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ARTICLE / ARTIGO

Architectural analysis of the main facade of the collegiate church of Osuna using high-density data collection

Análise arquitetónica da fachada principal da igreja colegiada de Osuna através da recolha de dados de alta densidade

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Abstract

This study examines the collegiate church of Nuestra Señora de la Asunción in Osuna, Spain, begun in the early 16th century. It presents numerous geometric alterations and a strong material heterogeneity, making it difficult to understand the construction sequence, and thus its heritage value for possible restoration work. The study aims to determine whether these anomalies are original or the result of later interventions. We therefore analyze both the structural and geometric details of the facade panels, approaching the subject from multiple perspectives thanks to the methodological improvements on the field of heritage building survey. The analysis of mass data collection suggests that geometric deviations are due to issues that emerged in the set-out survey for the building works, and that the facade was constructed in a continuous phase during the 1530s. The study concludes that the facade likely originates from the workshop of master Diego de Riaño.

KEYWORDS

Renaissance architecture
Photogrammetry
LiDAR
Point cloud data analysis
History of construction
Diego de Riaño

Resumo

Este estudo analisa a igreja colegiada de Nuestra Señora de la Asunción em Osuna, Espanha, iniciada no princípio do século XVI. A fachada apresenta muitas alterações geométricas e heterogeneidade material, dificultando a compreensão da sequência construtiva e, consequentemente, o seu valor patrimonial para eventuais intervenções de restauro. O estudo tem como objetivo determinar se estas anomalias são originais ou resultado de intervenções posteriores. Por isso, analisamos os pormenores estruturais e geométricos dos painéis da fachada, abordando o assunto de múltiplas perspetivas graças às melhorias metodológicas no campo do levantamento do património edificado. A análise da recolha de dados em massa sugere que os desvios geométricos da fachada se devem a questões que surgiram durante o levantamento das obras de construção e que a fachada foi construída numa fase contínua durante a década de 1530. O estudo conclui que a fachada é provavelmente originária da oficina do mestre Diego de Riaño.

PALAVRAS-CHAVE

Arquitetura renascentista
Fotogrametria
LiDAR
Análise de dados de nuvens de pontos
História da construção
Diego de Riaño

Introduction

The Renaissance collegiate church for the town of Osuna (c. 1531-1537) was a complex intervention financed by the fourth Count of Ureña (Figure 1). It is one of the essential buildings for understanding the transition from Late Gothic to Renaissance in Western Andalucia and, by extension, in the kingdom of Spain. The remit of the national Research and Development (R&D) project *Master Diego de Riaño and his stonemasonry workshop: Architecture and ornament in the context of the transition to the Renaissance in southern Europe* includes a complete study of the church; the work described here forms part of that project.

The facade presented an impediment for the definition and appreciation of the sixteenth-century design, primarily because the existence of significant geometric distortions and a puzzling material heterogeneity made it difficult to conduct a thorough analysis.

To conduct a rigorous analysis of the collegiate church facade, we used high-resolution orthophotos obtained with a laser scanner and drone photogrammetry to study the wall surfaces. As a supplementary source we used the information provided by the high-density point cloud. The result is twofold: an unprecedented reasoned sequence of the construction of the facade, which we ascribe to the design of Diego de Riaño; and a tested methodology that will improve the analysis and representation of heritage buildings using high-density data collection.

Figure 1. Plan of the town of Osuna and southwest view of the collegiate church.

The conclusion of these analyses is that the main facade of the church corresponds to a continuous construction process, associated with a single construction unit that would include the pillars, walls and vaults of the main nave and side aisles. Therefore, its execution is related to the design of the collegiate church of the second third of the sixteenth century.

It is important to emphasize that the result of the study allows us to accurately date the materiality of the facade of the temple, serving as a starting point for an adequate patrimonial interpretation for future restorations. All of it should be considered as a result of the Renaissance project and, therefore, of great architectural value and worthy of being preserved as far as possible.

Case study

In 1531 Juan Téllez-Girón succeeded his brother as the fourth Count of Ureña and Lord of Osuna. The new count was a generous patron of religious works, founding and funding numerous churches and monasteries throughout his large domain [1]. He paid particular attention to Osuna, where the collegiate church represents his most outstanding work.

Charting the history of this building is a complex task due to the lack of information and the numerous interventions that have distorted the original design. We know that the site on which it stands was once occupied by a parish church, the only one in Osuna [1], and that in 1526 the construction of a new chancel was under way [2]. A few years later, the fourth count embarked on an ambitious project to turn the parish church into a collegiate church. This gave rise to an entirely new nave-and-aisle section, likely respecting the existing apse and tower (Figure 2). As the only parish church in the town, religious services would have been conducted in the apse while the new section was being built. This apse must have been completed in 1534 because the flooring was laid and artworks were installed that year [1]. The building works commenced around 1531 and, soon after, the date 1533 was engraved on the main church portal. The project for collegiate church was likely initiated before official permission was received, because this only arrived in 1534 with publication of the papal bull for the creation of the institution [3]. Although we do not know for sure who authored the design, new data point to Diego de Riaño [4].

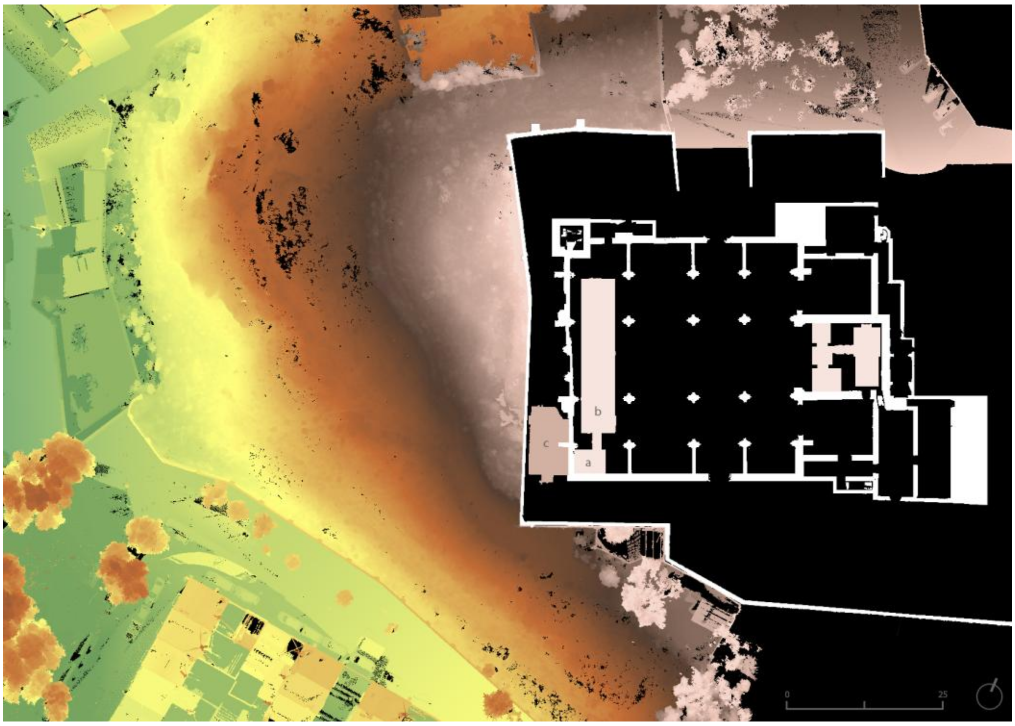

Figure 2. Point cloud horizontal cross section through the crypts with Digital Surface Model of the surroundings: *a)* crypt under the Chapel of the Kings; *b)* 1797 crypt; *c)* cryptoportico.

The collegiate facade represents an enigma in the original design. It faces west and stands on a raised atrium that compensates for the uneven terrain (Figure 1 and Figure 2). Today, the main facade opens on to waste ground, formerly the site of medieval Osuna that was abandoned and demolished after the townsfolk gradually moved outside the walled [5]. In addition to the accesses to the atrium via the side facades, a (now lost) stairway led directly up to the main entrance [6].

The facade is 20 meters high and 40 meters wide (Figure 3). It has four exposed buttresses and two stairwells that rise from the church floor to the roofs over the nave and aisles. There are three portals: the main one or *Puerta del Sol*, and two smaller ones that were walled up in 1798 [7].

A cryptoportico covered by two vaults was built under the atrium, taking advantage of the difference in ground level at the south-west corner (Figure 3). This space, currently accessed through the crypt near the church entrance, seems to have served as an extension to the funerary crypt and, more recently, as a storeroom.

The facade has undergone several interventions due to various traumatic events. For example, in 1918 the tower collapsed, possibly due to its structural weakness [7], as it was built with walls formed by exterior ashlars of "very inferior limestone" and by a "filling of rubble without any binding" [8]. Also, the facade foundations subsided when a crypt was excavated near the church entrance [8]. As a reinforcement mechanism, that same year the window over the main portal was bricked up [8-9].

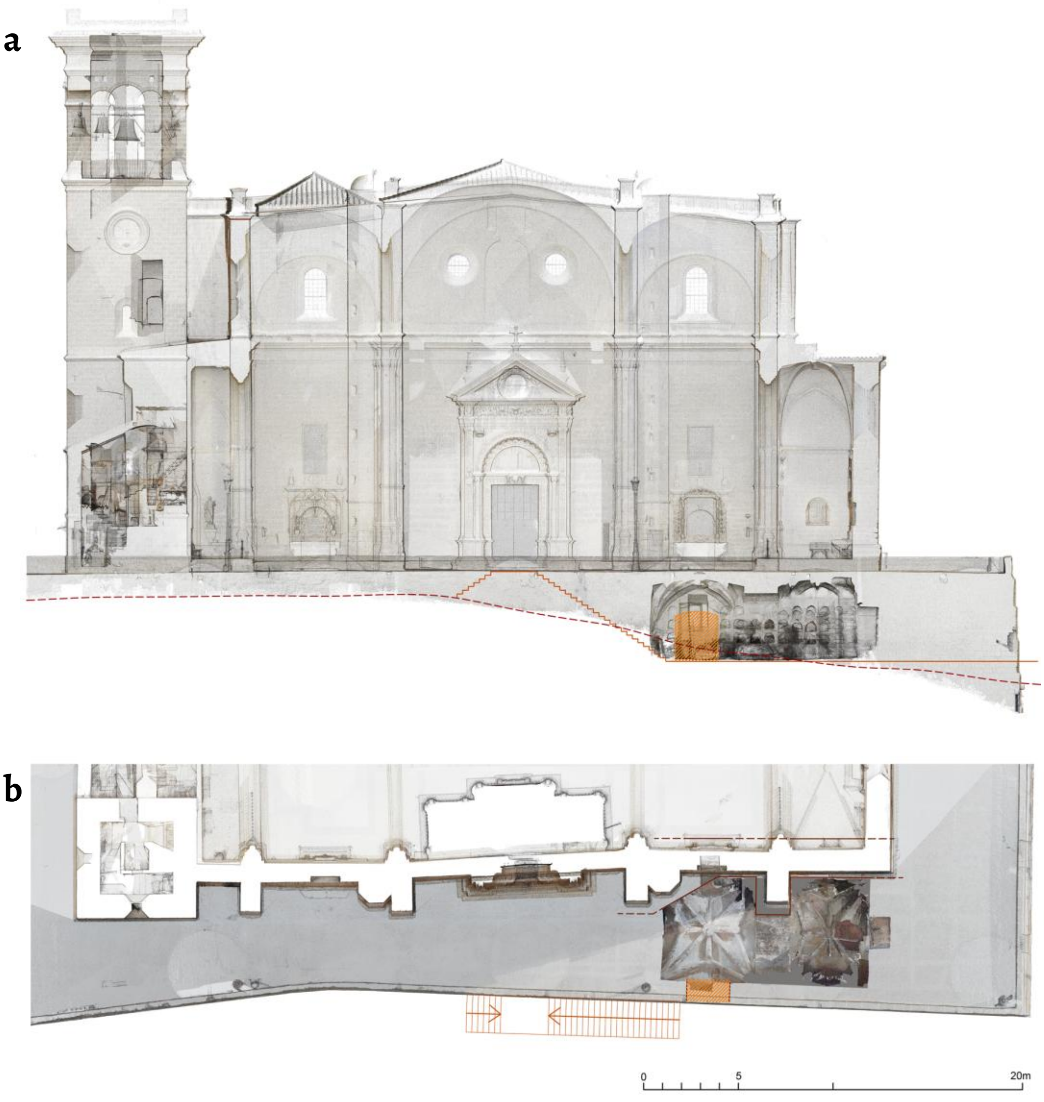

Figure 3. Facade with cryptoportico and possible stairway: *a)* floor plan; *b)* elevated plan.

Other transformations add even more challenges to our understanding of this elevation: the damage caused by Napoleon's troops during the French occupation [1], the mortar cladding over the entire interior elevation and the repairs to joints and ashlars in the lower part of the facade [10].

Lastly, the main elevation presents erosion issues due to the action of the sun and wind, areas of biological colonization and dirt, etc.

Research aim

The main aim of this study is to elucidate the building sequence of the facade and, by extension, contribute new data about the development of the overall church design for future conservation works.

The analysis of the aforementioned geometric distortions and material heterogeneity visible on the facade, which we undertook as a necessary step to determine how the execution of this part of the church fits in with the overall building process, prompted us to conduct a detailed study of the facade surfaces. That task required extending our research to the section of the atrium in front of the facade and the semi-underground cryptoportico (Figure 3), both of which were likely built at the same time as the facade.

Meanwhile, the continuous development of data collection devices, which tend to increase both the volume and typological diversity of the data collected, coupled with the improvement of data management software, should lead to changes in the methodology we use to analyze these data. This article explores the application of these advances to the study and representation of heritage architecture.

Materials and methods

As our first step, we created a cognitive corpus that allowed us to formulate an initial hypothesis about the construction of the building, which in turn enabled us to establish the aims of the following stages [11]. Next, we laser scanned the collegiate church and urban vicinity. For this task we used a Riegl Vz-400i scanner (Table 1) with a Nikon camera (Table 2) for coloring the point cloud. However, for the narrow space of the crypts we used a smaller and lighter scanner, a Leica BLK360 (Table 1).

We opted for photogrammetry to generate the orthoimages of the facade used to study the wall panels. Due to the height of the elevation and the narrow dimensions of the atrium, we decided to use aerial photographs with a DJI Mavic 2 Pro (Table 2). As the most restrictive data item, we established the minimum safe distance between the drone and the wall (proximity sensors activated) and obviated the GSD (< 0.05 cm/pix). We obtained this value by calculating the overlapping distance between captures.

The next step was to process the 600 photographs with Agisoft Metashape 1.5. To ensure the correct geometry and orientation of the photogrammetry point cloud it was necessary to introduce control points in the cloud [12]. For this purpose, we opted for circular coded markers that had been uniformly placed on the surface of the facade prior to data collection (Figure 4a). We collected these markers with the scanner to obtain their geographic coordinates. Once they were entered into Agisoft Metashape – the program recognizes them automatically, we obtained a total error of less than one pixel and less than three millimeters.

To optimize the point clouds and reduce the tie point errors, we followed the recommendations of Mayer, Gomes Pereira and Kersten [13]. We compared the two point clouds: the one from the scanner has a higher density, only in the lower areas of the facade, but greater heterogeneity in the whole (Figure 4b-1), while the photogrammetry cloud has a lower but more constant density of points (Figure 4b-2).

Table 1. Scanner specifications.

Model	Type	Range measurement performance			Scan pattern				
		Wavelength	**Max. range**	**Min. range**	**Measures**	**Resolution at 20m**	**Registration**	**GNSS Receiver**	**Weight**
RIEGL VZ-400i	Pulsed ToF	Near infrared	250 m	0.5 m	500.000 pts/s	7 mm	After acquisition	GPS	9600 g
Leica BLK360	Pulsed ToF	830 nm	60 m	0.6 m	360.000 pts/s	8 mm	After acquisition	None	1000 g

Table 2. Camera specifications.

Model	Sensor				Lens		
	Effective mpx	**Type**	**Stabilization**	**Shot on**	**Focal (35mm)**	**Autofocus**	**Aperture (f)**
Nikon D810	36.30	Full Frame CMOS	No (tripod)	JPEG (fine)	21	Phase detection	Continuous 2.8
DJI Mavic 2 Pro	20.00	1" CMOS	3-axis	RAW	28	Contrast detection	2.8-11

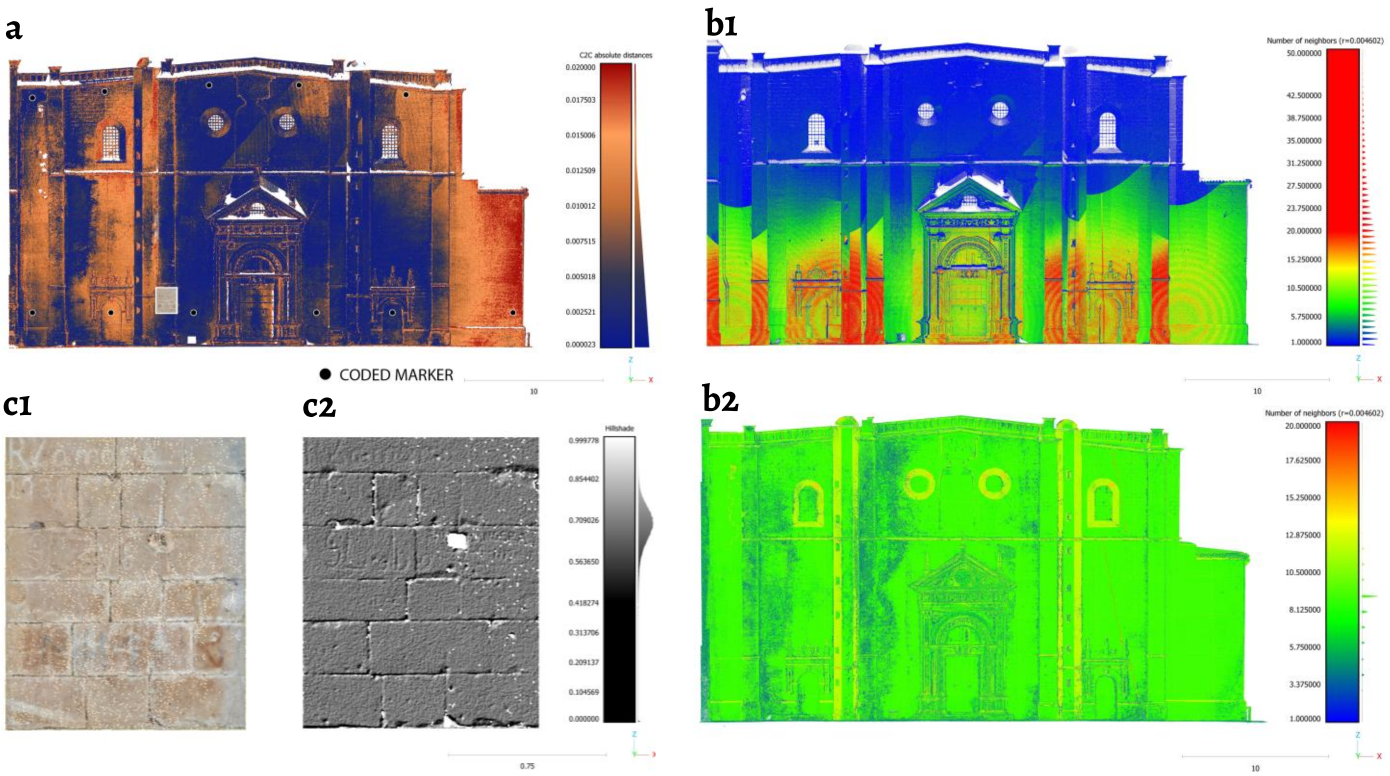

Figure 4. Hypothesis: *a)* Deviations between the cloud obtained by photogrammetry and the cloud obtained with the scanner; *b)* point density (number of neighbours) of the scanner point cloud (b1) and the photogrammetry point cloud (b2); *c)* relief surface detail: point colors view (c1) and Hillshade view (c2).

To check the geometric accuracy of the photogrammetry, we compared the drone cloud with the scanner cloud by aligning them in CloudCompare 2.13 with the ICP (Iterative Closest Point) procedure [14]. Next, we calculated the direct cloud-to-cloud distance using an approximation of the Hausdorff method [15]. This demonstrated that the distance variations between the two clouds are practically imperceptible, except for the right angle of the facade where more photographs would have been needed (Figure 4a).

Figure 5. Exploded orthophoto of the main facade and detail of the cartouche from 1533.

After validating the quality of the point clouds, we generated a series of images to analyze and illustrate our research. With the indoor and outdoor scanner cloud, at CloudCompare we obtained see-through visualizations generating a large JPG without altering the scale of the dots [16]. On the other hand, to calculate the best fit plane deviation in Figure 8, which we discuss later, we generated a Height Map (DEM) following two steps in CloudCompare: i) we created a plane on the reference wall section based on a representative selection of points on the surface (via Fit Plane); and ii), we calculated the distance between the plane and the point cloud (via Cloud/Primitive Dist.), the depth information was stored as a scalar value of the 3D cloud [17-19].

Also in CloudCompare and for specific cases, like checking elements that were not visible in the 2D photographs (Figure 4c-1), such as incisions, depressions, etc., we generate a Hillshade view (Figure 4c-2), through the Rasterize command selecting the most favorable sun position, of the cloud with a more homogeneous density, i.e., that of the photogrammetry (Figure 4b-2). Lastly, in Agisoft Metashape we generated orthoimages of the main planes of the facade, selecting manually the photographs for better orthophoto creation [20]. This produced a combined orthophoto with a resolution approaching the gigapixel size (Figure 5) [21].

Results and discussion: an approximation to the building process of the main facade of the collegiate church

The influence of the terrain in the initial phases of execution

As mentioned in the introduction, the study of the facade must take into account the ways in which the church was adapted to its urban vicinity, given that the highly uneven topography of the site impacted the building process.

An extensive system of retaining walls was erected to regularize the natural terrain, defining a horizontal plane of support that stretches beyond the church boundaries to generate a horizontal platform around the north, west and south facades (Figure 2). To the west, the archaeological data suggests the existence of an asymmetrical double flight of steps adapted to the topography. The remains were discovered during archaeological excavations carried out in the El Higueral sector. The archaeological report has not yet been published, but we refer to the information included in [22]. These steps define a profile of the terrain that is fairly close to what we see today (Figure 3). Consequently, the terrain on which the church was built presented a sharp south-west gradient similar to the current one, with a difference in height of more than four meters.

In the western sector we located several spaces beneath the level of this esplanade, two inside the church and one outside. Near the entrance, on the Epistle side, the crypt of the Chapel of the Kings, owned by the Alaya family, was built (Figure 2a), at least, since 1601, when the interior walls were painted [23]. Also, near the entrance, a large crypt was excavated in 1797, possibly accessed from the former crypt (Figure 2b). Outside the perimeter of the church, a vaulted structure was built under the platform, taking advantage of the difference in height, to serve as a cryptoportico with external access (Figure 2c).

Curiously, these spaces adopt a different layout (Figure 6). The crypt from the late eighteenth century maintains a safety distance from the nearby constructions – both the facade and the line of interior piers – in keeping with a procedure commonly followed in excavations to preserve the integrity of nearby foundations. However, both the Ayala crypt and the cryptoportico extend right up to the facade wall, without respecting this safety distance. The position of these two crypts adjacent to the wall is explained by the fact that these spaces were not excavated but built, taking advantage of the difference in height that existed at the south-west corner between the horizontal plane of the platform and the natural terrain.

This wall shared by the cryptoportico and the Ayala crypt is the continuation of the facade wall and reproduces the buttress and stairwell at a semi-underground level, albeit with a greater thickness. We therefore believe it is a basement wall that was necessary to reach the foundations, located below -4.00 m (Figure 6 and Figure 7). Given the continuity between the ribs of the vaults and this extension of the wall facade, and the embedded position of the side arches in that wall, the cryptoportico must have been built at the same time as the church facade. These data were deduced from the analysis of the cryptoportico walls performed with the high-resolution scanner (Figure 7).

We conclude that the terrain on which the works for the new church began presented a depression at the south-west corner that led to the construction of retaining walls and a basement wall that extended the facade down to the foundation level. The cryptoportico and the Ayala crypt were built between these walls. This represents a first phase of execution based on a general set-out survey of the church on two levels: on the Gospel side, the works were carried out at approximately the floor level of the church, while on the Epistle side they were conducted four meters below that floor level (Figure 7).

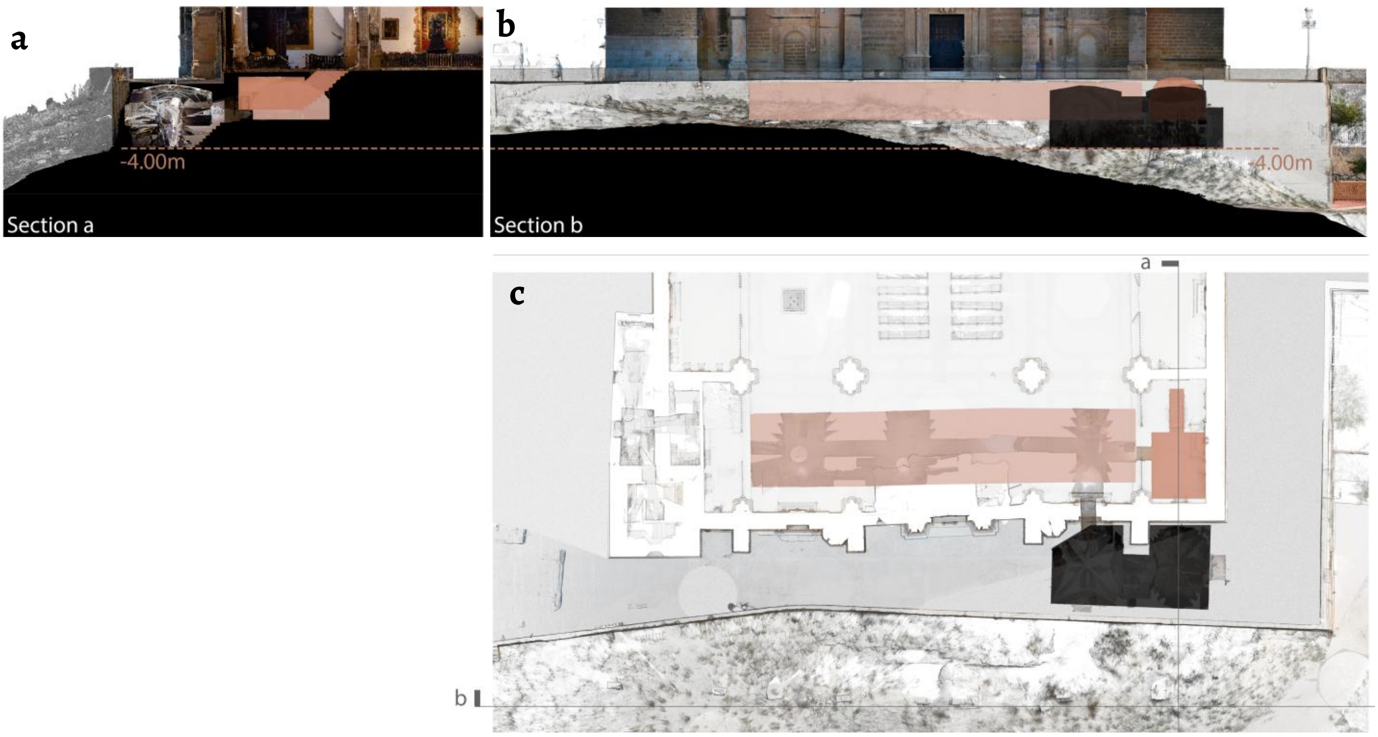

Figure 6. Sections through the west crypts: *a)* cross-section; *b)* longitudinal section; *c)* floor plan.

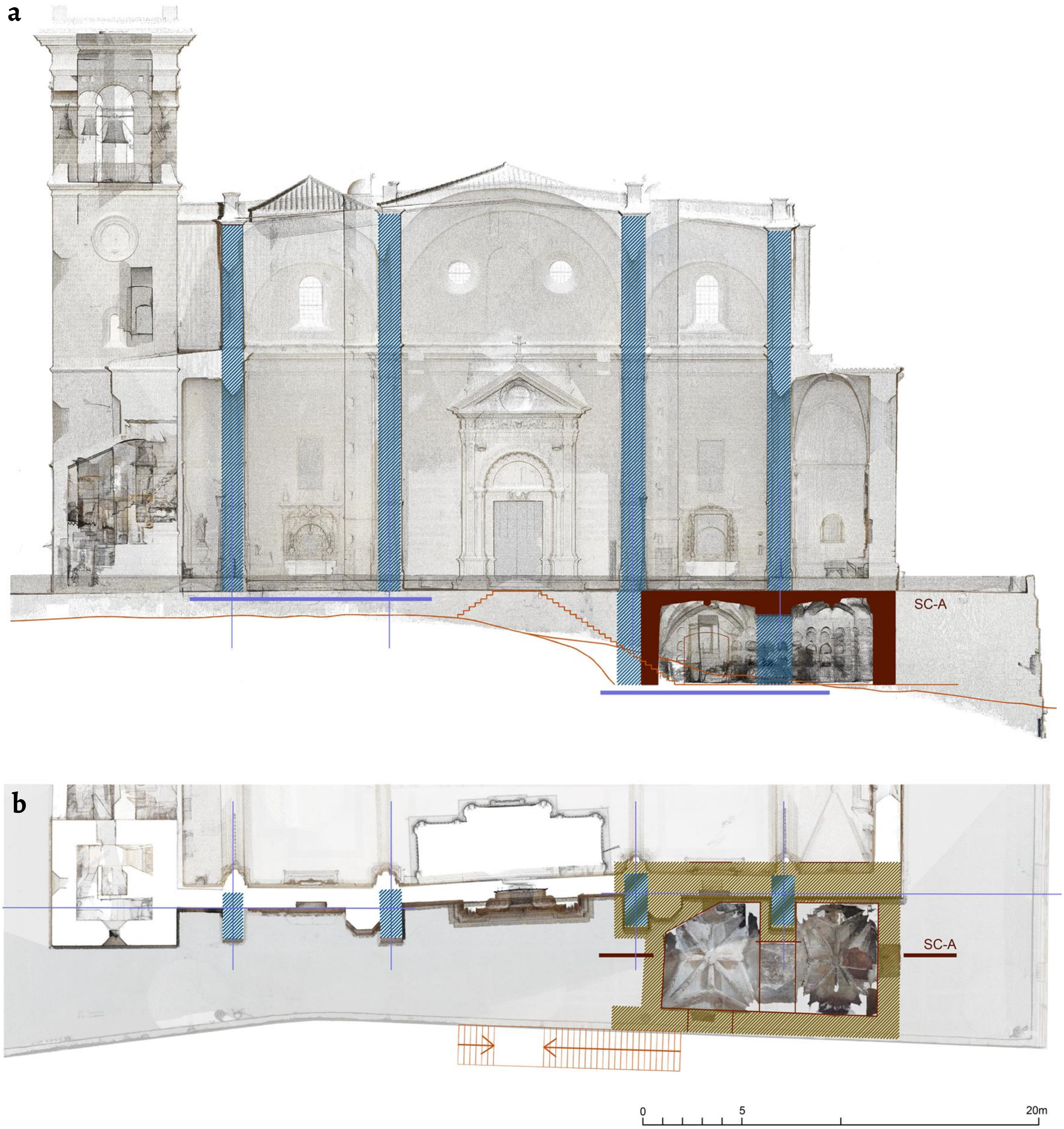

Figure 7. Facade indicating the internal structure of the nave and aisles and possible staircase: *a)* floor plan; *b)* elevated plan. The initial construction levels are indicated in purple.

Alterations introduced due to the different set-out survey levels

Before explaining the geometric distortions, we must point out two important aspects.

The first is the possible existence of two separate teams working simultaneously, one on the Gospel side and the other on the Epistle side. Inside the church, the study of the mason's marks reveals that these two groups worked more or less independently, one on each side of the nave [4]. This led to small discrepancies in the solution adopted for the pier bases, differences in the quality of the stonework, and the hasty resolution of certain elements on the Epistle side. This same duality is discernible on the facade: the buttresses on the Gospel side present a continuity with the brick courses but this is not the case with the ones on the Epistle side. Furthermore, the openings for the stairwells are inserted at different heights and on different faces of the octagon (Figure 5). The work at different levels that we suggested above supports the existence of these two teams working simultaneously.

Secondly, the Gospel side evidences greater regularity in the proportions and dimensions, which are more closely adapted to whole values in Castilian yards. This indicates that the set-out survey for that sector was more accurate than the one for the Epistle side. We therefore take the orientation and position of the facade section corresponding to the nave, aisles and Gospel chapels as the "correct" placement and closer to the master's set-out survey.

Assuming this hypothesis for operative purposes only, a comparison of the geometry of this sector of the facade with the rest of the elevation reveals that the symmetrical section, corresponding to the nave and Epistle chapels, presents a significant horizontal displacement (Figure 8). However, the correspondence that is clearly discernible between both facade sections cannot be coincidental.

The area marked as 1 (Figure 8b) is the reference plane. The wall of the gospel chapels has also a height of 0.00 m. Although the walls of the epistle and its chapels are separated, they have a constant distance of about 0.41 m and, therefore, are parallel to sector 1.

In between, the central section of the facade appears to deliberately reconcile the two orientations established in the aisles. The unusual geometry of this section of the facade and its nature as a type of "adjustment piece" are visible on the interior face, where the overlap of the side piers is avoided by reducing their thickness with respect to the adjacent wall sections.

We hypothesize that the complex execution resulting from the conditions described above – primarily, the existence of two teams working at two different levels – led to a significant set-out survey error between the two simultaneous work areas. This error did not affect the orientation of the two sections, which could easily be checked, but it did impact their total length, since working on sloping terrain and making transversal checks and adjustments demanded a degree of expertise.

