# USE OF 3D LASER TECHNOLOGIES IN THE RESTORATION WORK OF THE HALL OF THE KINGS

## UTILIZACIÓN DE LAS TECNOLOGÍAS LÁSER 3D EN LOS TRABAJOS DE RESTAURACIÓN DE LA SALA DE LOS REYES


PEDRO CANO OLIVARES

pcano@ugr.es

JUAN CARLOS TORRES CANTERO

jctorres@ugr.es

RESEARCH GROUP IN COMPUTER GRAPHICS AND VIRTUAL REALITY OF THE UNIVERSITY OF GRANADA



**ABSTRACT** Counterforms placed under the vaults were used to protect the leather vaults during the restoration process. To build these counterforms, the vaults have been scanned using a laser scanner.
The data generated by the scanner has been cleaned to remove non-vault structures. The resulting model has been simplified and its noise has been reduced. The surface of the vault in this model has been moved to make room for a thin layer of polyurethane foam that cushions the contact between the counterform and the vault.

In order to insert the support into the vault and ensure correct contact, it has also been necessary to break down the counterforms into eleven pieces.

The 3D models of the pieces have been used to manufacture the expanded polystyrene counterforms using numerical control machining systems. These counterforms have served to support the vaults during the restoration process.

This article describes the process followed from data collection to the placement of the counterforms, emphasizing the digitalization and processing methodology of the data generated by the scanner.



**KEYWORDS** 3D scanner, Restoration, 3D printing, Alhambra, Hall of the Kings



**RESUMEN** Para proteger las bóvedas de piel durante el proceso de restauración se utilizaron contraformas colocadas bajo las bóvedas. Para construir estas contraformas se han escaneado las bóvedas usando un escáner láser.

El resultado del proceso de escaneado se ha limpiado para eliminar las estructuras ajenas a la bóveda. El modelo resultante se ha simplificado y se le ha reducido el ruido. La superficie de la bóveda en este modelo se ha desplazado para dejar espacio para una fina capa de espuma de poliuretano que amortigua el contacto entre la contraforma y la bóveda.

Para insertar el soporte en la bóveda y asegurar un contacto correcto además ha sido necesario descomponer las contraformas en once piezas.

Los modelos 3D de las piezas se han utilizado para fabricar las contraformas en poliestireno expandido, utilizando mecanizados con sistemas de control numérico, que han servido para sustentar las bóvedas durante el proceso de restauración.

Este artículo describe el proceso seguido desde la toma de datos hasta la colocación de las contraformas, haciendo énfasis en la metodología de digitalización y procesamiento de los datos generados por el escáner.

**PALABRAS CLAVE** Escáner 3D, Restauración, Impresión 3D, Alhambra, Sala de los Reyes

**COMO CITAR/ HOW TO CITE:** CANO OLIVARES, P., TORRES CANTERO,J.C., Utilización de las tecnologías láser 3D en los trabajos de restauración de la Sala de los Reyes, *Cuadernos de la Alhambra*, 2021, 50,pp. ISSN 0590-1987


Recibido: octubre 2021 | Revisado: noviembre 2021 | Aceptado: noviembre 2021 | Publicado: diciembre 2021
ISSN: 0590 - 1987 I eISSN: 2695-379X I Depósito legal: GR 70-1965

The "Hall of the Kings" is a group of three naves next to the Palace of the Lions in the Alhambra. Their names come from the motifs of the paintings that decorate the ceiling of the central hall. The vaulted ceilings are made of leather supported by a structure of wood and bamboo. This place was used for receptions and as a rest area.

The structure supporting the leather surface had deteriorated. To restore it, it is necessary to replace the wooden supports. This process must be carried out by accessing the roof and removing the external covers. In order to prevent possible detachment of the vaults and accidental blows to the vaults that could damage the paintings, it was proposed to build counterforms to support the vaults during the time when they were not protected by their roofs.

Initially, these counterforms were to be built completely by hand, manufacturing a series of wooden pieces which, like ribs, would be adapted to different sections of the vaults to form a supporting framework. In addition to being costly, this alternative was not very accurate[1].

