and BLK360 laser scanners were used. The C10 has a dual-axis compensator with 1" accuracy and with 6 mm accuracy in position determination. The software

used for the registration and for the processing of the point cloud were Cyclone 360 and 3DReshaper, respectively.

The photogrammetry was carried out with a Sony Alpha 7 ILCE-7K Full frame (35 mm) 24.3 Mpix camera and a 28-70 mm F3.5-5.6 lens. In order to obtain photographs with a greater approximation and resolution, the camera was mounted on a pole of approximately 2.5 m in height. In addition, supplementary lighting was necessary due to the lack of natural light in the room and the dark colour of the ceiling itself. To this end, a focus of 0.60×0.60 m was mounted on an auxiliary pole. The data processing was carried out using the photogrammetric software Agisoft Metashape version 1.5.2.

2.3.1. Scanner Laser

Most of the scans were carried out with the BLK360 scanner due to its faster speed and its ability to capture images in High Definition Range (HDR), although it does not capture levelled scans. To obtain the whole set in the same reference and levelled system, the scanning process started from the E-1 and E-2 stations of the C10 scanner, which can be levelled and oriented to a predetermined direction (in our case, the courtyard gallery where E-1 was located).

The C10 capture parameters both in E-1 and E-2 included the following: capture of points at medium spatial resolution at which each point is separated from its neighbours by 1 cm assuming a plane located 10 m away; the image resolution captured by the scanner was 1920×1920 pixels. The remaining scans were carried out with the following BLK360 parameters: medium spatial resolution (1 cm at 10 m) while the images were taken in HDR at those scan stations where the lighting conditions were scarce or where there was a lot of light contrast.

The registration between the C10 and BLK360 scans was made through the C10 located in E-1 and the BLK360 located in BLK-1. Figure 9 shows the path followed by the BLK scanner until reaching the mezzanine where the ceiling under the study is located (Figure 9). Figure 10 shows a detail of the scan distribution inside the mezzanine room (Figure 10).

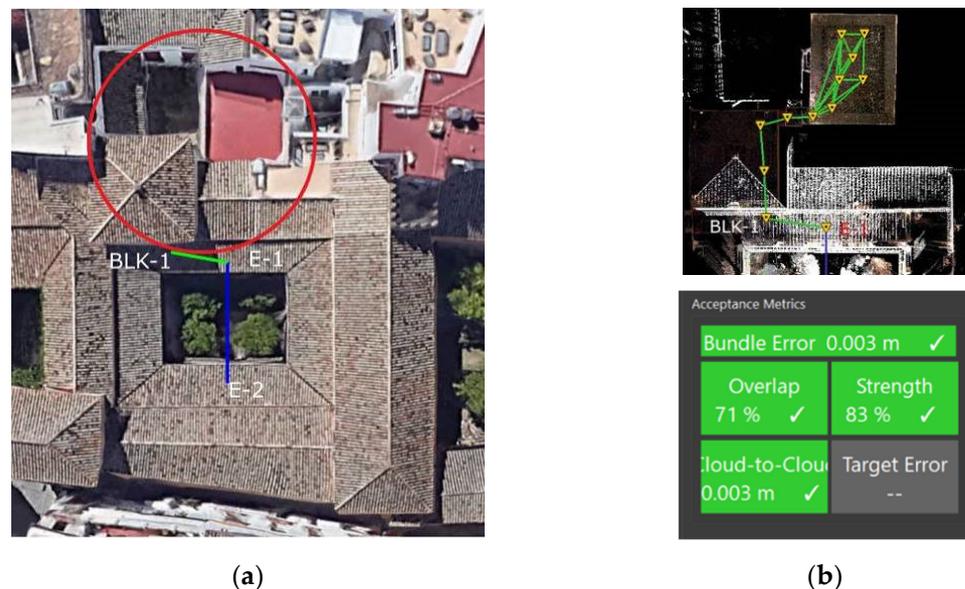


Figure 9. Scan path and distribution. (a) General view. (b) Fit and error values of the scans.

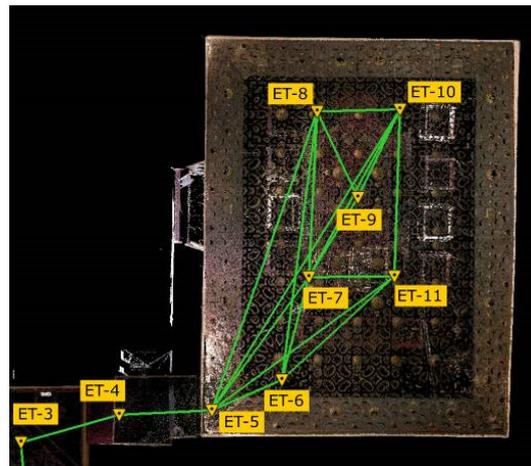


Figure 10. Detail of the scanner station positions within the mezzanine room.

The global point cloud composed of scan stations E-1, BLK-1, and ET-1 to ET-11 is made up of 124,093,128 points, while the cloud corresponding only to the room contains 60,168,936 points and is made up of the ET-6 to ET-11 scan stations.