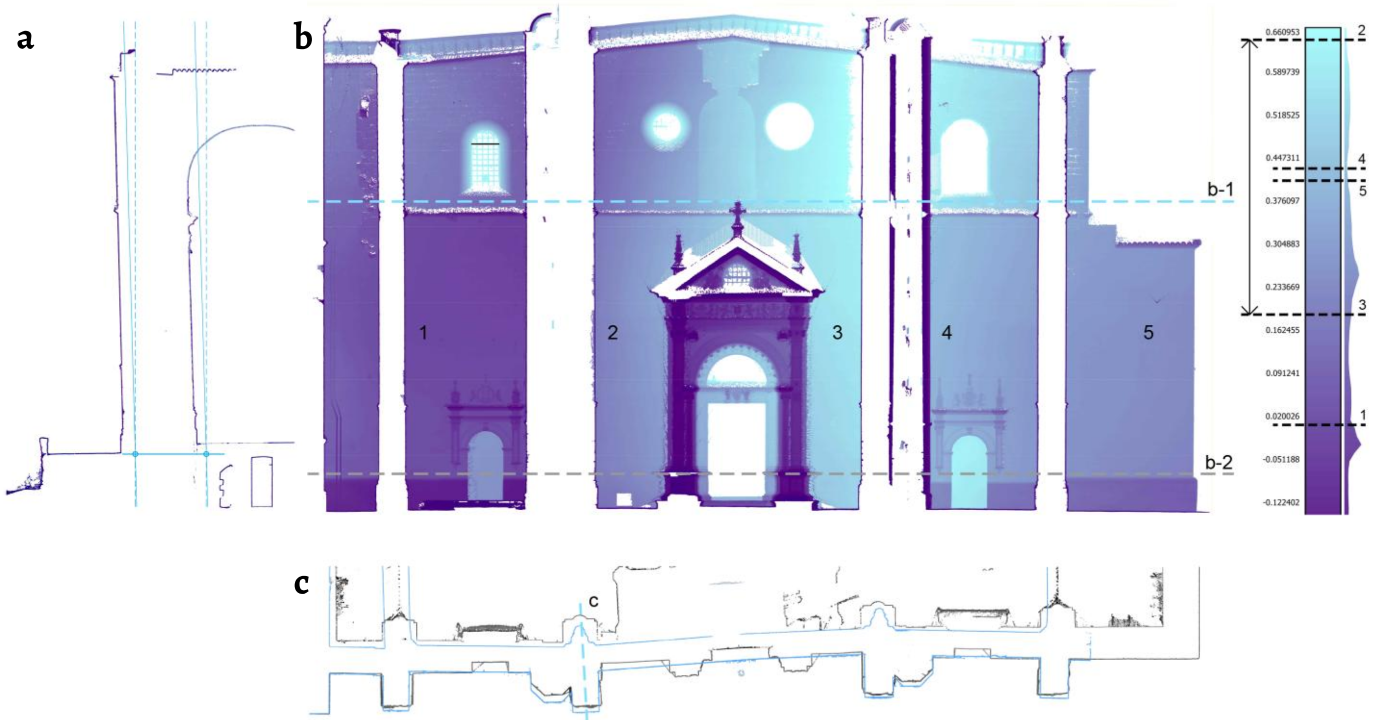

Figure 8. Facade views: *a)* elevation with deviations of the facade wall surfaces with respect to a selected plane; *b)* horizontal cross-sections of the facade at different heights; *c)* cross-section through a buttress.

Building process and material diversity

The study of the facade materiality enabled us to assess its extraordinary heterogeneity in relation to two important issues: i) whether it obeys aspects of the original design or subsequent modifications of the Renaissance proposal; and ii) whether it obeys the existence of reused building elements on different surfaces of the facade.

The buttresses

The first elements we analyzed were the buttresses, whose singular characteristics presupposed their consideration as independent building units.

In the orthophotos, the lower section of the facade reveals a lack of material continuity between the buttresses, the stairwells of the spiral staircases and the adjacent wall surfaces (Figure 9a). The buttresses and staircases were executed with a more compact and better quality of stone, possibly brought from the nearby town of Estepa [24]. They were cut with precision and bonded with minimal joints, especially between stones, whereas the general wall surfaces were built out of a local porous stone, cut in an irregular fashion and bonded with generous joints. The position of the horizontal rows also displays significant variations between the stairwells, buttresses and general surfaces (Figure 9b).

The section above the main cornice displays a material homogeneity and greater continuity between surfaces (Figure 9a). The better quality of stone has disappeared and the rest of this entire section of the facade is executed with the stone used for the facade walls. In addition to the use of the same type of ashlar, the continuity detected in the rows of the surfaces and the buttresses suggests that they belong to the same construction unit. However, although the same material was used for the stairwells, there is a discontinuity between the rows, which are situated at a different level (Figure 9b). We therefore deduce that the buttresses and general wall surfaces were executed simultaneously, while the stairwells were built at a slightly later time, probably because these stone blocks were more complex than the rest of the facade.

Figure 9. Facade panel analysis: *a)* materials; *b)* continuity of bed joints.

The correspondence between the facade walls of the vaults and this continuous elevation formed by the buttresses and surfaces of the upper section of the facade suggests that these elements were all executed together. The comparison of the collapse of the buttresses and of the facade wall support this hypothesis (Figure 8a). The angle of inclination is exactly the same, confirming that the facade did not undergo any thrusts before the buttresses were executed. This also disproves the hypothesis formulated in other studies about the possible execution of the buttresses to resolve thrust issues caused by the vaults [7].

In addition to this continuity in the upper section of the facade, the aforementioned presence of the facade buttress on the basement wall below the floor level of the church, corresponding to the first phase of the building works, enables us to conclude that the buttresses formed part of the original facade design, assuming that a vaulted system to cover the church was envisaged from the outset. The difference in the size and material of the ashlars of the buttresses and walls in the lower section justifies the lack of continuity between these elements, while the difference in quality between the stone used in the lower and upper sections of the buttresses obeys a reduction in building costs that is also discernible inside the church, where above the same level the better-quality stone was abandoned, the ornamentation was reduced and the ribs in the vaults were simplified.

The continuity of surfaces

The hypothesis about the simultaneous execution of the buttresses and wall surfaces does not rule out the possibility that a specific section of the walls was built earlier or later than the rest of the facade. Our analysis of the continuity between the elevations of the nave and aisles sheds light on this matter.

The central section displays an inferior type of bond that is not repeated anywhere else on the facade. Its layout is related to the execution of the main portal for two reasons: i) the rows of brick in the bond serve to align the stone bed joints in the wall with the configuration of the stones in the portal; and ii) this inferior bond is delimited by the shape of the pediment (Figure 10).

Figure 10. Detail of the main portal: continuity of stone bed joints thanks to the rows of brick.

Above the portal and these adjacent sections is a complete section executed with the general bond used for the facade that we mentioned earlier (Figure 9b). This same bond was used on the entire vertical deployment of the aisle and chapel elevations. All three portals that were resolved with a bioclastic limestone [9], a better quality of material more appropriate for stonework (Figure 9a). In addition to sharing the same material and type of bond, the last rows beneath the main cornice of the nave, aisles and side chapels display a clear horizontal correspondence with the central section, with coordinated bed joints, offering unequivocal evidence of the existence of a common building process (Figure 9b). Consequently, the continuity between the surfaces above the main cornice, as mentioned above, is also observed in the rows below the cornice, up to the height of the central portal.

We can therefore assert that the facade walls were executed during the same building process, except for the section around the main portal where we can only surmise its sequence in the overall process: namely, that it corresponds to an execution unit completed before the rest of the facade and was therefore the first section built above the floor level of the church.

Proposed timeline of building phases

Lastly, we divided the time frames for the execution process into three phases.

The first one is easy to establish because of the cartouche that pinpoints the portal and adjacent facade wall to the year 1533 (Figure 5).

As for the second phase, there are compelling reasons to consider that the interior and exterior were designed simultaneously. For one thing, there is a clear geometric and structural concordance between the facade and the church nave and aisles. Furthermore, there are nearly 30 types of mason's marks present on both the facade and interior piers [4]. This design likely corresponds to the Renaissance church of the second third of the sixteenth century, probably begun by Diego de Riaño and completed by Martín de Gainza. If we accept this hypothesis, the second phase must have been a continuity of the first phase, occurring after 1533 or 1534. Why this material discontinuity between two phases that possibly belong to the same building process? We cannot offer a reasoned explanation for this, but we must consider the possibility that the stones in the portal, a separate workshop element, had been delivered to the site at an early date in the process and the portal was erected in its definitive position before the material for the rest of the facade had arrived. This would explain the adaption of the facade wall to the portal geometry and the use of a bond that was not repeated anywhere else in the building.

The third phase, which includes all the elements above the main cornice, was likely the continuation of the second phase and was completed in about 1537, when the bylaws for the new collegiate institution were published and read by the church council from the choir [1]. The church must have had a roof by then, as this would have been necessary to ensure appropriate conditions for the ceremony to take place. However, we cannot infer that the vaults had been executed because if a timber roof existed, it was common practice to build this before the system of vaults, using the timber framework for support [25-26].

Conclusions

The analysis of the geometric characteristics of the facade confirms the existence of sharp deviations between the orientations of the facade wall surfaces. Furthermore, the study of those surfaces clearly reveals the lack of correspondence between the walls, buttresses and stairwells up to the level of the main cornice, all executed with different materials and bonds. As is made clear throughout the article, this lack of continuity is not the result of chronologically distant construction phases. The study of the initial stages of execution of the church provides a reasoned explanation for the significant geometric deviations between surfaces, attributable to problems during on-site layout and not to different construction phases, while the detailed analysis of the materials seems to confirm a continuous time frame for the overall execution, although probably within a complex and uneven construction process. In summary, we can confirm as the main conclusion that the main facade of the church corresponds to a continuous construction process, associated to a single construction unit that would include the pillars, walls and vaults of the central and lateral nave. Therefore, its overall execution is related to the design of the Renaissance collegiate church of the second third of the sixteenth century.

The material characterization of the facade, including the precise dating of its components, serves as a starting point for a proper heritage evaluation for future restorations, ensuring that there are no errors of interpretation that involve the transformation or demolition of original architectural elements. In this case, the entire facade should be considered as the result of the Renaissance project, of great architectural value and worthy of being preserved as far as possible.

Lastly, the increased density of the data collected offers new analysis possibilities, two with particular application to the study of heritage buildings: i) improved software for analyzing surfaces with point clouds opens up interesting fields for studying deformations, orientations or surfaces; ii) the use of the different point cloud attributes permits new forms of graphical representation and analysis.

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CONSERVAR PATRIMÓNIO

ARTÍCULO / ARTIGO / ARTICLE

Implementación de HBIM para la gestión, conservación y difusión de un edificio patrimonial protegido del siglo XX: el Real Club Náutico de Donostia-San Sebastián

Implementação de HBIM para a gestão, conservação e divulgação de um edifício patrimonial protegido do século XX: o Real Club Náutico de Donostia-San Sebastián

Implementation of HBIM for the management, conservation and dissemination of a protected 20th-century heritage building: the Real Club Náutico of Donostia-San Sebastián

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Resumen

El Real Club Náutico de San Sebastián (1929), Bien Cultural desde 2001, es un referente del Movimiento Moderno en España. No obstante, su preservación enfrenta retos debido a la dispersión documental y a su singular condición de edificio patrimonial del siglo XX en uso activo como club privado con espacios públicos. Este estudio propone, mediante el desarrollo de un modelo 3D HBIM (Historic Building Information Modeling), un sistema de parametrización e integración de datos documentales, históricos y constructivos, que mejoren la gestión, conservación y difusión del inmueble. La recopilación y clasificación bibliográfica, la organización de los elementos constructivos del modelo en fases histórico-constructivas y la identificación de patologías actuales, permiten la trazabilidad histórica del edificio y el intercambio de información entre agentes implicados. Asimismo, mejora la toma de decisiones, y ofrece nuevas oportunidades para la divulgación y puesta en valor del inmueble, contribuyendo a su perdurabilidad a largo plazo.

PALABRAS-CLAVE

Real Club Náutico de San Sebastián (RCNSS)
HBIM
Movimiento Moderno
Arquitectura Patrimonial
Conservación
Reconstrucción

Resumo

O Real Club Náutico de San Sebastián (1929), Bem Cultural desde 2001, é um marco do Movimento Moderno na Espanha. No entanto, sua conservação enfrenta desafios devido à dispersão documental e à sua singular condição de edifício patrimonial do século XX em uso ativo como clube privado com espaços públicos. Este estudo propõe, através do desenvolvimento de um modelo 3D HBIM (Historic Building Information Modeling), um sistema de parametrização e integração de dados documentais, históricos e construtivos, que melhore a gestão, conservação e difusão do imóvel. A compilação e classificação bibliográfica, a organização dos elementos construtivos do modelo em diferentes fases histórico-construtivas e a identificação de processos patológicos no estado atual permitem a rastreabilidade histórica do edifício e o intercâmbio de informações entre os agentes envolvidos. Melhora, também, a tomada de decisões e oferece novas oportunidades para a divulgação e valorização do bem, contribuindo para sua preservação a longo prazo.

PALAVRAS-CHAVE

Real Clube Náutico de San Sebastián (RCNSS)
HBIM
Movimento Moderno
Arquitetura Patrimonial
Conservação
Reconstrução

Abstract

The Real Club Náutico of San Sebastián (1929), designated a Cultural Heritage Site since 2001, stands as a landmark of the Modern Movement in Spain. However, its preservation faces challenges due to fragmented documentation and its unique status as a 20th-century heritage building in active use as a private club with public areas. This study presents a 3D HBIM (Historic Building Information Modelling) approach, offering a system for parameterising and integrating documentary, historical, and construction data to enhance the building's management, conservation, and dissemination. The bibliographic compilation and classification, the organisation of construction elements by historical-constructive phases, and the identification of current pathological conditions enable the building's historical traceability and facilitate information exchange among stakeholders. Furthermore, it supports informed decision-making and opens new avenues for the promotion and appreciation of the property, thereby contributing to its long-term preservation.

KEYWORDS

Royal Nautical Club of San Sebastián (RCNSS)
HBIM
Modern Movement
Heritage Architecture
Conservation
Reconstruction

Introducción

El edificio del Real Club Náutico de San Sebastián (RCNSS) (Figura 1), inaugurado en 1929 y declarado Bien Cultural con la categoría de Monumento en 2001 (BOPV nº16, 23-01-2001), representa un referente arquitectónico del Movimiento Moderno en España y un símbolo distintivo de la ciudad de Donostia-San Sebastián [1]. Diseñado por los arquitectos José Manuel Aizpurua Azqueta (1902-1936) y Joaquín Labayen Toledo (1900-1996), el edificio ha sido objeto de diversas intervenciones a lo largo de su historia [2-7], lo que ha generado una fragmentación documental significativa y ha dificultado su conservación, gestión y difusión

A pesar de su condición de bien protegido, el edificio del RCNSS pertenece a un club social privado, lo que restringe su acceso y limita las iniciativas de mantenimiento preventivo y sensibilización social. Sin embargo, parte del inmueble está arrendada para un espacio gastronómico de pública concurrencia, generando un complejo equilibrio entre su uso privado y público, planteando retos adicionales en el uso sostenible del edificio, incrementando la necesidad de herramientas innovadoras que permitan centralizar la información y optimizar la toma de decisiones técnicas para su preservación y administración eficiente.

En este contexto, la metodología Historic Building Information Modeling (HBIM) se ha consolidado en los últimos años como una solución innovadora para la gestión del patrimonio arquitectónico [8-17]. Esta metodología permite la creación de un modelo tridimensional que integra datos geométricos, históricos y constructivos en un entorno común de datos [13], proporcionando una representación detallada de las distintas fases evolutivas del edificio.

Figura 1. Edificio del RCNSS, Donostia-San Sebastián, Gipuzkoa (Foto: J. García Moreno, 2024).

Estudios previos destacan el potencial del HBIM para minimizar errores en los procesos de restauración y fortalecer la comunicación interdisciplinar [8] ya que funciona como un soporte colaborativo accesible a todos los agentes involucrados en cada intervención [18]. Al integrar información geométrica (modelo 3D, levantamientos tridimensionales) y no geométrica (alfanumérica y archivos vinculados como planos históricos, fotografías de época, informes, etc.), esta metodología genera un repositorio digital del edificio, permitiendo un análisis más preciso de su evolución constructiva y material. Esto no solo mejora la precisión en la ejecución de intervenciones, sino que también optimiza costes y contribuye a la sostenibilidad de los proyectos de rehabilitación y mantenimiento preventivo y correctivo del patrimonio construido, así como para su difusión cultura [19-20].

El RCNSS, cuya volumetría y configuración original ha sido alterada a lo largo de los años para adaptarse a las necesidades cambiantes del club [1-7], encuentra en la aplicación de HBIM un soporte clave para garantizar la sostenibilidad patrimonial del inmueble a lo largo de todo su ciclo de vida. La presente investigación tiene como objetivo principal demostrar que la aplicación de la metodología HBIM, junto con la integración de datos geométricos, históricos y constructivos en un entorno digital unificado, puede mejorar significativamente las estrategias de salvaguarda y puesta en valor del edificio, optimizando la toma de decisiones en futuras intervenciones y garantizando una gestión más eficiente y sostenible del patrimonio edificado [21].

La conservación de un bien patrimonial depende de la rigurosidad del conocimiento obtenido de la información previa disponible [20, 22]. Por ello, la base de esta investigación se sustenta en la recopilación y sistematización exhaustiva de la información disponible sobre las distintas fases histórico-constructivas del edificio, obtenida a partir de diferentes registros históricos (documentos, memorias, informes, bibliografía, planos, fotografías, anotaciones, etc.). Esta base documental servirá como soporte para el desarrollo del modelado 3D HBIM de las fases constructivas más relevantes del RCNSS. A partir de estos planteamientos, se han definido una serie de objetivos específicos. En primer lugar, el desarrollo de un modelo 3D HBIM de las fases constructivas más relevantes del edificio que represente tanto su estado actual como sus estados previos integrando la información documental y constructiva obtenida.

Una vez construido este modelo virtual del edificio, es necesario evaluar su precisión y utilidad en contextos de restauración y estrategias de musealización, analizando su potencial para mejorar la interpretación y protección patrimonial del inmueble. Asimismo, se pretende optimizar la organización de los datos históricos y técnicos y analizarlos principales desafíos técnicos y metodológicos enfrentados durante el proceso de implementación de la metodología HBIM con el fin de generar conocimientos aplicables a futuras investigaciones y proyectos de conservación.

Con este enfoque, se busca establecer un flujo de trabajo replicable que permita el uso del HBIM como una herramienta clave en la preservación, administración eficiente y puesta en valor del patrimonio arquitectónico.

Metodología

La investigación se fundamenta en la aplicación de la metodología *Design Science Research* (DSR) orientada a diseñar, desarrollar y evaluar soluciones innovadoras en contextos reales [23]. Siguiendo el marco propuesto por Takeda et al [24] y Holmström et al. [23], la investigación se desarrolla en cinco fases: la identificación del problema, el desarrollo y diseño conceptual del modelo HBIMa partir de los datos recopilados incorporando las fases histórico-constructivas seleccionadas del edificio, la implementación del modelo HBIM, la evaluación del modelo mediante un “Focus Group” [25] y extracción de conclusiones en las que se analizan los resultados obtenidos y se proponen mejoras para su aplicación futura.

En la primera fase de diagnóstico, se identificaron diversos problemas. Entre ellos destacan la fragmentación documental (planos, fotografías y registros en otros formatos), lo que dificulta su acceso y consulta, así como las dificultades de gestión y mantenimiento del inmueble por su condición de bien protegido y privado, sumado a su doble función de acceso restringido y público.

A ello se le suma la necesidad de garantizar la integridad física del edificio, afectada por su proximidad al mar y el desgaste natural de sus elementos históricos, muchos de los cuales carecen de registros digitales precisos, incrementando así el riesgo de pérdida patrimonial.

Para abordar estas problemáticas, se han establecido los requisitos para el desarrollo de un modelo 3D HBIM que contenga las fases constructivas más relevantes del RCNSS y permita integrar y estructurar la información geométrica, histórica y constructiva del edificio en un entorno digital unificado, facilitando la exploración virtual del inmueble en sus distintas fases constructivas, la gestión de los espacios y la toma de decisiones para la conservación y el mantenimiento del patrimonio arquitectónico durante todo el ciclo de vida del edificio. Asimismo, se ha adoptado una perspectiva ética en la digitalización del patrimonio, que implica garantizar la integridad, veracidad y contextualización de la información recopilada [26-28].

Para optimizar el proceso de modelado HBIM, las guías uBIM de *BuildingSmart Spanish Chapter* [22], los documentos de la Comisión Interministerial BIM [29-30] y el manual del Ministerio de Cultura y Deporte [31], establecen la necesidad de definir previamente los objetivos, usos y nivel de desarrollo del modelo HBIM, mediante la adopción de niveles de definición como el *Level of Development* (LOD), que integra el *Level of Geometry* (LOG) y el *Level lof Information* (LOI), que habitualmente se distinguen cinco niveles que van del 100 al 500 abarcando desde modelos conceptuales hasta representaciones *as-built* [32-34]. Pero, dada la variabilidad en la calidad y el detalle de la documentación gráfica y textual de las diferentes fases, se optó por aplicar únicamente los valores de LOG y LOI de forma específica para cada elemento de cada fase, ajustándolos a la información disponible en cada caso. No obstante, con el fin de ofrecer una referencia del nivel de definición alcanzado en cada fase, se calculó un LOD orientativo considerando el valor más bajo entre los LOG y LOI más repetido entre los elementos de cada fase. Esta aproximación se podría relacionar con el concepto de *Level of Knowledge* (LOK) definido por Castellano-Román et al [12], que refleja el grado de conocimiento incorporado en el modelo y se organiza también en cinco niveles. De esta manera, en las fases más recientes, con información más detallada, es posible alcanzar un LOD/LOK 400 (modelado de elementos constructivos y estructurales con todas sus capas de acabado), mientras que, en las primeras fases, donde la información es más limitada y menos detallada, no es posible alcanzar un LOD/LOK superior a 200 (nivel de desarrollo geométrico e informativo medio).

Por esta razón, ha sido necesario ajustar los usos y objetivos específicos de cada fase, destinando las fases más recientes a procesos de conservación y futuras intervenciones, y las más antiguas a fines documentales y de exposición [18] (Tabla 1).

El desarrollo del modelo HBIM se ha estructurado en tres fases principales. En primer lugar, se ha realizado una depuración de la información obtenida, asegurando la coherencia y fiabilidad de los datos. Posteriormente, se ha establecido un sistema de clasificación que permita visualizar las distintas fases constructivas del edificio de manera clara y ordenada, Finalmente, se ha llevado a cabo el modelado de los elementos constructivos y estructurales de cada una de las fases del edificio, integrando la información histórica y constructiva mediante la creación sistemática de nuevos parámetros.

A pesar de la geometría aparentemente sencilla del edificio del RCNSS, de los materiales empleados en su construcción y de la ausencia de elementos arquitectónicos complejos e irregulares, característicos de muchos edificios patrimoniales históricos [13], no ha sido un proceso de modelado sencillo. No sólo por la complejidad de la configuración interior del edificio, que de por sí ha representado un reto significativo, sino por la variedad de desafíos encontrados durante el desarrollo del modelo HBIM.

Tabla 1. Clasificación de valores LOD y LOK, y usos y objetivos de cada fase según la documentación geométrica y no geométrica disponible (Elaboración: J. García Moreno).

Fase	Descripción	Año	Documentación disponible	LOD / LOK	Usos
01	Antigua piscifactoría	1905	Planimetría esquemática con escala gráfica	100	PDD
02	Remodelaciones interiores y exteriores	-	Descripciones documentales extraídas de publicaciones especializadas y libros	200	PDD
03	Proyecto de Aizpurua y Labayen - 1ª propuesta	1928/11/26	Planimetría esquemática sin escala gráfica y registro fotográfico de una maqueta	200	PDD
04	Proyecto de Aizpurua y Labayen - 2ª propuesta	1929/01/07	Planimetría esquemática sin escala gráfica	200	PDD
05	Proyecto de Aizpurua y Labayen - Construcción	1929/03 a 1929/08	Planimetría esquemática sin escala gráfica, fotografías de archivo en blanco y negro, memoria descriptiva simplificada del proyecto, descripciones documentales extraídas de publicaciones especializadas y libros	200	PDD
06	Ampliación de la terraza de la p.ppal.	1956/05/04	Planimetría detallada con cotas y descripciones técnicas, fotografías de archivo en blanco y negro	300	PDD
07	Cobertura y el cerramiento de la terraza superior	1963/05/07	Planimetría detallada con cotas y descripciones técnicas, fotografías de archivo en blanco y negro, fotografías de archivo en color y alta resolución de años posteriores	300	PDD
08	Consolidación de la cimentación y nueva p. sótano	1998/03	Planimetría detallada con cotas y descripciones técnicas, registro fotográfico exterior e interior en color y alta resolución, memoria descriptiva detallada del proyecto	400	PC
09	Reforma p. superior - Espacio gastronómico GU	2012 a 2014/12/21	Planimetría detallada con cotas y descripciones técnicas, registro fotográfico exterior e interior en color y alta resolución, informes técnicos complementarios	400	PC
10	Estado actual	2024	Nube de puntos obtenida mediante escaneo láser y fotografía 360 °, registro fotográfico exterior e interior en color y alta resolución, planimetría detallada de actuaciones previas recientes	400	PC

*PDD= Procesos Documentales y de Difusión; PC= Procesos de Conservación; LOD/LOK 100 = Modelo simplificado para identificación del edificio; LOD/LOK 200 = Modelo de geometría más próxima a la realidad e información histórico-constructiva básica asociada para protección y difusión.; LOD/LOK 300 = Modelo con elementos estructurales y constructivos detallados orientado a la investigación avanzada.; LOD/LOK 400 = Modelo con definición material, mayor talle de los elementos constructivos y con información exhaustiva asociada para proyectos de conservación e intervención.; LOD/LOK 500 = Modelo estratigráfico para gestión integral y planificación periódica.

Antes de iniciar el modelado 3D HBIM, fue necesario realizar un trazado previo en 2D sobre los planos originales escaneados mediante AutoCAD, lo que permitió alinear correctamente los planos de las distintas fases constructivas y realizar ajustes que habrían sido más complejos y propensos a errores si se hubiesen abordado en 3D. Este proceso se vio dificultado por la baja precisión de los planos, la ausencia de cotas y escalas gráficas, el grosor de las líneas y las discrepancias entre documentos de diferentes épocas (nivel de detalle, forma, dimensiones y ubicación de los elementos). Para resolver estas limitaciones, se emplearon superposiciones iterativas, comparaciones con el modelo 3D del estado actual, análisis fotográficos y una evaluación crítica basada en criterios constructivos y estructurales. En los casos más conflictivos, se contrastó la información con la nube de puntos del escaneo láser y fotografías 360°, seleccionando las soluciones más fieles a la realidad construida. Este análisis detallado permitió detectar inconsistencias entre la documentación gráfica y la obra construida, pero también identificar elementos comunes y afinar la precisión del modelo final. No obstante, algunas imágenes de archivo presentaban problemas de datación, con rangos temporales demasiado amplios, lo que impidió su uso como referencia cronológica precisa para fases constructivas específicas.

Tabla 2. Listado de parámetros aplicados en el modelo HBIM (Elaboración: J. García Moreno).

Parameter	Values	Data Type	Pa. App.	Pa. Scope	Applied to
Parameter Group: General Data (GD)					
GD_Element Code		Text	I	Project	CE
GD_Constructive description		Ml. text	I	Project	CE
GD_LOG – Level of Geometry		Integer	I	Project	CE
GD_LOI – Level of Information		Integer	I	Project	CE
GD_Space Type	Members Area | Service Area | Office Space | Public Areas | Plant Rooms	Text - Ddm	I	Project	Rooms
Parameter Group: State of Conservation (SC)					
SC_ State of Conservation	Recently restored | Good conserv. Condition | Lack of maintenance | Severely degraded | Not determinable	Text - Ddm	I	Project	CE
Parameter Group: Damage Data (DD)					
DD_Damage Form	Localised | Linear | Superficial	Text - Ddm	I	Project	CE
DD_Damage Type	Structural Cracks and Deform. | Moisture Issues | Coating and Cladding Deterioration | Surface Damage| Bio. and Chem. Alterations	Text - Ddm	I	Family	DF
DD_Damage Code		Text	I	Family	DF
DD_Description		Ml. text	I	Family	DF
DD_Documentation - URL		Image	I	Family	DF
DD_Repair Docum. - URL		URL	I	Family	DF
DD_Damage Repaired		Yes/No	I	Family	DF
DD_Repair Date (start/end)		Text	I	Family	DF
DD_Severity of damage	No apparent risk | Risk to other elements | Risk of prog. dtrt | Risk to third parties	Text - Ddm	I	Family	DF
DD_Urgency of interv.	Immediate | Very urgent | Urgent | Necessary med-term | Maintenance	Text - Ddm	I	Family	DF
Parameter Group: Interventions Data (ID)					
ID_Prev. Interv. (author–year–ref.)		Ml. text	I	Project	CE
ID_Prev. Interv. – Docum. – URL		URL	I	Project	CE
Parameter Group: Historic Data (HD)					
HD_Construction project – Author		Text	I	Project	CE
HD_Cons. project – Year		Integer	I	Project	CE
HD_Cons. project – Phase		Text	I	Project	CE
HD_Cons. project – Ref. info		Text	I	Project	CE
HD_Cons. project – Docum. – URL		URL	I	Project	CE
Parameter Group: Bibliographic References (BR)					
BR_Academic articles		Ml. text	T	P. info.	BR
BR_Non-academic articles		Ml. text	T	P. info.	BR
BR_Books		Ml. text	T	P. info.	BR
BR_Historic archives		Ml. text	T	P. info.	BR
BR_Academic theses		Ml. text	T	P. info.	BR

*Pa.=Parameter; Ddm=Dropdown menu; Ml.=Multiline I=Instance; T=Type; P.=Project; DF=Damage Family; CE=Constructive Element; BR=Bibliographic Reference

Superada esta etapa de interpretación y validación, se desarrolló el modelo 3D HBIM de cada fase constructiva del edificio. Durante este proceso se evidenciaron ciertas limitaciones de la herramienta de modelado que condicionaron decisiones de modelado. En particular, con el objetivo de reflejar con precisión la evolución material y constructiva de los elementos del edificio a lo largo de las distintas intervenciones, fue necesario modelar las distintas capas de revestimientos y acabados de los muros (revestimientos cerámicos, capas de pintura, etc.) como muros independientes debido a que el *software* no permite asignar fases constructivas a las capas internas de un mismo muro. Esto incrementó la complejidad del modelo HBIM, ya que hubiera sido mucho más sencillo y eficiente poder asignar fases constructivas a las capas de un mismo elemento.

El siguiente paso en la implementación del modelo HBIM fue la integración de la información recopilada. Uno de los aspectos clave fue la organización del modelo en fases constructivas diferenciadas, lo que permitió visualizar la evolución del edificio a lo largo del tiempo. Para estructurar de manera eficiente la información histórica y constructiva dentro del modelo HBIM y garantizar así la vinculación precisa de los datos, se ha elaborado un listado de parámetros atendiendo a las características y necesidades del edificio y fundamentado en experiencias recogidas en publicaciones académicas anteriores [1, 10, 12] (Tabla 2).

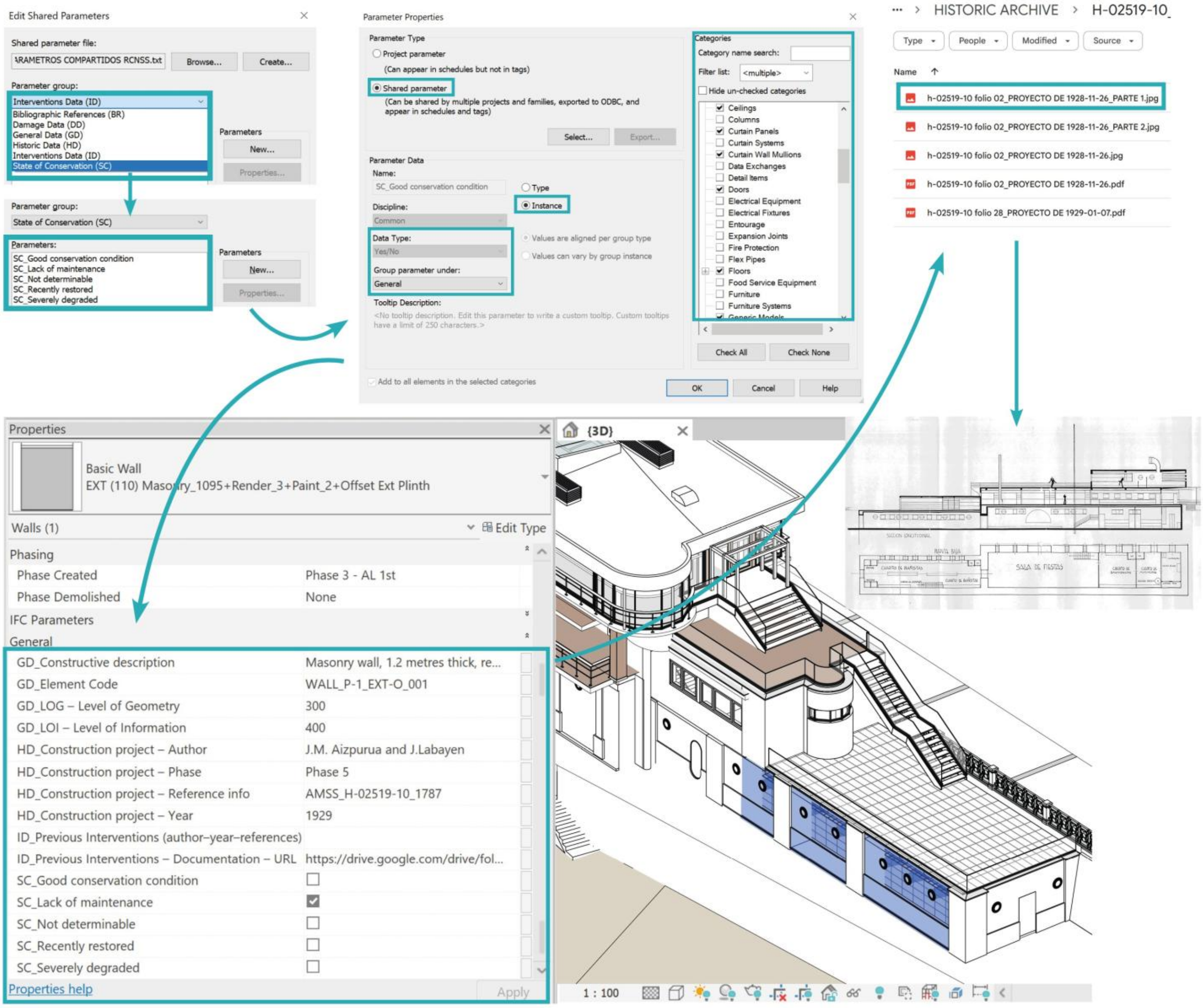

Figura 2. Composición de capturas de pantalla que ilustran el proceso de generación y clasificación de parámetros compartidos según los grupos definidos previamente. Se muestra su vinculación a elementos constructivos del modelo, especificando el tipo de información y las categorías de elementos a las que se aplica cada parámetro. Asimismo, se representa la introducción de datos mediante el panel de propiedades y la apertura de documentos alojados en una nube de datos, accediendo a través de enlaces URL insertados en los parámetros del elemento seleccionado (Elaboración: J. García Moreno).