Analysing the different technological possibilities available at the time, it was decided to build expanded polystyrene counterforms that would adapt exactly to the vaults in order to obtain better support. This required digitisation of the vaults. Digitisation techniques have been applied to both movable and immovable heritage for different purposes:

- As graphic documentation. The digital model provides accurate documentation of the shape of the element, which is particularly valuable when an intervention is to be carried out. This technology was used to record the previous state of the lion sculptures in the Palace of the Lions prior to their restoration[2].
- Dissemination of heritage, generating images, animation or virtual visits. As an example, the digitisation of the Fountain of the Lions has been used to create a virtual reality application that makes it possible to compare the lions and study the evolution of the fountain over time[3].
- Physical layout. Combined with 3D printing techniques, it can generate scale or life-size replicas of the elements.
Analysis. It is possible to calculate physical properties, or to compare the state of the element at two different points in time, e.g. before and after an intervention.
- Information support. Most of the information relating to heritage elements is associated with locations on their surface. The digitised model can be used to support a 3D information system[4], which can be used to record information on the interventions carried out on the element[5].

In this work, the digitisation served on the one hand as a graphic documentation of the state of the vaults and their supports, and on the other hand to make a physical model, although not of the vaults, but of the space underneath them.

In order to build the counterforms, it was necessary to generate a three-dimensional model of each vault so that the surface of the counterforms could be built in the exact shape of each vault. This model was used to model the space under the vault to be occupied by the counterform.

This paper describes the process followed to digitise the vaults and model and make the counterforms. This work was carried out as part of the contract "Project for the restoration of the paintings on leather in the Hall of the Kings in the Palace of the Lions of the Alhambra. 3D modelling of the vaults", signed between the Alhambra and Generalife Board of Trustees and the Research Group in Computer Graphics of the University of Granada, directed by the professor of the University of Granada, Mr Pedro Cano Olivares, and coordinated by the head architect of the conservation service of the Alhambra and Generalife Board of Trustees, Mr Francisco Lamolda Álvarez.

The following section briefly describes the scanning and printing technology used. Section 3 discusses the methodology used in the process. Finally, the fourth section shows the results obtained and the conclusions of this work.

1. GONZALEZ, María José; MONTERO, Araceli; BAGLIONI, Raniero. The paintings in the Hall of the Kings of the Alhambra in Granada: a project, a method, an intervention. PH Magazine. Instituto Andaluz del Patrimonio Histórico. N. 83. October 2012. pp. 74-89

2. CANO, Pedro; LAMOLDA, Francisco; TORRES, Juan Carlos; VILLAFRANCA, María del Mar. Use of 3D laser scanner to record the pre-intervention state of the Fountain of the Lions in the Alhambra. Virtual Archaeology Review. Vol 1 N. 2. pp. 89-94. May 2010.

3. CANO, Pedro; GARCÍA, Manuel; TORRES, Juan Carlos; LAMOLDA, Francisco; PEREZ, Silvia. Interactive 3D Application for the multimedia valorization of the restoration process of the Fountain of the Lions of the Alhambra based on 3D laser scanner registration. In Digital Heritage 2015. International Congress on Digital Heritage - EXPO. IEEE.

4. LÓPEZ, Luis; TORRES, Juan Carlos; ARROYO, Germán; CANO, Pedro; MARTÍN, Domingo: An Efficient GPU Approach for Designing 3D Cultural Heritage Information Systems. Journal of Cultural Heritage. 2020. 41, pp. 142-151.

5. TORRES, Juan Carlos; LÓPEZ, Luis; ROMO, Celia; ARROYO, Germán; CANO, Pedro; LAMOLDA, Francisco; VILLAFRANCA. Using a cultural heritage information system for the documentation of the restoration process. In: 2013 Digital Heritage International Congress (DigitalHeritage). IEEE, 2013. pp. 249-256.

## TECHNOLOGY

Two technologies were combined for this work: 3D scanning with laser scanners and 3D printing. Both were emerging technologies at the time.

### 3D scanning

A laser is a device that generates a coherent beam of light (the phase relationship in the beam is constant). If the medium in which it is transmitted is non-dispersive, the beam travels in a straight line, making it possible to match the position at which the beam strikes the object with the direction in which it was emitted.

Laser scanners are devices that send a low-intensity laser to the object and capture its reflection using an optical sensor. Two laser scanner technologies can be distinguished according to how the measurements are made: time-of-flight and triangulation, depending on how the sensor works. The sensor can be used to measure the time it takes for the laser to travel, which is proportional to the distance, or the angle at which the reflected laser arrives.