The registration of the scans was carried out visually using Cyclone 360 software in order to maintain greater control over the results (Figure 9b). For each contiguous pair of scans, their plan projections were visually aligned (Figure 11a), and then displayed in elevation and, if necessary, levelled (Figure 11b; in this image the slope of the lower scan has been intentionally exaggerated). After levelling (Figure 11c), the lower scan was moved vertically until the two scans were roughly aligned (Figure 11d), to finally activate the optimisation algorithm which completed the alignment with more accuracy and reported the fitting error, which in our case was 1.6 mm (Figure 11e). The two scan registered with its true colour are shown in Figure 11f where the yellow triangles represent their scan positions.

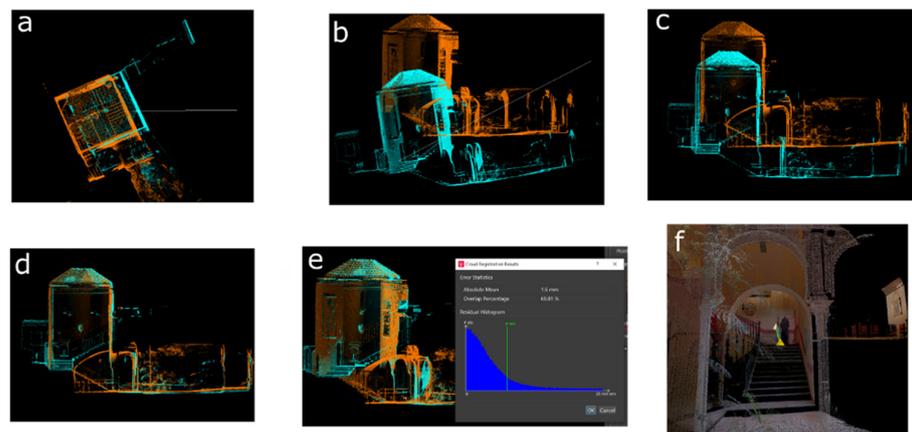


Figure 11. Manual recording of two scans with indication of the fitting error.

In the optimisation phase, the software strives to make the best registration using points from overlapping scans and if it succeeds, then it marks the links that took part in the registration with straight lines. The colour of the links indicates the registration suitability, whereby green is the indicator of a good registration. In this case, the error made in the whole set (Bundle) was 3 mm (Figure 9b). Other quality parameters regarding the registration refer to the existing overlap between scan stations (% of object surfaces covered by two scans), registration strength (the better the three directions of space (x, y, z) are covered, the greater the registration strength) and cloud-to-cloud error.

To better understand the spatial environment, a perspective view of the point cloud was obtained, from the gallery to the mezzanine floor passing through the main staircase (Figure 12).

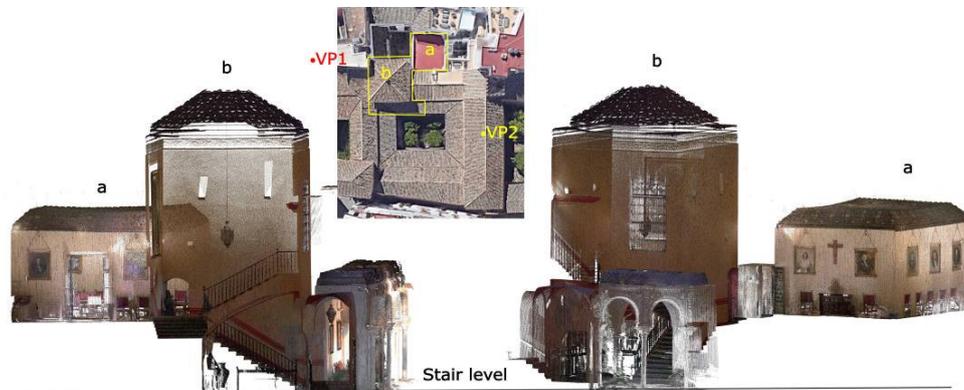


Figure 12. 3D orthographic views extracted from the point cloud to better understand the different levels for the mezzanine (a) and the tower above the staircase (b). Central image shows the polygonal sections (yellow) and the viewpoints VP1 and VP2; the left image was observed from VP1 and the right image was observed from VP2.

2.3.2. Photogrammetry

Ceiling photographs were taken by bringing the camera closer with a pole, with additional lighting provided on another pole (Figure 13a). In this way, 89 photographs were obtained (Figure 13b).