En concreto se han propuesto cinco grupos de parámetros de diferente tipo de información. con el objetivo de proporcionar una base de datos robusta que facilite la creación de un modelo 3D HBIM que no solo sirva como herramienta de análisis histórico, sino que también ofrezca información relevante para la toma de decisiones en materia de mantenimiento y restauración. Este proceso de integración de metadatos históricos y constructivos mediante parámetros de Revit ha permitido la vinculación directa de información en las propiedades de los elementos constructivos y estructurales del modelo, como muros, pavimentos, techos, carpinterías, elementos estructurales (pilares, vigas, forjados), etc. Para enriquecer esta integración, se han incorporado hipervínculos que permiten el acceso directo a registros fotográficos, planos, detalles constructivos relevantes o estudios previos asociados a los elementos del modelo. De este modo, se optimiza la accesibilidad y la interrelación de la información dentro del modelo digital (Figura 2).

Para garantizar la trazabilidad de la información y facilitar la localización de los elementos en el modelo, cada elemento ha sido identificado con un código alfanumérico a partir de los campos "Tipo de Elemento", "Nivel", "Elemento Interior o Exterior", "Orientación" y "Número". Así, un muro situado en la fachada oeste del edificio en la planta semisótano quedaría de la siguiente manera: WALL_P-1_EXT-O_001. Para evaluar y validar la efectividad del modelo 3D HBIM generado en la gestión, conservación y divulgación del edificio del RCNSS, se han implementado diversas acciones de evaluación precedidas por un "Focus Group" con perfiles estratégicamente seleccionados por su relación directa con la gestión, intervención técnica y valoración patrimonial del edificio. Participaron la gerente y un técnico de mantenimiento del RCNSS, una doctora en historia especializada en arquitectura patrimonial y varios doctores arquitectos especializados: uno en historia de la construcción, otro en rehabilitación, otro en escaneo láser y otro la aplicación del BIM para la gestión patrimonial.

Este enfoque colaborativo asegura que el modelo desarrollado se convierta en un prototipo avalado por un panel de expertos y que no solo refleje con precisión la información histórica y constructiva del edificio, sino que también responda a sus necesidades de mantenimiento y gestión a largo plazo. La evaluación del modelo HBIM en el contexto real se centró en dos criterios: efectividad (capacidad para resolver los problemas identificados) y eficiencia (usabilidad). Durante el "Focus Group" se presentó el modelo 3D HBIM y se llevaron a cabo una serie de aplicaciones prácticas vinculados a los procesos patrimoniales, mencionados anteriormente, para mostrar así al comité multidisciplinar los beneficios de la metodología HBIM y comprobar su utilidad y funcionalidad, y señalar de forma consensuada los aspectos mejorables del mismo. La sesión se estructuró en fases de demostración, exploración guiada y discusión participativa, abordando cuestiones clave como la precisión geométrica, la coherencia histórico-constructiva, la usabilidad, la interoperabilidad y las oportunidades de transferencia y musealización. Al final de la sesión, el comité realizó una breve encuesta que evaluó la accesibilidad del modelo, la capacidad de búsqueda de información y su aplicabilidad en la planificación de intervenciones, gestión del edificio y generación de contenido divulgativo. Entre los resultados obtenidos destaca la valoración positiva de la trazabilidad documental y la utilidad del modelo como herramienta para la toma de decisiones preventivas, así como la identificación de mejoras prioritarias: reforzar la interoperabilidad con plataformas municipales, protocolizar la actualización del modelo y simplificar la interfaz para perfiles no técnicos mediante vistas o tablas de datos preconfiguradas (Tabla 3). A partir de las observaciones se realizaron algunos ajustes y mejoras en el modelo, obteniendo los resultados detallados a continuación en los siguientes apartados.

Tabla 3. Síntesis del Focus Group: hallazgos (fortalezas y limitaciones) y recomendaciones (Elaboración: J. García Moreno).

Perfil del participante	Hallazgos principales	Recomendaciones
Gerente del RCNSS	Valora la centralización documental y la trazabilidad, aunque señala la complejidad de uso para personal no técnico.	Simplificar interfaces, ofrecer formación básica y vistas preconfiguradas.
Técnico de mantenimiento del RCNSS	Destaca la utilidad del modelo para localizar puntos críticos y planificar mantenimiento, pero advierte la falta de definición de instalaciones y la ausencia de protocolos claros de actualización y registro.	Establecer procedimientos de registro y actualización; capacitar al personal o implementar herramientas simplificadas interoperables.
Doctor Arquitecto experto en historia de la construcción	Reconoce la precisión geométrica y la correcta vinculación de fases históricas, pero identifica falta de detalle en acabados y sistemas ocultos.	Incluir fichas de detalle y reforzar la documentación de capas constructivas.
Doctor Arquitecto especialista en rehabilitación arquitectónica	Valora la integración de datos históricos y la posibilidad de documentar patologías, pero detecta dificultad para mantener actualizado el modelo tras intervenciones menores sin generar documentación gráfica.	Implementar protocolos de registro durante cada intervención y establecer un plan de actualización periódica del modelo.
Doctor Arquitecto Especialista en escaneo láser	Destaca la precisión entre nube de puntos y modelo y la replicabilidad, pero observa la falta de un protocolo de actualización y control de versiones de la nube de puntos.	Definir plan de mantenimiento, programar campañas de escaneo periódico y asignar responsables para revisión.
Doctor Arquitecto experto en BIM para gestión patrimonial	Resalta la coherencia de parámetros y la posibilidad de replicar el modelo, pero advierte riesgo de duplicidad de datos sin estándares claros.	Establecer estándares de codificación y un manual de interoperabilidad.
Doctora en Historia especializada en Arquitectura Patrimonial	Valora la representación fiel de fases constructivas con referencias cruzadas, pero observa la falta de integración de relatos orales y testimonios complementarios.	Vincular testimonios y relatos patrimoniales como metadatos enriquecidos.

Conservación y planificación de intervenciones

El modelo HBIM contribuye significativamente a la documentación y conservación del edificio, permitiendo diagnósticos precisos y propuestas de jerarquías de intervención fundamentadas. A partir de los datos introducidos en los parámetros de cada elemento del modelo, es posible generar filtros de representación que permitan visualizar las vistas 3D de cada planta del edificio mediante códigos cromáticos que faciliten la detección del estado de conservación de cada elemento del modelo. Esto permite identificar patologías más fácilmente, priorizar las intervenciones más urgentes y controlar así gastos de intervención. Si además se combina con la representación de cada espacio mediante un código de colores que diferencia cada zona según el tipo de uso (espacios de servicio, cuartos de instalaciones, espacios comunes para los socios, espacios de oficina y espacios públicos), es posible organizar las intervenciones en las diferentes áreas del edificio, no sólo por la urgencia de la patología o su relevancia patrimonial, sino también por el grado de uso del espacio en el que actuar, minimizando así las molestias a los usuarios (Figura 3).

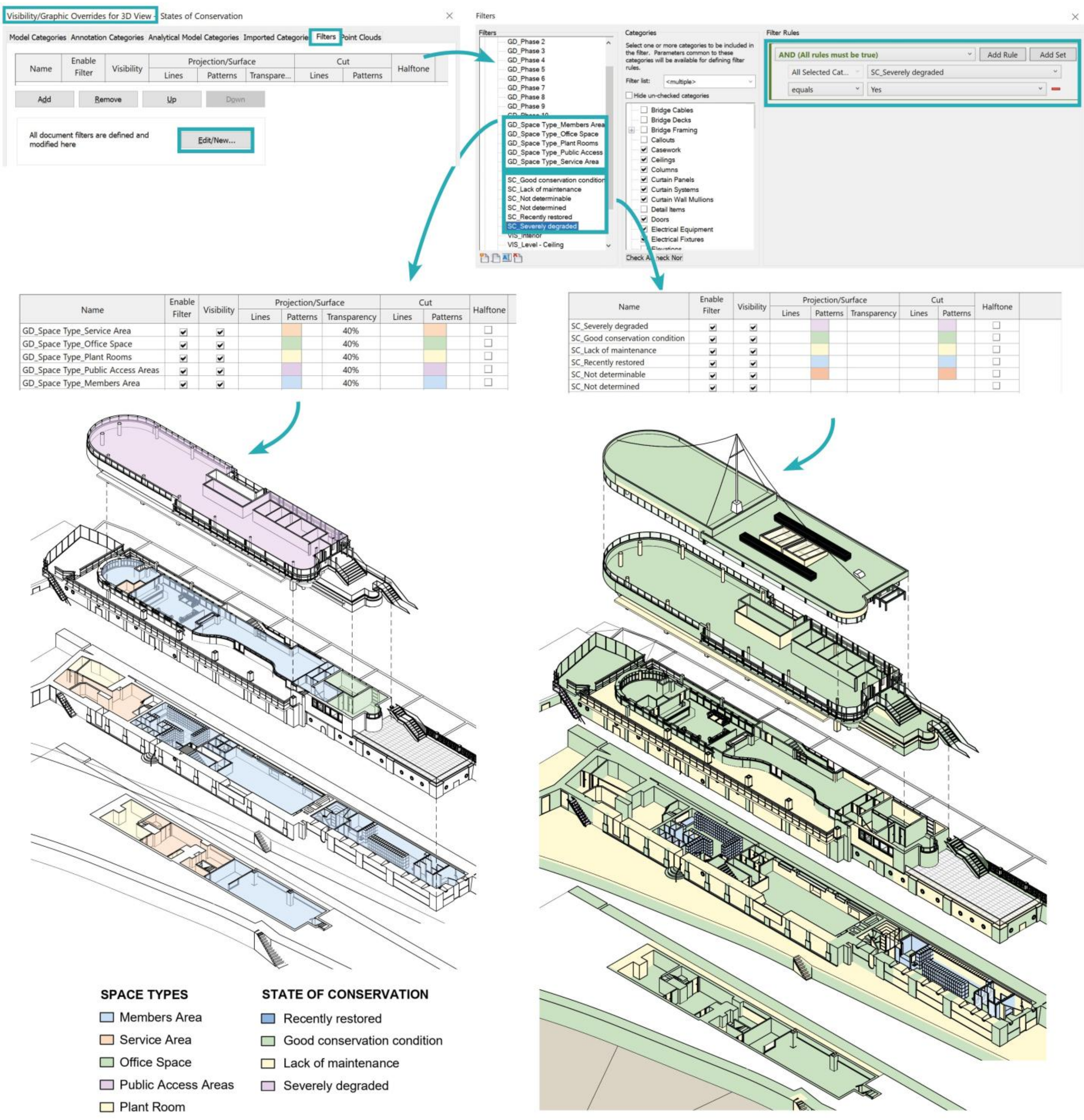

Figura 3. Aplicación práctica del modelo. Creación de filtros que permiten representar, mediante códigos cromáticos, la clasificación de los espacios según su tipología de uso y el estado de conservación de cada elemento constructivo del edificio. Cada filtro se configura asignándole un nombre, seleccionando las categorías a las que se aplica y definiendo la regla de filtrado en función del valor *True* de los parámetros homónimos previamente generados y asignados a los elementos del modelo HBIM (Elaboración: J. García Moreno).

Este enfoque visual, facilita la toma de decisiones estratégicas y permite planificar, además, de forma separada o integrada, las intervenciones de mantenimiento y restauración según el tipo de uso (por ejemplo, mayor desgaste y necesidades de seguridad en la zona pública, y requerimientos de privacidad y confort en la parte privada). De esta manera, quienes gestionan el edificio (propietarios, técnicos de conservación, administraciones públicas, etc.) pueden, mediante el modelo, contar con una base de datos confiable y actualizada que agilice la planificación de restauraciones, mantenimientos u obras futuras. Esto posibilita, además, el análisis de impacto de modificaciones potenciales sobre el bien patrimonial.

No obstante, es posible profundizar aún más en la planificación de las intervenciones mediante la incorporación de información específica sobre patologías en el modelo, utilizando para ello los parámetros de patologías previamente definidos. Pero dichos parámetros no estarán vinculados a un elemento constructivo del modelo, dado que una patología no siempre afecta a la totalidad del elemento o porque un mismo elemento puede presentar múltiples patologías diferenciadas. Para resolver esta limitación, se ha desarrollado una familia específica, basada en publicaciones científicas previas, que puede insertarse sobre cualquier elemento del modelo [35]. Esta familia está diseñada para alojar los parámetros relativos a las patologías y permite añadir información detallada sobre cada una de las incidencias detectadas en el edificio. Su forma se asemeja a una señal de emergencia rodeada por una circunferencia, y tanto el símbolo como el contorno adoptan diferentes colores, los cuales indican el nivel de urgencia de intervención o el grado de riesgo asociado a la patología representada. Durante el proceso de configuración de esta familia, se han creado listas de valores predefinidos para los distintos parámetros, lo que permite su selección a través de menús desplegables. De esta manera, se evita la introducción manual de los datos y se garantiza una mayor homogeneidad y precisión en el registro de la información (Figura 4).

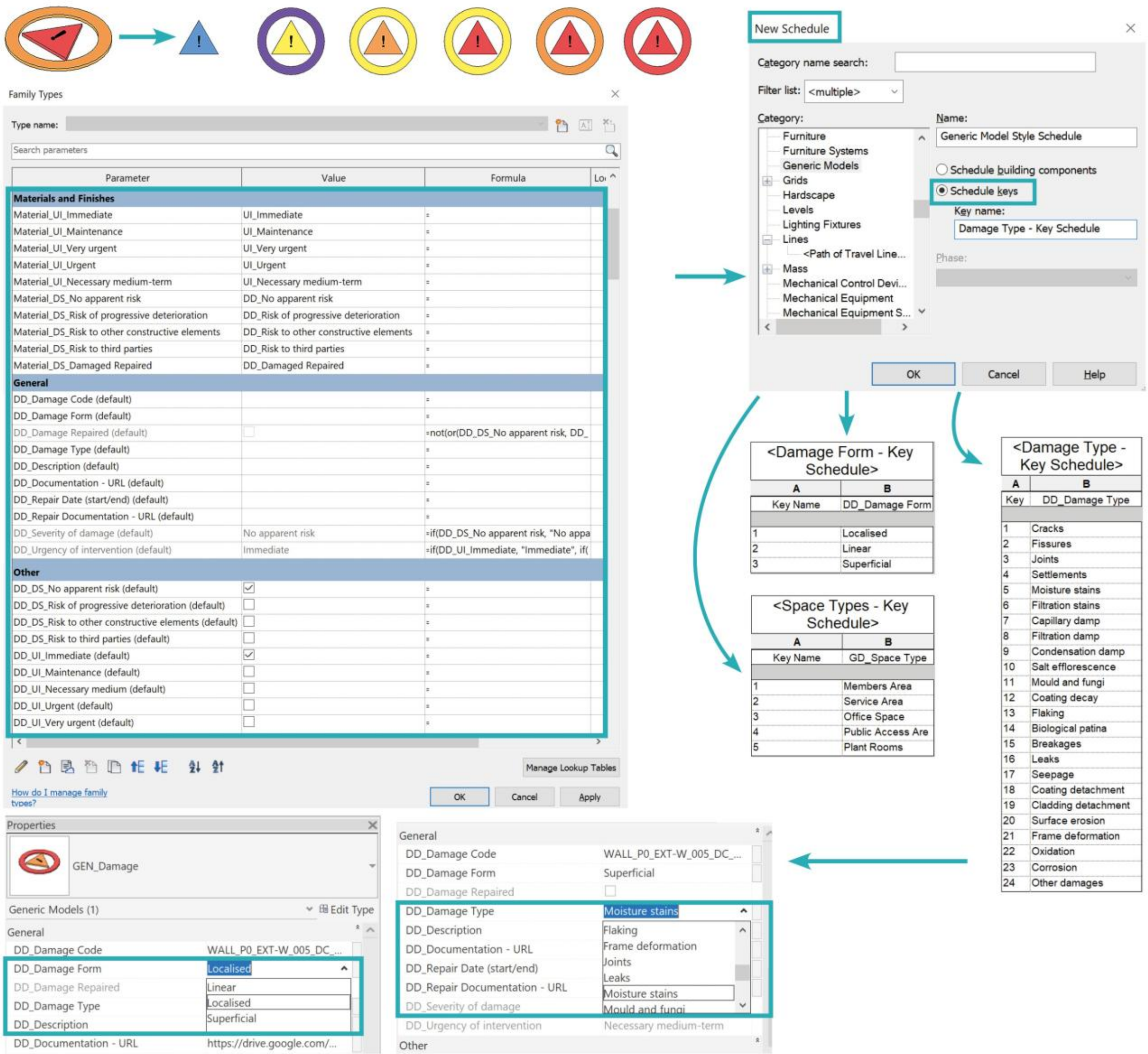

Figura 4. Representación de las diferentes formas y colores de la familia paramétrica desarrollada para la visualización de patologías, así como muestra de los parámetros incorporados en la familia para permitir, desde el archivo del modelo HBIM, la modificación de su aspecto en función de los valores asignados a los parámetros de patologías previamente creados y vinculados a los elementos del modelo. Se ilustra, además, el proceso de definición de valores preestablecidos para los parámetros relativos al tipo y forma de la patología, de modo que estos se presenten como listas desplegables con valores seleccionables dentro de dichos parámetros (Elaboración: J. García Moreno).

Una vez generada la familia, colocada en el modelo y completados sus parámetros, es posible acceder a los elementos enlazados como fotografías asociadas a cada patología. Asimismo, se puede generar un listado completo de las patologías presentes en el edificio, que incluirá toda la información registrada en los distintos parámetros (Figura 5).

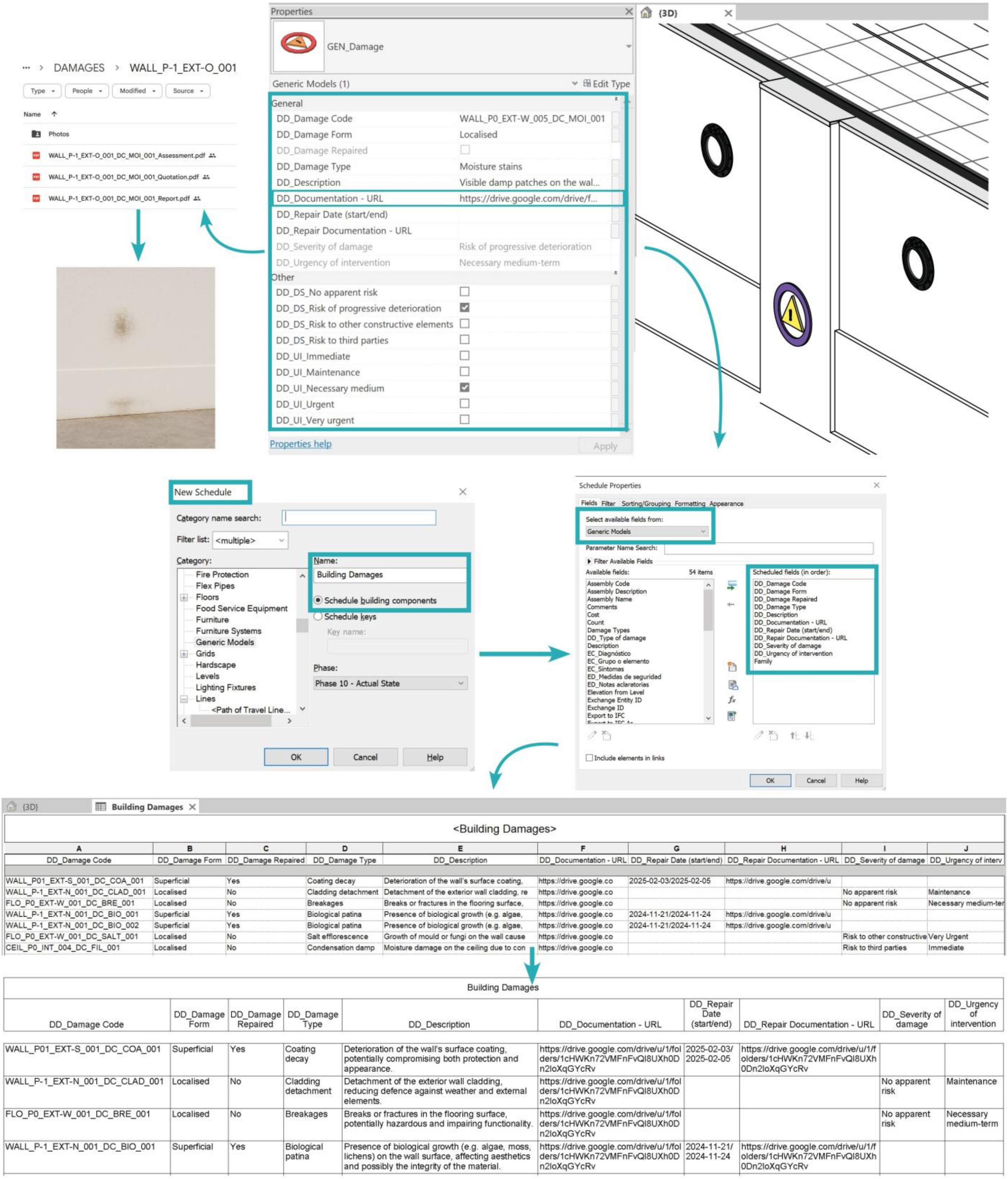

Figura 5. Aplicación de la familia de patologías desarrollada en el modelo, con muestra de los valores asignados a los parámetros creados dentro de la familia, desde los cuales es posible acceder a documentos alojados en la nube mediante la dirección URL insertada en el parámetro de documentación de la patología. Asimismo, se representa el proceso de generación de tablas de información que centralizan los datos asociados a las distintas patologías identificadas en el edificio (Elaboración: J. García Moreno).

Con el objetivo de facilitar la identificación y localización de cada patología dentro del modelo, se ha establecido un sistema de codificación alfanumérica. Este código comienza con la referencia correspondiente al elemento constructivo afectado, seguida del acrónimo que identifica el tipo de patología y, finalmente, un número correlativo. De este modo, por ejemplo, una rotura localizada en el pavimento exterior de la planta baja, ubicada en la fachada oeste, se codificaría de la siguiente manera: FLO_P0_EXT-W_001_DC_BRE_001. Esta denominación corresponde a: FLO (Floor, suelo), P0 (Level P0, planta baja), EXT-W (exterior west orientation, exterior fachada oeste), 001 (número identificador del elemento), DC (damage code, código de patología), BRE (tipo de patología breakage, rotura), 001 (número correlativo de la patología).

Divulgación y representación evolutiva del edificio

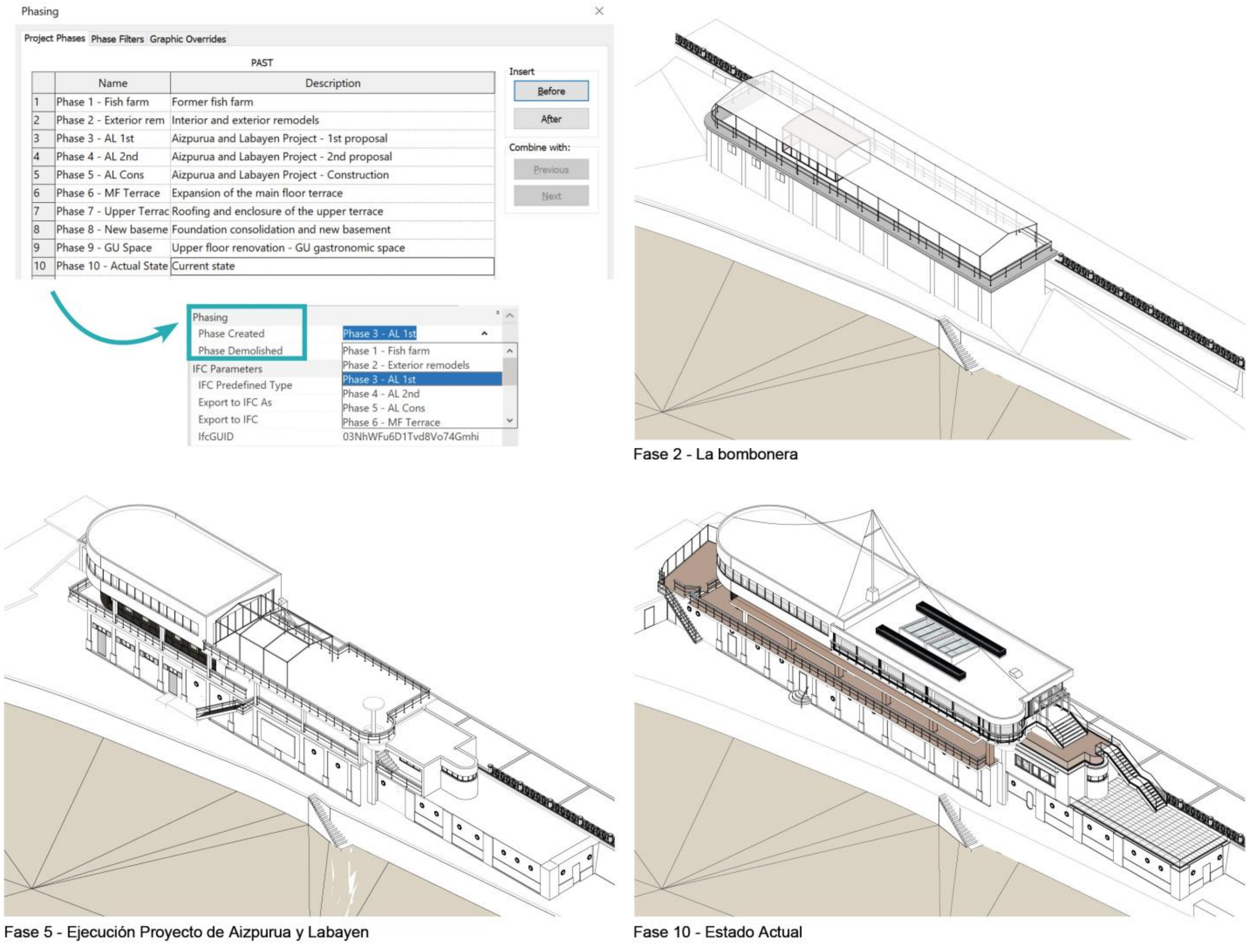

Figura 6. Representación del listado de fases histórico-constructivas generado dentro del modelo HBIM, el cual permite asignar a cada elemento constructivo un valor de fase de creación y otro de fase de demolición, con el objetivo de posibilitar, entre otros usos, la representación tridimensional de estas tres fases del edificio del RCNSS (Elaboración: J. García Moreno).

El modelo HBIM actúa como un repositorio integral que centraliza y organiza documentos históricos, fotografías, informes técnicos, información geométrica, nubes de puntos, etc. Esto permite superar la fragmentación de la documentación y facilita su acceso y consulta por parte de los agentes involucrados en los procesos de restauración y comunicación. Asimismo, el modelo HBIM permite representar digitalmente las distintas fases constructivas del edificio, lo que contribuye a una mejor comprensión de su evolución histórica. Para ello, se ha creado un listado de fases dentro del modelo y se ha clasificado cada uno de sus elementos asignándoles una Fase de Creación y, en su caso, una Fase de Demolición. A partir de esta clasificación, es posible generar vistas 3D correspondientes a cada una de las fases, lo que permite visualizar de manera clara y estructurada los elementos propios de cada periodo y sus transformaciones a lo largo del tiempo (Figura 6). Este enfoque no solo facilita la lectura cronológica del edificio, sino que también mejora la interpretación de su valor patrimonial fomentando una mayor apreciación tanto del inmueble como de la arquitectura que representa.

En esta misma línea, es posible realizar un estudio estratigráfico del edificio, mediante la creación de un filtro de representación específico. Este filtro asigna un color diferente a los elementos del modelo en función de la fase constructiva a la que pertenecen, lo que permite identificar con claridad las sucesivas intervenciones realizadas a lo largo del tiempo, facilitando un análisis inmediato de la evolución constructiva del edificio (Figura 7). Constituye una herramienta de gran utilidad tanto para la investigación histórica como para la planificación de futuras actuaciones.

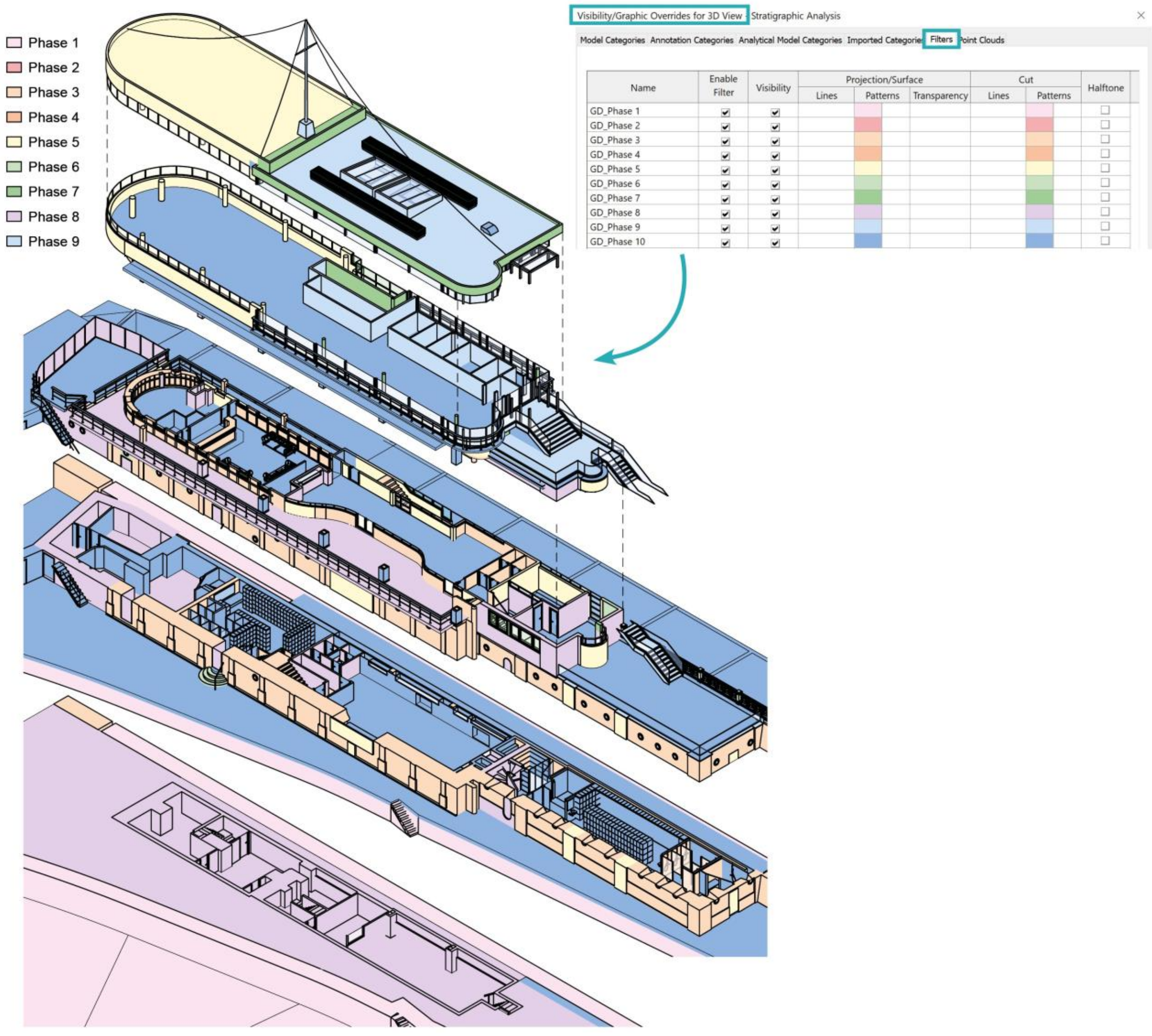

Figura 7. Muestra de los filtros generados para representar en el modelo 3D, mediante códigos cromáticos, los elementos correspondientes a cada fase sobre el modelo del estado actual del edificio. Estos filtros se basan en el valor asignado en el parámetro de fase de creación de cada elemento constructivo del modelo (Elaboración: J. García Moreno).

La capacidad del modelo HBIM para ser ampliado, modificado y actualizado de forma continua conforme se dispone de nueva información o se llevan a cabo nuevas intervenciones en el edificio [21] permite que el modelo evolucione como un sistema vivo, en constante desarrollo, adaptado a las necesidades cambiantes de la gestión patrimonial. De este modo, cualquier intervención (de carácter estructural, funcional, estético o de mantenimiento) puede integrarse en el modelo, documentando su localización, fecha de ejecución, materiales empleados y criterios de intervención.

Para garantizar la eficacia de este proceso, es imprescindible estructurar el modelo de forma estratégica desde el inicio. Esto incluye la organización por fases temporales, la incorporación de parámetros específicos para registrar intervenciones, la generación de vistas filtradas, y la vinculación de documentación complementaria. Estas medidas permiten que el modelo sea fácilmente actualizable, manteniendo su coherencia interna y su valor como repositorio dinámico de información. Esta capacidad de actualización no solo enriquece la trazabilidad histórica del edificio, sino que también garantiza que el modelo HBIM se mantenga como una herramienta vigente y fiable para futuras investigaciones, proyectos de restauración, tareas de mantenimiento y estrategias de conservación preventiva.

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Adicionalmente, a partir de los parámetros de referencias bibliográficas asociados al modelo (clasificados en distintas categorías como libros, artículos científicos, trabajos académicos, archivos históricos o artículos no académicos) es posible generar tablas de contenido organizadas por tipología (Figura 8).

