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Graphic Restitution and Recovery of the Chronos Pavement of the Marquis of Benicarlo's House

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Abstract: The Marquis of Benicarlo's House is a prime example of 18th-century Baroque civil architecture in the Valencian region. Inside, it preserves ceramic panels from this period of great historical and heritage value. However, prior to its designation as a Cultural Heritage Site, the building lost some of its most architecturally significant elements, such as the flooring in one of the main rooms, which was decorated with rich iconography. Fortunately, the original tiles from this flooring have been located in the collections of the National Museum of Ceramics. This study presents the recovery and graphic restitution of the flooring based on the pieces found in the museum's collections. This work allows us to understand the original appearance of the flooring before its dismantling and may enable its in situ restoration through digital ceramic printing techniques, thus returning one of its most unique architectural elements to the building. It also details the process of digitally restoring the flooring to its original location using advanced digitization techniques. This enables the visualization of the hall in its authentic state using virtual reality methods, thereby facilitating its appreciation and dissemination as a heritage architectural space.

Keywords: decorative ceramics; baroque; Marquis of Benicarlo's House; graphic restitution; ceramic digital printing; ceramic flooring; architectural heritage; virtual reality

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1. Introduction

Decorative ceramics have been a widely used decorative art form throughout the history of architecture, especially during the Baroque period, known for its opulence and stylistic exuberance. During this time, decorative ceramics not only served a utilitarian function, but also became a decorative element used to embellish palaces and noble residences to reference the purchasing power of their owners, due to their elegance and sophistication.

These decorative ceramics were mainly used in under-balconies, kitchens, and other rooms, ceramic baseboards, as well as in salon floors. Decorative ceramic floors sometimes replaced or imitated carpets, which occasionally covered them in winter, aiding in their preservation. Esclapés in 1737 already mentioned that the tile factories in Valencia had managed to produce ceramic carpets imitating those of Messina [1,2].

However, in many cases, the passage of time and the inevitable effects of deterioration have caused these ceramic works of art to suffer irreparable damage. In other cases, elginism [3] has led to these architectural coverings, like other elements of great artistic and patrimonial value, being stripped from the buildings that housed them.

The restoration of these decorative ceramic coverings becomes a significant challenge, as on one hand, the historical and stylistic authenticity of the pieces must be preserved, and on the other hand, efforts must be made to avoid their use conditions affecting their original properties and characteristics. Some technical, scientific, and interdisciplinary works on conservation and restoration serve as a reference and background to this study, such as the publication of Ascensión Ferrer on ceramic conservation in architectural restoration from a strictly physical perspective (cleaning, dampening, consolidation, chromatic

reintegration, etc.) [4]. However, it is not so common to work on ceramic conservation from a virtual and digital perspective in which it is possible to share the results in a way that is accessible to the general public, as the study presented here aims to do, among others. In the field of archaeology, it is common to study, analyze, and restore ceramic objects with historical and museum-based cultural interest in order to preserve them [5,6].

In the field of architecture, studies on digital preservation and the use of virtual reality (VR) in restoration projects collectively highlight the significant advancements and methodologies in preserving cultural heritage. Some integrate 3D laser scanning, architectural heritage building information modeling (AHBIM), and VR to protect and visualize historical buildings, emphasizing accurate documentation and immersive experiences [7]. Others delve into virtual restoration, creating digital replicas of artworks to restore and recontextualize them within artificial simulations, ensuring the reliability and authenticity of the original content while enhancing user interaction [8]. Additional studies demonstrate the application of VR in reconstructing and restoring historic buildings and murals, using techniques like topography and photogrammetry to create interactive VR environments that preserve and present dilapidated sites digitally [9,10]. These works underscore the transformative role of VR in the digital preservation of cultural heritage, offering innovative solutions to document, restore, and engage with historical sites.

In addition, this type of restoration is of interest to promote both educational and touristic values. For example, the work of Mortara and his team explores educational aspects using virtual environments to enhance the experience of cultural heritage to a wide audience through the use of serious games [11] and the recent work of Amin on Egyptian historical architecture, which uses virtual technologies to enable the acquisition of learning skills to students of architecture in that country [12]. Regarding tourism, it is well-known that new technologies play a role in improving the visitation experience [13,14] and even the visitation intention for cultural heritage [15].

The restitution of this hall, including these decorative ceramics, presents a significant challenge, requiring the preservation of historical and stylistic authenticity while safeguarding their original properties and characteristics. Digital modeling techniques allow us to graphically restore these architectural elements in their original buildings and to visualize and contextualize them using virtual reality (VR) techniques [16]. The virtual restoration of architectural models requires the use of various techniques, on the one hand, those related to the geometric aspects of the architectural space and its details and, on the other hand, to the chromatic aspects. Below, we will write a case study in which all these processes can be seen.

2. The Study Case

The Marqués House, also known as *Casa dels Miquels*, located in the municipality of Benicarló in the province of Castellón, is a masterpiece of Valencian civil Baroque architecture. It was built in the last quarter of the 18th century by Mr. Joaquín Miquel Lluís, on the site where the old Encomienda house used to stand, headquarters of the Commander of the Order of Montesa. The house consists of a ground floor, mezzanine, main floor, and attic. The building is organized around a large double-height entrance hall and a continuous gallery, accessed by an imperial staircase located in the second bay. Behind the staircase, there is access to a rear garden surrounded by masonry [17]. The most notable elements of the building, besides the staircase, are the ceramic coverings of the chapel, located on the ground floor, the ceramic floors, and decorative paintings of the noble rooms on the main floor, and especially the kitchen, which is completely covered in decorative tiles that recreate culinary scenes from that era [1,2]. The ceramic pieces were manufactured at the Faure Factory in Valencia between 1770 and 1780 [18].

The building was declared a singular BIC (Cultural Heritage) by the Valencian Government on 28 September 2007 [19] and definitively listed as BIC by the Ministry of Culture on 9 December 2008, classified as a first-category Real Estate with Monument status, with registration number R-I-51-0012141 [20]. Nowadays, the Casa dels Miquels is a private property whose view is not open to the general public. Also, some of the original pavement

is located in the National Museum of Ceramics and Decorative Arts "González Martí" (NMCDAGM), as discussed below.

Within the decorative ceramic coverings of the Casa del Marqués de Benicarló, we can distinguish between vertical coverings and horizontal coverings or pavements. The format of all the decorative ceramics is 21.5 cm × 21.5 cm.