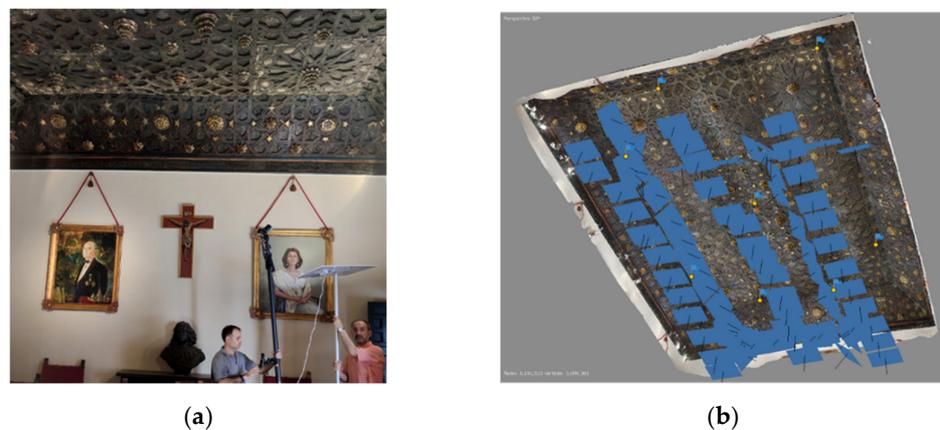


Figure 13. Photogrammetry on the mezzanine: (a) Data capture. (b) 3D photogrammetric model.

The focal length of the camera was set to 28 mm and the resolution to 24.3 Mp for each image. The photograph alignment was computed using Metashape software with the *Accuracy* parameter set to medium. The dense point cloud was obtained with *medium quality* that computed 30,957,566 points, and the model mesh was processed setting the *Faces count* parameter to high, thereby obtaining a total of 6,191,513 faces. Finally, the texture was computed by setting the following parameters: *Mapping mode* (Generic), *blending mode* (Mosaic) and *Texture size/count* (8000 × 1). The alignment adjustment was carried out by means of control points whose coordinates were obtained from the scans recorded in the previous phase; those coordinates were extracted using the 360° visual capabilities of Jetstream software for each scan station. The total (bundle) mean error was 6.5 mm (Figure 14). This figure also offers an orthogonal image of the ceiling with the location of the control points that were employed in the adjustment.

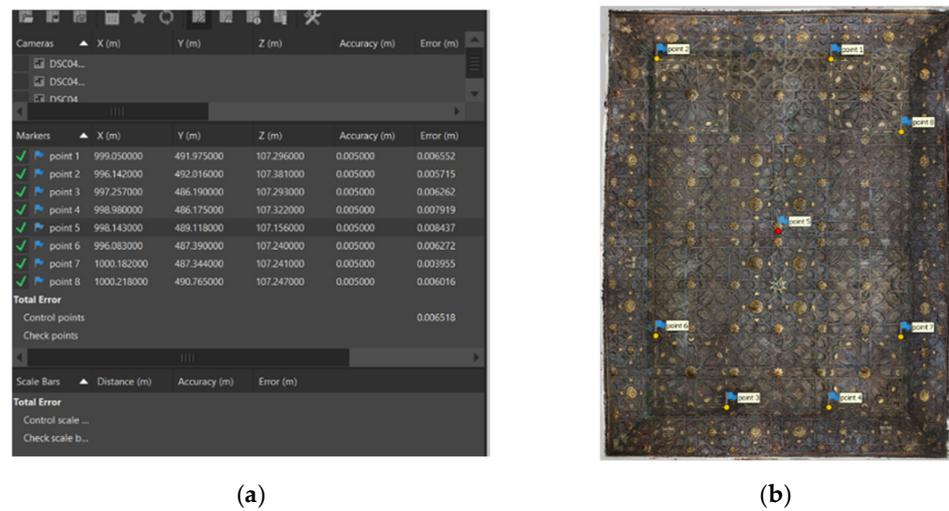


Figure 14. Photogrammetric adjustment: (a) Coordinates and error adjustment. (b) Control-point location.

By using the parametric values indicated above, an orthophotograph of high spatial and spectral resolution with a pixel size of 0.5 mm was reached.

3. Results and Discussion

The results are derived from the point cloud obtained with the scan and from the photogrammetric 3D model. The scan provides a 3D structure that integrates the walls and the ceiling, thereby enabling their deformations to be measured. Photogrammetry allows material details to be visualised thanks to the high-resolution texturing of the 3D surface model.

The first analysis detected significant geometric deformations that may have already existed in the original construction, as often occurs in historic buildings. The image obtained from the point cloud shows a plan that theoretically should be rectangular, but actually has different lengths on its parallel sides: the longest sides differ by 0.065 m. and the smaller ones differ 0.091 m (Figure 15).

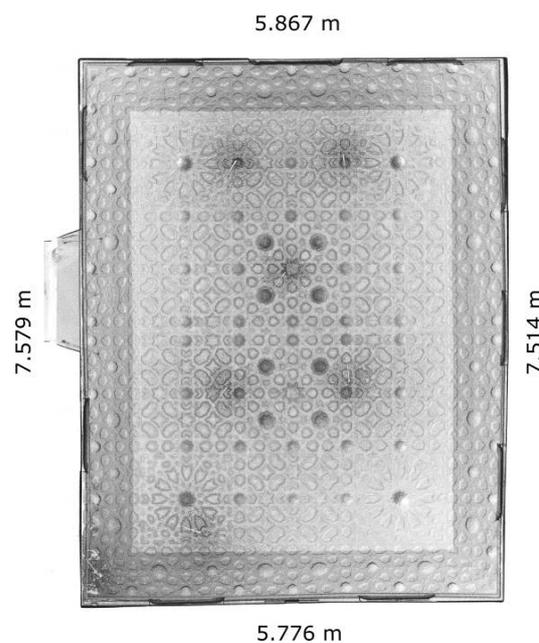


Figure 15. Ceiling dimensions from point cloud (orthogonal projection).