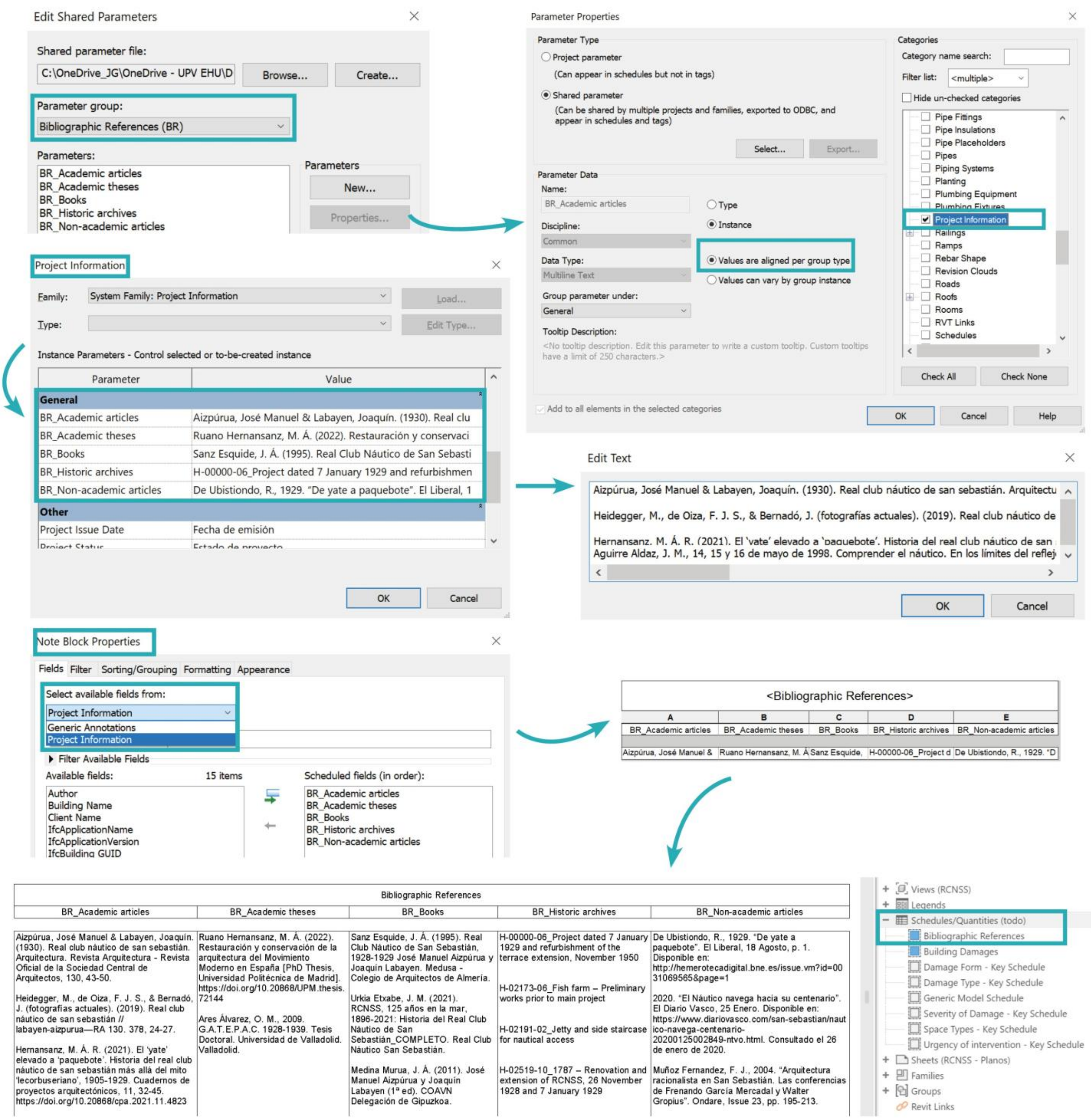

Figura 8. Muestra de los parámetros compartidos generados para la gestión de referencias bibliográficas y su posterior vinculación en el archivo del modelo HBIM como parámetros de proyecto, lo que permite incorporar desde el modelo un listado de referencias relacionadas con el edificio de estudio, clasificadas según el tipo de documentación bibliográfica. Asimismo, se representa el proceso de elaboración de una tabla con las referencias bibliográficas clasificadas, generada a partir de los datos introducidos en los parámetros de información de proyecto previamente creados (Elaboración: J. García Moreno).

Estas tablas pueden exportarse a otros formatos, lo que facilita el intercambio de información con los distintos agentes implicados en la gestión del patrimonio. Esta funcionalidad no solo contribuye a la trazabilidad de las fuentes utilizadas en el proceso de documentación, sino que también mejora la transparencia metodológica y promueve la colaboración interdisciplinar. Al integrar directamente las referencias en el entorno del modelo HBIM, se establece un vínculo directo entre la información bibliográfica y los elementos del edificio a los que se refiere, fortaleciendo así la coherencia y solidez del proceso de análisis y conservación.

Interoperabilidad y gestión de datos

La interoperabilidad y la adecuada gestión de los datos es fundamental en el desarrollo de modelos digitales aplicados al patrimonio, especialmente cuando se trabaja en entornos colaborativos o se prevé la integración del modelo en diversas plataformas. En este contexto, la usabilidad del modelo HBIM y su compatibilidad mediante formatos abiertos, como el IFC (Industry Foundation Classes), han sido aspectos clave considerados desde las etapas iniciales del proceso. Con el objetivo de evaluar el grado de interoperabilidad del modelo, se han llevado a cabo múltiples pruebas de exportación en formato IFC hacia distintas plataformas BIM (Dalux y BIMVision) comúnmente utilizadas en el ámbito profesional (Figura 9).

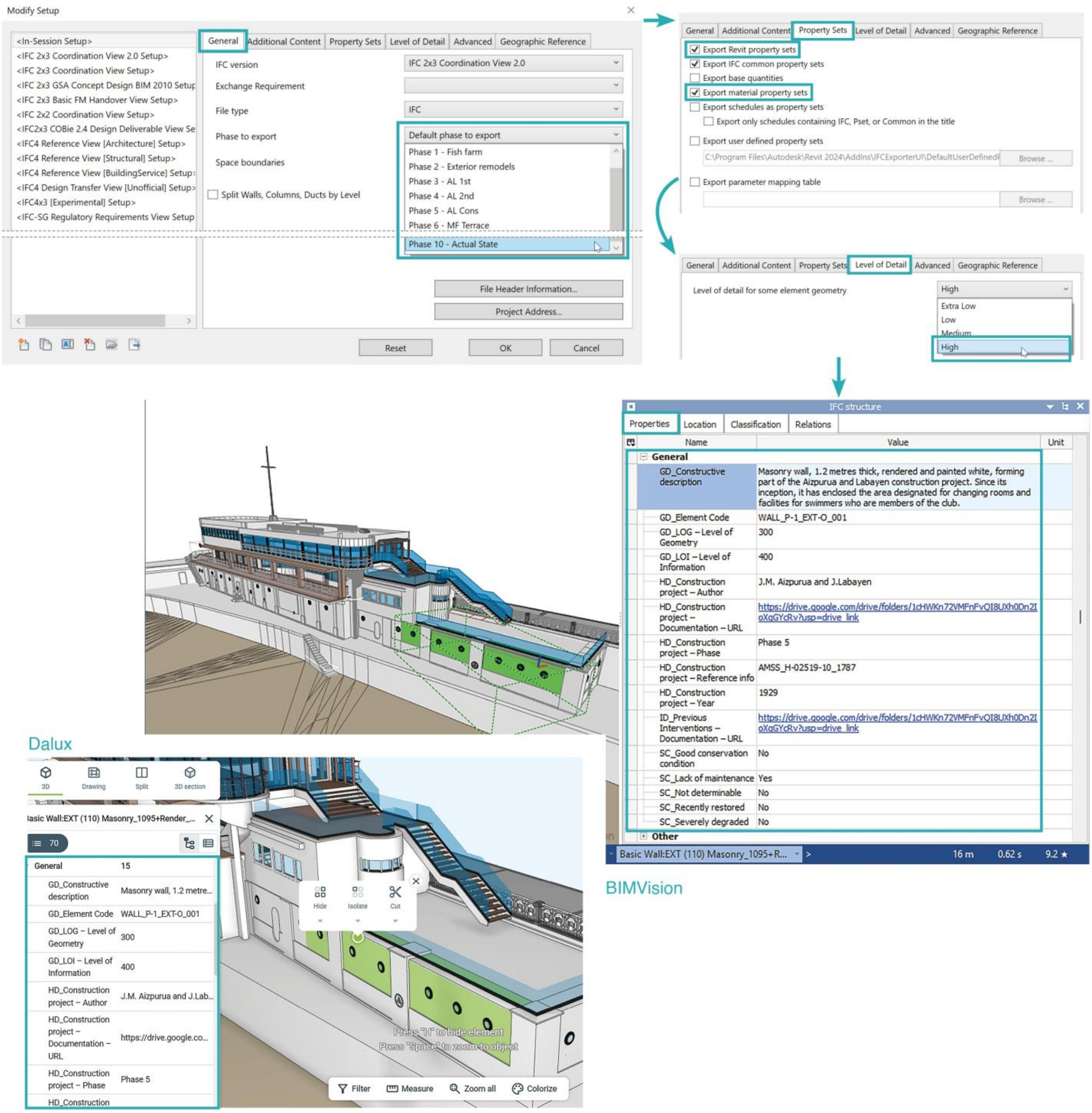

Figura 9. Muestra del proceso de exportación, desde Revit, del modelo del estado actual en formato IFC, indicando las opciones seleccionadas para ello, así como la importación del archivo IFC resultante en las plataformas de visualización BIM Dalux y BIMVision, donde se ha verificado la correcta transferencia y visualización de los datos de los parámetros definidos en el modelo de Revit (Elaboración: J. García Moreno).

Estas pruebas han permitido verificar la correcta transferencia de los elementos del modelo, asegurando que se conservaran atributos esenciales como la denominación de los componentes, su asignación a fases histórico-constructivas específicas y otras propiedades semánticas relevantes definidas durante la fase de modelado. Para alcanzar estos resultados, ha sido necesario ajustar los parámetros de configuración de exportación. Estas acciones permitieron mejorar sustancialmente la fidelidad de la transferencia de información entre plataformas, favoreciendo así un modelo más coherente, trazable y funcional en distintos entornos digitales.

En suma, este proceso de revisión y ajuste continuo no solo ha garantizado una interoperabilidad técnica efectiva, sino que también ha reforzado la capacidad del modelo HBIM como herramienta para la documentación, gestión y difusión del conocimiento patrimonial.

Conclusiones

El enfoque DSR ha permitido desarrollar un modelo HBIM funcional, replicable y validado por un panel de expertos, con un impacto positivo en la preservación, coordinación y difusión del edificio del RCNSS. La metodología HBIM ha facilitado la centralización de la documentación histórica y constructiva en un entorno digital unificado, actualizado y accesible, superando la fragmentación documental inicial.

Mediante la parametrización, cada elemento arquitectónico queda representado geométricamente y enriquecido con información relevante, lo que posibilita la preservación digital y la consulta y extracción de datos en múltiples formatos. Esta estructuración de datos favorece el análisis de intervenciones previas y la identificación de elementos que requieren intervención, mejorando los diagnósticos de conservación y una toma de decisiones más informada. Al mismo tiempo, mejora la difusión del conocimiento sobre el edificio, permitiendo que este sea accesible para públicos no familiarizados con metodologías BIM.

Además, la adopción de formatos interoperables como IFC refuerza la integración con otras herramientas de análisis y gestión patrimonial y garantiza la sostenibilidad y accesibilidad de la información a largo plazo.

El modelo HBIM mejora los procesos de diagnóstico, planificación y ejecución de intervenciones gracias a su capacidad para identificar una afección, localizarla en el modelo, consultar la información relativa a sus materiales y antecedentes de intervención, y así tomar decisiones técnicas más fundamentadas y eficientes. Favorece, asimismo, la detección temprana de patologías y su seguimiento, lo que permite reducir costes de rehabilitación y minimizar el impacto sobre el bien.

Como limitaciones, cabe señalar que la efectividad del modelo HBIM depende en gran medida de la calidad y consistencia de la documentación disponible. En este caso, la condición de propiedad privada del inmueble, que ha restringido el acceso al edificio, la falta de planos detallados de las instalaciones (electricidad, fontanería, climatización, etc.) y de documentación sobre intervenciones recientes, así como la baja precisión de algunos planos históricos y la ausencia de datación en parte del archivo fotográfico, han dificultado el modelado de elementos ocultos como instalaciones o componentes estructurales y constructivos. Sin embargo, esta información podrá ser incorporada progresivamente a medida que se obtengan más datos o se ejecuten nuevas intervenciones reforzando el carácter dinámico, escalable y ampliable del modelo como repositorio digital del edificio. Estas limitaciones evidencian la necesidad de continuar la recopilación de datos y establecer protocolos de actualización continua, incluyendo una figura revisora encargada de garantizar la coherencia, integridad y fiabilidad del modelo a largo plazo.

Para investigaciones futuras, resulta prioritario ampliar el modelo mediante técnicas de diagnóstico no invasivas, que permitan registrar elementos ocultos o de difícil acceso sin comprometer la integridad del edificio, y consolidar protocolos de colaboración entre equipos multidisciplinares que garanticen la actualización continua del modelo asegurando su vigencia y escalabilidad.

Asimismo, es relevante fomentar el potencial de integración del modelo HBIM con tecnologías de visualización inmersiva para desarrollar aplicaciones de realidad aumentada, virtual y mixta dirigidas a la divulgación y educación patrimonial, generando experiencias que acerquen el conocimiento arquitectónico a públicos diversos y refuercen el modelo HBIM como herramienta de transferencia y valoración colectiva del patrimonio.

En conclusión, la implementación de la metodología HBIM se consolida como una herramienta clave para la documentación, conservación, administración y proyección social del patrimonio arquitectónico reciente del siglo XX. Si bien persisten ciertos desafíos técnicos y metodológicos, su evolución y aplicación futura ofrecen un gran potencial para optimizar la gestión patrimonial y promover nuevas formas de interacción con el conocimiento arquitectónico, tanto en el ámbito profesional como en el educativo y divulgativo.

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CONSERVAR PATRIMÓNIO

ARTICLE / ARTIGO

Let's talk to the artist… In the search for conservation and exhibition solutions for contemporary works made with textiles in the Basque Country

Vamos conversar com o artista… Em busca de soluções de conservação e exposição para obras contemporâneas feitas com têxteis no País Basco

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Abstract

In the 1980s, various factors led to the development of new artistic typologies in the Basque Country, introducing fabrics and textiles into sculptures and installations now housed in major museum collections. Institutions responsible for the maintenance and exhibition of contemporary art agree that the main problems in textile-based works are mostly related to materials, formats and execution techniques but also to their exhibition and curatorial requirements. Understanding both the technical and material aspects of artistic practices, along with their conceptual foundation and artistic intent, is decisive for determining conservation needs. This research explores the conservation of contemporary art made with textiles through case studies, emphasizing the challenges related to their unique typologies and materials. It also reviews the strategies and measures implemented by important contemporary art museums in Spain and the Basque Country, underscoring the crucial role of direct collaboration with artists in ensuring their proper preservation and display.

KEYWORDS

Contemporary art
Textiles
Basque Country
Conservation
Exhibition
Artistic intent

Resumo

Na década de 80, vários fatores levaram ao desenvolvimento de novas tipologias artísticas no País Basco, introduzindo tecidos e têxteis em esculturas e instalações agora expostas nas principais coleções de museus. As instituições responsáveis pela manutenção e exposição de arte contemporânea concordam que os principais problemas nas obras baseadas em têxteis estão relacionados principalmente com os materiais, formatos e técnicas de execução, mas também com os requisitos de exposição e curadoria. Compreender os aspetos técnicos e materiais das práticas artísticas, a base conceptual e intenção artística, é decisivo para determinar as necessidades de conservação. Esta investigação explora a conservação da arte contemporânea têxtil através de casos de estudo, enfatizando os desafios relacionados com as suas tipologias e materiais únicos. Também analisa as estratégias e medidas implementadas por museus de arte contemporânea em Espanha e no País Basco, sublinhando o papel crucial da colaboração direta com os artistas para garantir a sua preservação e exibição adequadas.

PALAVRAS-CHAVE

Arte contemporânea
Têxteis
País Basco
Conservação
Exposição
Intenção artística

Introduction

Until the mid-seventies of the twentieth century, Basque artists have had a little contact with the international artistic scene due to the political situation of the region. The new social and cultural context generated after the years of dictatorship, facilitated the exchange of artistic experiences that were already being developed in other countries [1].

During the 80s different factors converged in the Basque Country that propitiated the expansion of new artistic typologies, as well as the renewal of the materials used in art creation during the posterior decades. The impact of international artistic currents and trends would be key in this transformation process [2] but also the creation of a whole cultural network constituted by art institutions and creation centres will be decisive in the development of contemporary artistic practices, giving a notable boost to new types and disciplines of art production [3].

In addition, the normalization of women artists in the artistic scene, whose presence had been very limited until that period, will be essential in the process of artistic legitimation of new experimental works. Fragile and ephemeral materials such as textiles and fabrics, feathers, resins and foams, as well as fashion accessories and clothing items will be introduced to art practice, together with those traditionally used like stone, metal or wood.

The gradual introduction of textile elements and synthetic fabrics to sculpture along with the increasing development of new artistic typologies such as installations can be already observed at the end of the 70s. Artists like Andrés Nagel (San Sebastián, 1947) or Ángel Bados (Olazagutía, 1945) will be pioneers in the introduction of textiles in their works. Progressively, these materials will gain presence and become usual in the artistic production of the following decades [4].

Nowadays, different museums and institutions conserve within their collections works of art created by the most important authors from that period along with more recent creations that show a surprising number of textile materials and related elements. Guggenheim Bilbao Museum, the Museum of Fine Arts of Bilbao or the Basque Museum Centre of Contemporary Art-Artium in Alava are some regional examples, along with the most important Spanish institutions such as the Reina Sofía National Art Center Museum in Madrid or the Würth Museum located in La Rioja.

Institutions responsible for the maintenance and exhibition of contemporary art agree that the main problems in artworks made with textiles are mostly related to their constituting materials, the diversity of formats and execution techniques but also to their exhibition and curatorial requirements. They are often made of different elements and mixtures of natural and synthetic materials and produced with experimental and unstable techniques, so a correct characterization of these work is essential to guarantee that they are properly preserved.

Nevertheless, the conservation, display and transmission of these works also involves the understanding of conceptual aspects in addition to those purely formal or material ones and can significantly alter their meaning if disrespected.

As different authors have pointed out [5-7], the requirements for the conservation and exhibition of this type of works have evidenced the need to redefine their intervention criteria, as well as the measures directed to conserve new experimental contemporary typologies made with textiles.

Fortunately, during the last decade the field of textile conservation and restoration has developed and spread spectacularly, encompassing other disciplines such as costume or fashion and implementing new methods of intervention and preventive conservation that can be extended to contemporary works. This is well reflected in contributions like the MPhil dissertation of current textile curator at the Museum of London, Emily Austin [8], as well as in other recent publications [9-10].

This research examines textile-based contemporary art conservation through case studies, highlighting the challenges posed by their typological and material features, as well as the measures and protocols implemented by the major Spanish and Basque contemporary art museums. To explore those issues, several Basque creators such as Naia del Castillo, Txaro Arrazola or Sahatsa Jauregui, among others, have been interviewed during this study, in order to better understand the conceptual aspects in their work that can be conflictive with their material stability.

Conservation of contemporary art: materials and artistic intend

A key criterion for preserving contemporary art objects establishes the necessary equilibrium between conserving the materials as well as the idea behind its creation. This need to balance conservation of materials and artistic or conceptual intent in contemporary art has been widely developed since the 80s, first by Heinz Althöfer [11] and later through other reference authors like Antonio Rava, Hiltrud Schinzel, Iwona Szmelzer, IJsbrand Hummelen or Glenn Wharton [12-19]. Rosario Llamas- Pachecho or Carlota Santabárbara are also some of the Spanish authors that have extendedly analysed this issue [20-25]. Nowadays, we know that this can be achieved through minimal intervention and traditional methods, or, in certain cases, by replacing elements or even reproducing the whole work to preserve the artist's intent.

In the case of contemporary textile artworks, obviously the proper identification of materials and correct characterization of the works turns out essential, since a large part of the conservation problems are usually related to the use of unstable materials and experimental techniques [26], all factors influencing their behaviour and stability.

These contemporary artistic expressions will reflect the incorporation of new materials throughout the twentieth century. Alongside traditional natural fibers like cotton, linen, wood or silk, a wide range of synthetic textiles and polymeric materials, such as nylon, polyester or PVC, began to appear, originating from industrial contexts. The coexistence of these diverse materials complicates the classification and cataloguing of such works, while also presenting significant conservation challenges due to their varied and often unstable nature.

Along with the choice of unstable materials, the artistic procedures and experimental techniques will likewise be determining factors in the behaviour of these works that, in some cases, become a source of deterioration from the very moment of their creation. In fact, the degenerative processes that affect textiles often begin during their manufacturing and continue with their subsequent aging and the influence of the environment.

The speed of these degradation processes will depend on very different reasons but it is known that textile materials are seriously affected by external factors such as light exposure (factor to which they are especially vulnerable to), relative humidity, temperature, dust or atmospheric pollution, together with the action of biological agents or damages of anthropic origin.

However, along with their characterization, study and analysis, other factors should be addressed in the decision-making regarding its interpretation and museographic exhibition. In order to ensure the preservation of this kind of contemporary artworks, the artist's intention must be considered in conjunction with formal and material aspects when making conservation and display decisions. Even if authors like Dykstra [27] or Wharton suggest [28] that "artist intention" is an ambiguous term that should be used with caution, we conservators have the professional duty to account for it, whenever it is possible.

In addition to foreseeing possible technical solutions and in order to envision integral conservation protocols, we must recognize that material selection can play a crucial role in the artwork's intention because, as stated by textile conservator Ann French [29], the choice of the textile medium may be part of its conceptual basis. Consequently, the conservation approach must treat it as a work of art, not as a functional or decorative item or applied art that might have once been intended for a practical purpose [30] as it may happen in the case of some pieces of costume or domestic and ethnographical textiles.

This craft-related terms hovering over works made of textiles are, still today, lightly used to denominate any kind of textile-based art or creation, regardless of its artistic conception and identity, conditioning its adequate conservation and interpretation.

It is known, that practices related to textiles have traditionally been classified as second-class artistic media despite the fact that the revision of concepts such as crafts, design or art was radical during the twentieth century. At an international level, the use of textiles in artistic practices was mainly promoted since the late 1960s, mostly by feminist movements, which proposed the recovery and inclusion of practices that had traditionally been relegated to a lower status, such as embroidery, weaving techniques and other applied sewing techniques [31-32].

Although these initiatives represented an enormous step in the legitimization of textile practices in the field of contemporary art, it is also true that the expansion of new artistic typologies made with textiles and related techniques has led to some confusion at the time of exhibiting them. For instance, many of this works, have been misinterpreted and assumed as vindicative of the female gender and therefore, incorrectly displayed and transmitted to the public, without taking into account that there are several artists who work with textiles just for their formal, technical or metalinguistic values [33].

This highlights the importance of involving artists, whenever possible, in the various stages of interpreting and presenting their work. As Llamas-Pacheco states [24] it is clearly beneficial to gather information about the artist's visual intention, aesthetic discourse, and intellectual universe through talking to creators themselves. Their input can enhance decision-making and problem-solving [34] by providing valuable insights into the materials used, their intended purpose, the artwork's visual discourse, and guidelines for its proper display.

Indeed, various studies have pointed out that conservation is closely related to aspects related to its exhibition, registration and storage protocols, evidencing the need for multidisciplinary collaboration between the different fields involved in order to adequately preserve and transmit contemporary artworks properly [28, 35-37].

New materials and techniques, new conservation problems

As mentioned in the introduction, the new political and cultural situation that emerged in the Basque Country at the end of the seventies gradually allowed the influx of new international artistic influences and forms of artistic expression, which would have a significant impact on the Basque art scene [3, 38].

What art historian Peio Aguirre called "the great transformation of Basque art" [2] led to the introduction of new artistic typologies, materials and elements of very diverse nature and origin (natural and synthetic fibers and fabrics, plastics, ersatz materials, foams, resins, etc.), each with their own conservation challenges and issues.

As can be seen in Figure 1, the present study has shown the presence of diverse materials in the multiple artistic typologies reviewed, observing the inclusion of traditional textiles and yarns such as cotton fabrics, linen canvas or silk tissues to non-woven fabrics like felt or suede. These last ones can be found, for example, in the cotton cleaning cloth wrapped structures characteristic of the first creations of Gema Intxausti (Guérnica-Lumo, 1966) (Figure 1a-b).

It is also noteworthy that, parallel to the introduction of new fabrics, the use of other imitation materials, feathers (Figure 1c-d) or fur will begin to gain presence as well as other costume related elements and clothing accessories, such as shoes and hats [4] that will be added to the list of elements that will become part of contemporary Basque creations.

Along with these multiple materials, the expansion of artistic and creative techniques that will be incorporated into these increasingly experimental works is remarkable. New media and techniques such as crochet (Figure 1e-f), sewing or embroidery (Figure 1g-h) as well as an endless number of painting, printing or stamping techniques will be incorporated to artworks.

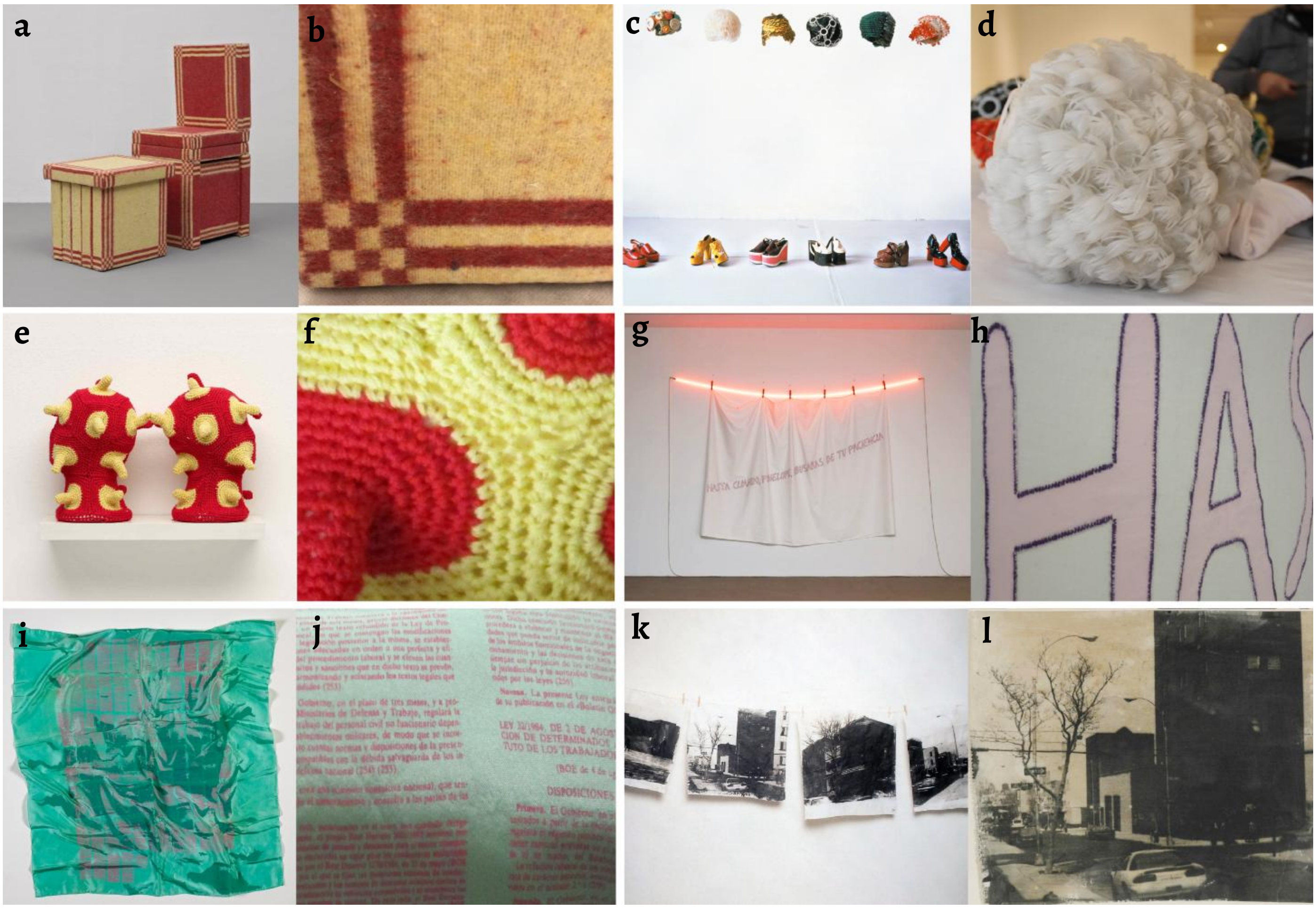

Figure 1. Materials and techniques in various contemporary works: *a-b) Saint George and the dragon* by Gema Intxausti, 1991 and detail of the cotton suede cloth, Basque Government Collection (photos: Restoration Department of the Bilbao Fine Arts Museum and Basque Government Collection – RDBFAM & BGC); *c-d) Women on platform shoes* by Ana Laura Álaez, 1992 and a detail of a feather headdress, La Caixa Collection (photos: RDBFAM); *e-f) Fingers* by Ana Laura Álaez, 1993 and detail of the crochet technique in acrylic wool, Artium Collection; *g-h) Penelope* by Itziar Elejalde, 1980 and detail of the machine embroidery on cotton fabric, Artium Collection; *i-j) Silk scarf* by J. L Moraza1999 and detail of the screen printing on silk, Artium Collection; *k-l) Passing Sensations* by Txaro Arrazola, 1998-1999 and detail of a piece showing the transfer on cotton, Artium Collection (photos: Gert Voor in't Holt).

The choice of media such as solvent transfer, sublimation printing or screen printing can be found in the work of important artists like Juan Luis Moraza (Vitoria, 1960) (Figure 1i-j), Txaro Arrazola (Vitoria-Gasteiz, 1963) (Figure 1k-l) and more recently artists like Naia del Castillo (Bilbao, 1975), entailing various difficulties for its conservation. The behavior of these works will differ substantially depending on the materials and techniques used for their creation making necessary to study individually each work in order to establish conservation needs.

Many of the problems detected in those works (fading of inks and dyes, bleeding of colors, yellowing and blurring of the original images in the presence of photoemulsion based works, etc.) are sometime closer to photographic or graphic work pathologies than those traditionally related to textiles. Additionally, they often appear in combination to other emerging problems linked to their typological and formal characteristics as well as to their display systems, like deformation of fabrics, tearings or unwanted creases.

Something similar must be taken into consideration in the case of works such as *Su Tu Tumba* (2017) created by the young artist Sahatsa Jauregi (Salvador de Bahía, Brasil, 1984). This installation is composed of 27 printed images on polyester fabric cloths displayed pinned to the wall with domestic pushpins. It requires strict preventive measures when exhibited because digital print media and inks used to produce it are especially sensitive and may suffer discolorations and color modifications due to long periods of exposure to light or inadequate humidity and temperature conditions.

Figure 2. Packaging and assembly systems in large-format works: *a)* rolling system for *Project converted into installation*,by Juan Pérez Agirregoikoa, 2007, Guggenheim Bilbao Collection (photo: Department of Conservation of the Guggenheim Museum Bilbao – DCGMB); *b)* installation of *Penélope*, by Itziar Elejalde, 2004, Artium Collection (photo: Artium Musem).

The use of highly fragile materials such as hair, skin or feathers (especially vulnerable to biological attack too) and even vegetal elements in conjunction with fabrics can also be found in the work of important artists Javier Pérez (Bilbao, 1968), Ana Laura Aláez (Bilbao, 1964) or Zigor Barayazarra (Bilbao, 1976). The multimateriality of these proposals raises conservation issues due to their organic nature and needs that are equally diverse and creative.

On the other hand, the formal characteristics of installations and works made with large textiles are also an important factor when preserving and exhibiting them. Handling and mounting protocols have been designed to face the conservation challenges of works like *Penélope* (1980), a huge embroidered cotton bed sheet hanging from a neon tube by clothespins made by artist Itziar Elejalde (Bilbao, 1953), Asier Mendizabal´s (Ordizia, 1973) textile *Tangrams* or the painted hanging banners made by Juan Pérez Agirregoikoa (Donostia-San Sebastián, 1963).

These types of works present format features and spatial specificities that conditionate their storage and/or exhibition, requiring a great coordination when handling and mounting them (Figure 2). Their manipulation and setup protocols include steps from reception and transportation packaging to final installation, ensuring careful handling and protection to preserve the piece's integrity, always under the supervision of a conservator.

Conservation of contemporary works made with textiles

Works of art such as the ones mentioned so far, which may include fabrics and elements of both natural and synthetic origin can be considered fragile. In fact, it must be taken into account that their handling and display entails, on each and every occasion, a risk for its conservation.

When asked during the present research, museums and institutions responsible for maintaining and exhibiting contemporary art acknowledge that the primary conservation challenges in textile-based works stem not only from the materials, compositional elements and execution techniques but also from their exhibition requirements and curatorial demands. Aspects related to display systems, climatic and illumination conditions during exhibition periods or implications coming from handling during transportation and mounting processes, have a big impact in the conservation of textile-based artworks.

Figure 3. *Friends from Bilbao* by Andrés Nagel Tejada, 1980: *a)* with the original textile gauze behind the installation; *b)* detail of the fragile fabric presenting tears and a torn areas; *c)* sewing and consolidation of the textile during restoration process (photos: RDBFAM).

Although obviously it is sometimes necessary to restore a work following traditional criteria and methods, the effort usually focuses on preventing damage. In the case shown in Figure 3a, the thin gauze hanging behind the figures moved constantly when the artwork was displayed and as a result, the fabric had torn in several places (Figure 3b). Museum restorers repaired the tears by sewing and with polyamide and a heated spatula and filled fabric losses to stabilize the textile element (Figure 3c) and a new mode of exhibition was designed to prevent further deterioration.

However, since the multimateriality of this kind of works does not always allow taking into account every specificity and need in an individualized way, they usually require a more general and comprehensive approach. The conservation strategies of the main museum institutions are mainly directed to the implementation of preventive conservation measures and risk control of collections.

Climate control

As in the case of costume collections or historical fabrics, the control and monitoring of climatic conditions that surround artworks is vital, since these materials are highly sensitive to light and relative humidity or temperature fluctuations, as well as especially vulnerable to biological attack due to their organic nature.