- **Vertical coverings**

These can be found on the baseboards of the chapel, located on the ground floor, featuring religious motifs (see Figure 1), and in the kitchen, which is completely covered with decorative ceramics depicting culinary scenes (see Figure 2).



Figure 1. Ceramic baseboard of the chapel of the house of the Marquis of Benicarló.



Figure 2. Ceramic panel of the kitchen of the house of the Marquis of Benicarló.

- **Pavements**

These are found throughout the main floor of the palace (first floor). The first floor has two large halls connected by the central staircase: one located to the southeast and the other to the northwest. Each of these halls provides access to two large bedrooms with an antechamber and a chamber connected by a mixed-line arch. All the spaces (except the southeast bedroom) have decorative ceramics with vegetal motifs that cover the entire rooms, each with a different design. Only in the northwest hall is there a central panel with a genre scene featuring buildings, a river, and a noble character fishing, surrounded by servants and pets. See the 3D model of the current state by opening the QR code in Figure 3.

Figure 3. QR Code of the 3D model of the main floor of the house of the Marquis of Benicarló obtained **with Matterport**. Current state.

Currently, in the south-east hall on the first floor, the one located at the south-east corner, it can be observed that the central part of the original flooring has been replaced with white ceramic tiles, 20 cm × 20 cm in size, of recent manufacture, contrasting with the original tiles of the same color and 21.5 cm × 21.5 cm in size that make up the perimeter flooring of the room and the adjacent room (see Figure 4).



Figure 4. Marquis of Benicarlo's House. Floor view of the south-east hall of the main floor get with **Matterport**.

The room where the pavement of the Four Seasons was located corresponded to the antechamber of one of the four main bedrooms of the house. Specifically, it was situated at the south-east end, with a window overlooking the large outdoor terrace and the interior garden. This prime orientation and the views suggest it was one of the best rooms in the house, enhanced by its unique pavement.

These decorative ceramics have been studied by Coll Conesa, J. [21] and specially by Pérez Guillén, I. V. in his publication "Azulejos de Benicarló. La Casa de los Miquel y otras arquitecturas" [22].

A pavement with similar characteristics, known as the Disdier Pavement from Calle San Vicente, nº 4, is currently located in the González Martí National Museum of Ceramics, inventory number: CE1/11655 [23]. Other examples to highlight are the pavements of the College of High Silk Art, in Valencia.

The manufacturing techniques of this flooring included molding, glazing, and painting [24]:

- **Molding**

Molds were used to produce parts in series. The liquid or semi-liquid clay was poured into the mold, where it was allowed to partially dry before being removed and given the necessary finishes.

- **Glazing**

Enamels were made by mixing metal oxides with a flux, such as silica. These components were finely crushed and mixed with water. This mixture was applied by immersion, pouring, or brushing. The glazed piece was fired at high temperatures in a kiln, where the glaze was vitrified, forming a smooth and shiny surface.

- **Painting**

Painting was often performed on the glazed surface, although in some cases, it was performed directly on raw clay. The first technique allowed for a greater variety of colors and details, but required additional firing at a lower temperature to set the pigments without damaging the glaze.

Decorated ceramics have been highly prized by noble families in Valencian palaces since the Middle Ages, despite their fragility. Notably, the Valencian Pope Alexander VI (Borgia) ordered his Vatican rooms to be decorated with these ceramics [25], which can still be admired on a visit to the Vatican Museums.

3. Materials and Methods

3.1. The Ceramic Tiles of the González Martí National Museum

In the storage of the National Museum of Ceramics and Decorative Arts González Martí (NMCDAGM), the pieces of a disassembled ceramic floor are stored. In the text of the Assembly Plan, Annex No. 3 (see Figure 2), the following appears:

> "Hypothetical reconstruction of the panel, following the plan provided by the sellers (Annex 4), which counts 540 tiles. The numbering corresponds to that found on the back of the tiles of each scene (the four seasons and the central panel of time), which have been noted in the count conducted by museum technicians in December 2021. The colors are based on those of the paper in which the tiles were originally wrapped (see illustrations in Annex 2). The rest, in white, corresponds to the white tiles needed to complete the panel. In this scheme, 180 are calculated, and the sales offer included fewer: 103 white tiles wrapped in groups of four in newspaper paper. The remainder consists of 36 tiles from the corners, 216 from the border, 64 from the seasons, and 44 from the central figure, which would be slightly shifted to the left".

This pavement is classified into different closed plastic boxes containing a specific number of perfectly packaged pieces. They are first wrapped in white tissue paper and second in wrapping paper of different colors, which correspond to the different decorative compositions according to the pavement scheme developed by the museum's technicians (see Figure 5).

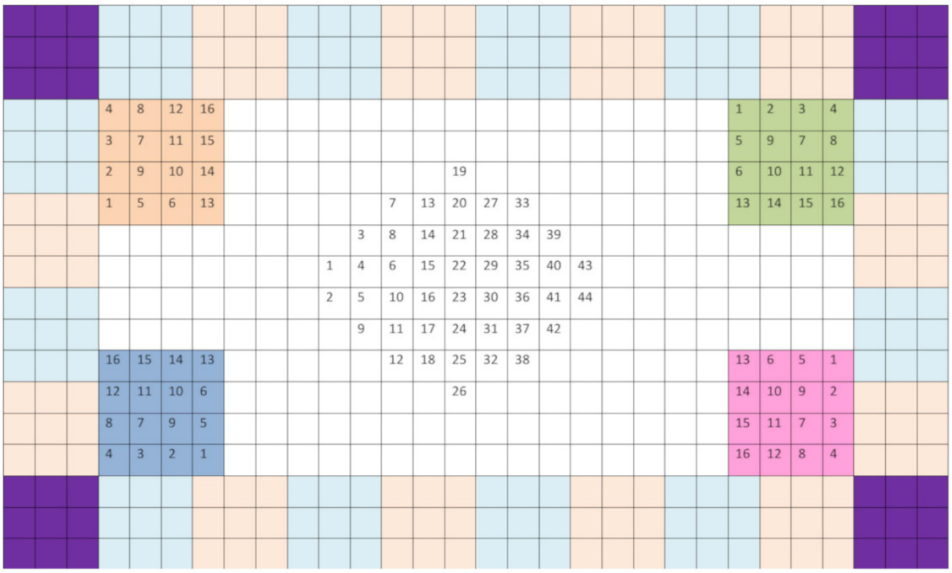


Figure 5. Assembly plan of the flooring, Annex No. 3. NMCDAGM storage. Green tiles: spring panel, pink tiles: summer panel, dark blue tiles: autumn panel, dark beige tiles: winter panel, purple tiles: corner border design, light blue and beige tiles: linear border design, number white tiles: Chronos panel.