The differences in measurements on the room floor are not visible to the naked eye from inside the room. However, the ceiling deformations are indeed perceptible. In order to provide a clearer first view of the deformations, two perpendicular interior section-elevations were obtained, cutting through the centre of the room (Figure 16).

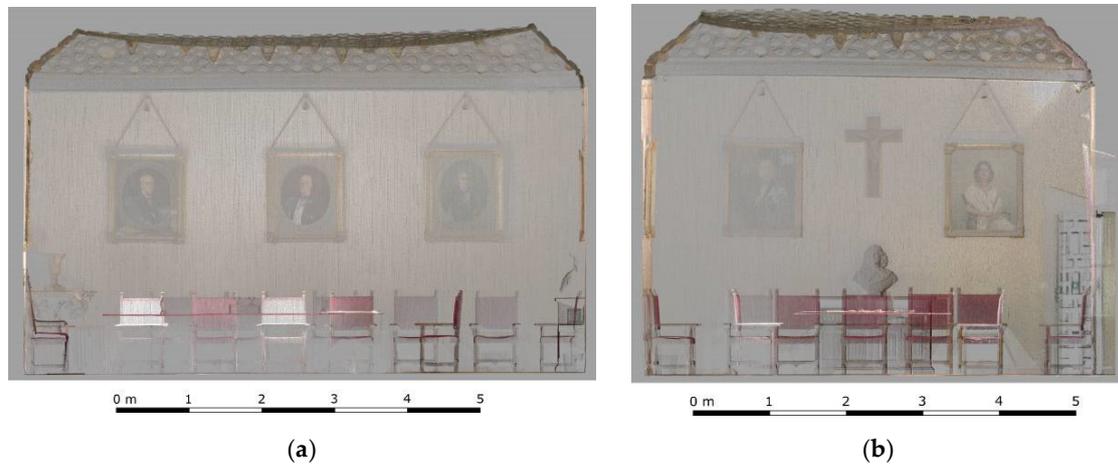


Figure 16. Sections through the mezzanine centre: (a) Longitudinal. (b) Transversal.

To quantify the magnitudes of the main deformations, three longitudinal sections (parallel to the longest sides of the room) were made and different heights were sampled therein, whereby the most significant data was chosen (Figure 17).

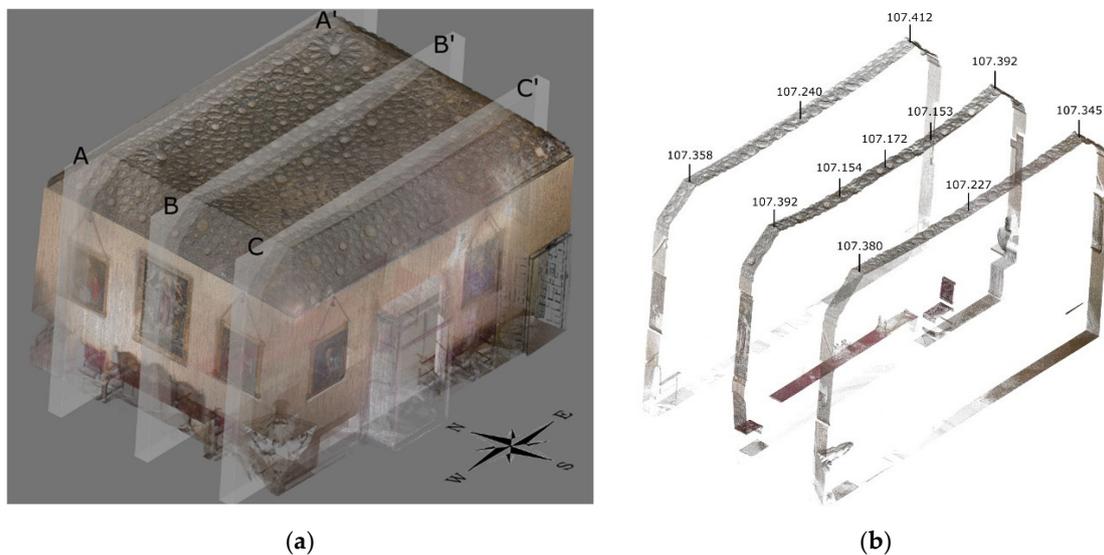


Figure 17. Mezzanine sections: (a) Sections AA', BB', CC'. (b) Heights in sections AA', BB', CC'.