The alteration of the physical and chemical properties of the fabrics, in addition to the presence of additives, light-sensitive dyes or other added elements, can lead to irreversible damages in to composing materials and their characteristics. This can also have a big impact in the work´s artistic intend and even bring the conceptual destruction of the work.

Currently, the standards for proper storage, conservation and display of works made with textiles recommended by the ICOM International Committee for Museums and collections of Costume, Fashion and Textiles are established at 18 °C temperature and 50-55 % Relative Humidity, with fluctuations allowed between ± 2 °C and ± 5 % respectively.

Continuous humidity and temperature oscillations or inadequate conditions can cause mechanical stress, accelerate material deterioration and promote the appearance of insects and mould, especially affecting natural textiles of cellulosic and protein origin due to their higroscopicity.

In relation to the control of lighting the general recommendation is a maximum of 50 lux for periods of no more than three months and ideally, the pieces on display should rotate. Textiles sustain irreversible damage from both visible and ultraviolet light and as the effects of light and heat are cumulative, fabrics or garments previously exposed to strong lighting, should be displayed less frequently and avoid UV radiation by using filters or protective display cases. For instance, sensitive textiles such as silk or those dyed with natural pigments should be limited to a maximum of 3 to 6 months per year, followed by a rest period in dark storage.

Correct illumination is essential, especially to appreciate the characteristic textures, hues and transparencies, and most of the interviewed artists give great importance to lighting during their exhibition even though many of them are very aware of the light-induced deterioration of the material over time.

But although some damages are inevitable or even assumed by the artist, in other cases, the unexpected modification of plastic properties, like the fading or loss of an especially significant dye or surface color modifications in monochromatic fabrics (yellowing, darkening...), can lead to a significant alteration of the concept and the message of the work.

An example of the symbolic use of color in works of this nature and the dilemma that can arise regarding their conservation can be observed in the work *The Two Sisters* (2005) by Naia del Castillo preserved in the Würth Museum, located in La Rioja. This textile-based sculpture belonging to the *Offerings and Possessions* series represents two dressed bodies in an intense sapphire blue silk. The artist collaborated with jewellers to obtain colored fabrics inspired by precious stones like ruby red, emerald green, and sapphire blue. Over time, the saturation and luminosity of the original color has fainted in some areas of the work, modifying its original aspect but also its original meaning and intent.

To prevent this kind of unwanted and irreversible situations and despite the complexity in balancing visibility with conservation, as Mateo points out [39], it is essential to find a middle ground between preserving the piece and ensuring an appropriate exhibition display conditions.

Storage systems

The multitude of formats, shapes and sizes that we find in this specific discipline is uncountable and can become a real challenge for conservators when designing packing and conservation systems. Storage systems vary greatly depending on the type of work, ranging from basic systems such as conservation boxes, adapted hanging systems on padded hangers to storage systems that simultaneously serve for exhibition avoiding unnecessary manipulations during storage and mounting.

In the preventive conservation of textiles and costume, materials are selected based on their chemical stability and compatibility with the objects. Evidently, each type of garment or textile work may require specific combinations of materials depending on its nature (structure, materials, conservation condition) and its use (storage, exhibition, or transport) although all materials should be stable and inert, avoid acidic agents, adhesives and tapes or volatile plasticizers. They must not cause abrasion and should support the textiles gently, particularly during storage periods.

Commonly used materials include archival cardboard to customize storage boxes, acid-free paper, tissue or films such as Tyvek or Cellplast to serve as protection layers and together with unbleached cotton fabrics for making covers and wraps. For accessories or three-dimensional objects, polyethylene foams (Ethafoam, Plastazote) and wadding fillings or quilted molleton paddings are also frequently used for custom supports and mannequins [9, 39-40].

Other more creative alternatives and solutions are designed especially to preserve more fragile works that literally “need to rest” in horizontal position after extended exhibition periods or others that can, ideally, enable the viewing of the works inside through windows or transparent Plexiglass/Perspex surfaces (Figure 4) along with many other casuistries that may require specific designs.

Given the impossibility of systematizing packaging methods for the enormous variety of contemporary works, systems are often recovered from other conservation disciplines, as storage systems for large format paintings and ever rugs and/or tapestries that are stored rolled up with the decorated side protected outwards as shown in Figure 2.

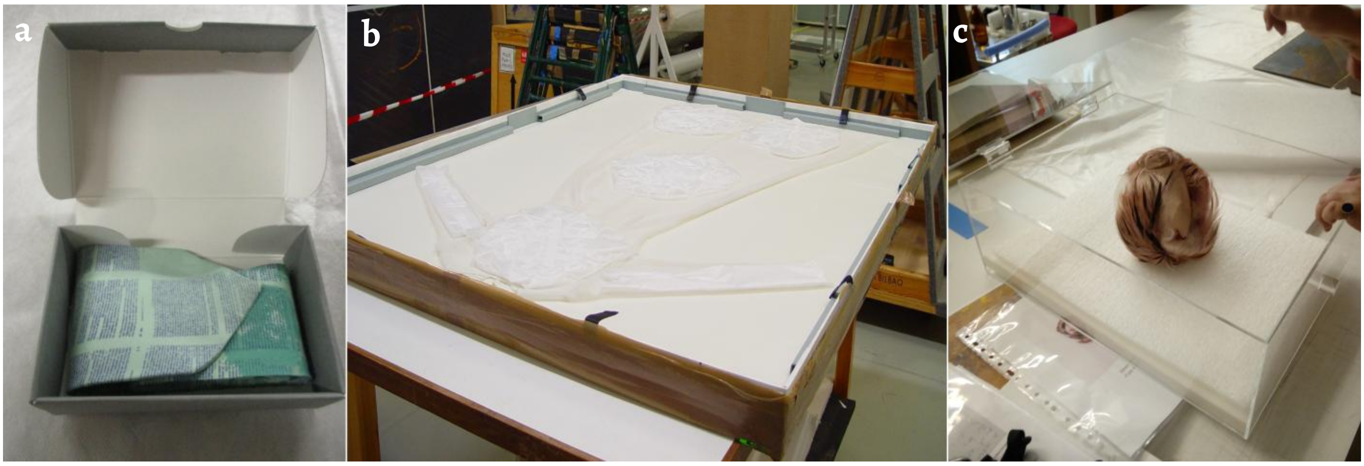

Figure 4. Packaging and storage systems: *a)* conservation box for *Tie* by J. L. Moraza, 1994, Artium Collection (photo: Artium Musem); *b)* flat storage system for the dress from *Mask of Seduction* by Javier Pérez, 1997 (photo: DCGMB; *c)* methacrylate urn for *If I were you… red* by Miren Arenzana, 1993 (photo: RDBFAM).

Figure 5. Handling and installation process of *Women on platform shoes* (1992) by Ana Laura Aláez in the Bilbao Fine Arts Museum: *a)* packaging system to ensure safe transport and protection of the constituent elements; *b)* checking and condition reporting process; *c)* a tulle hat from the installation; *d)* a shoe from the installation; *e)* assembly and display of the different elements of the installation in the museum gallery; *f)* final exhibition setting of the installation (Caixa Forum Collection VEGAP, Barcelona, 2025) (photos: RDBFAM).

In the case of installations made up of various elements or parts, it is usual to keep strict registration protocols because it's crucial for the conservation of this type of works to ensure a good record of all the component elements. Risks can be minimized through accurate documentation of the works regarding materials, techniques and conservation periodical inspections and reports and by ensuring they are stored in appropriate environmental conditions [41-42].

This should be taken into account also when exhibiting the works. For the mounting practice to identify and properly register specific needs for their correct handling and care is essential, even more if we are dealing with non-replaceable elements.

The work *Women on platform shoes* (1992) by the artist Ana Laura Aláez, belonging to the contemporary art collection of the La Caixa Foundation, constitutes an excellent example of the multimateriality of this type of contemporary works, as well as a complex display of objects found and built by the artist herself (Figure 5).

In the installation, six headdresses made from materials of various textile origin, rubber objects, plastic, metal, etc. are suspended from the ceiling with their corresponding six pairs of shoes dating from the seventies, also made with a wide variety of materials, generating sets in which the female figure is absent, but at the same time represented

As we will see in the following section, display is closely linked to registration. An installation guide or map that includes precise documentation of the positioning and spatial relationships between elements is essential, particularly when the artist wishes to preserve the original configuration of the work [43], as is the case.

Display and exhibition systems

Modes of display can vary significantly from one exhibition to another depending on the resources of the hosting institution, the exhibition space, the requirements of the curatorial staff or the artist's decision. Obviously, the conservation condition of the works it's also a determining factor when it comes to design exhibitions and choose display methods. Every museographic resource is usually proposed and agreed between conservators, curators and artists taking into account the space and the exhibition discourse.

Even one same work can be exhibited in several ways. In the case of clothing, fashion exhibitions or sculpture, it is common to find works installed on mannequins, bases or plinths, inside display cases and occasionally, without any type of barrier or means of protection that isolates them from the floor, so that they can be more or less exposed to possible sources of deterioration (Figure 6).

But, meanwhile some protection measures and exhibiting conditions can be modified or replaced if necessary, some of the exhibition resources mentioned, such as pedestals or display cases, can be an integral part of the artwork. This is the case of *Archery* (2002) by Naia del Castillo. Constituting elements (the arch, the arrow, archery glove, etc.) are displayed inside a wooden and glass urn as if they were archaeological objects, a factor that must also be taken into account for their correct presentation and interpretation, as stated by the artist (Figure 7).

In the case textile works with different display systems (Figure 8), the means used to hang them, such as thumbtacks, pins, lag bolts or other suspension systems using nylon thread or steel cables, can seriously affect the mechanical properties of the fabrics and the stability of the materials.

However, it must be taken into account that these can be an essential part of the work, so the solutions proposed must involve respecting the choices of the authors and alternatives that do not interfere with their message.

This works and installations may have extremely diverse characteristics and often they can be complex to record and document so according to Huys [41] stablishing clear guidelines is the basis and often the only guarantee for the correct exhibit of these artworks. Beside drawings, written guidelines, manuals and photographic documentation, instructional videos of the mounting process made by the artists are becoming usual to help conservators in these tasks.

Figure 6. The installation *Saint George and the Dragon* by Gema Intxausti, 1991, Basque Government Collection: *a)* packaging system to transport it; *b)* display resources for its exhibition at the Bilbao Fine Arts Museum (photos: RDBFAM).

Figure 7. Exhibition systems at the Naia del Castillo exhibition at the Artium Museum in 2004: *a*) various works from the series named *About Seduction* with *Luciernaga II*, 2002, at the front exhibited on a mannequin displayed on a base; *b*) hanging system and display case for *Seductor*, 2002 (photos: Artium).

Figure 8. Display systems: *a-b)Su Tu Tumba*, by Sahatsa Jauregi, 2017, Provincial Council of Bizkaia (photos: Provincial Council of Bizkaia) and a detail of the pushpins holding the printed cloths from the installation; *c-d) Domestic Space – Labors* by Naia del Castillo, 2001 and the hanging system with nylon thread used to exhibit the work at the Museum of Contemporary Art of Cantabria (photos: Instagram @luisalonsoatelier); *e-f)* Silk dress of *Mask of Seduction* by Javier Pérez,1997, Guggenheim Museum in Bilbao and a detail of the pins that hold it (photos: DCGMB).

Let's talk to the artist... The essential role of artists in the conservation of contemporary art

According to Llamas-Pacheco [44], it is not the conservator's task to decide "what is art and what is not", but proper interpretation of works is indeed a part of contemporary art conservators´ responsibility [45].

During the past two decades there has been extendedly discussed how the conservator's interpretation must take into account the symbolic, aesthetic, and conceptual value, in addition to the material aspect and in order to do that artists must be listened to during the decision making process. Along with the already mentioned authors, different theories [46-47] and initiatives have reinforced that "the artist's voice is primary in developing preservation strategies and their participation is essential for future conservation and presentation of their work" [48].

Currently, the need to consult and record the opinion of creators is an assumed methodology in the conservation of contemporary art [49-54]. Gathering artists' opinion can enrich the search for solutions and decision making through the information regarding materials and the intentionality implicit in them as well as the work's plastic discourse [34] together with the guidelines and instructions on its correct display.

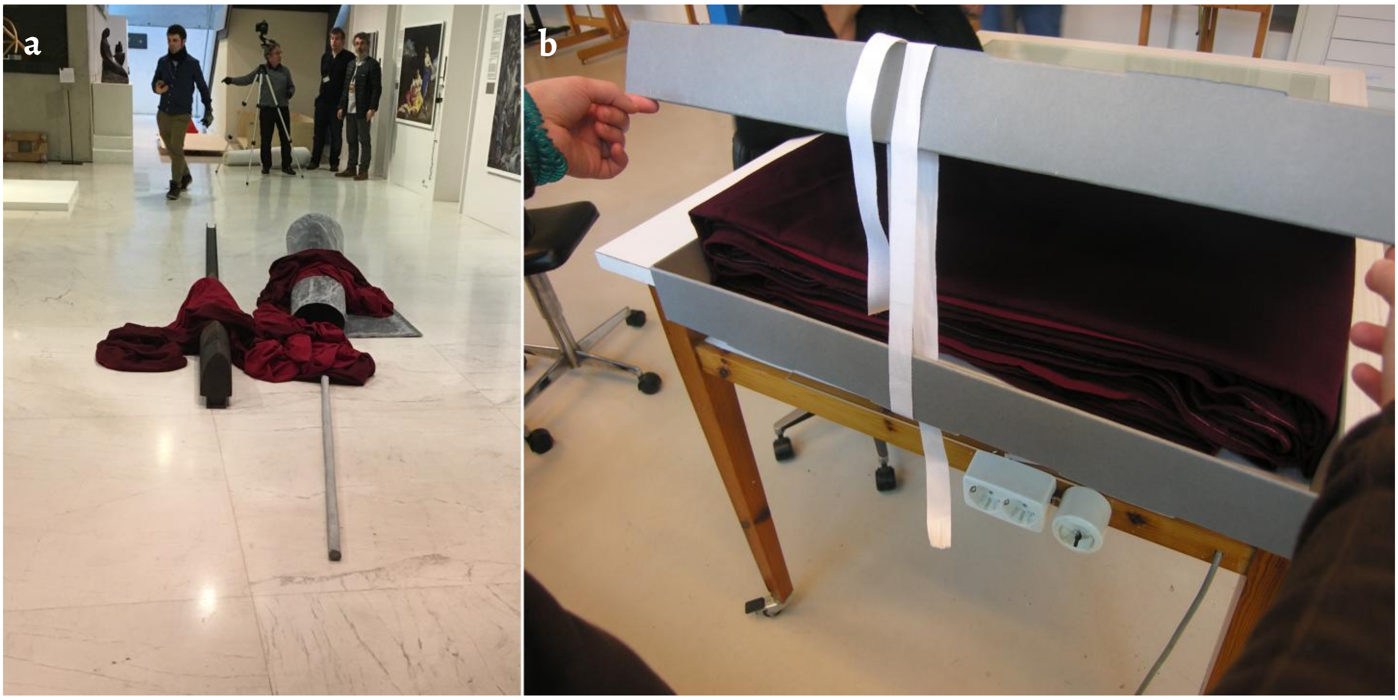

Figure 9. Artist Ángel Bados supervising the mounting of his work *Untitled*, 1985 at the Bilbao Fine Arts Museum: *a)* display of the installation conducted by the artist and the conservation department; *b)* storage system for the textile element of the installation (photos: RDBFAM).

The cases studied here evidence that all the measures adopted to guarantee the conservation and correct understanding of these works, both conceptual and material, require the collaboration of the artists and other disciplines involved in the processes of study, mounting and exhibiting of works in galleries and institutions [34-36, 55]. Artist's presence and instructions are needed to install the textile element of his work thus this varies in each display due to its fluid nature (Figure 9 and Figure 10).

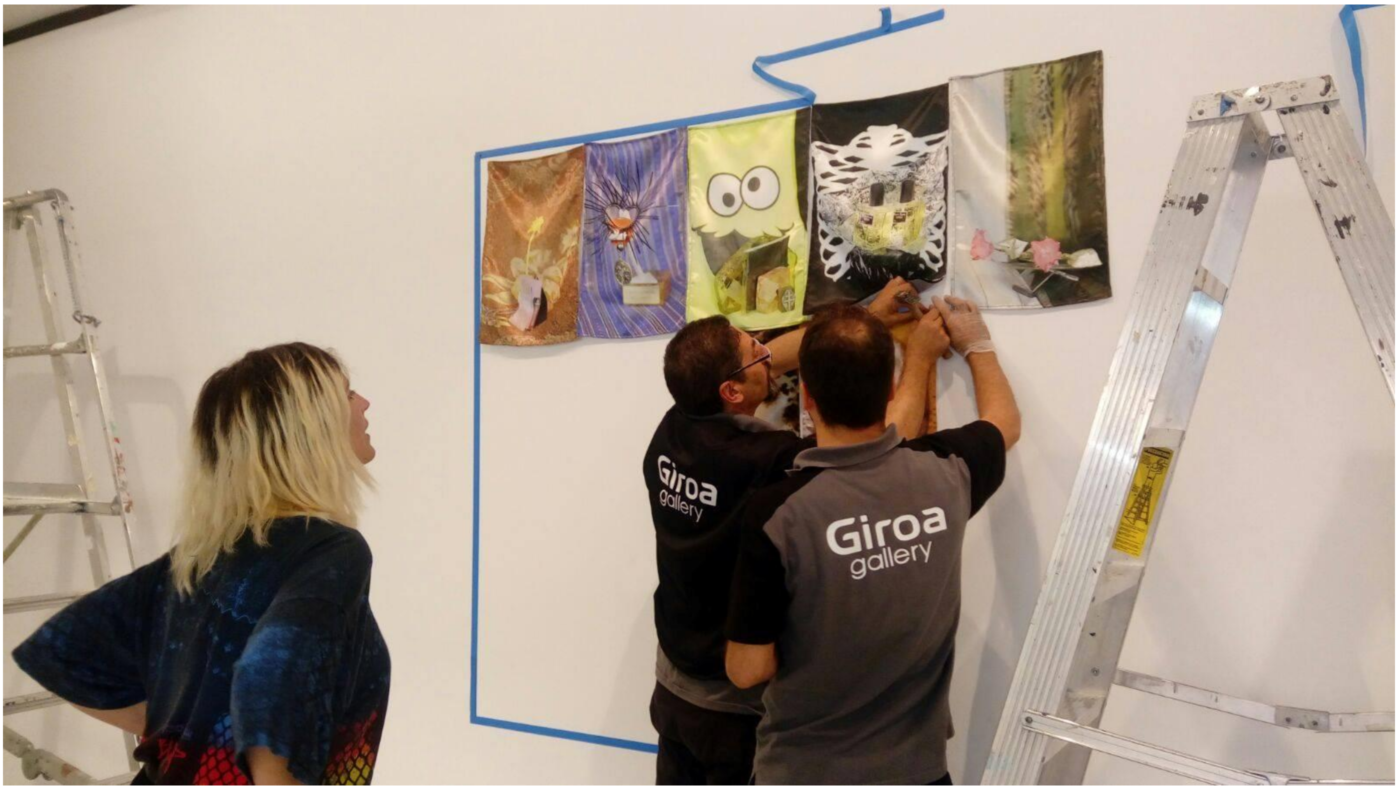

Figure 10. Artist Sahatsa Jauregi supervising the mounting and installation of her work *Su Tu Tumba*, 2017, in the Sala Rekalde. Rekalde Gallery´s Facebook.

Undoubtedly, as French points out [30], this sometimes can raise complex issues of communication and interpretation [56-57] and, therefore, complicate the implementation of necessary conservation measures.

Occasionally, authentic "negotiations" can take place between the agents involved in the organization of exhibitions (owners, institutions, artists, curators, etc.), especially during the installation and mounting processes [37] but usually their presence and opinion is rather clarifying and absolutely necessary

Conclusions

The review carried out has allowed us to show the notable presence of multiple artists from the Basque artistic context who, from the 1980s to the present day, have resorted to the use of textile materials and fabrics and whose work is currently preserved in important museums and institutions of contemporary art.

By the 80s, multidisciplinary artists such as Andrés Nagel, Ángel Bados or Juan Luis Moraza began incorporating small textile objects and fabrics into their works. Later, as already noted by Porcel and Artetxe [4], it is undeniable that artists from the early 1990s generation such as Gema Intxausti, Ana Laura Aláez or Txaro Arrazola shared a common interest in exploring and reflecting on concepts of identity and gender through textile materials, a tendency that would later be continued by artists like Naia del Castillo.

The material and formal aspects of the works studied evidence the multiplicity of typologies, materials and exhibition systems that can conditionate and determine their conservation, leaving a field of work to take into consideration in museums and institutions that house and disseminate contemporary art. The conservation of works of contemporary art made with textiles represents a complex specific field that also poses a series of practical and ethical difficulties. This, as Eastop states [58], forces the contemporary art conservator to be continually making decisions that consider, in addition to material and technical factors, those of a conceptual and legal nature.

The presence of experimental works and contemporary typologies such as installations have opened the door to the inclusion of clothing, accessories and other objects related to the field in museums and galleries. This artistic reality, together with the incorporation of synthetic materials of different nature and behaviour, as well as the use of experimental techniques and procedures, necessarily pose different requirements for its conservation.

This is clearly observed in works that incorporate techniques such as screen or digital printing or heavy embroideries and applications expanding the range of possible problems due to the instability of these procedures under deterioration factors such as light or incompatibility between materials.

Likewise, the variety of contemporary artistic typologies presented here stand as a big challenge when it comes to establishing conservation measures, especially for their exhibition and display features. Not all works are shown with simple or systematizable methods and, in fact, the exhibition systems themselves (like thin needles or pushpins) can have a huge impact on the deterioration of these textile-based pieces and become potential deterioration factors themselves.

The complicated balance between the conservation needs of these materials, the artists´ requirements or the curatorial and exhibition discourse itself, occasionally leads to serious conservation problems due to prolonged exhibition periods or disregarding other preventive measures during display. In many occasions these predictable accidents could have been avoided with specific preventive measures and display recommendations as the ones mentioned in the text.

After the study carried out in art centres, institutions and museums in charge of their safeguarding, the need to continue researching the materials that make up these works, as well as the processes used for their creation, is still observed. Registration protocols and correct cataloguing can avoid problems arising from incomplete or incorrect identifications and help establish more effective conservation, restoration, storage and exhibition protocols.

The case studies have also shown how closely conservation is linked to aspects relating to its storage and exhibition protocols, while also highlighting the need for multidisciplinary collaboration between the different fields involved (creation, curatorship, conservation, history, etc.) in order to properly preserve and transmit these works of art.

The information obtained from conversations with the authors during this study has been decisive for the correct understanding of the significance of the materials and techniques used in their production, as well as to assess the importance of their exhibition requirements and conservation needs in order be thorough and likewise preserve their artistic intention.

It's clear that conservation, exhibition and diffusion of these works involve the understanding of conceptual aspects in addition to purely formal or material ones that can significantly alter their meaning if they are not respected in an integral way. Undoubtedly, the engagement and active participation of artists throughout the various stages of interpreting and presenting their work can be regarded as essential.

Acknowledgements
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CONSERVAR PATRIMÓNIO

ARTÍCULO / ARTIGO / ARTICLE

El levantamiento científico para determinar las fases de construcción de la Iglesia de San Miguel en Zaragoza

O levantamento científico para determinar as fases de construção da Igreja de San Miguel em Zaragoza

The scientific survey to determine the construction phases of the Church of San Miguel in Zaragoza

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Resumen

La capilla de San Miguel, conocida como la Parroquieta, fue erigida en la Catedral de La Seo de Zaragoza como panteón del arzobispo Don Lope Fernández de Luna en el siglo XIV. El objetivo de este estudio es esclarecer sus fases constructivas, bajo la hipótesis de que corresponde a la macla de dos proyectos distintos. La metodología se fundamenta en un levantamiento geométrico mediante escáner láser, fotogrametría y reconstrucción virtual, complementado con análisis arquitectónico detallado de sus componentes. Los resultados muestran tres incongruencias principales: la irrupción de ventanales góticos en una fachada cerámica de composición unitaria, la interrupción de bóvedas enjarjadas en la cripta y la presencia de epigrafía árabe en la cúpula funeraria. Estos hallazgos permiten concluir que el edificio integra dos técnicas constructivas diferenciadas, sugiriendo la reutilización de muros de la antigua mezquita aljama de Saraqusta.

PALABRAS-CLAVE
Levantamiento geométrico
Mudéjar
Gótico aragonés
Escáner láser
Fotogrametría
La Seo del Salvador

Resumo

A capela de San Miguel, conhecida como La Parroquieta, foi erguida na Catedral de La Seo de Zaragoza como panteão do arcebispo Don Lope Fernández de Luna no século XIV. O objetivo deste estudo é conhecer as suas fases de construção, partindo da hipótese de que corresponde à fusão de dois projetos distintos. A metodologia baseia-se num levantamento geométrico através de scanner a laser, fotogrametria e reconstrução virtual, complementado com uma análise arquitetónica detalhada dos seus componentes. Os resultados mostram três incongruências principais: a irrupção de janelas góticas numa fachada cerâmica de composição unitária, a interrupção de abóbadas em treliça na cripta e a presença de epigrafia árabe na cúpula funerária. Essas descobertas permitem concluir que o edifício integra duas técnicas construtivas diferenciadas, sugerindo a reutilização das paredes da antiga mesquita aljama de Saraqusta.

PALAVRAS-CHAVE
Levantamiento geométrico
Mudéjar
Gótico aragonés
Escáner láser
Fotogrametría
La Seo del Salvador

Abstract

The Chapel of San Miguel, known as La Parroquieta, was erected in the Cathedral of La Seo de Zaragoza as the pantheon of Archbishop Don Lope Fernández de Luna in the 14th century. The objective of this study is to clarify its construction phases, under the hypothesis that it corresponds to the twinning of two different projects. The methodology is based on a geometric survey using laser scanning, photogrammetry, and virtual reconstruction, complemented by a detailed architectural analysis of its components. The results reveal three main inconsistencies: the emergence of Gothic windows in a ceramic façade of a uniform composition, the interruption of lattice vaults in the crypt, and the presence of Arabic epigraphy in the funerary dome. These findings lead to the conclusion that the building integrates two distinct construction techniques, suggesting the reuse of walls from the old main mosque of Saraqusta.

KEYWORDS
Geometrical survey
Mudejar
Aragonese Gothic
Laser scanner
Photogrammetry
La Seo del Salvador

Introducción

La Parroquieta es el nombre comúnmente utilizado para referirse a la capilla de San Miguel. Esta capilla ubicada en la cabecera de la Catedral conocida como la del Salvador en su Epifanía, popularmente llamada La Seo, fue erigida por el arzobispo Don Lop Fernández de Luna (1321?-1382), en la segunda mitad del siglo XIV para albergar su enterramiento [1], un sarcófago gótico situado en un arcosolio en el presbiterio de la capilla.

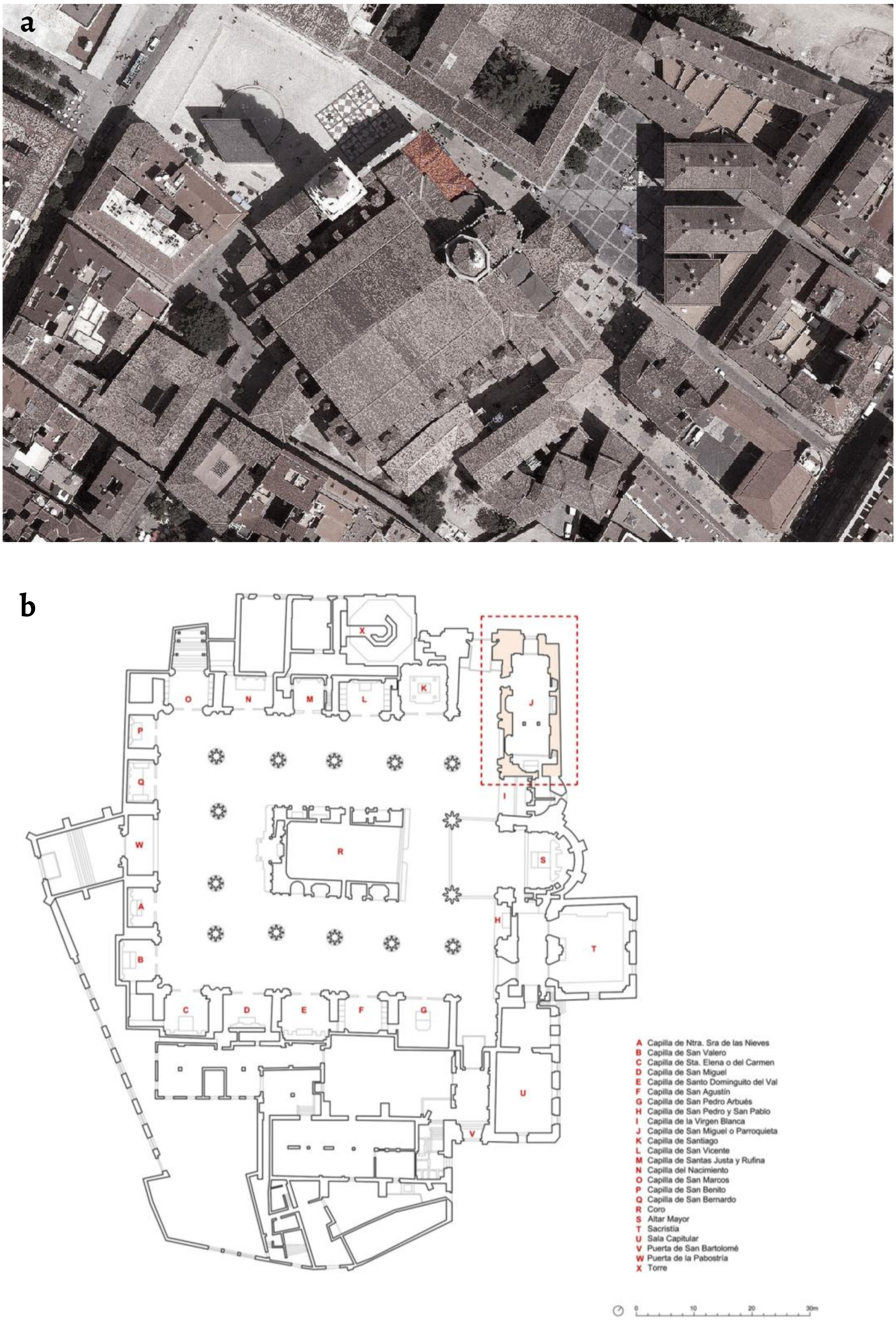

Figura 1. Catedral de San Salvador, La Seo, de Zaragoza: *a)* ortofoto PNOA , en la que se destaca la Parroquieta (foto: ICEARAGÓN); *b)* ubicación de la Parroquieta en la planta general de la Catedral.

La referencia más antigua sobre la construcción de la capilla proviene del cronista Diego de Espés [2], reverendo archivero de La Seo, quien en 1574 menciona el hecho en su obra *Historia eclesiástica de la Ciudad de Zaragoza desde la venida de J.C. Señor y Redentor nuestro, hasta el año 1575*. En ella señala que en 1374 el arzobispo ya había iniciado la edificación de la capilla dedicada a San Miguel Arcángel, concebida como lugar de su sepultura. Además, en su testamento, fechado el 3 de febrero de 1382, se estipula la creación de diez capellanías que oficiarían en el altar de la capilla una vez estuviese concluida, lo que indica que la obra no había finalizado aún en esa fecha.

El edificio está adosado al ábside lateral del Evangelio en su lado sudeste y a la nave del crucero en su lado suroeste, siendo exterior en los otros dos lados (Figura 1). Sus dimensiones exteriores son aproximadamente de 22,5 × 10,0 m, con una altura de 17,0 m hasta llegar al mirador, que tiene una altura adicional de 1,30 m y actualmente corona el edificio. Interiormente es una iglesia de nave única de aproximadamente 10,5 × 6,4 m y 14,7 m de altura, compuesta por dos tramos, cubiertos por bóvedas de crucería, trabajadas en piedra. La nave, a través de un grueso arco de medio punto de 2 m de anchura da paso al presbiterio, de planta cuadrada 6,5 × 6,5 m cubierto por una cúpula de madera, la cual de planta cuadrada pasa a planta octogonal decorada con mocárabes de 4,5 m de altura [3]. En el lado norte, en un arcosolio, se ubica el sarcófago gótico que contiene los restos del arzobispo. Bajo el presbiterio, y con dimensiones similares, se encuentra la cripta.

La restauración llevada a cabo en 1936 por el arquitecto Francisco Íñiguez Almech devolvió al edificio su aspecto medieval. Durante este proceso se revelaron dos tramos de bóveda de crucería gótica, cuyas claves exhiben pintadas las armas de la familia Luna. Además, se solucionó la transición entre los tramos de bóveda de crucería y la zona del presbiterio, cubierta por un artesonado situado a menor altura, mediante la construcción de tres arcos apuntados sobre pilares, que funcionan a modo de iconostasis [4].

Materiales y métodos

La metodología de análisis e investigación aplicada a la Parroquieta de La Seo de Zaragoza se fundamenta en el análisis arquitectónico, dada la carencia de fuentes documentales. La antigüedad del edificio y los periodos convulsos que ha atravesado desde su construcción, dan lugar a ciertas pequeñas incongruencias entre la realidad constructiva del edificio y su interpretación teórica. Sin afectar a los aspectos esenciales, estas discrepancias invitan a adoptar una visión más amplia que la estrictamente centrada en su unidad estilística.

Con el objetivo de realizar un análisis exhaustivo, se ha llevado a cabo un examen riguroso de la arquitectura existente, considerando sus características constructivas, estructurales, decorativas y los materiales empleados. Este estudio se ha complementado con la revisión de investigaciones arqueológicas e históricas previas, integrando diferentes fuentes para contextualizar el edificio en su evolución histórica. Para una comprensión integral del edificio y de los componentes procedentes de otras construcciones que conforman el conjunto actual, el primer paso ha sido la realización de una reconstrucción virtual. Esta herramienta permite analizar con precisión las relaciones entre los diferentes elementos constructivos, tanto en el exterior como en el interior, así como descubrir detalles que podrían pasar desapercibidos en una observación general [5].