Time-of-flight scanners measure the time it takes for a pulse of the laser beam reflected from the surface to return. These times are very small (in the order of thousandths of a nanosecond). These devices have a very long range, which can exceed one kilometre. In order to capture a large area of the object, the device modifies the angle at which the laser beam is emitted. This can be done by rotating the scanner head or using mirrors. Usually the scanner head is rotated to change the angle to the vertical and mirrors are used to change the tilt. Some scanners are capable of scanning in all directions (except the area underneath it), capturing the entire space surrounding the position in which they are located. As an example, the Callidus CP3200 scanner used in this work can capture 360° horizontally and 140° vertically.

Scanners of the first type are called time-of-flight scanners, and are used to digitise objects over long distances, from a few metres to kilometres.

Triangulation scanners place the sensor at a position distant from the emitter, which allows them to measure the angle between the incident and reflected beams. They are used to digitise objects in close proximity, from centimetres to a few metres. The accuracy of triangulation scanners is higher than that of time-of-flight scanners.

In either case, the device returns the coordinates of points on the surface of the object, using the position of the scanner as the origin of coordinates. The device is often able to take photographs of the object and can return colour information in addition to the coordinates of the points. In some cases it is also possible to obtain information on the reflected laser intensity, which is dependent on both the distance and the reflectivity of the surface.

One aspect to consider when using laser devices is the level of protection required to use it. The UNE EN 60825-1/A2 standard establishes seven classes of laser devices according to their hazardousness, of which only class 1 lasers are safe under all foreseeable conditions of use, including when the beam strikes the eye. This not only makes them safer to use, but also allows them to be used in public spaces without the need to set up a security cordon.

Regardless of the technology used, digitisation involves taking data from the object (which can be done either with a laser scanner or with other technologies) and processing it with special software.

The data acquisition performed by a 3D scanner is essentially the measurement of the positions of a dense set of points on the surface of the object, usually referred to as a point cloud. Two of the most important characteristics of a digitisation system are the error in the measurement of these points and the density of points taken on the model. The measurement error indicates the margin of uncertainty in the positions obtained, and is intrinsic to the capture device. The distance between samples (related to the sampling density, and usually referred to as resolution) indicates the size of the smallest surface detail that can be captured, depending on the device, the configuration used and the distance to the object.

In the capture process it is necessary to record the entire surface of the object. In one scanner shot, we will only have those parts of the element that are visible from one of the two sides of thepositions in which the scanner has been placed. It will usually be necessary to take several shots, either by moving the object or by moving the scanner. In each shot the scanner will measure positions of the object surface visible from its position, these positions will be referenced to the position of the scanner in the shot.

Computer processing generates a 3D model of the object from the point cloud. The 3D model is essentially a set of data structures containing the surface representation of the object. This information normally includes both geometric (shape of the object) and colour information.

The structure and complexity of the geometric model will depend on the type of processing we want to do with it, and will determine the complexity of the processing to be done to create it. We need simpler models to visualise the object than to calculate its volume.

In some cases the model may simply be a set of points. In this case, the processing is limited to merging the different shots taken of the object.

- Geometric models can be used for:
- Visualising the model: generating images of the model. The visualisation can try to be as similar as possible to a photograph (photo-realistic visualisation) or try to be similar to a drawing (expressive or non-photo-realistic visualisation).
- Generate animations: create animation sequences by camera movement or modification of elements.
- Edit the model: make changes to the model. For example, for anastylosis or to plan restoration processes.
- Documentation support: manage element information associated with the element surface.
- Calculate physical properties: calculate weight, volume, surface area, moment of inertia or centre of gravity.
- Making physical copies: use of 3D printing techniques to make life-size or scaled copies.

Both for the 3D printing of the model and for property calculations, the model must be a closed polygon mesh that does not contain self-intersections. A polygon mesh is a set of connected polygons covering the outer surface of the object. Closed implies that there are no cracks in the mesh, such that there is no path from the inside to the outside without crossing the mesh. The absence of self-intersections implies that no two triangles of the mesh intersect. Together, these properties are necessary to be able to orient the mesh, i.e. to be able to determine which is the inner and which is the outer face of the surface. Such a mesh is often referred to as a solid model, as it is used to describe a physical solid.

Meshes generated from laser scanner point clouds consist of triangles only. The creation of the mesh from the point cloud is done by generating triangles and joining neighbouring points. In order to check that the mesh is closed and to calculate properties, the adjacency relations between the triangles must be stored in addition to the coordinates of the vertices.

Once the mesh has been created, it is necessary to check that it is closed, detecting and covering any cracks.

Therefore, the digitisation process, from the capture to the generation of the valid polygon mesh, is usually carried out as follows[6]:

6. BERNARDINI, Fausto; RUSHMEIER, Holly. The 3D model acquisition pipeline. In Computer Graphics Forum. Oxford, UK: Blackwell Publishers Ltd, 2002. pp. 149-172.