On the wrapping of one of the pieces, the following handwritten text appears:

"Floor from a salon of the Marqués de Benicarló's house. Alcora, 18th century. In the center, a group representing CHRONOS, and in each corner, a season: SPRING, AUTUMN, WINTER, SUMMER (16 tiles each)", (see Figure 6).

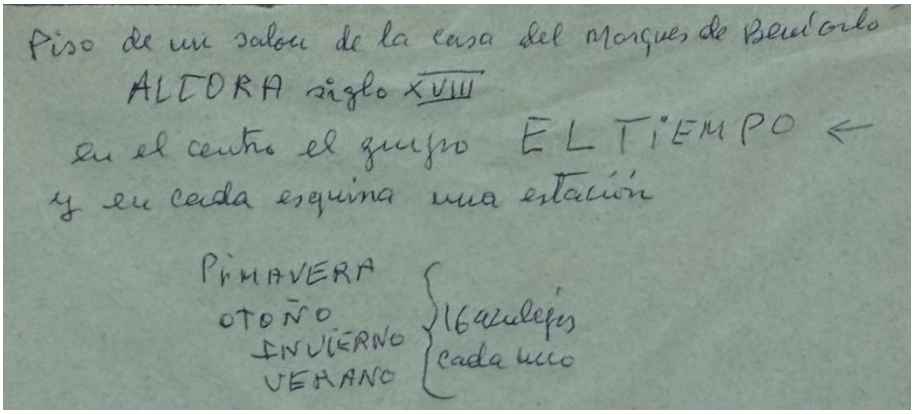


Figure 6. Handwritten text on the wrapping of one of the pieces reporting the designs and origin of the tiles.

Although this annotation says that the pieces were manufactured in the Royal Factory of Alcora, researchers from the National Museum of Ceramics place their production in the Faure Factory in Valencia [18].

3.2. Methodology

Within the methodology, we must differentiate between the graphic survey work carried out within the building itself, the data collection work conducted in the museum, and the graphic processing carried out based on the initial information.

3.2.1. Field Work in the Building

To conduct in situ data capture within the building, state-of-the-art tools utilizing active 3D imaging systems, such as 3D scanners, as well as passive image systems, such as photography or photogrammetry, have been employed [26]. These tools are utilized for subsequent graphic representation and to obtain a 3D graphical survey or digital replica of the original model. With this model, it becomes possible to clearly identify various structural issues, such as diseases, lesions, or deformations affecting the building. This approach ensures that data collection activities do not alter or modify the physical conditions of the buildings, treating them as unchanged samples (non-intrusive measurement), thereby avoiding the high costs associated with employing auxiliary means for data collection [27,28].

The outcome is a tangible reverse architecture representation of the building segment in question. Fieldwork was undertaken to materialize these results, involving data collection to capture the buildings' metric, geometric, and graphical characteristics.

Sensor-based 3D passive systems, specifically the advancement in automated digital photogrammetric lifting systems, facilitate the creation of highly accurate 3D images defining the object to be represented. These systems generate a point cloud, spatial meshes, and textured meshes with real color application derived from the obtained photos.

Regarding the massive data-collection systems utilized in these case studies, it is noteworthy to highlight the accuracy and quantity of information provided by the 3D terrestrial scanner based on class-one long-range invisible laser pulses. This scanner allows for fast and agile surveying work. Data capture is supplemented with a digital camera.

A Leica-branded BLK360 3D Imaging Laser Scanner was employed for graphic surveying. This 3D scanner features a built-in spherical imaging system and operates with a single

button or device. It weighs 1 kg and measures 16 cm × 10 cm. It incorporates a high-speed distance measurement system enhanced by waveform scanning (WFD) technology. It is classified as a Class 1 laser according to IEC 60825-1:2014 [29].

Its technical characteristics are:

- Laser Class 1 in accordance with IEC 60825-1: 2014;
- Vision field: 360° (horizontal)/300° (vertical);
- Distances: min. 0.6—max. 60 m;
- Valuation of measurements of points up to 360,000 points/sg;
- Precision status: 4 mm at 10 m and 7 mm at 20 m.

The device has three integrated HDR digital cameras of 13 M pixels, a full dome capture of 150 Mpx, HDR, LED flash, and calibrated spherical image, 360° × 300°.

The tripod used to position it was a Vanguard Alta Pro 363AT 63–165 cm.

To carry out correct surveys, fieldwork was planned by determining the number of stations to be placed on the main floor of the building. Outside, a minimum of 30% of the scanned surface area is considered; a scan is planned for each smaller room and at least two scans for larger rooms.

For field surveying, the Cyclone Field 360 software, version DS-1219-LR, installed on a tablet with the Android operating system can be used. Medium quality of the scanner was chosen and images were captured in HDR. This software allows the visualization of both scanning and images in real time, and for pre-aligning stations in situ by facilitating subsequent point cloud registrations.

The data collection work for the building was completed by creating a photogrammetric model of the main floor using Matterport online software, version 24.2.0.0 [30], utilizing a RICOH THETA Z1 360° photographic camera with the following technical specifications:

- Image sensor: 1.0″ × 2 back-illuminated CMOS;
- File size (still images): RAW: 7296 × 3648; JPEG: 6720 × 3360;
- Aperture: F2.1, F3.5, F5.6;
- Lens construction: 14 elements in 10 groups × 2;
- Capture mode: still image/video: automatic, shutter speed priority, ISO sensitivity priority, aperture priority, and manual;
- Capture distance: approximately 40 cm to ∞ (from the front of the lens);
- Exposure control mode: AE program, AE shutter speed priority, AE ISO sensitivity priority, manual exposure;
- Exposure compensation: manual compensation (−2.0 to +2.0 EV, in 1/3 EV steps);
- ISO sensitivity (standard output sensitivity): still image/video: [Auto] ISO 80 to 6400, adjustable upper limit; [Manual] ISO 80 to 6400.

The resulting 3D model can be viewed at the following link: https://my.matterport.com/show/?m=vYLvtJDU47z&lang=es, accessed on 10 June 2024.

3.2.2. Field Work in the Museum

To capture images of the ceramic pieces, a 10.2-megapixel Nikon D-80 digital camera and a Nikon 5200 24-megapixel camera, fitted with a conventional lens between 18 and 135 mm, with a focal aperture of f/3.5–5.6, a Sigma wide-angle 8–16 mm lens, and a focal aperture of f/4.5 to 5.6 mm.