The measurement data is unexpected, since it would be logical to find the greatest deformation in the ceiling centre. However, when observing section BB' or its orthogonal view (Figure 18), it is verified that the greatest height differences are found 1.05 m from the centre of the room with height differences of 0.238 m from B and 0.239 m from B'. The difference in height from both B and B' to the centre is 0.220 m. Therefore, between the lowest point of the ceiling and the centre there is a height difference of 0.018 m. These results are coherent with the existence of anchors placed in the 1968 consolidation work directed by Gómez-Millán to alleviate the stresses derived from its own weight.

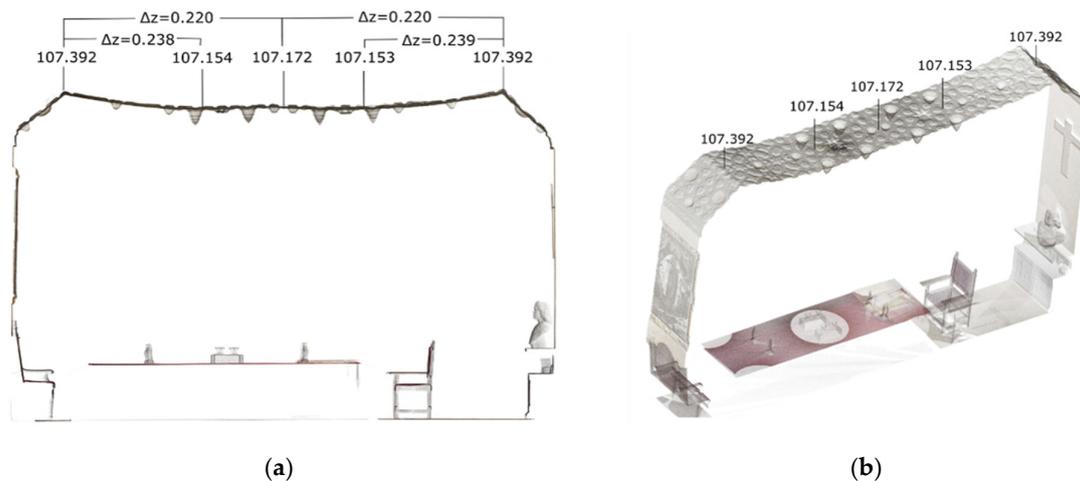


Figure 18. Longitudinal cross-section through the room centre including measurement of deformations: (a) Section BB'. (b) Section-perspective view.

The lack of uniformity in the deformations is also observed in the north-south transverse direction. While in section A'B'C' there is a descending slope from north to south, in section ABC there is an ascending slope from A to B and descending from B to C with different values of increments: 0.034 m and 0.012 m respectively. This is also explained by the placement of various anchors during the consolidation work in the late 20th century.

On the other hand, the roof surface (Figure 19) has also been reconstructed through photogrammetry, and a textured 3D model was obtained that may be of great interest for future conservation or restoration work, and for the heritage communication.

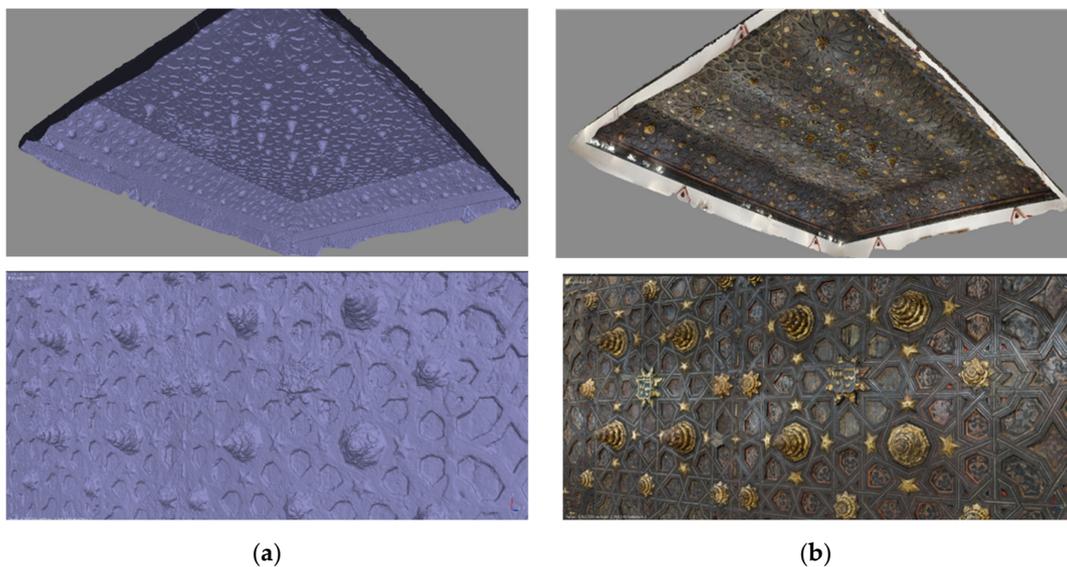


Figure 19. General view and details of the mezzanine ceiling from photogrammetry: (a) 3D surface model. (b) 3D textured model.