Capture planning, determining the number of shots required and the position of the scanner for each shot. Each area of the surface of the object must appear in at least one shot, and each shot must have a significant area of overlap with the rest.

Data collection A measurement is made at each of the positions set for the scanner, resulting in a point cloud for each one.

Merging of point clouds. One single point cloud is created by blending the different point clouds. This requires transforming the different clouds to place them in the same coordinate system. The transformations to be applied can be determined by identifying points that appear in different shots. In this process, duplicate points can be removed, points that are too close together can be filtered out or noise generated by the scanner's measurement error can also be filtered out. This process can be automated by using markers in the shots.

Generation of the triangle mesh. The dots are joined in threes to form triangles that cover the surface of the object.

Detection and filling of cracks and self-intersections. Some of the process can be done automatically, but most of the cracks have to be filled manually.

Here we are omitting the capture of colour, as it is not relevant in this work.

### 3D printing

3D printing creates a physical object from a computer model. In a way, it is the reverse of digitisation. 3D printing has now become popular thanks to the development of fused filament 3D printers. These devices perform additive manufacturing, where material is added layer by layer to create the object.

This technology was not available at the time of the work, and it is not easy to build objects of the required size with it.

The alternative is to use Computer Numerical Controlled Machining (CNC), which performs a subtractive process, starting with a block of material from which the excess material is cut to create the object. To do this, computer-controlled cutters and rotating tools are used. This system makes it possible to create objects of large size and high precision using virtually any type of material.

## METHODOLOGY

The solution proposed in this work was the creation of Porexpan moulds, printed from the digitisation of the vaults, and placing them under the vaults to achieve a more exact fit and continuous contact.

Porexpan, also known as expanded polystyrene (EPS), is a product commonly used as protection in the packaging of delicate products or as a building material. It is light, highly resistant to shocks and impacts, and does not allow bacteria to grow.

Porexpan is also rigid, so its contact surface is hard. For smooth contact with the vaults, the counterforms are coated with a thin layer of polyurethane foam. Polyurethane foam is a porous and flexible material which, by cushioning the counterform, absorbs vibrations. For this foam layer to be added, the surface of the counterforms have to shrink and leave a small gap between them and the surface of the vaults.

The upper surface of the counterforms, which must have the shape of the vault, is obtained by the digitising process. To define the rest of the counterform surfaces, a bottom plane must be added, which must be placed horizontally (regardless of the deformation of the counterform) in order to facilitate its positioning, and lateral planes that must not collide with the walls of the room.

On the other hand, the dimensions of the room are smaller than those of the vault itself, so it is necessary to divide the counter-vault into several parts. The parts must be marked on their bottom surface so that they can be placed in the correct positions.

The different steps of the process are described in detail below.

## Digitisation

A Callidus CP 3200 laser scanner was used to digitise the vaults. This is a time-of-flight laser scanner with a maximum range of 80 m and an accuracy of 5 mm equipped with an integrated digital camera for colour capture, controlled from a computer. This scanner uses a class 1 laser.

The head of the device is fitted with a servo-driven system that allows it to rotate 360º on the horizontal plane in steps of between 0.0625º and 1.0º. With the help of a rotating mirror, the laser beam is dispersed in a fan shape, covering an area of 140º on the vertical plane. This allows it to automatically rotate and collect the coordinates of surrounding objects at a rate of over a hundred thousand points per minute. The 3D measurements are recorded on the Callidus LMS protected field computer, which is part of the system.

In order to record the counterforms, the scanner was placed, without a tripod, on the scaffolding placed in the vault, as shown in Figure 1. To eliminate vibrations and occlusions during capture, the control computer was placed on the floor outside the scaffolding. The shots were taken with no one on the scaffolding.

Three shots were taken of each vault, one by placing the scanner in the centre of the vault and the other two by placing the scanner in the centres of the circles described by the ends of the vaults. In all three cases with the scanner on the scaffolding. It was necessary to take three shots, despite the fact that the surface was theoretically simple, due to the irregularities and deformations of the counterforms, which meant that in each shot there were areas that were not captured. These irregularities were the most important part of the process. Colour is not captured in these shots because, on the one hand, it is not relevant to the process, and on the other, the vaults were already covered with a layer of protection, which would have made it impossible to capture the colour of the paintings. In addition, capturing colour would have required the use of artificial lighting to ensure proper operation of the scanner's camera.