The camera was placed on an adjustable focus support stand on a table. This support allowed for taking orthogonal images of the pieces. To improve the camera adjustment, a millimeter template base was placed on the support table, and once the camera was adjusted, the different ceramic pieces were placed to capture the images. To prevent lens movements, the images were taken using a remote trigger using the SnapBridge application (see Figure 7).

In addition to capturing the photographs, both the obverse and reverse, of each of the pieces, they were weighed with a digital weighing machine and measured with a caliper.

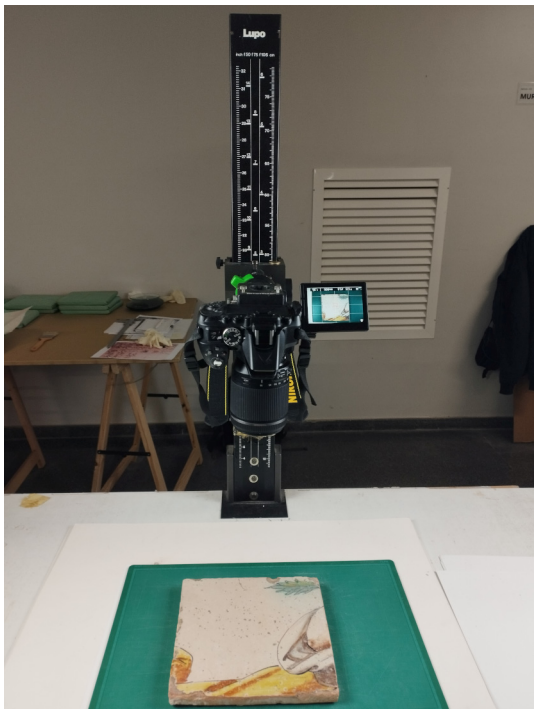


Figure 7. Photo shooting with adjustable focus support stand on a table.

3.2.3. Graphic Process

To be able to work with the point clouds obtained with the scanner, nine different point clouds were recorded by assembling and orienting them. This operation was performed with Leica Geosystems Cyclone Register 360 software, version 2021.1.2. It imports *.blk files from the scan that are registered through visual alignment to generate a whole cloud.

For the graphic survey of the south-east area of the main floor, where the room housing the pavement is located, a total of nine stations were set up, whose point clouds were joined by ten links, generating the overall cloud. This cloud was cleaned and an orthogonal coordinate system to the facade was generated. According to the registration report, the overall cloud had a strength of 64% and an overlap of 55%, with an overall error of only 2 mm, resulting in a model with more than acceptable accuracy for the work to be carried out (see Figure 8).

From the point cloud, it was possible to obtain a digital model of the southeast room where the original pavement was located.

The next step was the digital processing of the images obtained from each of the ceramic tiles. For this purpose, they were encoded and numbered according to the initials of each of the sets. For the completion of this process, the graphic restitution work of the pavement of the Sanjoans Palace [31] was used as a reference.

The images were rectified using PTlens software, version 9.2, to correct the fisheye lens distortion, also known as "barrel distortion" (see Figures 9 and 10).

In most of the images, this rectification process was sufficient due to the conditions of capture using a support orthogonal to the pieces. In some cases, due to the warping of some of the pieces, it was necessary to rectify them later with ASRix software, version 2.0 beta, to obtain fully orthogonal images of the pieces. The photographs rectified by this software were: EA07, BA01, BA02, BA03, BA04, BA05, and BA10. These operations ensured the orthogonality of the piece based on the measurements taken in situ.

Once each of the images was rectified, they were cropped to remove the background using the GIMP photographic retouching tool (see Figure 11) and adjusted to a size of 21.5 cm $\times$ 21.5 cm.

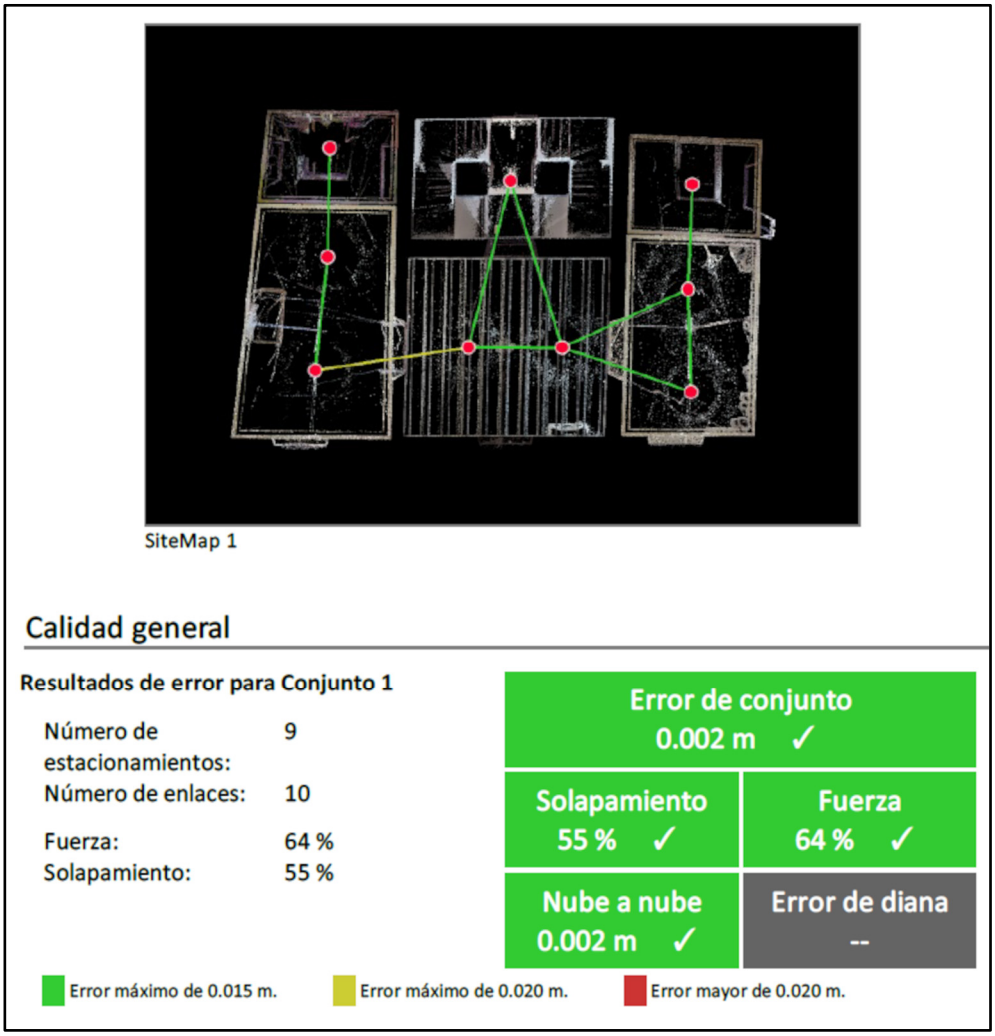


Figure 8. Registration report: registered and oriented point cloud of the set and general quality data. Green dot: maximum error of 0.015 m, yellow dot: maximum error of 0.020 m, Red dot: greater error than 0.020 m.