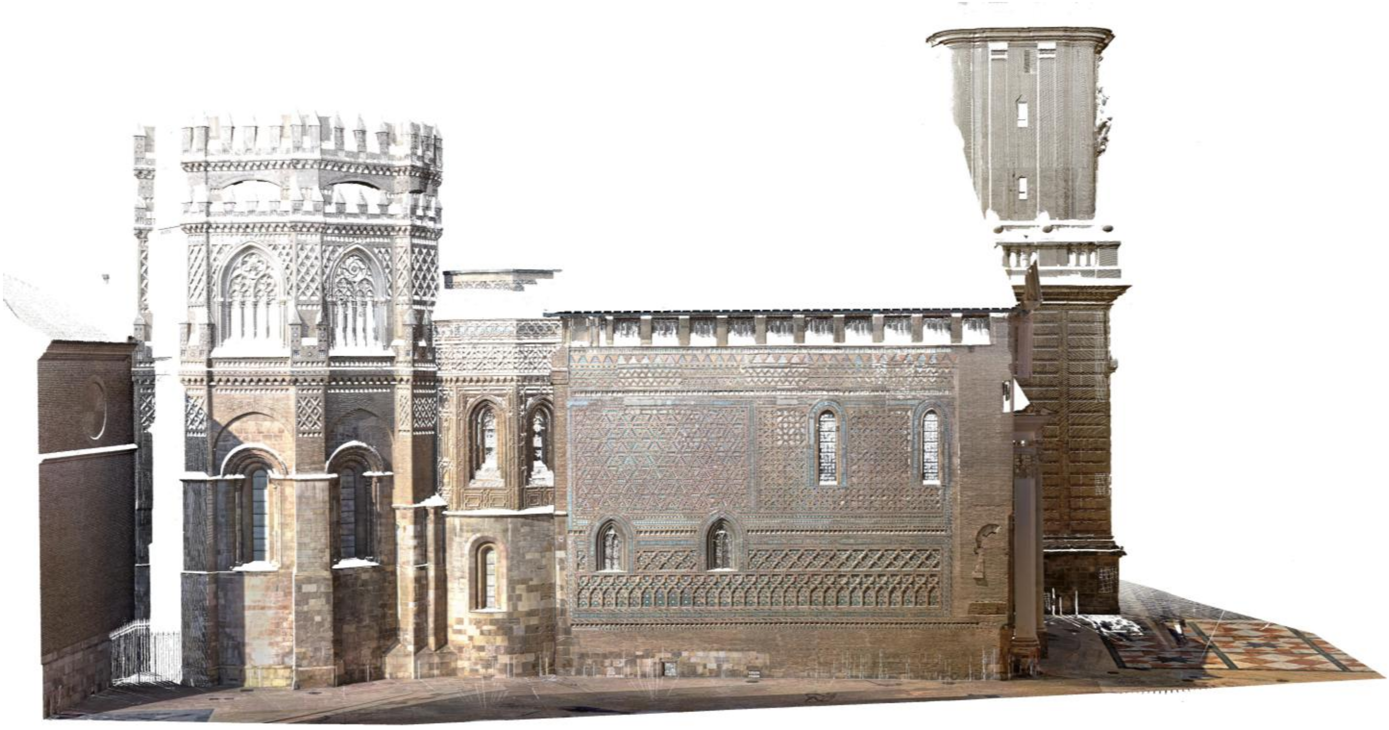

Figura 2. Nube de puntos del exterior de la Parroquieta obtenido mediante escáner láser.

La reconstrucción geométrica de la capilla, se ha desarrollado utilizando tecnología de escáner láser y fotogrametría, con el fin de obtener una nube de puntos de alta precisión que facilite el levantamiento detallado del edificio. El escáner láser empleado fue el *Faro Focus S 70*, capaz de capturar imágenes en alto rango dinámico. Se realizaron 38 estaciones de escaneo en el interior y 12 en el exterior, adaptando el trabajo a las características específicas del ladrillo y la cerámica. Además, para capturar la parte superior del edificio y obtener valores colorimétricos de la mejor calidad, se llevó a cabo una campaña de vuelo con dron, que generó un total de 360 imágenes de alta resolución. Con los datos recopilados, se procedió al levantamiento virtual del edificio utilizando el software *Scene*, para posteriormente exportarlo a un programa de CAD, donde se dibujó la nueva planimetría [6]. Esta fue necesaria, ya que la documentación existente no ofrecía una calidad, ni rigor suficiente, para determinar con precisión la geometría y las relaciones volumétricas del conjunto (Figura 2).

Para abordar el análisis arquitectónico, se segmentó el edificio en sus distintas partes, lo que permite un estudio detallado de cada componente sin perder de vista la totalidad. En primer lugar, se analizarán los dos muros exteriores: el principal, más largo y orientado al nordeste, y el más estrecho, orientado al noroeste, haciendo especial énfasis en la cerámica vidriada que caracteriza ambos cuerpos. Posteriormente, se examinará el interior de la capilla, compuesta por una nave dividida en dos tramos y dos capillas laterales.

Análisis del edificio

La arquitectura gótica en Zaragoza se caracteriza en su mayoría por el uso del ladrillo, tanto en el interior como en el exterior, encuadrándose dentro del estilo mudéjar. La Parroquieta, sin embargo, se distingue por la pureza del arte gótico, en piedra, que se aprecia en el interior en contraste con el exterior de ladrillo, no sólo en cuanto a materiales y ornamentación, sino también por la solidez lisa de sus muros, en oposición al juego de volúmenes característico de la arquitectura gótica tradicional. Esta dualidad convierte al edificio en un modelo singular, digno de un análisis detenido.

Exterior

La Parroquieta, tiene dos de sus cerramientos exteriores: el más largo orientado al nordeste, con aproximadamente 23 × 18,5 m, está ocupado en su mayor parte por un rectángulo apaisado de fábrica de ladrillo profusamente decorado, de 19,5 × 14,0 m. Apoya sobre una base o zócalo de unos 2,5 m de altura. La mitad izquierda es de piedra sillar hasta una altura aproximada de 1,5 m, formato y aspecto parecidos a la antigua muralla romana que cerraba la ciudad [7]. El resto, que se corresponde con el presbiterio y la cripta bajo el mismo, es de ladrillo con un pequeño zócalo de piedra similar al descrito, salvo su extremo derecho que hace esquina con la plaza, que también es de piedra. El lado derecho de la fachada, también de unos 2,5 m de anchura, recorre toda la altura del edificio. Es de ladrillo y conserva las huellas del paso cubierto sobre la calle, el arco del arzobispo. El lado superior de la fachada corresponde al mirador adintelado de 1,5 m de altura, que resulta ser un cuerpo añadido a la fábrica original.

La segunda fachada del edificio, más corta y orientada al noroeste que da a la plaza, continúa la misma disposición decorativa que el muro nordeste en el lado izquierdo. Desde este punto, una nueva fachada neoclásica blanca se superpone, ocultando el resto de dicha fachada. La parte medieval visible, conserva parcialmente la decoración.

Muro nordeste: cerámica, cuerpo inferior

En el cuerpo inferior, se observan dos bandas decorativas longitudinales que recorren toda su extensión, enmarcadas conjuntamente por una orla de mayor grosor, la cual está decorada con cerámica vidriada compuesta por pequeños azulejos cuadrados y rectangulares dispuestos en forma de rombos. Los colores de la cerámica incluyen tonos melados, blancos, verdes y morado-negruzcos mientras que el lado derecho sustituye estos motivos por un castillo blanco en fondo verde. Una segunda orla, en este caso partida longitudinalmente y también estrecha como las descritas en torno a los frisos de esquinillas, enmarca los dos tableros del cuerpo, estando decorada con azulejos cuadrados en losange o con cadenas tricolores.

La banda inferior está compuesta por arcos mixtilíneos entrecruzados, con el interior rehundido y enlucido, decorado con tres tipos de azulejos: estrellas blancas de ocho puntas enmarcadas por piezas verdes o azules; platos de cerámica verde; y baldosas blancas en forma de rombo con las armas de los Fernández de Luna. La banda superior, más estrecha, sustituye los arcos por una sucesión de hexágonos curvilíneos entrelazados que generan rombos curvilíneos, formados por dos arcos mixtilíneos enfrentados a lo largo de un eje horizontal de simetría. El fondo también está enlucido y decorado con azulejos en forma de estrellas y platos cerámicos, de dos tamaños y en tonos verde y azul.

Este patrón se ve interrumpido por las dos ventanas ojivales que flanquean el sarcófago del arzobispo, siendo la izquierda la que rompe la continuidad geométrica de la banda. Ambas se apoyan sobre la orla central, de proporciones estrechas, y presentan jambas y arcos ojivales enmarcados por una doble orla: una interior más ancha y otra exterior más estrecha. En las claves de ambas ojivas se insertan azulejos con las armas del arzobispo. En el extremo derecho de este tablero superior del cuerpo bajo, hay una inscripción en árabe dispuesta a ambos lados de la parte inferior del rombo, reproduciendo en caracteres cúficos la expresión [8-9]:

عمل / سلامة بن غالب   Lo hizo / *Salāma bn Gāli*

Muro nordeste: cerámica, cuerpo central

El cuerpo central, mide unos 19,0 × 6,0 m, consta de dos grandes tableros decorados, de iguales dimensiones, lo rodea una orla ancha partida verticalmente por la mitad, está decorado con los mismos azulejos pequeños del cuerpo inferior, excepto el lado inferior y el tramo del derecho hasta la jamba de la ventana, cuya decoración consiste en estrellas blancas de 8 puntas en fondo verde.

El tablero de la derecha está completamente adornado con un motivo de lazo de ocho. El fondo está alicatado con azulejos blancos verdes y morados con diversos motivos geométricos.

Este tablero también queda interrumpido por otras dos ventanas ojivales, éstas situadas en los ejes de los dos tramos de la nave, rompiendo ambas la secuencia geométrica del tablero e invadiendo las orlas superior y derecha del mismo. También están acompañadas de una doble orla, ancha en el interior y estrecha en el exterior, pero sin escudo en las claves. El tablero izquierdo también está totalmente decorado, pero con lazo de seis [10]. La parte inferior está levemente invadida por las dos ventanas del presbiterio.

Muro nordeste: cerámica, cuerpo superior

El cuerpo superior constituye el remate de la fábrica original y habría funcionado como un antepecho en caso de que el edificio contara, en su estado primitivo, con una cubierta plana en lugar de la actual cubierta inclinada sobre el mirador. Este cuerpo se compone de dos partes. La mitad inferior, situada por encima del friso de esquinillas más elevado, presenta dos bandas de decoración en zigzag. Sobre estas dos bandas se extiende una cenefa igual que las orlas estrechas de los cuerpos inferiores, decorada con puntas de flecha, blancas y verdes. Esta cenefa da paso a una serie de merlones triangulares alicatados con pequeños azulejos triangulares blancos, verdes y morados. Una última banda de esquinillas, en este caso decorada con dobles columnitas verdes, corona esta parte del edificio dando paso al mirador adintelado.

La cerámica vidriada

El azulejo constituye el elemento decorativo más destacado de toda la fachada. Como puede observarse, la apertura de las ventanas incide directamente sobre esta decoración, interrumpiendo algunas de las orlas revestidas con azulejos. Esta circunstancia sugiere la posibilidad de que los trabajos relacionados con la fábrica de ladrillo, la aplicación del revestimiento cerámico y la disposición de las ventanas ojivales respondieran a programas constructivos distintos o no plenamente coordinados. En el siglo XIV, Aragón contaba ya con ceramistas cualificados, cuya actividad se documenta tanto en solados de capillas y palacios como en revestimientos exteriores de edificios religiosos.

Por la razón que fuere, los azulejos que acompañan a las ventanas y los de algunas partes de las orlas se encargaron a dos sevillanos [11]. De esta forma, según Álvaro Zamora [12], la parte cerámica más visible por estar más cerca del espectador, la de los paños inferiores, correspondería a la intervención realizada por artesanos aragoneses, precisamente aquella que no habría sido del agrado del arzobispo. Por otro lado, el autor afirma que la técnica de alicatado era desconocida en los talleres aragoneses durante este periodo. Sin embargo, esta afirmación resulta discutible, ya que se conservan ejemplos de azulejos contemporáneos utilizados tanto para pavimentos como para revestimientos murales, como los de la iglesia de San Pedro Mártir de Calatayud, obra del arquitecto Mahoma Ramí, al servicio del Papa Benedicto XIII [13].

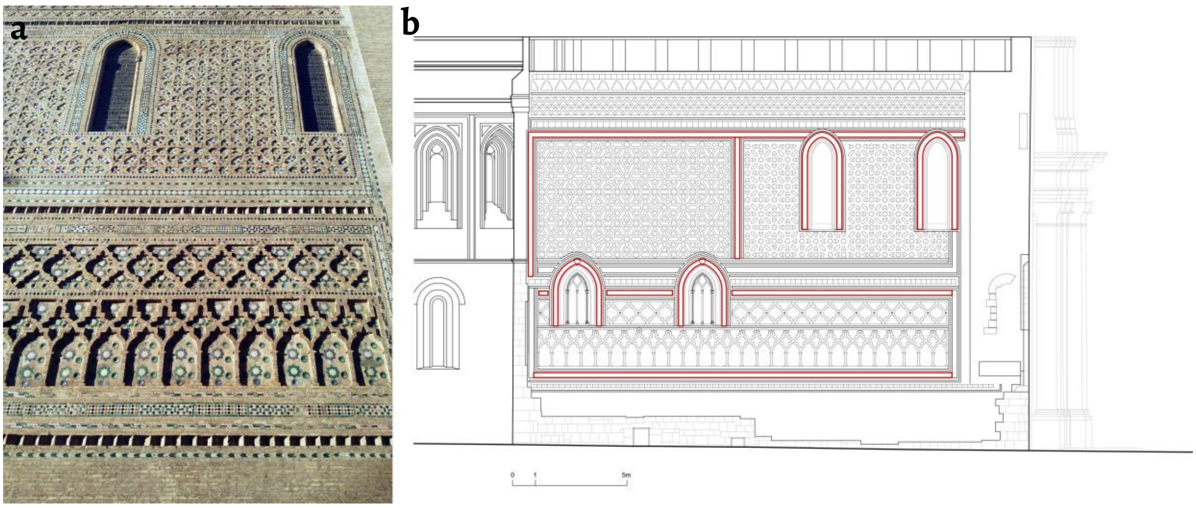

Figura 3. Fachada donde se distinguen las distintas tipologías básicas de cerámica: *a)* detalle (foto: Luis Agustín); *b)* ubicación de la cerámica sevillana, enmarcada en rojo.

Todos estos indicios sugieren que la decoración cerámica de la fachada pudo haberse realizado en dos momentos distintos. Por un lado, una intervención menor en el siglo XIV, atribuida a los azulejeros sevillanos - cuyo trabajo está debidamente documentado - y que, por su coste y alcance limitado, no habría abarcado una superficie extensa. Por otro lado, una fase anterior de mayor envergadura, correspondiente probablemente al momento original de construcción (Figura 3).

La cerámica que puede datarse con certeza en el siglo XIV es la que enmarca las ventanas góticas. Se trata de un alicatado compuesto por pequeñas piezas que forman paneles decorativos de aproximadamente 0,85 × 0,22 m, con patrones repetitivos. Uno de los motivos está formado por pequeños cuadrados amarillos, verdes y morados dispuestos en losange sobre fondo blanco; el otro, combina rectángulos verdes colocados en disposición vertical y horizontal, con cuadrados morados en losange también sobre fondo blanco. Este mismo tipo de cerámica se extiende igualmente por las orlas anchas, a excepción de algunos tramos verticales y de todo el lado horizontal bajo los dos grandes paños de lazos de seis y ocho. El tratamiento de las intersecciones entre las orlas anchas y estrechas, así como su relación con los tableros decorativos, no sigue una pauta geométrica constante, lo cual resulta especialmente llamativo en un muro donde la única alteración significativa de la armonía geométrica proviene de las ventanas. Por último, los azulejos con las armas del arzobispo, embutidos directamente en el enlucido de yeso, deben atribuirse igualmente al siglo XIV.

El interior de la Parroquieta

La iglesia es de una sola nave de dos tramos con dos capillas, una a cada lado, situadas de forma excéntrica respecto al eje del primer tramo. Entre ambos tramos se abren dos arcos de dimensiones equivalentes a las embocaduras de las capillas, los cuales albergan puertas (Figura 4). La puerta situada a la izquierda, según se accede desde el exterior, conduce a la escalera que da acceso al coro; la opuesta, a la derecha, permite la comunicación con el interior de la catedral. El aspecto actual de la nave, salvo las bóvedas y el coro, se debe al arzobispo Francisco Ignacio de Añoa y Busto (1742-1764), quien entre 1753 y 1758 reformó la capilla adecuando “una nueva cabecera con una pequeña sacristía…y de tres retablos…” [14]. El acceso desde el exterior, ubicado en el hastial, se realiza a través de una puerta de madera de dos hojas, decorada con un motivo de lazo de cuatro.

Los dos tramos de la nave, ejecutados a diferencia del exterior con piedra sillar, se cubren con bóvedas de crucería cuyos nervios se apoyan sobre ménsulas. Las claves de ambas bóvedas están decoradas con pinjantes que incorporan las armas del arzobispo [15]. La iluminación se resuelve mediante dos ventanas ojivales, perfectamente alineadas con los ejes de cada tramo situadas a la altura de las ménsulas. Estas ventanas, descritas anteriormente en relación con el tablero exterior de lazo de ocho, presentan un acusado derrame hacia el interior, debido a la necesidad de conciliar su posición con la disposición de la lacería exterior y el espacio gótico interior. En el hastial, se abre un óculo circular que fue transformado en 1770.

El acceso al coro se efectúa por escalera de dos tramos, situada en el interior del muro de dos hojas, cubierta mediante bovedillas enjarjadas o de aproximación, propias de la arquitectura medieval aragonesa. La puerta de entrada al coro está situada unos metros más abajo que otro acceso medieval que se delata por un arco ojival de piedra sacado a la luz durante la restauración de 1937. Esta puerta, conservada en mal estado, parece ser un fragmento de otra de mayores dimensiones. El coro actual, fruto de la reforma integral del edificio en el siglo XVIII, permite aún observar la decoración esgrafiada medieval en las paredes. En el muro que separa la capilla de la nave del crucero de la catedral se encuentra un segundo arco ojival tabicado, de la misma factura y altura que el previamente descrito.

El presbiterio, separado de la nave mediante un triforio, es un paralelepípedo con una longitud interior de 6,5 m por lado. Actualmente, la altura de este espacio es mayor debido a la demolición de las bóvedas de la cripta y al rebaje de la rasante para igualarla con la de la nave.

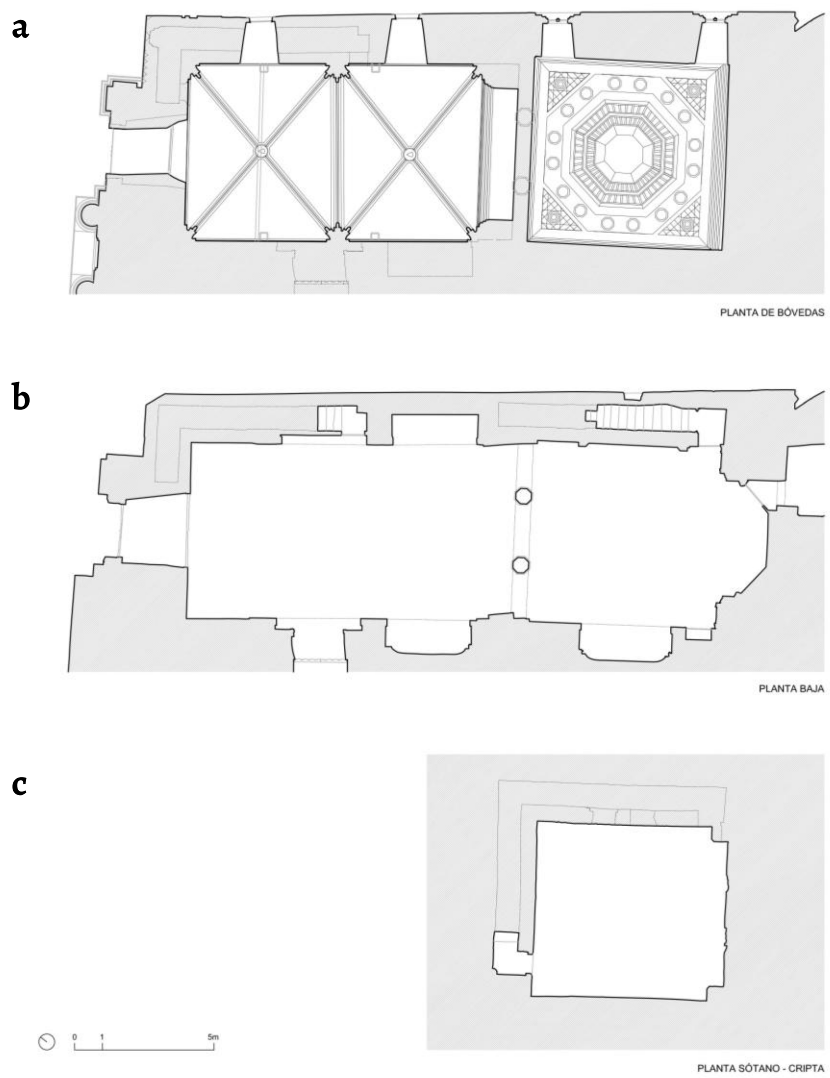

Figura 4. Plantas obtenidas a partir de delineado sobre la nube de puntos: *a)* planta de bóvedas; *b)* planta baja; *c)* planta sótano – cripta.

Aunque preside el presbiterio el altar barroco dedicado al titular de la capilla, San Miguel Arcángel, el protagonismo del espacio lo ocupa el sarcófago gótico del arzobispo, ubicado en un arcosolio y flanqueado por las dos ventanas restantes que se abren en el muro nordeste (Figura 5). Éstas, al tener que salvar el amplio grosor del muro de dos hojas y estar enrasadas al exterior, presentan también un acusado derrame en su cara inferior. Las jambas laterales son perpendiculares a los muros y la superior se resuelve con bóvedas baídas decoradas con estrellas y bandas estrechas, como las del exterior del muro. Se decora el conjunto del presbiterio con un alto arrimadero de cerámica mudéjar de cuerda seca, datable en el siglo XVI.

El espacio está cubierto por una cúpula ochavada de madera, de base cuadrada, que consta de dos niveles. A través de cuatro cuadrantes, la estructura transforma la base cuadrada en un octógono también de dos niveles, aunque de mayor altura que el cuerpo inferior (Figura 6). La cúpula, realizada en madera dorada, presenta una decoración basada principalmente en diversas bandas de bovedillas de mocárabes que se alternan con paneles ornamentales. Estos incluyen lazos de variados tipos, veneras y, de manera destacada, varias bandas epigráficas que incorporan la heráldica del arzobispo.

> *La base cuadrada se decora con un friso dividido en doce zonas, independientes entre sí, con bandas epigráficas y seudo-epigráficas. Todas estas inscripciones dispuestas en la parte superior de la capilla funeraria del arzobispo Lope Fernández de Luna hacen referencia a Dios y a su reino, así como a la protección que Él brinda a los creyentes, a los que premiará en la otra vida. Al-Hafiz, El Protector, El Conservador, El Preservador, rodea todas las cosas con su*

omnipresencia para preservar su existencia. Al-Mulk, El Rey, mantiene su soberanía sobre los cielos y la tierra, en cuanto que Dueño (Malik) y Señor (Rabb) de todas las cosas [16].

Figura 5. Vistas del interior de la Parroquieta: *a)* Bóvedas; *b)* Sarcófago; *c)* Nave (fotos: Javier Peña).

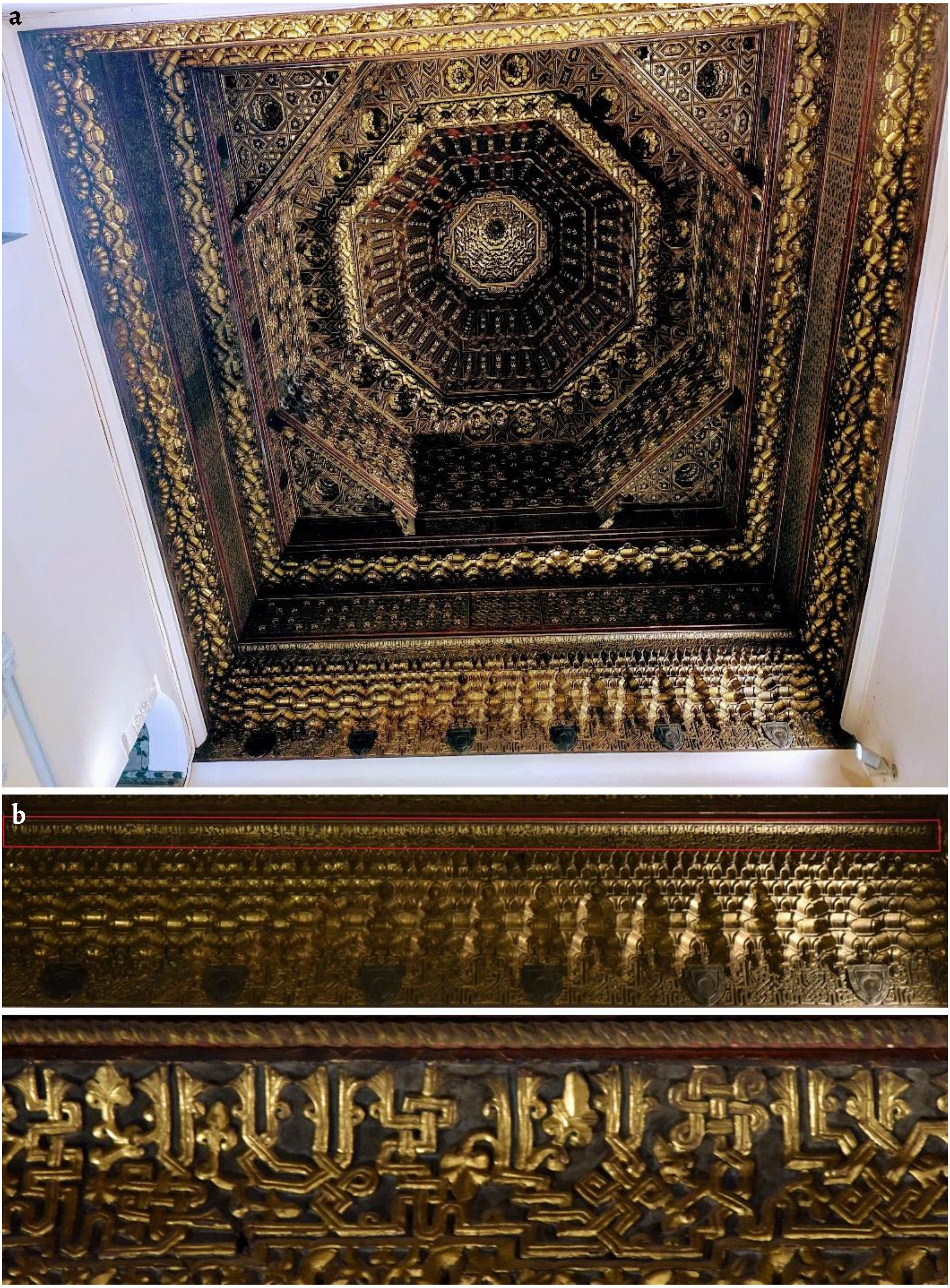

Figura 6. Cúpula ochavada de madera: *a)* vista general; *b)* detalle de la banda epigráfica singular (fotos: Javier Peña, Luis Agustín).

Una pequeña puerta situada en un rincón bajo la ventana derecha del presbiterio conduce a la cripta, situada bajo el espacio del presbiterio. Las escaleras discurren entre el muro de doble hoja, construido en piedra sillar, y están cubiertas por bovedillas de ladrillo, excepto en el espacio correspondiente al arcosolio, donde estas bóvedas fueron demolidas y reemplazadas por una losa plana apoyada sobre viguetas. Este mismo espacio del arcosolio se prolonga hacia la cripta con un gran arco rebajado que la conecta visualmente con este tramo de escalera. La escalera tiene dos tramos en ángulo recto y desemboca en la cripta mediante un arco ojival que, a diferencia de los descritos en el coro, de factura gótica, están decorados con molduras y el despiece de las dovelas coincide con el arranque del arco. El de la cripta no tiene molduras y las dovelas empiezan en los costados del arco. Bajo los apoyos de los arcos se conservan cuatro ménsulas de piedra y el arranque de sendos nervios que indican que la cripta estuvo cubierta con bóveda de crucería y que el suelo del actual presbiterio estuvo a una cota más alta.

Discusión de los resultados a partir del análisis constructivo del edificio

Ante la limitada y parcial documentación histórica disponible, se plantea como vía metodológicamente válida la realización de un análisis arquitectónico, sustentado en el estudio morfológico y constructivo desarrollado en el apartado anterior, con el objetivo de responder a algunas de las incógnitas que su construcción plantea.

El encargo del arzobispo, consistía en construir una capilla anexa a la nave del crucero de la catedral, con acceso directo desde la plaza, junto a su puerta más importante. Resulta lógico que tanto el edificio como el elemento central de la capilla – el sarcófago del arzobispo – fueran confiados a los artistas más destacados y competentes del reino. En cuanto a la sepultura, fue encargada al escultor Pere Moragues, con quien Fernández de Luna debió tener contacto durante su episcopado en Vic [17].

La primera incongruencia arquitectónica observada es la disposición de las cuatro ventanas del cerramiento nordeste, que lejos de guardar relación con la composición geométrica de los tableros decorativos exteriores donde se ubican, la interrumpen de forma evidente, como se aprecia en los alzados mostrados en la Figura 7. Se trata de uno de los escasos ejemplos de fachada de edificio medieval aragonés, de ladrillo y yeso, cuya decoración alcanza la práctica totalidad de la misma. Otros dos ejemplos contemporáneos a la Parroquieta, serían las iglesias de S. Martín de Tours de Morata de Jiloca y la iglesia de la Virgen de Tobed (Figura 8). Estas difieren de la de la Parroquieta en dos aspectos principales: primero, por sus dimensiones, que son menores; segundo, por la integración de los huecos en el sistema decorativo de sus fachadas. Ambas presentan ventanas y portadas perfectamente integradas en la decoración de lacería. En el caso de la Virgen de Tobed, construida pocos años después que la Parroquieta, las ventanas, de mayor tamaño y similares a las de Zaragoza, no solo respetan la trama geométrica de la fachada, sino que forman parte de ella, a diferencia de lo que ocurre en La Seo.

La intromisión de la ventana alargada situada a la derecha es evidente, ya que la triple orla que enmarca el tablero derecho del muro donde se encuentra queda interrumpida por la orla estrecha que rodea la ventana. En el extremo izquierdo de esta ventana, la tira de medio ladrillo que conforma todos los lazos del muro, está desplazada en un ancho igual con respecto a la que sigue en el tablero. La orla doble de la ventana, también invade la parte superior de la triple orla del tablero, en cambio, el alféizar se apoya directamente en una de las tiras del tablero. La orla de la otra ventana alargada comienza justo después de sendas tiras verticales y horizontales del tablero, en el lado derecho e inferior de la orla, respectivamente, en el lado izquierdo, el borde vuelve a desplazarse de manera similar a la otra ventana, el arco también penetra en la triple orla del tablero. Las ventanas pequeñas comienzan desde la misma orla estrecha que las separa, además de compartir, entre el tablero inferior compuesto por arcos mixtilíneos entrecruzados y el siguiente, compuesto por rombos curvilíneos, ambas invaden con sus arcos los frisos y orla y algo del tablero grande izquierdo. El conjunto de doble orla y ventana, en la de la derecha se emplaza de forma adecuada con respecto al tablero de rombos; en la ventana izquierda, en cambio, encaja inadecuadamente y de forma dispar, ya que afecta a 2/3 del rombo situado a su derecha y a medio rombo del de la izquierda. Por el contrario, obsérvese en la reconstrucción de la fachada, propuesta por los autores, donde se han eliminado las ventanas y todas las orlas, frisos, arcos mixtilíneos y rombos coinciden perfectamente en una composición unitaria y armónica (Figura 9).

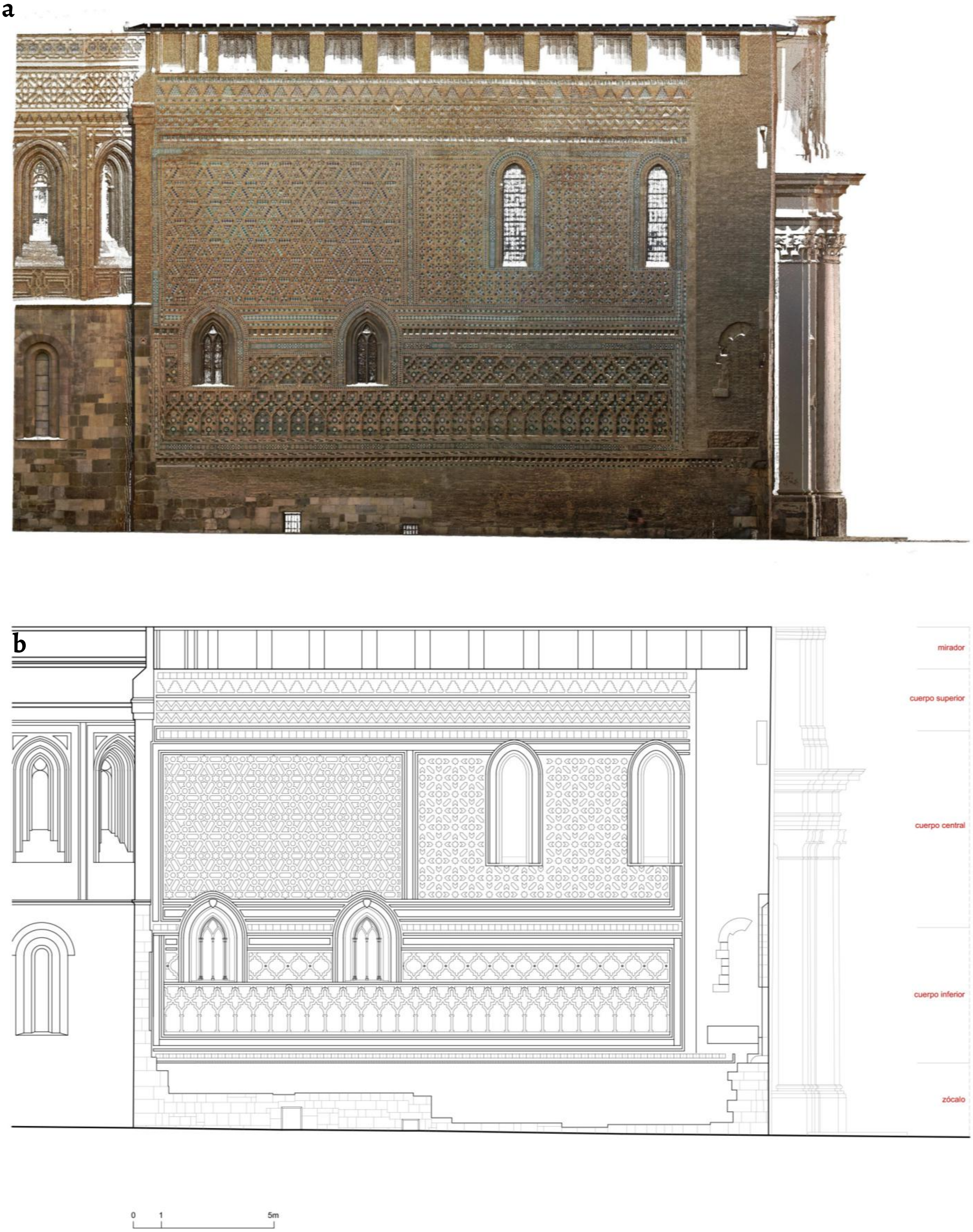

Figura 7. Estado actual de la fachada: *a)* ortofoto; *b)* delineado.