Each shot contained just over 800,000 points, with an average distance between points of 8 mm.

Besides the surface of the vaults, each shot includes all the elements present in the scene, such as walls, cornice, canvases and scaffolding.

## Point cloud processing

The data obtained by the scanner, consisting of a dense sampling of dots on the surfaces visible from the scanner in each shot. These clouds are processed to merge the three shots taken of each vault and they are then triangulated. The result is aa mesh of triangles representing the surfaces of all the objects in the scanned scene.

Il. 1. The scanner was set up without a tripod, placed directly on the scaffolding in the vaults. Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.

To generate the mesh, the scanner's own software was used, together with MeshLab[7] and programs developed specifically for the project, following the steps below:

Export of point clouds to files in ply format, suitable for exchange between different programs, enabling processing with software other than the scanner's native software.

Alignment of the three shots, making the three point clouds in the same coordinate system. For this purpose, the two side shots are transformed into the coordinate system of the central shot. This is done by selecting identifiable points in shot pairs, and then performing an iterative adjustment by minimising the distance between the three clouds.

The three shots were merged into one single shot. The result is one single point cloud.

Generation of a triangle mesh. The result is a triangle mesh of the entire scene.

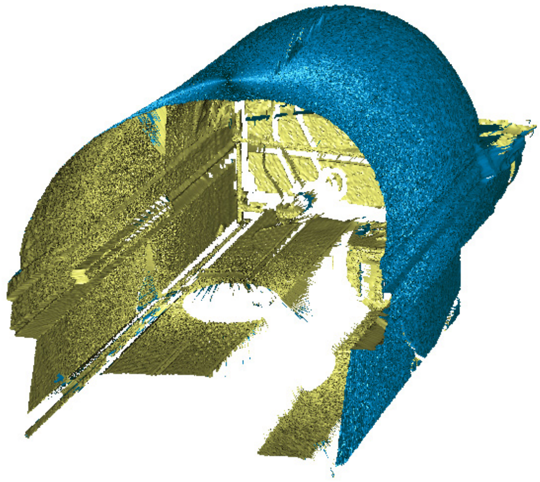
The model obtained at this point must be cleaned to eliminate the structures foreign to the vault (support scaffolding, fabrics, etc.), leaving in the working model only the surface of the vault, the cornice that supports it and the walls of the room that are necessary to build the desired model of the counterform. Figure 2 shows a section of the model of the first vault with the structure of the scaffolding. The resulting model is simplified and a denoising process is performed.

## Modelling of the counterforms

The resulting mesh is divided into two parts: the vault and the cornice that supports it (which is the area of interest) and the rest of the model used to adjust the measurements of the lower support that will be added to the model of the counterform to enable placement on the installed supports. Il. 3 shows the resulting model, in which only the area of interest has been left.

This mesh of interest for the model construction is finally processed to remove self-intersections and fill the cracks using MeshLab. Cracks are automatically detected and manually filled by closing the gap with a triangle mesh. The result of this step is a mesh representing the surface of the vault.

To generate the counterforms, it is necessary to construct a closed mesh, for which a surface section must be added to delimit the lower part of the counterform. To ensure perfect adaptation to the surface of the vault, we cut the model below



Il. 2. Section of the 3D model of a vault before the removal of structures outside the vault, in which the scaffolding can be seen. Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.

the cornice, guaranteeing a safety distance from the cornice supporting the vault. For this purpose, a horizontal plane is calculated that adapts to the deformations of the cornices, which is taken as a reference to create the cutting plane. As a result, we obtain the model of the part of the vault we are interested in for the construction of the supporting counterform.

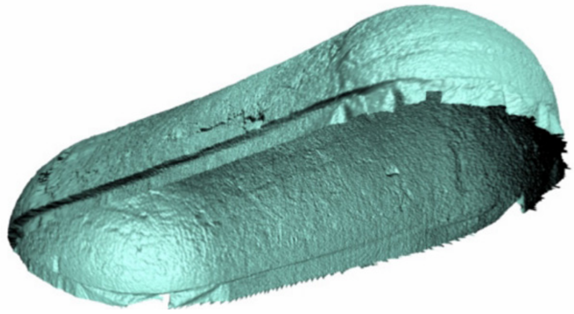
From the resulting mesh, a new mesh is generated by moving the vault surface inwards by a distance equal to the thickness of the polyurethane foam (2 cm), so that when the foam sheet is added, the counterform will fit into the vault space.