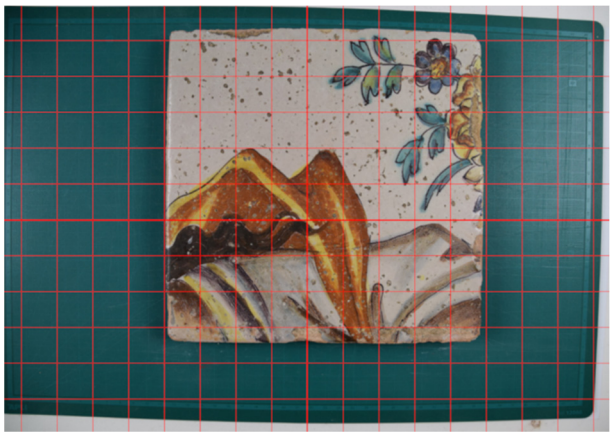


Figure 9. Original picture of piece PA08. Springtime panel, piece number 8, obverse.

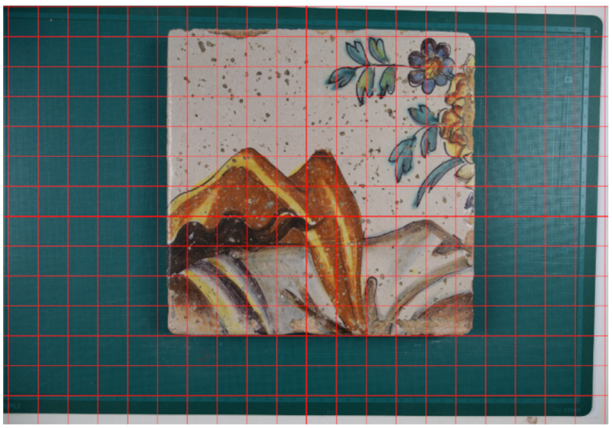


Figure 10. Piece PA08 rectified with PTLens software.



Figure 11. Piece PA08 rectified and cropped.

4. Results

In this section, the results obtained in the present work will be presented. These were classified into two parts: graphical restitution of the pavement, digital modeling of the room, and visualization of the set using VR techniques.

4.1. Graphic Restitution of the Flooring

Once cleaned and retouched, the images of the tiles were assembled into the different decorative panels using GIMP software, version 2.10, on a grid of 21.5 cm × 21.5 cm, creating a subset for each pattern: spring, summer, autumn, winter, Chronos, corner border, brown border, blue border, and white panel. The Four Season panels were made up of 16 tiles, Chronos panel of 44 pieces, and border and white panels of 9 tiles each (see Figures 12–14).



Figure 12. Spring panel.



Figure 13. Chronos panel.



Figure 14. Corner border panel.

After obtaining the individual patterns, a grid of 33 × 21 tiles was constructed, with each tile containing a distinct decorative pattern. Following this, the panel was finalized by incorporating a segment composed of undecorated white pieces (see Figures 15 and 16).

15	2	3	4	5	6	7	8	9	10	11	12	13	14	15	2	13	9	5	15	14	10	6	2	15	11	7	3	2	12	8	4	13
5	7	8	9	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	4	7	2	3
9	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6	2	5	8	6	7
13	1	2	3	7	8	9	7	8	9	7	8	9	7	8	9	7	8	9	7	8	9	7	8	9	7	8	9	3	6	9	10	11
2	3	6	9	4	8	12	16	13	9	5	15	15	2	3	4	4	8	12	2	13	9	5	1	1	2	3	4	7	4	1	14	15
6	2	5	8	3	7	11	15	14	10	6	2	5	6	7	8	3	7	11	15	14	10	6	2	5	6	7	8	8	5	2	3	4
10	1	4	7	2	6	10	14	15	11	7	3	9	10	11	19	2	6	10	14	15	11	7	3	9	10	11	12	9	6	3	7	8
14	3	6	9	1	5	9	13	2	12	8	4	13	7	13	20	27	33	9	13	2	12	8	4	13	14	15	16	7	4	1	11	12
3	2	5	8	15	2	3	4	2	15	14	13	3	8	14	21	28	34	39	4	15	2	3	4	2	15	14	13	8	5	2	15	2
7	1	4	7	5	6	7	8	12	11	10	1	4	9	15	22	29	35	40	43	5	6	7	8	12	11	10	9	9	6	3	15	2
11	3	6	9	9	10	11	12	8	7	6	2	5	10	16	23	30	36	41	44	9	10	11	12	8	7	6	5	7	4	1	5	6
15	2	5	8	13	14	15	2	4	3	2	15	6	11	17	24	31	37	42	2	13	14	15	2	4	3	2	15	8	5	2	9	10
4	1	4	7	16	15	14	13	4	8	12	2	13	12	18	25	32	38	14	13	4	8	12	2	13	9	5	1	9	6	3	13	14
8	3	6	9	12	11	10	9	3	7	11	15	14	10	6	26	12	11	10	9	3	7	11	15	14	10	6	2	7	4	1	2	3
12	2	5	8	8	7	6	5	2	6	10	14	15	11	7	3	8	7	6	5	2	6	10	14	15	11	7	3	8	5	2	6	7
2	1	4	7	4	3	2	1	15	5	9	13	2	12	8	4	4	3	2	15	15	5	9	13	16	12	8	4	9	6	3	10	11
15	9	6	3	9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	3	2	1	14	15
5	8	5	2	6	5	4	6	5	4	6	5	4	6	5	4	6	5	4	6	5	4	6	5	4	6	5	4	6	5	4	14	13
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13	12	11	10	9	8	7	6	5	2	15	14	13	12	11	10	9	8	7	6	5	2	15	14	13	12	11	10	9	8	7	6	5
9	8	7	6	5	4	3	2	15	12	11	10	9	8	7	6	5	4	3	2	15	12	11	10	9	8	7	6	5	4	3	2	15

Figure 15. Layout of the restored pavement with the numbering of the pieces Each color in the graphic reconstruction corresponds to a specific design or pattern, as illustrated in Figure 5. The exact pieces used have been individually numbered for reference.