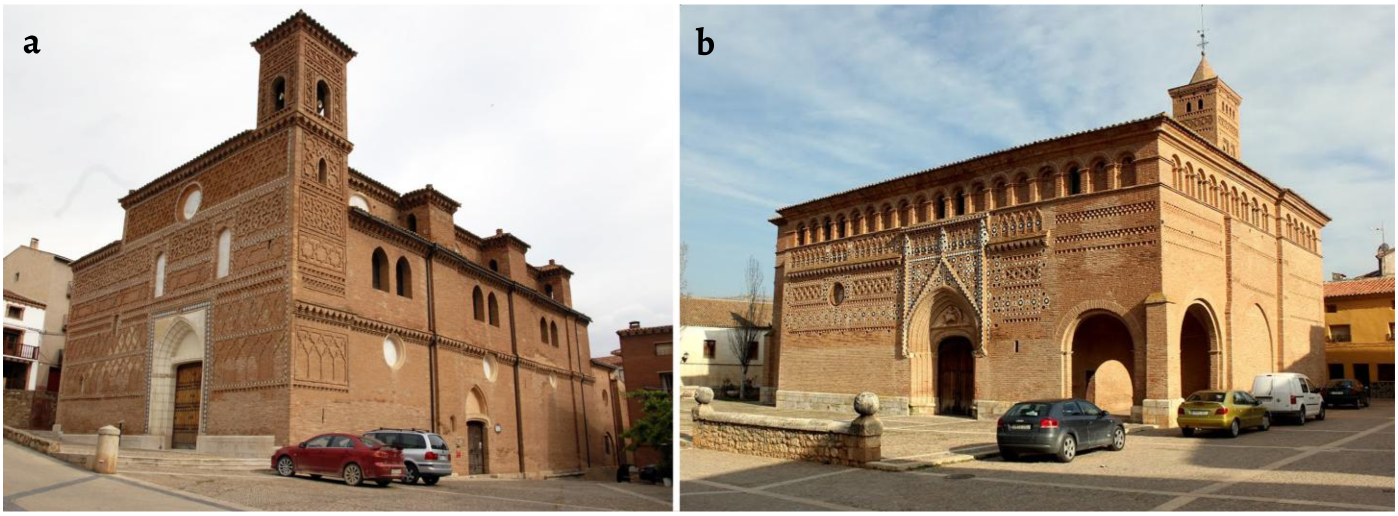

Figura 8. Ejemplos contemporáneos a la Parroquieta: *a)* Iglesia de la Virgen de Tobed; *b)* Iglesia de San Martín de Tours de Morata de Jiloca (fotografías: Luis Agustín).

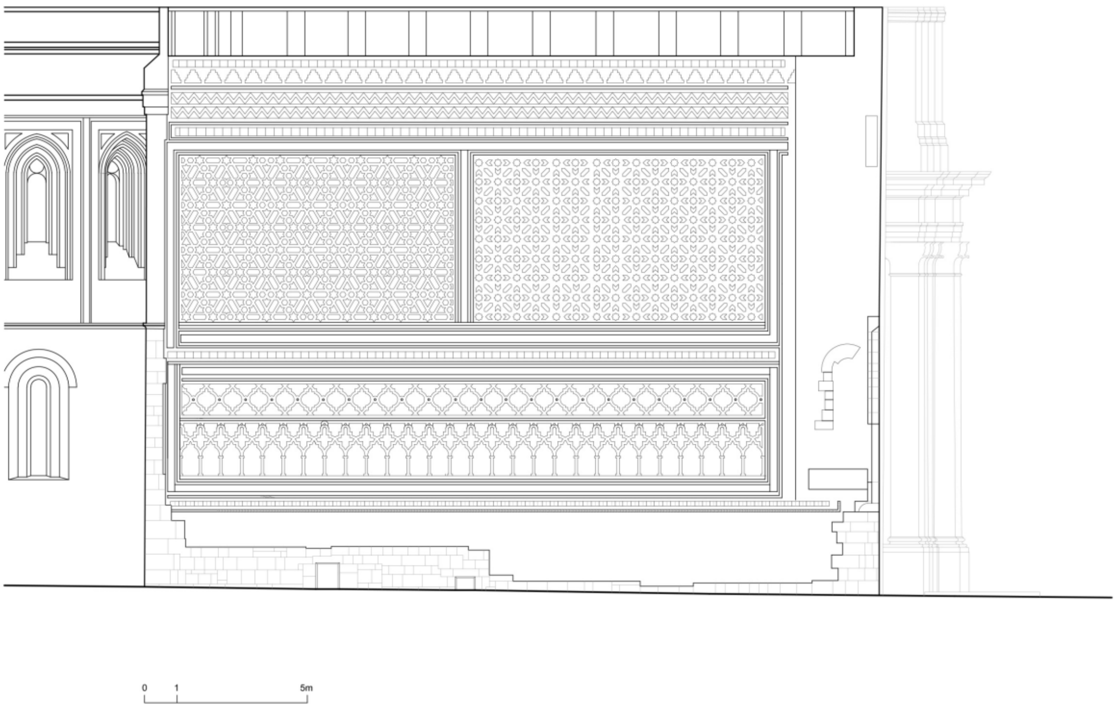

Figura 9. Delineado de la fachada del estado previo de la Parroquieta donde se observa el paño sin ventanas góticas.

Por el contrario, estas mismas ventanas, vistas desde el interior, están perfectamente ubicadas y enmarcadas, tanto en los ejes de los dos tramos de la nave, en el caso de las dos alargadas, siguiendo estrictamente las normas canónicas góticas, también las situadas a ambos lados del arcosolio, con una ubicación derivada de la composición arquitectónica de los elementos existentes en el interior [18-19]. Obsérvese la sección longitudinal y transversal en la Figura 10 generada por los autores, donde se ve esta incongruencia exterior-interior. Otra incongruencia constructiva observada es la interrupción de las bovedillas enjarjadas de la escalera que desciende a la cripta, justo en el tramo correspondiente con el tablero donde apoya el sarcófago. Según las normas de la buena construcción, que en un edificio señalado como éste sin duda hubieron de seguirse, se habrían replanteado las bovedillas de forma que no quedasen interrumpidas por el principal espacio del edificio: el arcosolio que aloja la sepultura.

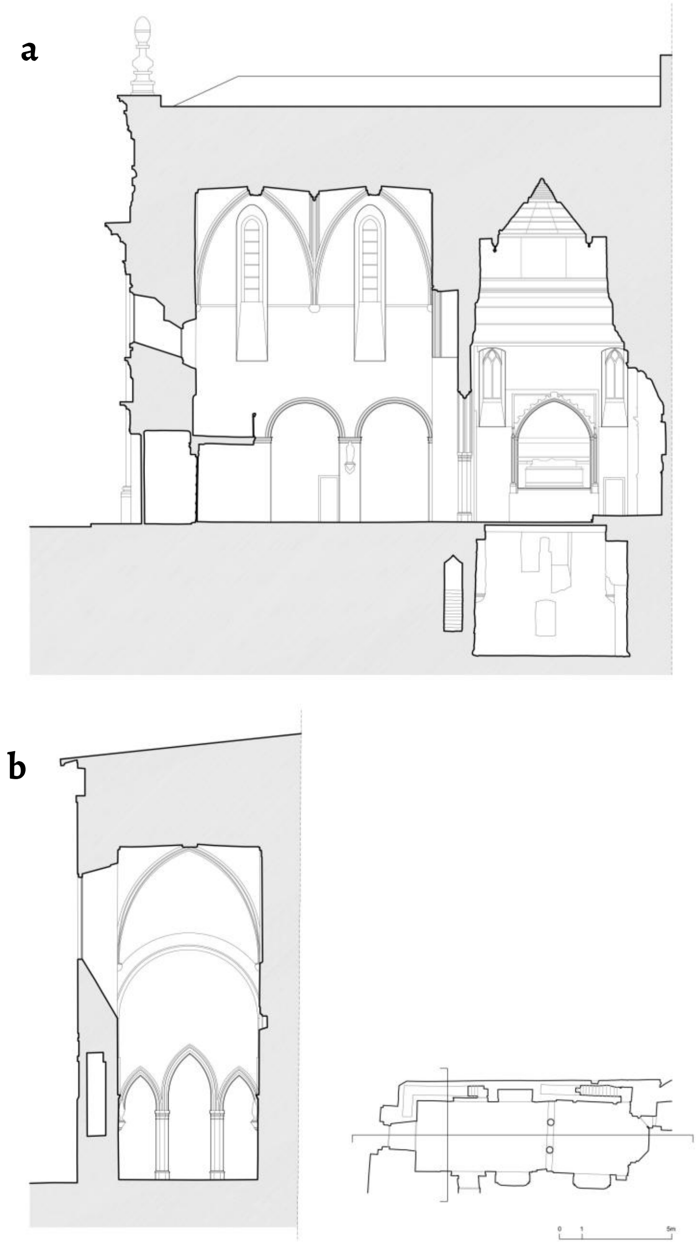

Figura 10. La Parroquieta: *a)* sección longitudinal por la nave y el altar, obtenida a partir de delineado sobre nube de puntos; *b)* sección transversal por ventana y nave.

La singularidad del edificio también se manifiesta en el uso de piedra sillar para las bóvedas – tanto nervios como plementerías – siendo la única construcción bajomedieval, junto con los ábsides contiguos de la catedral, que emplea este material en la ciudad. Esto se debe a la dificultad del transporte de piedra, dada la ausencia de canteras cercanas en el valle medio del Ebro. Tras su estancia en Vic, una región donde las iglesias están mayoritariamente construidas en piedra, y motivado por su admiración hacia el arte gótico canónico, el arzobispo debió decidir que su capilla también estuviera construida en este material. Otra obra del arzobispo, el castillo de Mesones de Isuela [20], también fue levantada con piedra sillar, siendo igualmente única en el entorno de Calatayud.

Los cerramientos del edificio están compuestos por un muro de doble hoja. Esta disposición, sustancialmente distinta a la de la arquitectura gótica cuyos elementos estructurales, contrafuertes y arbotantes no sólo no están ocultos, sino que forman parte sustancial del sistema decorativo gótico, permite alojar en su interior distintos corredores y escaleras que atraviesan los contrafuertes y otros elementos estructurales. Estas interrupciones de elementos sustanciales del edificio alcanzan también a las dos ventanas alargadas, aunque de forma más abrupta, ya que las escaleras y corredores que discurren en el interior del muro de dos hojas, se topan con las jambas de las mismas, dando lugar a escaleras o corredores sin continuidad ni acceso funcional.

El lado sudeste de la cúpula de madera con mocárabes, de clara influencia oriental y que corresponde al frente de la capilla, presenta una ligera diferencia respecto a los otros tres lados de la base. En su parte inferior, incorpora una nueva banda epigráfica árabe, la única de todas las bandas que ocupa toda la longitud de uno de sus lados, siendo más estrecha que las demás. Dada su singularidad y ubicación en lugar preferente, hubiese sido lógico que contuviera información sobre su promotor o el destino del edificio que cobija. El texto se presenta en forma de una composición jeroglífica, y quizá por ello se habría considerado, como otras, "seudo-epigráficas". Cabañero y Lasa [16] relacionan estas bandas epigráficas con las de la Alhambra de Granada. Como aquellas, este tipo de letra cúfica está formalmente relacionado con el de las bandas epigráficas de la cercana Aljafería, tanto en los alargamientos de las letras, como en los lazos o nudos que transforman el texto en un enigma jeroglífico. Este espacio no guarda relación con la construcción gótica en piedra ni con la estructura exterior de ladrillo, lo que sugiere la reutilización modificada de un espacio anterior.

Conclusiones

A partir del modelo tridimensional, así como del análisis formal, espacial y constructivo, se identifican incongruencias que cuestionan la consideración del edificio como una unidad constructiva y temporal.

En primer lugar, se observa que cuatro ventanales ojivales de piedra irrumpen de manera más o menos aleatoria sobre una fachada de ladrillo decorada con cerámica, la cual presenta una composición perfectamente estructurada. En la reconstrucción virtual, se evidencia cómo estos ventanales rompen la continuidad de la fachada, aunque en el interior se alinean con precisión en el centro de las bóvedas góticas, lo que indica una planificación específica para el espacio interno.

En segundo lugar, las bóvedas de ladrillo enjarjadas o de aproximación que conforman el techo de la escalera que desciende a la cripta, ubicadas justo debajo del arcosolio donde se encuentra la tumba del arzobispo, presentan interrupciones que sugieren un error de cálculo en su altura, razón por la cual fueron sustituidas por vigas.

Finalmente, en la parte inferior de la cúpula de mocárabes se distingue una banda epigráfica en árabe, un elemento poco adecuado para un templo funerario cristiano, lo que introduce una nueva contradicción en el discurso arquitectónico del edificio.

Estas incongruencias inducen a afirmar: que existen dos técnicas constructivas diferentes, dos proyectos constructivos diferentes y por tanto dos edificios diferentes, maclados entre sí, uno gótico de piedra, el más reciente, que ocupa la parte superior e irrumpe en el existente y otro, anterior, por su técnica, su posición y su geometría. Comparándolo con los documentos arqueológicos, se observa que la capilla está en el trazado de la mezquita Aljama de Saraqüsta, por lo que estos muros de ladrillo y decoración cerámica, declarados patrimonio mundial por la Unesco, podrían ser muros de la mezquita reutilizados en esos primeros años de conquista Cristiana.

Estas propuestas permiten una mejor comprensión del proceso constructivo original, lo que contribuye a orientar las intervenciones de mantenimiento, conservación y restauración de manera más fiel y respetuosa con las técnicas y materiales empleados en su momento de edificación.

Para continuar con el estudio de la antigüedad de la macla de edificios, se trabajará utilizando análisis químicos sobre los materiales, en concreto ladrillo, cerámica y morteros. También se está trabajando para replicar la metodología de trabajo en otros edificios que, datados como mudéjares, pueden tener vestigios del periodo islámico en Saraqüsta.

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The grand tour: a multi-analytical journey into the Palmela amphora of Panathenaic shape

O grand tour: uma viagem multianalítica pela ânfora de Palmela de forma Panatenaica

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Abstract

The Greek vase collection of the Duke of Palmela arrived in Portugal around 1834 and included the only (pseudo-)Panathenaic amphora in a Portuguese collection. The European art market was flourishing but so were restorations, copies, and forgeries. After acquiring this vessel, the MNA decided to examine it technically. Authenticity issues were raised by computed tomography imagery and material analysis. Distinct analytical techniques confirmed the modernity of the extensive overlayers. However, recent ultraviolet induced visible fluorescence imaging suggests some areas may be black glass-ceramic – an ancient technique only rediscovered in 1942. In light of the latest evidence, it is argued that further testing will be required to clarify if this is an ancient vessel with extensive overlayers of modern interventions or a completely modern product. The archaeological and historical interest of this vessel renders it of particular value to critically reflect on distinct analytical techniques, restoration practices, and antiques collecting.

KEYWORDS
Authenticity
Black-figure
CT imaging
Forgery
Pottery
UV-induced visible fluorescence imaging

Resumo

A coleção de vasos gregos do Duque de Palmela entrou em Portugal c. 1834. Incluía a única ânfora (pseudo-)panatenaica numa coleção portuguesa. Na Europa floresciao mercado de antiguidades, a par com restauros, cópias e falsificações. Após a sua aquisição, o MNA decidiu examiná-la por tomografia computorizada e análise de materiais, o que levantou questões de autenticidade. Distintas técnicas analíticas confirmaram a modernidade de camadas de pintura. No entanto, imagens recentes de fluorescência visível induzida por ultravioleta sugerem que algumas áreas podem ser vitrocerâmica preta – uma técnica antiga apenas redescoberta em 1942. À luz das evidências mais recentes, argumenta-se que mais testes serão necessários para esclarecer se este é um vaso antigo com extensas camadas de intervenções modernas ou um produto completamente moderno. O interesse arqueológico e histórico deste vaso torna-se de particular relevância para uma reflexão crítica sobre as distintas técnicas analíticas, práticas de restauro e coleções de antiguidades.

PALAVRAS-CHAVE
Autenticidade
Figuras negras
TAC
Falsificação
Cerâmica
Fluorescência visível induzida por radiação ultravioleta

Introduction

The MNA 999.1.1 vessel

According to Rocha Pereira [1], the Greek vase collection of the first Duke of Palmela (Duque de Palmela), Pedro de Sousa Holstein (1781-1850), was originally assembled by his grandfather and father – Manuel de Sousa (1703-1759) and Alexandre de Sousa e Holstein (1751-1803), respectively. While diplomats in Rome and art collectors, they adhered to the growing fashion for ancient cultures and antiquities. At some point, Alexandre even obtained permission to excavate around the roman city of Ariccia, near Rome [2-4]. This was the period of the Grand Tour in the eighteenth and nineteenth centuries. The European art market was flourishing but so were restorations, copies, and forgeries. Amid this activity, the Duke of Palmela's collection arrived in Lisbon around 1834. It comprised eighteen vessels, which included what was thought to be the only Panathenaic amphora in a collection in Portugal, said to have been originally brought from Herculaneum and Pompeii [1]. In May 1998, this amphora, together with a lid, was eventually bought by the Portuguese National Museum of Archaeology (MNA), in Lisbon – it was given the inventory number 999.1.1 and from now on is referred to as MNA 999.1.1 (BAPD 9023288 [5]) (Figure 1 and Figure 4).

The Palmela collection was studied by Rocha Pereira [1] (repeated in all her subsequent publications [6-8]), who described this amphora as being a pseudo-Panathenaic one. Bentz [9, p. 188] and Morais [10] also published studies on this amphora. The description of this black-figured vessel has so far not been reported in much detail. A stylistic analysis of ornamentation, shape, and iconography led Morais [10] to date the vessel from between 550 and 475 BCE, and tentatively attribute it to the Leagros Group. According to Rocha Pereira [1], the lid seemed to belong to the vessel.

In 2018, the MNA decided to technically examine MNA 999.1.1 in order to draw up a conservation and restoration treatment plan for it. The pseudo-Panathenaic amphora was being promoted – it would soon leave the museum's depot to at last be exhibited to the public. Micro-samples of some of the materials were analysed at Hercules Laboratory, University of Évora, under optical microscopy (OM), micro-Fourier transform interferometer (μ-FTIR), and scanning electron microscopy and energy dispersive x-ray spectroscopy (SEM-EDS), although the analysis resulted in an incomplete report. In 2019, an x-ray examination through computed tomography (CT) scan was undertaken at IMI-art/Affidea, in Lisbon, to determine its integrity. For the first time, authenticity issues were raised both by CT imagery and material/elemental analysis. But internal issues at the museum's collections department halted the initial plan.

In early 2021, Prates and I gathered all the available data on MNA 999.1.1 and set up a small team to proceed with further investigations (for details see [11]). This included a fine analysis of specific morphological features, forming techniques, and painted layers through CT imagery. It is worth mentioning that, to our knowledge, this was the first study to use the CT radiodensity of surface painted layers to help investigate the authenticity of a Greek vessel. To determine the antiquity of the ceramic clay, dosimetry by luminescence semiquantitative protocols and mineralogical analyses by x-ray-diffraction were undertaken at Center for Nuclear Sciences and Technologies (C2TN-IST), University of Lisbon. The results dated the ceramic paste to a maximum of 1000 years, indicating it was not an ancient Greek vessel. However, it is relevant to note that the quartz from the samples was in poor condition and did not have enough absorbed dose (information reported at team meeting, 2021/06/15), while some alteration of the original luminescence signal could be related to the CT imaging process.

More recently, a new visual inspection was carried out to analyse distinct surface features, followed by ultraviolet (UV) induced visible fluorescence imaging to further investigate non-destructively colours and materials. These new findings raise the following question about the antiquity of the vessel: "Is MNA 999.1.1 an ancient vessel with extensive overlayers of modern interventions" or "is it a completely modern product?"

To answer this question, it is important to examine the full picture. The focus of this article is on the findings of direct relevance to the authenticity of MNA 999.1.1 vessel, with an emphasis on Vis, UV, and CT imagery. Furthermore, this investigation intends to shed light on nineteenth-century restoration practices, materials, and techniques, as well as the current interest in and demand for Mediterranean antiquities [12-15]. Thus, let us dare to further examine it.

Panathenaic amphorae

The Greater Panathenaia (Παναθηναια), a state religious festival, honoured Athena Polias, the patron goddess of Athens. While the Lesser Panathenaia was an annual event, the Greater was an extended and more magnificent event held once every four years, between the sixth century BCE and the third century CE, which included musical, gymnastic, and equestrian contests.

Large ceramic vessels containing olive oil from the sacred grove of Athena at Akademia were given as prizes in the Panathenaic Games. The *amphoreis Panathênaïkoi*, that is to say, the Panathenaic amphorae, could be highly valued as lasting symbols of mastery and excellence. Only workshops which had the capacity to produce a large number of vessels by leading potters and painters were awarded such highly lucrative contracts. These vessels had a distinctive form with broad body, narrow neck, and a small echinus foot. They received standard composition and decoration by talented vase-artists, usually depicting Athena *Promachos* advancing between columns, holding a shield, and brandishing a spear. Along one of the columns, the official inscription ΤΟΝΑΘΕΝΕΘΕΝΑΘΛΟΝ – i.e., *ton athenethen athlon*, meaning “One of the prizes from Athens” – is written. Later, in distinct periods, the archon’s name or those of the treasurers and stewards of the games would be written too. The other side of the vessel would depict the event for which it was a prize.

Pseudo-Panathenaic amphorae – meaning, not prize amphorae but non-official imitations of the Panathenaic amphorae [16] – were produced in ancient times as well. They may have been used to commemorate a victory in a smaller contest, as an object of trade, or even as a souvenir.

Over the centuries, the Panathenaic amphorae have been much prized. As with other Greek vase types, they have been often heavily restored, replicated, and at times forged.

Primary forming techniques

The Panathenaic amphora is a special type of amphora shape. These vessels were not continuously curve (i.e., one piece) but were made in separate sections: neck/mouth, body – typically in one part, though Schreiber [17, pp. 85-86] identified a midsection join in a sherd indicating two parts – one foot, and two handles. All sections were wheel thrown, except for the handles which were made from coiled clay and then curved to the desired shape. When the clay was fairly firm but still mouldable, sections were joined by cementing them with slip at the neck/shoulder and at the body/foot. Handles were joined to the neck and shoulder, on opposite sides, also cemented with slip.

Likewise, lids were wheel thrown, made as separate pieces, fitted to measure, joined by cementing them with slip, and then turned. The lid itself was thrown upside down as an almost flat dish. It had a raised circular flange to fit inside the vessel’s mouth, to keep it still and prevent the contents from spilling, and to seal the vessel. Knob handles could be thrown as solid pieces or made hollow – typical forms were the pomegranate and pine cone. According to Noble [18, p. 33], the lid was made “at the same time as the amphora so that it could be given a proper fit (...). During drying, the lid was left on the vase so it would shrink uniformly with the vase”.

Black-figure technique

The Panathenaic amphorae were decorated exclusively with the black-figure technique, even long after the black-figure style had fallen out of fashion. The figures were initially painted on unfired, leather-dry vases with a clay slurry (i.e., a thick slip made from mixing a refined version of the throwing clay with illitic clay), which turned to black glass-ceramic (BGc) [19] after firing. Unpainted areas were left to provide a background for further decoration. Both black and red paint were made of iron oxide, with the black having the addition of illitic clay enriched with iron oxide particles. Outlines and details were incised into the slip before firing, allowing the underlying clay to be seen through the scratches. Details – such as women's skin, hair, clothing, accessories, and ornaments – were often reinforced and highlighted with white (made from pure clay with the minimum amount of iron oxide) and red/purple colours. As Sparkes [20, p. 16] once provocatively described this style: "black men, white women, no spatial depth, one ground line, all foreground".

After painting, the vase was fired in a kiln in a complex three-stage firing process. The first firing was at a temperature of about 800 °C, in oxidising conditions. The clay and slip would fire red (iron oxide in the form of hematite or maghemite). Next, the temperature of the kiln was raised to about 950 °C for a very short time, in reducing conditions (oxygen removed; carbon-rich environment) [21]. The clay and slip would turn black (as the illite clays vitrified and the iron oxides changed to black magnetite or hercynite, and some soot was absorbed). The slip, now sealed from the oxygen, would become glossy black by vitrification thus resistant to any further changes. Finally, the vents of the kiln were re-opened to lower the temperature, and the oxidising condition was restored. Once more, the renewed oxidisation would turn the unpainted areas reddish-orange (as the iron oxides changed to red hematite), but the slip-covered areas would remain BGc. The entire process lasted approximately 6 to 10 hours and required great precision and skill from the craftspeople.

Methods

CT imaging

In cultural heritage research, there is a body of scientific literature on the use of x-rays to investigate ancient Greek pottery. In particular, x-rays are used to document the internal and external geometries of vessels, as well as their joints, fissures and fractures, ceramic paste structure, forming techniques, and restorations [11, 21-25]. Occasionally, forgeries have been detected through x-rays.

As mentioned before, MNA 999.1.1 was imaged by CT scan in 2019 at IMI-art/Affidea, in Lisbon (Siemens Somatom Definition AS 128, spiral tomography; 100 kV, 400 mA; 1330 slices, 6 mm thickness with 50 % reconstruction overlap, 0.35 pitch, square matrix 512 × 512 pixels [11]). To further test the CT radiodensity of surface painted layers, six black-figured fragments (of which three belonged to the same object) from Alcácer do Sal, stored at MNA, were CT scanned in 2021, following the same protocol (for details see [11]). The radiodensity of a material is measured by the amount of x-rays that pass through it. The greater the radiodensity of a material (i.e., the higher its atomic mass), the fewer x-rays pass through it. Radiodensity is represented in greyscale images and quantified in Hounsfield units (HU) – on a scale with 4096 values (12 bit), ranging from -1024 HU to 3071 HU, where (at standard pressure and temperature) -1000 HU is air and 0 HU is distilled water.

3D Slicer v4.11.0 software [26-27] was used for 3D reconstruction from multiple slice images, segmentation, and separation of the clay paste. Geomagic Wrap 2017 software (3D Systems) was used for post processing the 3D data and computing distinct measurements [26, 29]. ODEEG App Package software [30] was used to automatically calculate the maximum filling volume and to generate cross-section scientific illustrations.

UV and Vis imaging

Ultraviolet (UV) and visible (Vis) imaging techniques are widely used in cultural heritage research. The fact that many materials absorb invisible UV rays and re-emit light in the visible spectrum enables them to be detected by the colours of UV light. UV-induced visible fluorescence and new Vis imaging were carried out at the National Museum of Archaeology, using an X-Rite ColorChecker (a standard colour reference target for camera calibration). The main features of the UV imaging system consisted of a near UV wavelength (365 nm) lamp, and a Canon EOS 550D camera, coupled with an AF-S Canon 18-135 mm f/3.5 lens and a Hama UV 0 filter.

All the aforementioned techniques have been used for several years and have provided valuable information for pottery studies.

Analysis and results

Shape and forming technique

Vessel

MNA 999.1.1 is a terracotta amphora of Panathenaic shape (Figure 1). It has an ovoid body, short neck, echinus mouth and foot, and almost cylindrical handles. Unlike neck-amphorae, the curve of the shape does not change radically between the neck and the shoulder. The wall thickness of the vessel is asymmetrical and uneven [11]. Table 1 displays some basic measurements of the vessel and the lid.

Figure 1. MNA 999.1.1 vessel views: *a)* obverse; *b)* left; *c)* reverse; *d)* right; *e)* top; *f)* bottom.

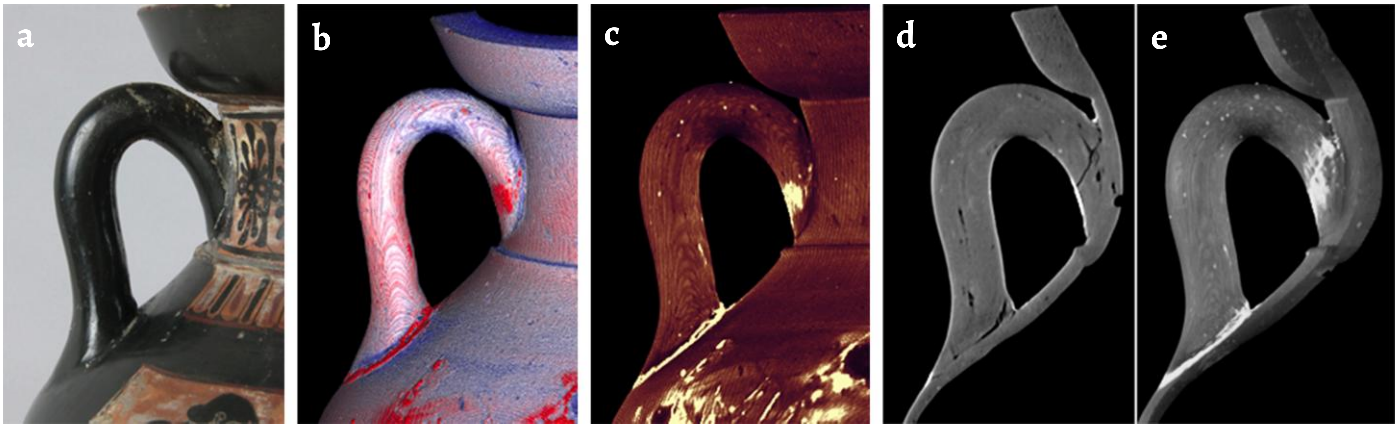

Figure 2. MNA 999.1.1 vessel, left handle (viewed from reverse): *a)* photograph of the black painted surface showing no visible signs of the restored fissures. CT imagery showing a material of high radiodensity added superficially to the upper oblique fissure and to the handle/shoulder joint fissure: *b)* 3D volume rendering; *c)* 3D cropped reconstruction; *d)* multiplanar reconstruction (MPR) sagittal view; *e)* maximum intensity projection (MIP) view (CT images: IMI-art/Affidea).

A close visual inspection of the surface of the vessel, confirmed by CT imagery, shows no clear evidence of any major fragmentation [11]. However, CT data reveals that a material of high radiodensity (possibly plaster) has been added beneath the visible black paint to repair some fissures in the left handle and at the handle and shoulder joints (Figure 2).

A few voids have a solid inclusion at their centre. The possibility of mineral aggregates or secondary mineral phases completely filling pristine pores during complex post-depositional transformations should not be ignored, as these may be wrongly identified as original inclusions [31]. Such inclusions can be intrinsic to the clay or added as temper. Likewise, some pores may in fact be negative interfaces, originating from the dissolution of the minerals forming the inclusions or from clay temper materials, such as the organic fibres which are burnt during the firing process. A comprehensive analysis of the clay fabric – to characterise its contents and distinguish original pores from negative interfaces (original or post-depositional) – is beyond the scope of this article so I use the generic term void.

Prates et al. [11] clearly demonstrate the following characteristics of this vessel: it was mainly wheel thrown; it is not a continuous-curve vessel; the neck/mouth, body, foot, and handles were separately made in sections that were joined by cementation with slip at the neck/shoulder, body/foot; and the handles were joined to the neck and shoulder on opposite sides. Some fissural air remnants can be still detected, especially at the joins between body/foot, handles/shoulder, and handles/neck. The primary forming technique was confirmed by: (1) the spiral pattern of ridges and grooves up and around the walls of the body, formed as the potter's fingers pulled the clay on the wheel; (2) the oblique orientation of elongated inclusions and voids in the clay paste/matrix; (3) and the orientation of inclusions and voids parallel to the walls (Figure 3). The oblique orientation and elongated shapes are characteristic of pulling the clay on a fast wheel [23]. The relatively narrow neck prevented the potter from removing the primary forming marks from the internal surface (which is not visible to the user). As for the handles, the elongated voids are centrally aligned and the orientation of inclusions and voids run parallel to the walls, clearly confirming that both were made from coiled clay and then curved.

Table 1. Basic measurements of MNA 999.1.1, from CT-derived 3D model. Note that the centre of the coordinate system is set at the centre of the 3D model's base. Weight of the physical vessel; Width refers to the maximum left-right distance (Figure 1b, Figure 1d) and length to the maximum reverse-obverse distance (Figure 1a and Figure 1c), while capacity refers to the maximum filling volume without dropping.