The 3D photogrammetric model has made it possible to obtain orthophotographs from the central horizontal part of the ceiling and from its tilted planes so that their details can be visualised with a high resolution (Figure 20). The tilted planes are laid flat in their true magnitude along with the central part. Geometric irregularities or deformations of the horizontal and tilted planes are clearly visible on the edges.



Figure 20. Ceiling orthoimage with the tilted side planes laid flat.

4. Conclusions

In order to ascertain, conserve, and disseminate architectural heritage, it is essential to attain suitable digital images. A graphically well-documented landmark will always have a better chance of surviving the passage of time, an unpredictable catastrophe, or unfortunate human interventions. In the worst scenario, when the architectural heritage is destroyed by some misfortune, its memory can be preserved if there are images that facilitate its material reconstruction or virtual recreation.

For the documentation and analysis of this 16th-century ceiling in the Pinelo Palace in Seville, this research has considered its historical background and has followed a methodology based on two complementary digital data captures: using a 3D laser scanner, and photogrammetry.

It has been found that in a room that should theoretically be rectangular, there are differences of 0.065 m when comparing the longest sides and 0.091 m on the shortest sides. These irregularities suggest that the Renaissance palace was able to reuse the

walls of a previous medieval building, in accordance with historical studies referred in the introduction.

After having analysed several geometric modules of the ceiling, it was found that it is made up of interlocking patterns of eight-point and 12-point stars, and not, as a text from 1542 erroneously describes it, of nine- and 12-point stars. In the final orthoimage (Figure 20), it can easily be observed that the ceiling is composed of “cuartillejos” or modules with a square base, but its modulation is altered in the central part, where a small strip is duplicated, to fit the design to the room dimensions. From this it follows that there was no unitary project for the whole building: the ceiling design had to be fitted to a room whose walls were probably deformed.

According to the historical documentation consulted, the ceiling was consolidated under the direction of the architect Jesús Gómez-Millán in around 1967–1970. The tile roof was replaced with a flat concrete floor and the ceiling was hung from two new metal beams. The deformations came into existence when this consolidation was completed approximately 50 years ago, but until now it had not been accurately quantified.

In the sections, the maximum ceiling deformation does not occur in the centre: the lowest point is at 1.05 m on both sides from the centre. This is explained by the placement of anchors that released stress due to their weight, although the maximum deformations are large: 0.238 and 0.239 m. A lack of uniformity has also been detected in the deformations: in the cross-sections towards the eastern end the deformations are descending, and towards the western end they are staggered. Therefore, under the direction of Gómez-Millán, wire rods were placed that successfully improved safety and stability, but also caused the current irregular deformations.

The high-resolution orthoimage provided allows the details of the ceiling to be viewed with precision. Without a thorough knowledge of what is to be preserved or restored, it remains impossible to propose suitable measures for its protection. The rigorous digital graphic documentation is expected to serve as a starting point for a future scientific plan for the conservation of this unique deformed ceiling and to disseminate on the web the image of a beautiful architectural element of the rich heritage of southern Europe.

Author Contributions: Juan Francisco Reinoso-Gordo, Antonio Gámiz-Gordo and PPedro Barrero-Ortega all took part in the entire research process. All authors have read and agreed to the published version of the manuscript.

Funding: This research has been funded by internationalisation grants to the Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC) of the VII Plan Propio de Investigación y Transferencia in the University of Seville.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: The present research has been made possible thanks to the collaboration of members and staff of the *Real Academia de Bellas Artes de Santa Isabel de Hungría de Sevilla* and *Real Academia Sevillana de Buenas Letras; Carpintería Los Tres Juanes; Ramón Queiro Quijada; Rafael Manzano Martos*. The authors are also grateful for the support from the research group *Expregrafica, Lugar Arquitectura y Dibujo (PAIDI-HUM-976)*, Programa de Doctorado en Arquitectura, Instituto Universitario de Arquitectura y Ciencias de la Construcción from the University of Seville; the research group *Ingeniería Cartográfica (PAIDI-TEP-164)* from the University of Jaén; and the Survey and Modelling Laboratory (SMLab) from the University of Granada.

Conflicts of Interest: The authors declare there to be no conflict of interest.

References

1. Falcón-Márquez, T. *La Casa de Jerónimo Pinelo Sede de las R.R.A.A Sevillanas de Buenas Letras y de Bellas Artes*; Fundación Aparejadores y Fundación Cruzcampo: Seville, Spain, 2006.
2. Manzano-Martos, R. La Casa de los Pinelo y los palacios sevillanos del siglo XVI [Discurso apertura curso académico 1996/97]. *Boletín de la Real Academia Sevillana de Buenas Letras Minervae Baeticae* **1997**, *25*, 7–20. Available online: <http://hdl.handle.net/11441/14695> (accessed on 31 January 2021).