Figure 16. Full design of the Four Seasons pavement.

The digital restoration technique used in this work can be exported to similar case studies where the original ceramics have been removed from their original location. It can also be applied in cases where some ceramics are preserved, while others have been dismantled or damaged due to use or alterations to the building, allowing for the recreation of the damaged designs. In the event of a loss of part of the original designs, the main obstacle is the lack of information about that part, which prevents the complete restitution [32,33] of the ceramic panels or necessitates redesigning based on the information that is preserved.

4.2. Graphical Modeling of the Hall

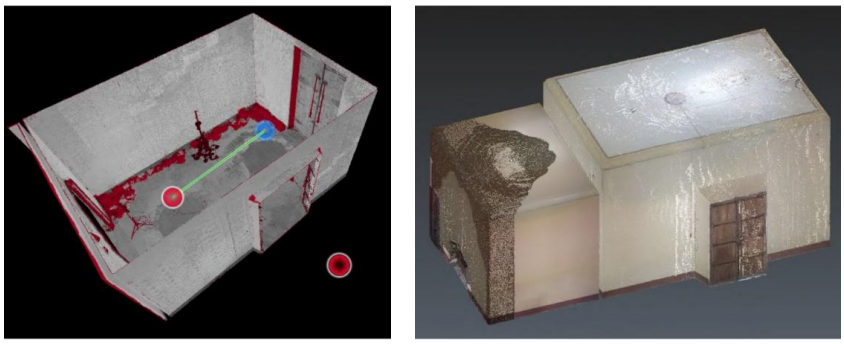
In this section, the results obtained from the modeling of the room using the various point clouds and images collected during the fieldwork will be presented.

4.2.1. Generation of the Point Cloud

To process the point clouds acquired from the scanner, we utilized LEICA GEOSYSTEMS CYCLONE REGISTER 360 software, version 2022.1. This software facilitated the recording and integration of the nine-point clouds by importing *.blk files from the scan and aligning them to identify three common points in each cloud, resulting in a consolidated point cloud. Furthermore, the software offered capabilities for refining and orienting the point cloud.

Using these unified point cloud data, we generated a digital model of the southeast hall, the location of the original pavement.

To enhance the clarity of the point cloud, we employed the "smooth surfaces" tool, which effectively eliminated excess points, focusing solely on the walls and floor. Any unselected areas were highlighted in red and subsequently removed automatically (refer to Figure 17).



(**a**) (**b**)

Figure 17. (**a**) Cleaning of the point cloud of the hall. (**b**) Color point cloud of the hall.

4.2.2. Meshing and Texturing of the Hall

To create the mesh, the point cloud was imported into the Cyclone 3DR program in an *.e57 format. Then, the "3D mesh creation" tool was selected, and the "two-step meshing" option was chosen (see Figure 18).

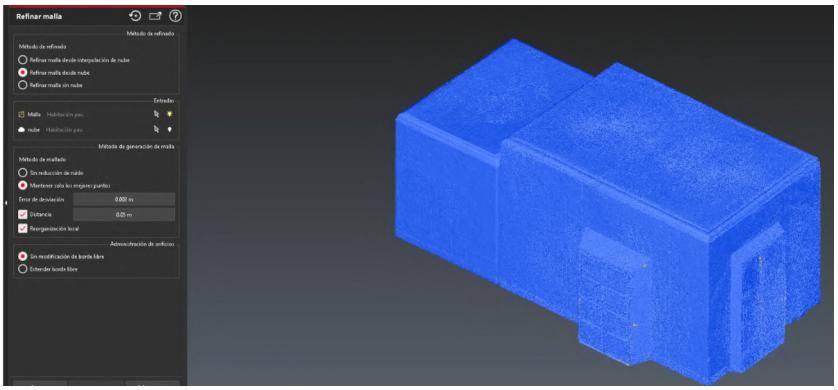


Figure 18. 3D mesh unrefined.

The next step was to select "refine mesh from cloud". From this process, a mesh of the hall was obtained. The next step was to improve the mesh for subsequent texturing.

Afterward, the "global smoothing" tool was used, and the "smooth noise" tool was selected, thus achieving a more homogeneous model. However, there were still several errors in the mesh that need to be corrected using different modeling tools.

Using the "clean/separate", "bridge", "fill holes", and "smooth mesh" tools, all poorly modeled parts were eliminated, and the mesh was adjusted. To delineate each part of the room for subsequently applying each texture in its correct place, a polyline was created on each one of the edges, its projection onto the mesh was performed, a constrained mesh was created, and subsequently the "sharp edges" tool was applied (see Figure 19).

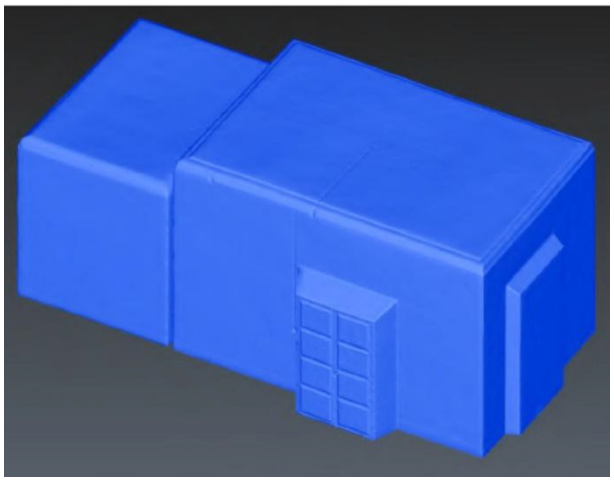


Figure 19. Tight and refined mesh.

With the GIMP software, version 2.10, the three spherical images captured by the scanner itself were edited to texture the room The main edits focused on fixing the lights that were generated on the walls and ceiling, removing the stacked tiles on one side of the hall, and eliminating the bed's headboard (see Figure 20).



(**a**) (**b**)

Figure 20. (**a**) Original spherical image of the hall. (**b**) Edited spherical image of the hall.

The adjusted and refined mesh was textured using different spherical images of the room once edited. With this procedure, a fully textured mesh of the room was obtained (see Figure 21).