The lower part of this model is vertically extended to ensure stable support of the counter platform on the scaffold. The length of this extension has been discussed with those responsible for the assembly process to ensure that there are no complications in fitting it to the designed supports. To facilitate the design of the supports, and given that the vaults are greatly deformed, the final model of the counterform is defined with a completely horizontal base.

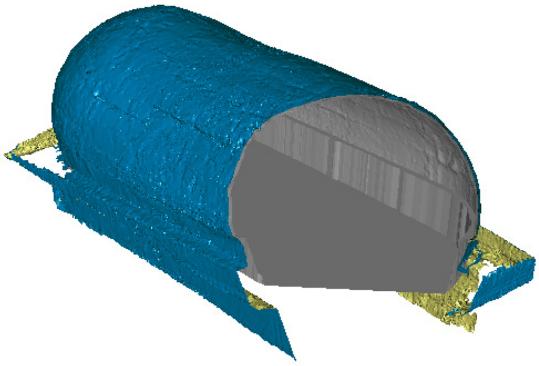
In the vertical extension of the lower area, a larger displacement than that used for the vault is used so that it can be adapted without colliding with the cornice that supports each vault. In some cases this ledge is completely missing, but the safety offset has been maintained as there is no need for adjustment in this area.

At this point, we have a solid model of the counterform. In figure 4 we can see the comparison of the model of the constructed counterform and the original model obtained in

7. CIGNONI, Paolo; CALLIERI, Marco; CORSINI, M.assimiliano DELLEPIANE, Matteo; GANOVELLI, Fabio; RANZUGLIA, Guido. MeshLab: an Open-Source Mesh Processing Tool. In: SCARANO, Vitorio; DE CHIARA, Rosario; ERRA, Ugo.Sixth Eurographics Italian Chapter Conference. (Salerno, Italy, 2008), pp. 129-136.



Il. 3. Area of interest of the model to build the counterform. In this model, all structures outside the vault have been removed. Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.



Il .4. Comparison of the model of the counterform (in blue) and the vault surface (in grey). Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.

the scan, where we can see the perfect adaptation of the surface maintaining the defined offset.

Since the surface of the vault is larger than that of the room, it is necessary to divide the counterform into smaller pieces to allow for its placement. In addition, this breakdown will enable adjustment of the counterform in the vault.

Therefore, a division of the counterform into pieces was made so that all the pieces were inserted in the centre and adjusted towards the sides, ensuring a correct positioning without dragging the pieces of the counterform on the surface of the vault. Figure 5 shows the pieces designed by Pedro Salmerón Escobar, together with the nomenclature used and details of the measurements of the defined offsets.

To ensure correct identification of each part, the labelling was marked as an extrusion of the part number on the inside of each part.

To divide the counterform into its eleven parts, the cutting planes shown in Figure 6 are defined. These drawings shall be used to cut the model of each counterform. For the labelling, a model is created with the numbering subtracted from the model of the counterforms, generating the numbering inscribed on the lower faces as shown in Figure 7. Figure 8 shows an infographic of the parts of the counterform (in blue) placed on the scanned model of the vault (in grey).

In order to check the accuracy of the constructed model, the distance between the solid model of the counterform and the digitised surface of the vault was calculated. Figure 9 shows an image of the calculation of the distance between the vault and the counterform, with a colour scale showing the distance in metres. It can be seen that for the counterform area it is between 1.5 and 2.2 cm. By calculating these distances, it was possible to verify that the distance between the counterform model and the vault was always within the established distance range.

## Creation of the counterforms

The result of the process described in the previous point is the solid model of the eleven pieces of the counterforms of the three vaults. These models have been used for the physical construction of the Porexpan counterforms. The manufacturing process was carried out by the company Tragacantos, S.L.