3. Barrero-Ortega, P. La Casa de los Pinelo. Las Transformaciones de un Palacio Renacentista en el Siglo XX. Ph.D. Thesis, Universidad de Sevilla, Seville, Spain, 2017. Available online: <http://hdl.handle.net/11441/63987> (accessed on 31 January 2021).
4. Barrero-Ortega, P. Las transformaciones arquitectónicas de la Casa de los Pinelo en Sevilla entre 1885–1981. *Temas de Estética y Arte* **2017**, XXXI, 153–172.
5. Barrero-Ortega, P.; Gámiz-Gordo, A. La Pensión Don Marcos en el palacio de los Pinelo (Sevilla, 1885–1964). *Quiroga Rev. Patrim. Iberoam.* **2020**, 18, 24–37. [[CrossRef](#)]
6. Almagro-Gorbea, A.; Manzano-Martos, R. *Palacios Medievales Hispanos*; Real Academia de Bellas Artes de San Fernando: Madrid, Spain, 2008; Available online: <http://hdl.handle.net/10261/19801> (accessed on 31 January 2021).
7. Manzano-Martos, R. Mudéjar, gótico y renacimiento en la Casa de los Pinelo [Discurso inauguración curso académico 2018–2019]. *Boletín de Bellas Artes* **2019**, XLVII, 19–24.
8. Barrero-Ortega, P.; Gámiz-Gordo, A. Las techumbres del palacio renacentista de los Pinelo en Sevilla. Conservación y restauración en el siglo XX. *Ge-conservación* **2020**, 18, 136–147. [[CrossRef](#)]
9. Barrero-Ortega, P.; Gámiz-Gordo, A. The Casa de los Pinelo in Seville according to a text from 1542. In *Graphical Heritage. EGA 2020*; Springer: Cham, Switzerland, 2020; pp. 163–165. [[CrossRef](#)]
10. Núñez-González, M. The Role of Drawing and Master Alarifes in the Study of the Sixteenth and Seventeenth Centuries Sevillian Housing from Graphical and Literary Documents. In *Graphic Imprints. EGA 2018*; Springer: Cham, Switzerland, 2018; pp. 685–698. [[CrossRef](#)]
11. Agustín-Hernández, L.; Vallespín-Muniesa, A.; Fernández-Morales, A. (Eds.) *Graphical Heritage, EGA 2020*; Springer: Cham, Switzerland, 2020. [[CrossRef](#)]
12. Luo, L.; Wang, X.; Guo, H.; Lasaponara, R.; Zong, X.; Masini, N.; Wang, G.; Shi, P.; Khatteli, H.; Chen, F.; et al. Airborne and spaceborne remote sensing for archaeological and cultural heritage applications: A review of the century (1907–2017). *Remote Sens. Environ.* **2019**, 232, 111280. [[CrossRef](#)]
13. Xiao, W.; Mills, J.; Guidi, G.; Rodríguez-González, P.; Gonizzi-Barsanti, S.; González-Aguilera, D. Geoinformatics for the conservation and promotion of cultural heritage in support of the UN Sustainable Development Goals. *ISPRS J. Photogramm. Remote Sens.* **2018**, 142, 389–406. [[CrossRef](#)]
14. Achille, C.; Adami, A.; Chiarini, S.; Cremonesi, S.; Fassi, F.; Fregonese, L.; Taffurelli, L. UAV-Based Photogrammetry and Integrated Technologies for Architectural Applications—Methodological Strategies for the After-Quake Survey of Vertical Structures in Mantua (Italy). *Sensors* **2015**, 15, 15520–15539. [[CrossRef](#)]
15. López, F.; Leronés, P.; Llamas, J.; Gómez-García-Bermejo, J.; Zalama, E. A review of heritage building information modeling (H-BIM). *Multimodal Technol. Interact.* **2018**, 2, 21. [[CrossRef](#)]
16. Anil, E.B.; Tang, P.; Akinci, B.; Huber, D. Deviation analysis method for the assessment of the quality of the as-is building information models generated from point cloud data. *Autom. Constr.* **2013**, 35, 507–516. [[CrossRef](#)]
17. Pritchard, D.; Sperner, J.; Hoepner, S.; Tenschert, R. Terrestrial laser scanning for heritage conservation: The cologne cathedral documentation project. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.* **2017**, IV-2/W2, 213–220. [[CrossRef](#)]
18. Shanoer, M.M.; Abed, F.M. Evaluate 3D laser point clouds registration for cultural heritage documentation. *Egypt. J. Remote Sens. Space Sci.* **2018**, 21, 295–304. [[CrossRef](#)]
19. Snavely, N.; Seitz, S.M.; Szeliski, R. Modeling the world from internet photo collections. *Int. J. Comput. Vis.* **2008**, 80, 189–210. [[CrossRef](#)]
20. Westoby, M.J.; Brasington, J.; Glasser, N.F.; Hambrey, M.J.; Reynolds, J.M. ‘Structure-from-Motion’ photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology* **2012**, 179, 300–314. [[CrossRef](#)]
21. Ferrer-Pérez-Blanco, I.; Gámiz-Gordo, A.; Reinoso-Gordo, J.F. New Drawings of the Alhambra: Deformations of Muqarnas in the Pendentives of the Sala de la Barca. *Sustainability* **2019**, 11, 316. [[CrossRef](#)]
22. Gámiz-Gordo, A.; Ferrer-Pérez-Blanco, I.; Reinoso-Gordo, J.F. The Pavilions at the Alhambra’s Court of the Lions: Graphic Analysis of Muqarnas. *Sustainability* **2020**, 12, 6556. [[CrossRef](#)]
23. Reinoso-Gordo, J.F.; Rodríguez-Moreno, C.; Gómez-Blanco, A.J.; León-Robles, C. Cultural Heritage Conservation and Sustainability Based on Surveying and Modeling: The Case of the 14th Century Building Corral del Carbón (Granada, Spain). *Sustainability* **2018**, 10, 1370. [[CrossRef](#)]
24. Roldán-Medina, F.J.; Reinoso-Gordo, J.F.; Gómez-Blanco, A.J. Registro y parametrización antropométrica del patrimonio arquitectónico: El Corral del Carbón de Granada. *Inf. Construcción* **2020**, 72, e337. [[CrossRef](#)]
25. León-Robles, C.A.; Reinoso-Gordo, J.F.; González-Quñones, J.J. Heritage Building Information Modeling (H-BIM) Applied to A Stone Bridge. *ISPRS Int. J. Geo-Inf.* **2019**, 8, 121. [[CrossRef](#)]
26. Roldán-Medina, F.J.; Gómez-Galisteo, M.T. Antropometría aplicada a la interpretación de la arquitectura histórica. El artesonado del Salón de Caballeros XXIV de la Madraza de Granada y las dudas sobre su origen. *Arqueol. Arq. 2019*, 16, e084. [[CrossRef](#)]
27. Candelas-Gutiérrez, Á. Trazado de armaduras de cinco paños según los tratados. Interpretación del manuscrito de Rodrigo Álvarez. *EGA Expresión Gráfica Arq. 2018*, 23, 174–185. [[CrossRef](#)]
28. González-Uriel, A.; de Miguel-Sánchez, M.; Fernández-Cabo, M. Los artesonados renacentistas del Palacio Ducal de Pastrana (Guadalajara): Análisis geométrico. *EGA Expresión Gráfica Arq. 2019*, 24, 60–71. [[CrossRef](#)]
29. Nuere, E.; Franco, E.; Fernández-Cabo, M.C. Armaduras de lazo toledanas. Evolución de las trazas geométricas con estrellas de ocho puntas y su relación con los diferentes sistemas constructivos empleados. *Inf. Construcción* **2019**, 71, e317. [[CrossRef](#)]