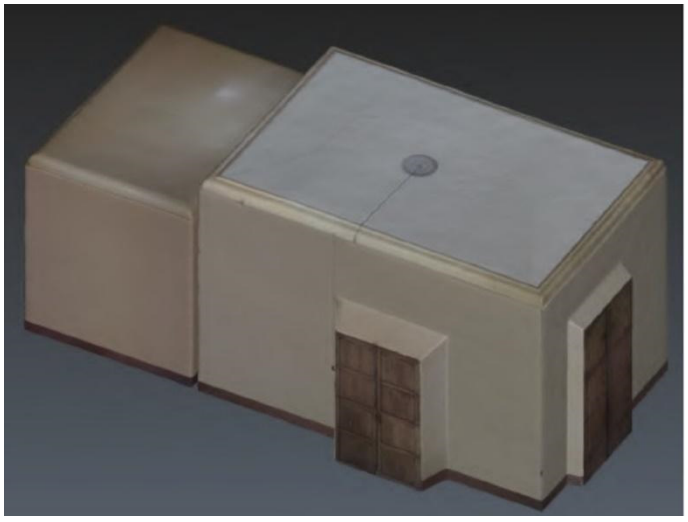


Figure 21. Mesh textured using spherical images.

For the creation of the flooring, two textures were created from scratch: one depicting the fully decorated flooring for the main room and another featuring a module of 4×4 white tiles for the adjacent room.

To facilitate the flooring placement, the flooring was divided into two parts and separated from the rest of the room, leaving a mesh of the walls and ceiling, one mesh on one floor, and another mesh on the other one. Each texture was applied separately by importing each image into the program, and using the "texture adjustment" tool, both textures were applied by adjusting the values of each image, so we positioned the images in their place.

By adjusting the values of each image, the images were placed in their correct positions. The result can be observed in Figures 22 and 23.

The result was a complete textured virtual model of the room that integrated the decorated ceramic flooring in its original location (see Figure 24).

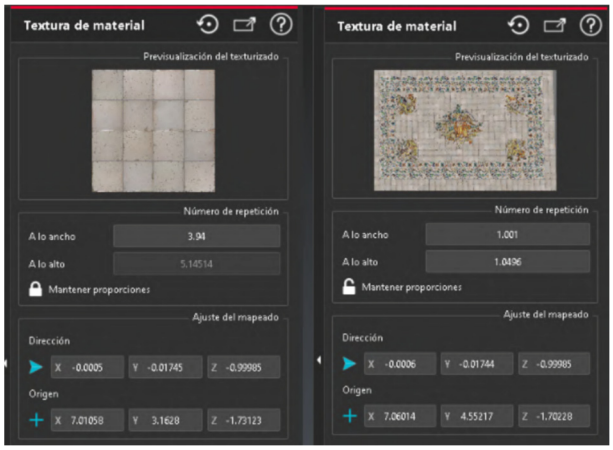


Figure 22. "Texture adjustment" tool.



Figure 23. Pavement texture adjusted to the mesh. Floor view.

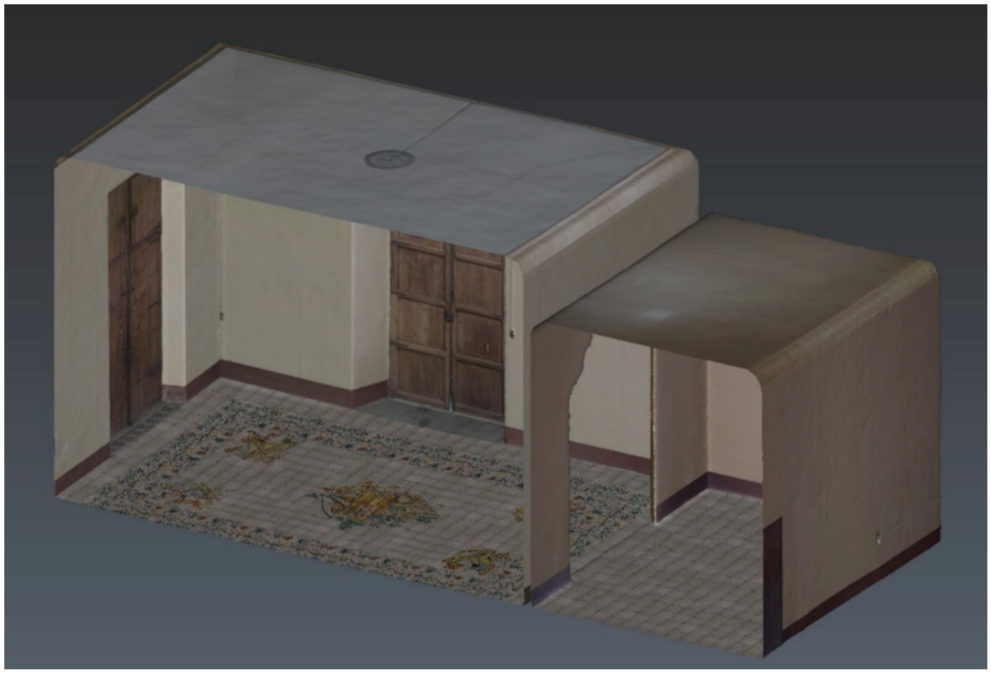


Figure 24. Mesh textured using spherical images. Longitudinal section.

4.2.3. Visualization of the Hall Using VR Techniques

To upload the model to the Sketchfab platform, the *.obj file size was reduced using MeshLab software, version 2023.12, as follows: Filters -> Remeshing, Simplification, and Reconstruction -> Simplification: Quadric edge collapse decimation (with texture) -> Target number of faces 500,000.

The model was uploaded to the Sketchfab platform, where it was possible to perform a 3D visualization of the model and navigate through it. The link to view the model is as follows: https://skfb.ly/oORSq, accessed om 10 June 2024 (see Figure 25).

Figure 25. QR code to access the 3D model.

5. Discussion

5.1. Physical Restitution through Digital Ceramic Printing Technology

In this context, the introduction of digital ceramic printing technology has revolutionized the field of restoration and preservation of decorative ceramics. This innovative technology allows for the precise and detailed reproduction of historical designs, providing an effective solution for restoring damaged or dismounted decorative elements, as in the case of the Marquis of Benicarló's House or other similar historic buildings.