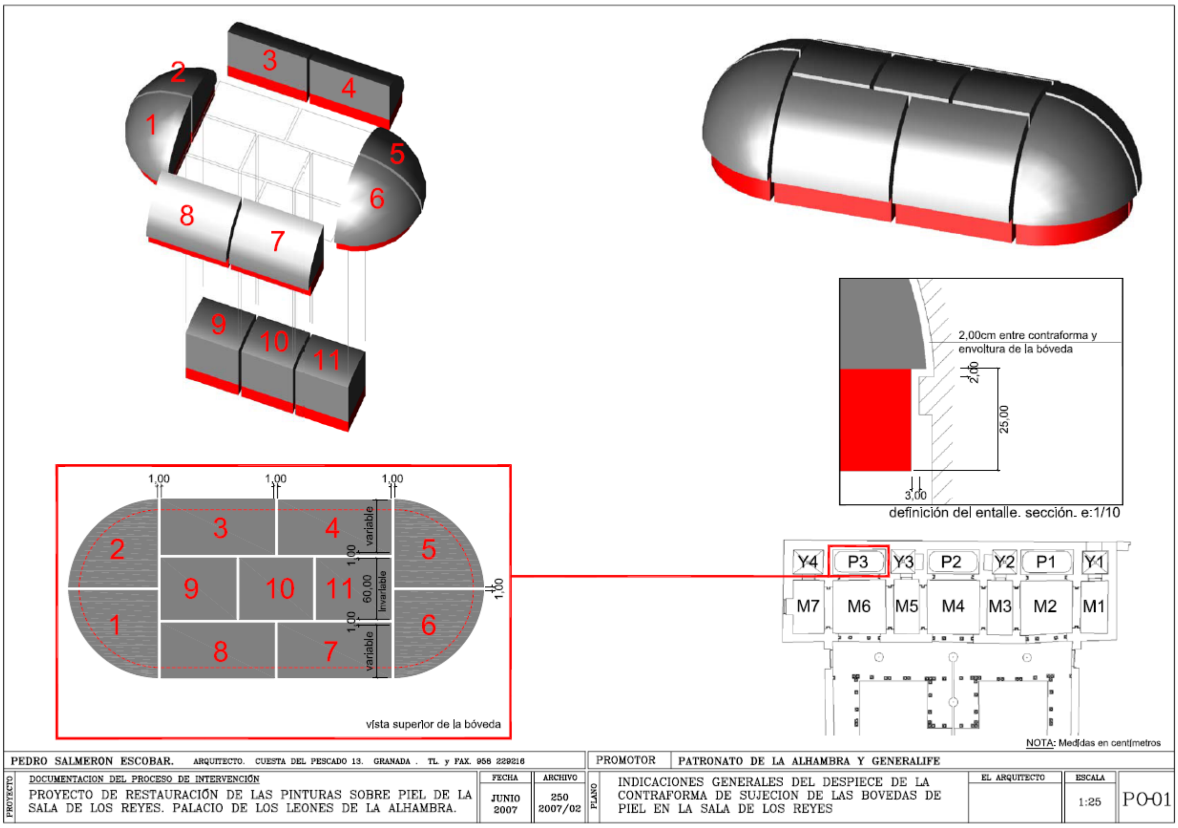
Figure 10 shows the Porexpan pieces of one of the counterforms. A layer of polyurethane foam was added to these parts in the areas where they were in contact with the vault. Figure 11 shows the placement of the polyurethane foam layer on one of the counterforms.

## Placement

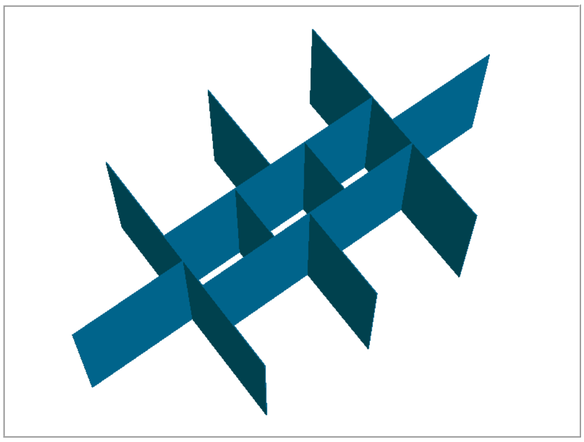
The counter platforms were mounted on wooden supports placed on the scaffolding (see figure 12), starting with the outer parts (one to eight) and closing with the interior parts (nine, ten and eleven). This ensures that the installation is carried out without displacement of the counterforms on the vault surface.