30. Nuere-Matauco, E.; Candelas-Gutiérrez, A.; de-Mingo-García, J. Análisis constructivo de la cúpula de madera del desaparecido Palacio de los Cárdenas en Torrijos (S. XV). *Inf. Construcción* **2020**, *72*, e353. [[CrossRef](#)]
31. Rafols, J.F. *Techumbres y Artesonados Españoles*; Editorial Labor: Barcelona, Spain, 1926.
32. López-Guzmán, R.J. Carpintería mudéjar en América. In *La Carpintería de Armar: Técnica y Fundamentos Histórico-Artísticos*; Universidad de Málaga: Málaga, Spain, 2012; pp. 17–44.
33. Prieto Vives, A. *El arte de la Lacería*; Colegio de Ingenieros de Caminos, Canales y Puertos: Madrid, Spain, 1977.
34. Fernández-Puertas, A. El lazo de ocho occidental o andaluz. *Al-Andalus* **1975**, *XL*, 199–203.
35. Donaire-Rodríguez, A. El trazado de lacería de ocho en alicatados. In *Actas del III Simposio Internacional de Mudejarismo*; Instituto de Estudios Turolenses, Centro de Estudios Mudéjares: Teruel, Spain, 1984; pp. 647–671.
36. Nuere-Matauco, E. Los cartabones como instrumento exclusivo para el trazado de lacerías. *Madr. Mitt.* **1982**, *23*, 372–427.
37. Nuere-Matauco, E. *La Carpintería de Armar Española*; Ediciones Munilla Leira: Madrid, Spain, 2000.
38. Nuere-Matauco, E.; Manzano-Martos, R. *Dibujo, Geometría, y Carpinteros en la Arquitectura*; Real Academia de Bellas Artes de San Fernando: Madrid, Spain, 2010; Available online: <https://cutt.ly/ufjO6fN> (accessed on 31 January 2021).
39. López-de-Arenas, D. *Breve Compendio de la Carpintería de lo Blanco y Tratado de Alarifes*; Luis Estupiñán: Sevilla, Spain, 1633.
40. De San-Miguel, F.A.; Báez Macías, E. *Obras de Fray Andrés de San Miguel*; Universidad Nacional Autónoma de México: Mexico City, Mexico, 1969.