The methodology for replicating the decorative designs and color palette of historic tiles developed by the Institute of Ceramic Technology (ITC) in collaboration with the company Fritta, S.L. facilitates the replacement of damaged or lost pieces, as well as the substitution of originals exposed by copies to ensure their preservation in optimal conditions. This methodology consists of three stages: characterization of the materials to be replicated, acquisition and digital processing of the decorative designs to separate the different colors, and development of a set of digital ink for inkjet printing that allows replicating the color palette of the tiles [31]. The use of reproductions produced with ceramic printing technologies using durable glazes could be an option to display the pavement to the public in its original environment. The duplicated pavement, being produced by means of glazes fired at high temperatures, could be walked on, while the original pavement was kept in suitable conditions in storage or museum showcases to guarantee its conservation.

5.2. Virtual Restitution through Digital Tools and VR Visualization

The tiles corresponding to the decorative scenes preserved in the museum (Four Seasons and Chronos) are in a good state of conservation, with two split tiles that were digitally retouched using the GIMP tool. As for the patterns of the linear and corner borders, many tiles exhibited significant wear due to usage. Since it was a repetitive pattern, a selection of tiles in good condition was made and arranged according to the design pattern to create a virtual reconstruction of what the flooring of the room would have looked like when it was laid at the end of the seventeenth century. Although the restoration of the tiles is technically possible, it would be very expensive and problematic due to their fragility, making them unsuitable for direct foot traffic. The virtual reproduction technique enabled a low-cost digital restitution, allowing the pavement to be visualized in its original location.

As a result of this digital treatment process, it is possible to offer better accessibility to architectural assets that would otherwise be difficult to access due to their private nature. In addition, the unique ceramic pavement is currently stored in the warehouses of the

NMCDAGM. Therefore, this study, through digital visualization techniques, exhibits in an open and free manner "hidden" cultural assets to the general public. These assets are not only better documented, but also exposed for other purposes of architectural, educational, and/or touristic interest that help to disseminate these cultural contents, and even open doors to further developments focused on the field of education and/or tourism, in tune with some of the literature mentioned [11–15]. In addition, using VR techniques, both the floor and the room itself can be visualized in a shared way in the cloud on the web. In this way, any interested person, including the scientific community, for example, specialists in restoration, can visualize the digitized room and its floor in a delocalized and non-synchronous way in order to continue studying the case in a way that is closer to the physical reality than using traditional photographic reproduction techniques. This, together with the relevant documentation provided by the written literature on the case, is an added resource that adds value for further studies (see Figures 26 and 27).

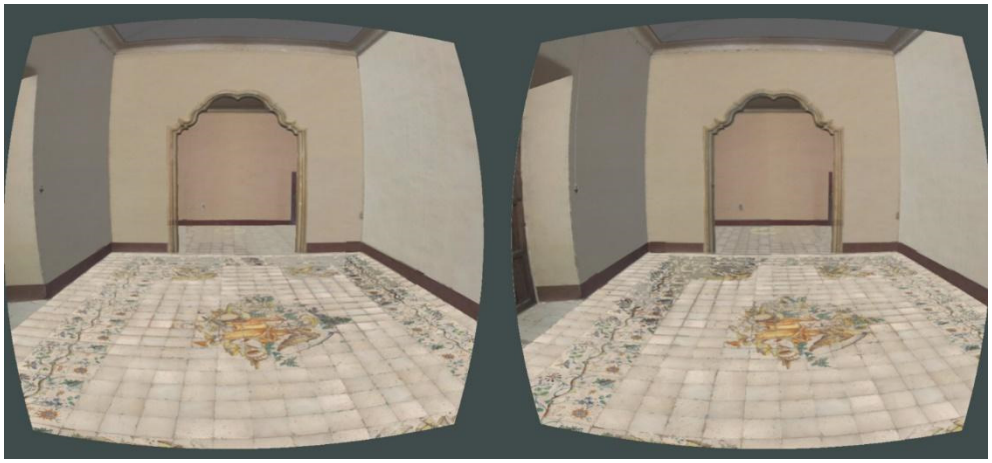


Figure 26. Visualization of the hall through VR.



Figure 27. View of the flooring in the 3D model of the hall.

6. Conclusions

This work has allowed the verification that the pavement preserved in the archives of the National Museum of Ceramics and Decorative Arts González Martí corresponds to the dismantled pavement of one of the noble rooms of the Marquess's House, as the dimensions of the dismantled panel (6.45 m × 4.12 m) match the measurements of the

panel preserved in the MNCADGM, as well as by the annotations found on the packaging of one of the pieces.

This pavement, due to its design and iconography, was the most important of all those found in the building, being together with the vertical cladding of the kitchen and the chapel the three decorative sets of the greatest artistic richness of the building; therefore, its recovery is very important as an architectural element of Baroque civil architecture in Valencian lands.

The good condition of the pieces that make up the main decorative motifs of the pavement (Chronos and Four Seasons) was verified, although some of their pieces have suffered minor damage or breakages during the dismantling process.

Regarding the pieces that make up the decorative borders, many pieces were found to have severe damage to their visible face due to use, although others were in better condition. This difference is undoubtedly due to their placement in areas of greater or lesser foot traffic within the room. The repetition of the module allowed the creation of three patterns: corner border, blue border, and brown border. A complete recreation of the pavement design was possible using these three patterns.

Due to the high heritage value of the ceramic pieces and their state of preservation, they should be fully restored by specialized technicians before their exhibition or relocation.

While the best way to enhance the value of this or any historical pavement is its placement in its original position as flooring, this poses a problem of conservation and maintenance.

A common solution is to place a protective sheet of transparent polyethylene; however, although these coverings prevent wear from abrasion, they do not prevent damage from impacts or overloading.

Another added problem is that these polyethylene sheets become yellow over time, so the pavements cannot be visualized with their original tone and brightness.

The methodology for reproducing historical tiles from an 18th-century Valencian kitchen, known for the complexity and richness of its chromatic decoration developed by technicians from the ITC [31], could be applied to the Four Seasons Pavement of the Marquis of Benicarló's House.

Therefore, an alternative solution to relocating the original pieces would be to manufacture a copy of the pavement using digital printing techniques from the digital model developed in this study and placing it in its original location, restoring the hall to its original architectural and heritage value.

This technique could also be applied to create virtual reproductions of the floors in the rest of the building's noble rooms, where the passage areas are heavily worn, but not the perimeters. It can also be applied to other pavements that have been dismantled from their original location or that are damaged or altered.

Thanks to this research work, the pavement has been included in the online catalog of the National Museum of Ceramics and Sumptuary Arts "González Martí" with the inventory number CE1/19025. This will allow other researchers to consult and study it [23].

Finally, this study serves as a starting point for the open nature of its results, to very diverse uses, mainly in the field of education, musealization, or even in the promotion of tourism.

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