## Digitisation of the backs of the vaults

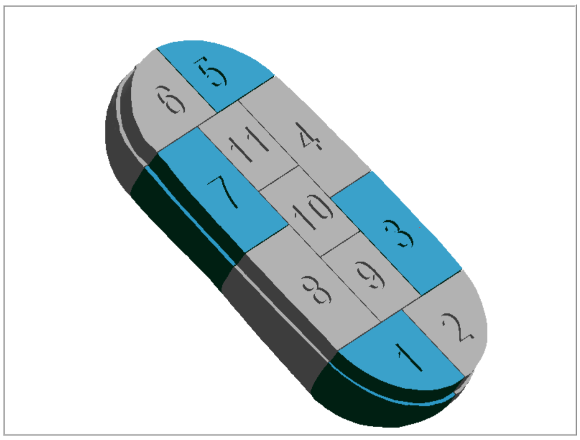
Once the counterforms had been placed and their covers removed, the supports of the vaults were digitised from the outside. A Minolta Vivid 910 scanner, which is a triangulation laser scanner, was used for this process. This device can only be used over short distances (no more than two metres), but allows measurements with high resolution and accuracy (in the order of tenths of a millimetre). This scanner was also used in the digitisation of the lions in the Palace of the Lions. These




Il. 5. Division of the counterforms into parts. Pedro Salmerón Escobar. 2007. Alhambra and Generalife Board of Trustees. Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees



Il 6. Drawings used to cut the counterforms into parts. Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.



Il 7. Final model of the counterform, divided into parts and labelled. Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.

models were used as documentation of the pre-intervention state. Figure 13 shows the digitisation of the reverse side.

## RESULTS AND CONCLUSIONS

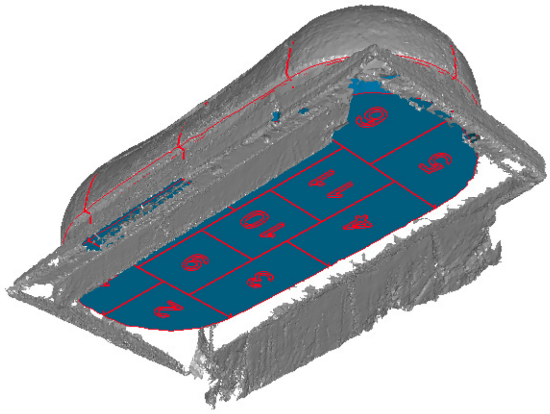
The method described in this paper was applied to vault number three. Once the assembly of the counterform was completed satisfactorily, the procedure was validated and applied in vaults one and two. The procedure used has ensured that the vaults were correctly and durably held in place during the entire restoration process, without affecting the leather or the paintings.

In their work on the intervention on the paintings in the Hall of the Kings in the Alhambra in Granada, Gonzalez, Montero and Baglioni, evaluate positively the results obtained with this methodology[8]:

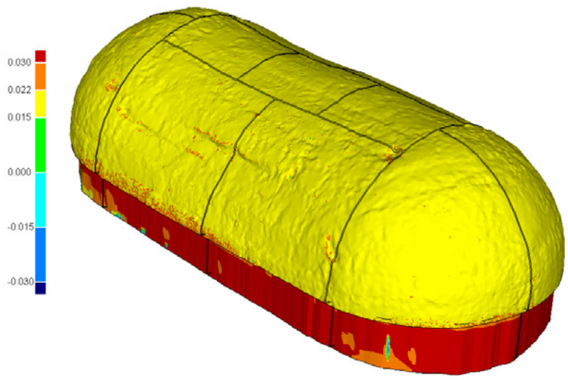
"This phase was completed with the design and application on the front of the paintings of two counterforms made of wood covered with various layers of shock-absorbing material. Thanks to advances in technological research and the 3D laser scanning of the three paintings, this was replaced by counterforms in expanded polystyrene, obtained by numerical control on the basis of the 3D scan. These counterforms were adjusted like a second skin to each pictorial surface that formed a solid and stable whole with each vault, also fulfilling the requirements demanded of this part, considered a key element in the moments of the project in which the vaults would be devoid of their natural support and supported exclusively by them."

## ACKNOWLEDGEMENTS:

This work has been funded by the "Alhambra and Generalife Board of Trustees" and the "Department of Innovation, Science and Enterprise of the Junta de Andalucía" through the PE-TIC-401 project.



Il 8. Simulation of the placement of the counterform (in blue) on the original model of the vault (in grey). Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.




Il 9. Verification of distances vis-à-vis the original model. It can be seen that the distance in the area of the leather vault is between 1.5 and 2.2 cm. Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.

8. Op. cit. Las pinturas de la Sala de los Reyes de la Alhambra de Granada (1)

Il 10. Porexpan parts of one of the counterforms. Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.

Il 11. Placement of the polyurethane foam layer on one of the counterforms. Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.

Il 12. Placement of the counterform. Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.

Il 13. Digitisation of the backs of the vaults. Pedro Cano and Juan Carlos Torres. Year: 2007. © Alhambra and Generalife Board of Trustees.