	Weight (g)	**Width/length** (mm)	**Height** (mm)	**Mesh volume** (mm^3)	**Max. filling height** (mm)	**Capacity** (cm^3)	**Mouth / lid diameter** (mm)	
							internal	**external**
Vessel	2678.7	233.3/234.2	361.9	1662539.4	357.2	6171.6	117.5	149.5
Lid	151.7	-	-	-	-	-	115.2	143.6

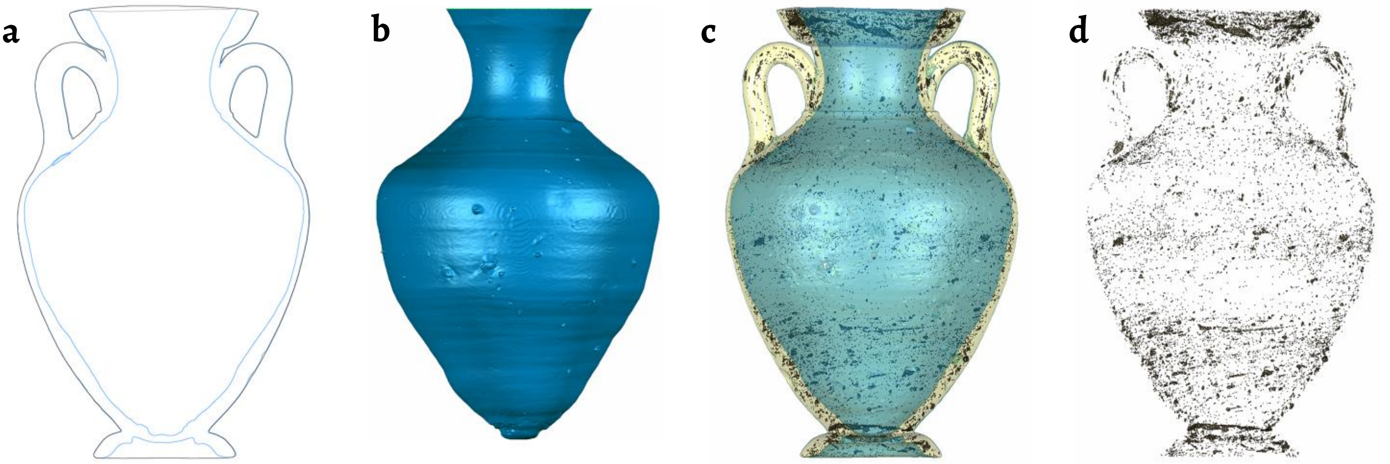

Figure 3. MNA 999.1.1 vessel: *a)* cross-section illustration automatically generated from the CT data, outer (black line) and inner (blue line) surfaces; *b)* 3D inner surface showing wheel marks (spiral pattern of ridges and grooves up and around the walls); *c)* 3D front view with transparency exhibiting voids (dark grey) in the clay fabric; *d)* voids in the clay fabric.

Lid

The lid (Figure 4 and Figure 5) has a circular shape, is almost flat, and has a hollow knob handle in a characteristic pomegranate shape. Underneath, a raised circular flange allows it to fit inside the vessel mouth to keep the vessel sealed and stop the contents spilling. In contrast to the vessel, the accompanying lid is considerably fragmented (for details on its state of preservation see [11]). The only mention of the lid in IPPAR's report nº 83 [32] notes that it had been glued with a cellulosic adhesive before its arrival at the museum. The CT imagery seems to confirm once again wheel throwing as the primary forming technique. The knob was made separately and cemented into place. The UV light revealed modern interventions that were not previously detected with the naked eye, such as repainted areas and other marks; black fluorescing filler used to fasten the sherds together; and modern overpaint and/or varnish fluorescing in a milky brownish-yellow tone, with some areas showing large brushstrokes.

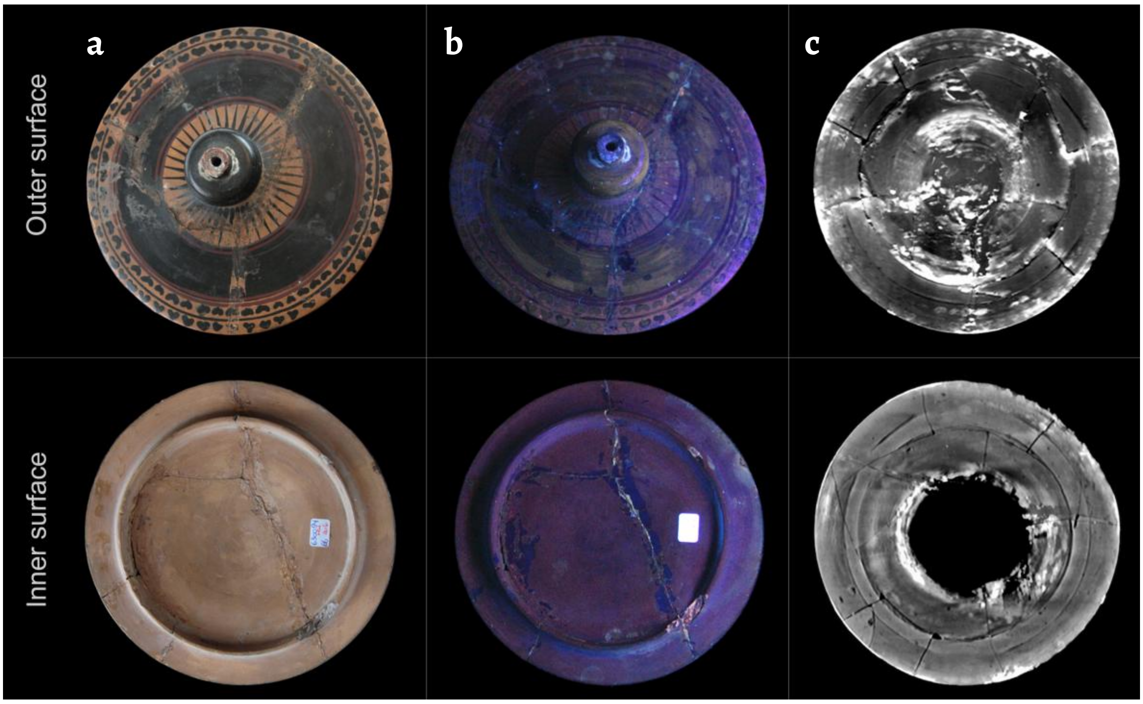

Figure 4. MNA 999.1.1 lid: outer (top) and inner (bottom) surfaces: *a)* visible; *b)* ultraviolet-induced visible fluorescence; *c)* computed tomography imagery (CT images: IMI-art/Affidea).

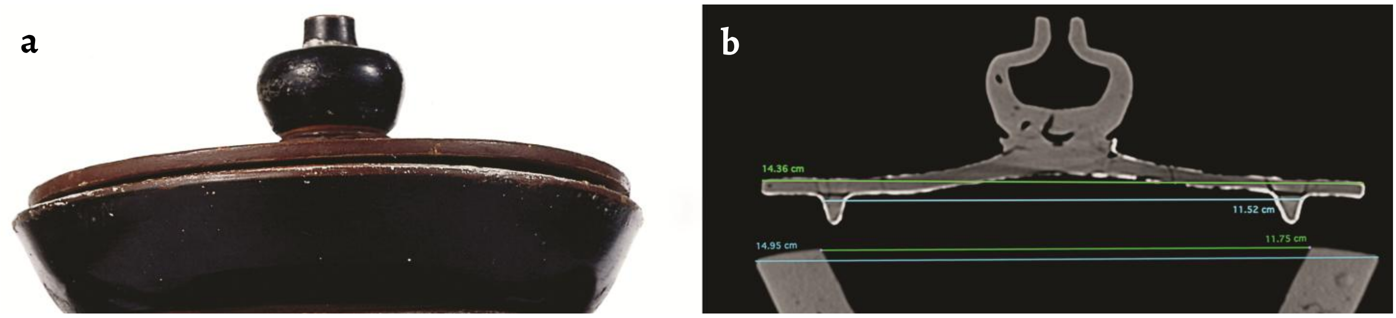

Figure 5. MNA 999.1.1 vessel mouth and lid: *a)* visible; *b)* computed tomography imagery showing how the lid fits onto the mouth of the vessel (CT image: IMI-art/Affidea).

As to whether the vessel and lid match, the geometrical features, acquired by CT scan, do not seem to match [11] (Figure 5): the lid does not entirely cover the upper surface of the vessel; the inner and outer diameters of the lid and vessel do not entirely fit (Table 1); and the horizontal edge of the lid does not completely fit the vessel's rim, which is tilted outwards. There is also a difference in the angle of the mouth's inner surface and the corresponding surface of the lid's flange, which prevents the lid from having a secure fit.

Surface decoration

Vessel

Designs black on red panels with incised and painted lines, with highlights in white and red (Figure 1). On side A (obverse), the panel continues up into the neck of the vase; on side B (reverse), the panel is separated from the neck of the vase by a black border. The neck has a double honeysuckle pattern, with a protruding ring and an alternating purple and black elongated tongue-pattern below. On the lower part of the body, there are two thin red bands on each edge of a broad black band, followed by a standard radiating elongated black pattern (of rays or leaves, perhaps) with a red band below. The outside of the foot is black, ending with a thin red band. A black band lines the inner surface of the mouth.

Side A depicts Athena *Promachos* (in the frontline of battle), in the typical striding, militant pose of the prize Panathenaic amphorae. She has a high-crested helmet that overlaps the tongues on the neck of the vessel with a tress or lock of hair over her shoulder. She wears an *aegis* covered with a vertical dot-pattern, with a snake-border on the back only, and a long *peplos*, belted at the waist. The *peplos* is patterned with small triplets of white spots and its folds are indicated by two broad bands down the centre and along the bottom with a wavy-pattern between the straight lines. She is short and stout; one foot is set forward and almost flat on the ground while the other is drawn back, heel raised. She wears a shield on one arm, with a central white drawing – it could be a *ketos* head [1], medusa, octopus, or lion head – and red spots on the antyx (border). The other arm is drawn back brandishing a spear. She is standing to the left, between two Doric columns.

Side B depicts a wrestling scene. In the middle, two nude red-bearded athletes engage in pankration (a combination of wrestling and boxing). The athlete on the left has his head covered by his opponent's head. To the left of the athletes, a red-bearded *brabeus* (adjudicator) stands watching; he is wrapped in his *himation*, which is decorated with small red spots, and holds a staff in one hand and three long stems in the other. On the right, a *paidotribes* (trainer) or *ephedros* (an odd contestant with a bye to the next round) looks on; he appears nude and beardless, with his right arm slightly raised and left hand on his hip. On the wall hangs a garment with folds depicted, and a pattern of small red spots and triplets of white spots. According to Rocha Pereira [1], this is quite a common scene on the back of Panathenaic amphorae.

The state of conservation of the vessel is generically and briefly described in IPPAR's report nº 83 [32], right after its arrival at the museum. The vessel was then "cleaned superficially (less adherent crusts removed) with cotton swabs soaked in ionised water and scalpel, under a binocular magnifier" (author's translation from the original Portuguese).

Figure 1, Figure 6, Figure 7 and Figure 8 show that overall, the figures and pictorial decoration of the vessel are not finely executed, revealing less technical and artistic skill than expected from leading vase painters. Most incisions are rather crudely drawn. Some details on the wrestlers' legs are not incised but painted over with thin coloured clay lines. The shield decoration is coarse, and its interpretation is not straightforward. Athena's *aegis* is covered with an incised vertical dot pattern, instead of the usual scales. The skin of her arm is painted in white over a black silhouette, instead of inside contour lines. The capitals of the Doric columns are too high so there is not enough space to depict anything on top – cockerels are often shown on top of the columns, or other figures resembling statues. Moreover, neither column presents the standard inscription ΤΟΝΑΘΕΝΕΘΕΝΑΘΛΟΝ, as one would expect from an official Panathenaic amphora – though one should be cautious about concluding too much from this as inscriptions were sometimes added later [33]. The inner surface of the mouth is decorated with a black band, although BGc would be unnecessary for a lidded vessel.

A significant number of surface losses and paint delamination (i.e., flaking) can be visually observed. Most pits are spread over the external surface of the vessel, especially on the decorated panels, and suggest a mechanical procedure of indeterminate cause; in some cases it is not possible to rule out intentionality. The faces of Athena and the *paidotribes* (or *ephedros*) are entirely damaged; the face of the wrestler on the right-hand side of the panel is partially damaged, while the *brabeus*' face is fully preserved. Delamination has occurred on the body of the vessel, predominantly to what one would expect to be the natural (i.e., ancient) reddish colour of the clay, but on the black surface too. Delamination is an evident sign of modern intervention, as originally these colours were not painted, but obtained through the black-figure technique (see section "Black-figure technique").

The UV light enabled to detect certain materials and to visually differentiate surface areas (Figure 4, Figure 7 and Figure 8). As a reminder, the two main colours in the black-figure technique were obtained as follows: the reddish colour of the clay was made from iron oxide, and black from iron oxide and illitic clay. White was obtained from pure clay with the minimum amount of iron oxide. These (ancient) coloured surfaces and ceramic clay should appear dark under the UV light, without any fluorescence. Indeed, some black areas, such as the honeysuckle pattern on the neck and the black elongated-tongue pattern underneath, do not fluoresce at all. However, other black areas (e.g., mouth, rim, handles, sides of the body) fluoresce in a milky brownish-yellow tone and large brushstrokes become visible, suggesting modern overpainting and varnishing. Conversely, the white paint on Athena's skin (hydrocerussite, lead white) is highly fluorescent; the surface losses have been filled with modern plaster, which fluoresces here in rose tones, and shellac, which fluoresces in orange or yellow tones [34]. Shellac is a resin of animal origin that was commonly used in nineteenth century restorations as a filler, adhesive or varnish; it is brittle and deteriorates over time. The surface patina fluoresces too, but in greyish-green tones. Surprisingly, this patina is not natural and only seems to occur on the external surface of the vessel, which is visible to the user. It was actually produced with several materials and pigments, including Prussian blue and lead(II)-chromate (chrome yellow), in an attempt to give the appearance of ancient burial deposits and calcareous or salt-like crusts. However, some stains and marks may in fact indicate real surface damage, some of which may result from the ageing properties of the shellac used in modern retouching [12] or the *aqua forte* (nitric acid) used for cleaning ceramics [14, 35]. In contrast to the inner surface of the vessel, which seems better preserved (see supplementary material [36]), crusts run over at the external surface onto the decorated sections and pits.

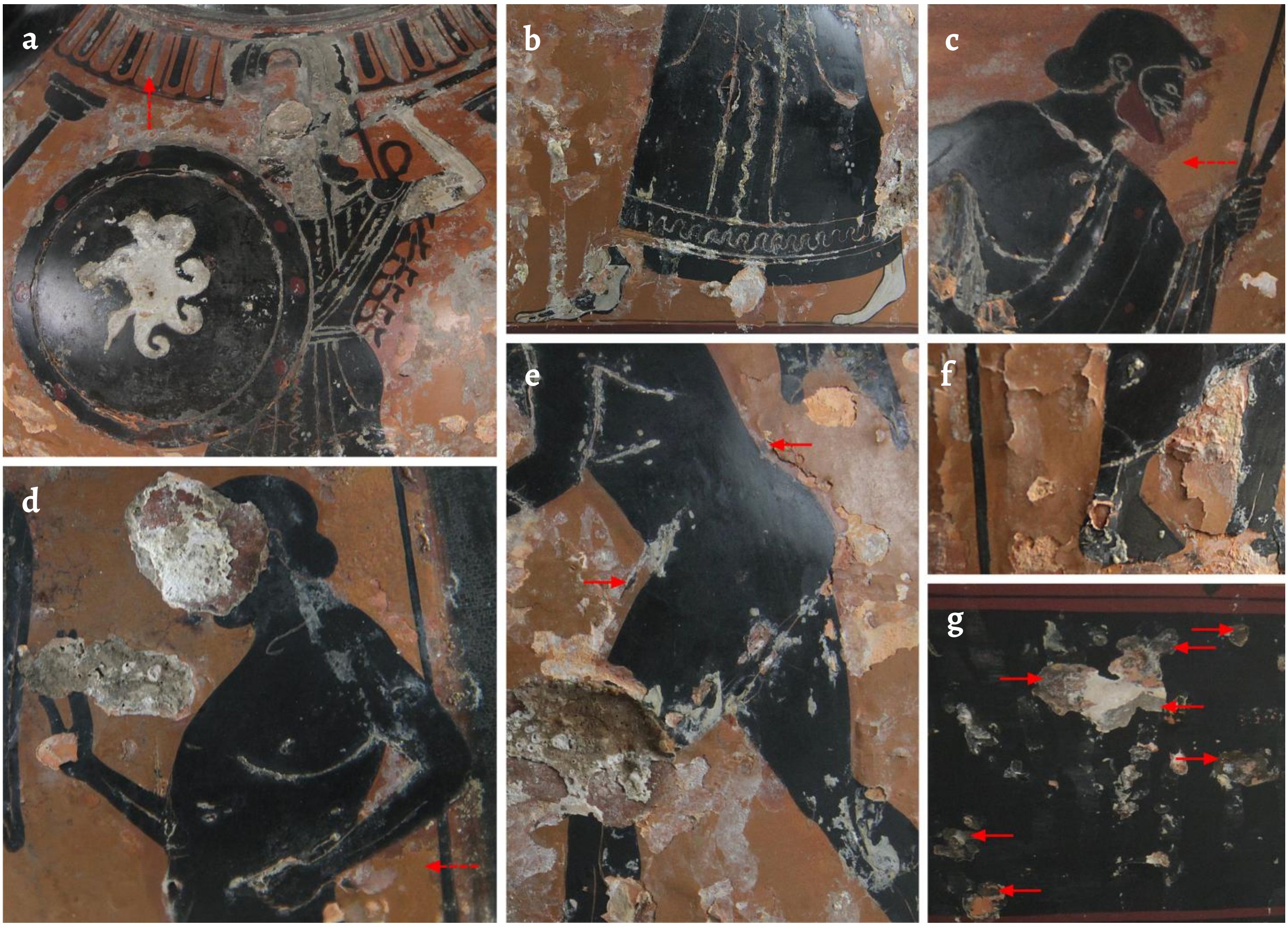

Figure 6. Details of the vessel illustrating figures and pictorial decoration not finely executed, surface losses, under (red arrows) and overpaint (dashed red arrows), and paint delamination. Side A panel: *a)* Athena's head and helmet damaged, *aegis* without the usual scales, arm painted in white over a black silhouette, coarse decorated shield, and capitals of the columns ending too high; *b)* Athena's *peplos* with crude incisions. Side B panel: *c)* overpainted background around the *brabeus*; *d) Paidotribes*' (or *ephedros*) right hand disproportionate; *e)* wrestler with crude incisions and overpainted details; *f)* paint delamination on and around the *brabeus*' feet. Lower part of the body: *g)* paint delamination revealing black colour underneath.

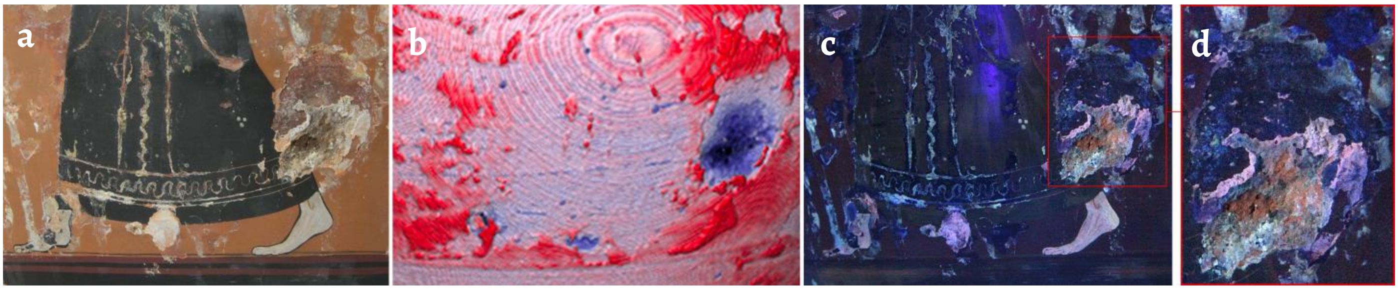

Figure 7. Side A panel, detail of Athena's feet and *aegis*: *a)* under visible light; *b)* CT 3D volume rendering showing a material of high radiodensity added superficially (in red); *c)* UV-light showing white paint on skin, *peplos* fluorescing in orange tones, and modern materials fluorescing in distinct colours; *d)* detail of pit filled with modern materials. The exposure, gamma correction, and sharpness of the UV images have been adjusted for higher readability of some features (CT image: IMI-art/Affidea).

The CT scan undoubtedly detected surface losses and fissures, while revealing large areas covered with a material of high radiodensity (plaster, possibly to smooth over surface irregularities) and overpainted layers – which may represent "severe limitations on the CT analysis of any underneath ancient Greek paint, like the black-figure technique" [11, p. 266]. In contrast, the experimental study carried out by Prates et al. [11] on a small set of fragments from Alcácer do Sal indicated that: (a) fired iron oxide has low radiodensity; and (b) the thin slip layers, difficult to access due to the curved shape of the clay wall, can go easily undetected by CT scan.

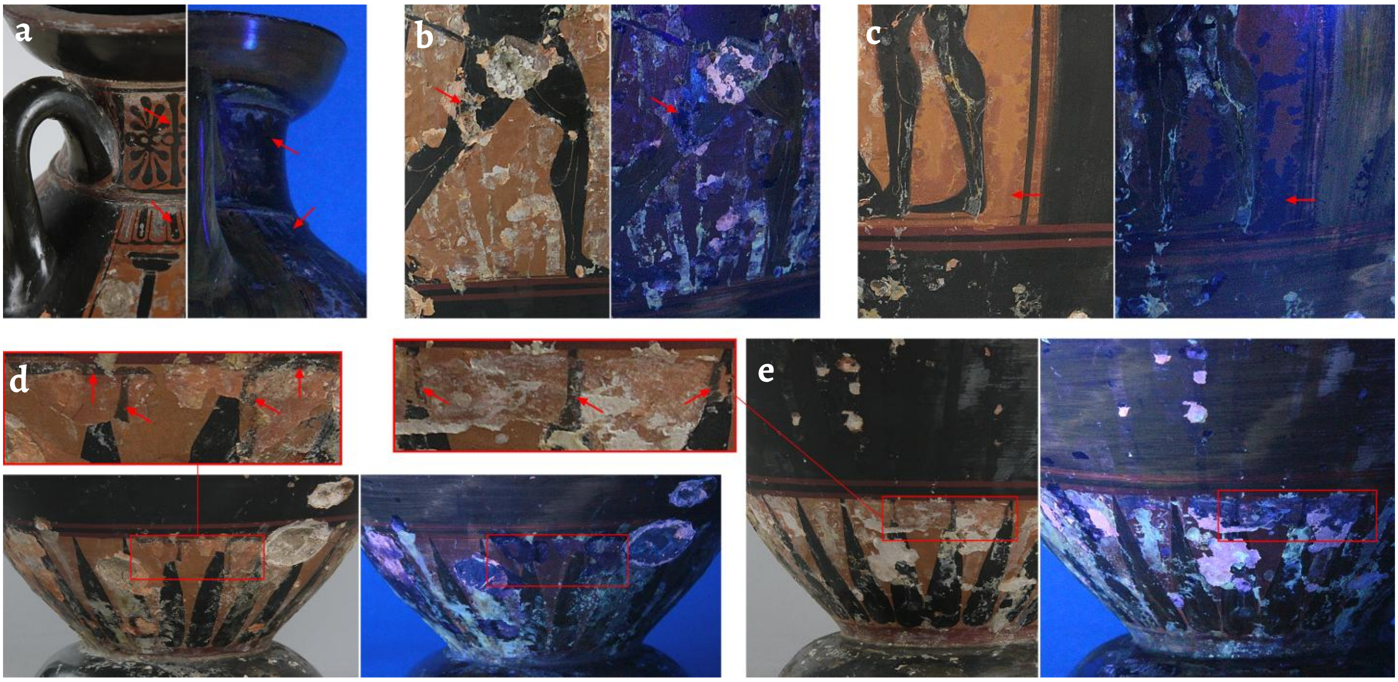

Figure 8. Vis and UV imagery details revealing at least two distinct painting interventions: *a)* the honeysuckle pattern and clay on the neck and the black elongated tongue pattern below appear dark under the UV light, without any fluorescence (red arrows), while other black areas (e.g., rim, handles, sides) fluoresce in a milky brownish-yellow tone with visible brushstrokes. Side B panel: *b)* black colour beneath the wrestler's leg; *c)* overpainted background around the *Paidotribes* (or *ephedros*). Lower part of the body: *d-e)* details showing modern painted layers with a similar pattern underneath. The exposure, gamma correction, and sharpness of the UV images have been adjusted for higher readability of some features.

Surprisingly, some details on the lower part of the body reveal a modern painted layer atop another painted layer – which could be original, ancient or modern – with similar painted motifs (Figure 6 and Figure 8). A few details on the side B panel and elsewhere also indicate similar colours beneath. These unexpected findings are also supported by UV imagery analysis, and to some extent by CT radiodensity data. This means that the coloured layer beneath did not fluoresce under UV light and went undetected by CT scan.

Lid

The outer surface of the lid is entirely decorated with concentric patterns and coloured bands (Figure 4). It has a black knob with a red band below, followed by a pattern of radiating elongated black shapes (possibly rays or leaves), and two thin red bands on each edge of a broad black band. On the border, there is black ivy with a stem but without petioles. It has a red edge.

The lid is overpainted and varnished, as confirmed by UV and CT imagery. It also has thick crusts over the black sections and the fragmented surfaces of the knob while thinner crusts (which may have been partially removed during restoration work) have spread over the top of the lid. The inner surface of the lid is neither decorated nor exhibits crusts.

Discussion and conclusions

So, returning to the initial question: "Is MNA 999.1.1 an ancient vessel with extensive overlayers of modern interventions" or "is it a completely modern product?"

In short, it is possible to confirm with confidence that this vessel has extensive overlayers of modern interventions – these results are in line with Prates et al. [11]. However, in light of the latest evidence, which leads to a reassessment, I cannot confirm with confidence that it is a completely modern vessel, as I discuss next.

Dimensions and integrity

The size of this vessel is interesting, 361.9 mm high (Table 1): it is smaller than the usual prize-amphorae from the Panathenaic Games, but smaller versions of prize-amphorae do exist [18, 37] – and this vessel could fall into the lower range of the group of pseudo-Panathenaic amphorae (36-46 cm) [9, p. 113]. So it could be an ancient pseudo-Panathenaic amphora [1, 9-10] or a completely modern product dated to a maximum of 1000 years ago [11]. In view of this, I propose that MNA 999.1.1 should instead be referred to as a terracotta "amphora of Panathenaic shape".

Concerning the integrity of MNA 999.1.1, the CT imagery shows two very distinct conditions: overall, the vessel is in a non-fragmented state of conservation, but there is extensive fragmentation of the lid. Complete ancient Greek vessels do exist and the state of this vessel could be explained by having been kept in a well-preserved context (e.g., a sanctuary or funerary). Lids are prone to breakage or loss, and the black band lining the inner surface of the vessel's mouth may suggest that it originally had no lid [17]. The UV fluorescence of this black band may not be enough *per se* to cast doubt on the antiquity of the vessel, as it may merely indicate a simple overpaint or a decorative innovation. Nonetheless, the significant geometrical differences between the amphora mouth and the lid suggest that they may not belong to each other [11, 18] – it is also conceivable that, in antiquity, a lid that did not fit exactly could be intentionally placed on the vase, so long as it fulfilled its function. Although mineralogical-petrographic analysis would help to determine if the vessel and the lid are made from the same or distinct clays, I doubt this merits further study.

Surface layers

It is hardly surprising that the authenticity of the extensive overpainted pictorial layer went unnoticed by scholars for so long. Delamination is a clear sign of modern intervention, as originally the colours were not exactly painted but obtained through the black-figure technique (see section "Black-figure technique"). The extensive surface delamination, supported by UV-induced visible fluorescence and CT radiodensity data, immediately confirmed the presence of modern heavily painted overlayers rather than small occasional retouches. Filling surface losses with plaster and extensive repainting on a plaster ground (to smooth the surface) were common in the 19th century [38–39]. Likewise, the modernity of the visible black paint on the handles, body sides and upper/lower bands, and mouth was substantiated by: CT images showing fissures on the ceramic clay repaired with a material with high radiodensity, but beneath the visible black paint [11]; and UV light showing the material fluorescing in a milky brownish-yellow colour, characteristic of shellac, which was commonly used in the nineteenth century but not in ancient times. This shows that these areas are modern and have been painted in black after the clay was fired.

It is also well-known from the scientific literature (and from personal experience) that the ancient coloured surfaces acquired through the red- and black-figure techniques should appear dark under UV light, without any fluorescence, as with the honeysuckle pattern on the neck and the black elongated tongue-pattern below, and the black coloured underlayer areas of the vessel (Figure 6 and Figure 8). The fact that the ancient BGc technique was only successfully rediscovered in 1942 [40-42] is of particular relevance here (Figure 9). Hence, if the black colour on the neck and/or underneath the modern paint overlayers is BGc, it would have to be either ancient or produced after 1942. This makes it difficult to date this vessel as it entered Portugal much earlier than 1942 (~1834) but the ceramic paste has been dated to a maximum of 1000 years ago. To this end, further testing would be required to determine if the black colour is either BGc (i.e., ancient) or some black pigment (i.e., modern). And this would eventually help us solve the last piece of the authenticity puzzle.

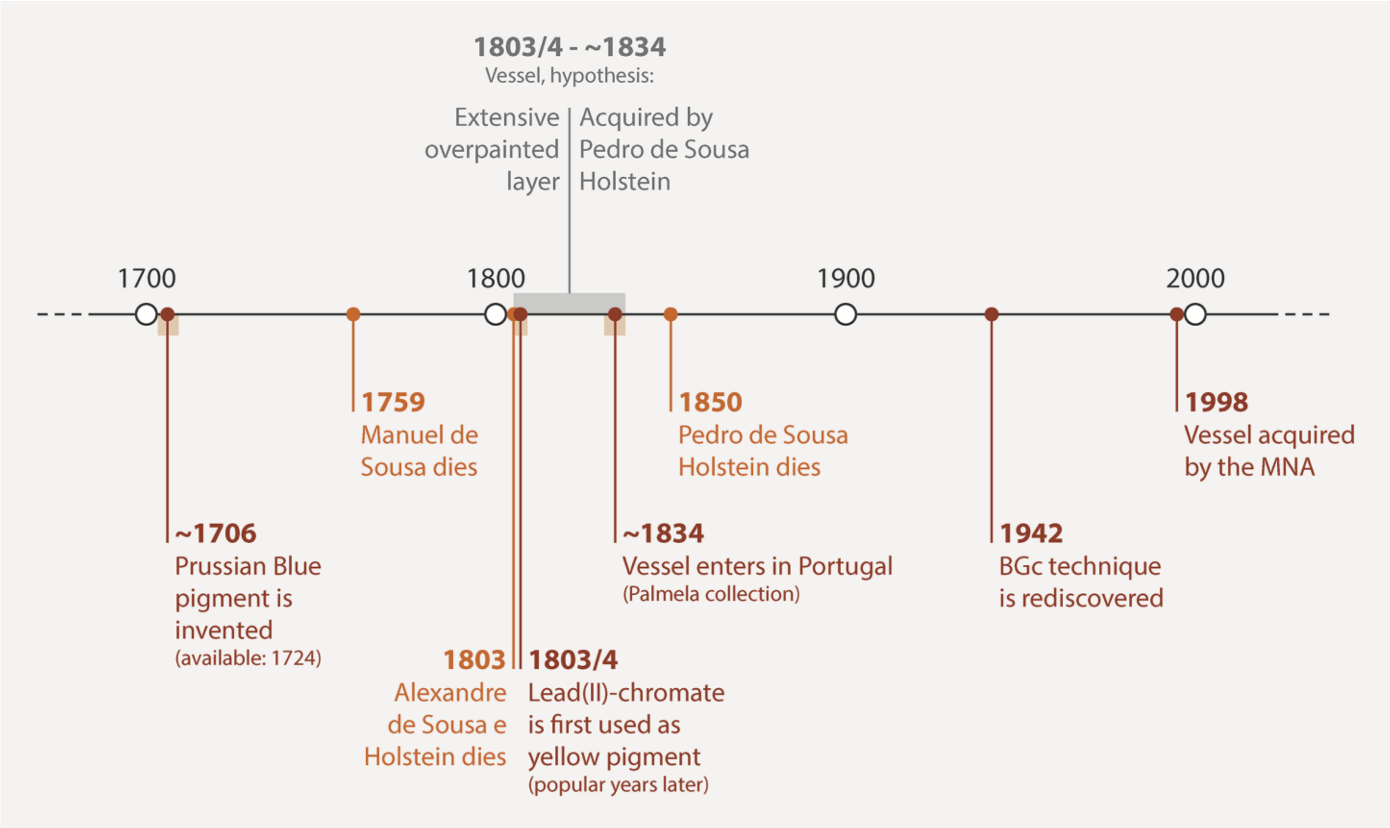

Figure 9. Timeline of some relevant events related to the MNA 999.1.1 vessel.

Interestingly, the detection of modern pigments by UV light and μ-FTIR helped to establish a temporal frame for the extensively overpainted surface layer and patina. The invention of the Prussian blue pigment can be dated back to the beginning of the 18th century [40-42], while lead(II)-chromate was first used as a pigment for yellow in 1803 or 1804 [45-47]. For this vessel, both have been used to produce the greyish-green patina, while the latter was used for the clay colour. Although the year of acquisition of the vessel is unknown, we should recall that the vessel entered Portugal around 1834, as part of the Duke of Palmela collection of antique Greek vases. Accordingly, it is possible to assume that this extensive overpainted layer or "restoration" intervention may have taken place sometime between 1803/4 and ~1834 (Figure 9).

As to why this vase was heavily overpainted, I can only speculate. Perhaps the decoration underneath – which could be original, ancient or modern – was in a poor condition, or it just did not meet early nineteenth-century taste or expectations. Likewise, it could be that its bad condition was somehow recreated to give more 'realism' and hence increase its commercial value.

Considering the analytical data hitherto available and that nineteenth-century restorers, such as the Neapolitan Raffaele Gargiulo or the French Jean-Jacques Lagrenée, often altered the painted decoration, it was not possible for me to confirm whether the overpainted motifs fully and faithfully reproduce the ones underneath.

Despite not being able to trace back the location of the "restoration" (or forgery?) at this stage, I am lured into believing that it took place in Italy, possibly in or around Rome or Naples. It is known that Manuel de Sousa, Alexandre de Sousa e Holstein, and Pedro de Sousa e Holstein had all been diplomats in Rome. The former even obtained permission to excavate around Ariccia, near Rome. As to the artist's name, well, to discover this would be an undertaking in its own right.

Provenance and acquisition

Although said to have been brought from the Herculaneum and(or?) Pompeii excavations [1], the original provenance of the vessel has never been confirmed. At the same time, the growth in antiquities collecting among the European aristocracy and bourgeoisie during this period must be taken into account. This in turn created a demand for imitations and replicas as gifts and souvenirs, while also attracting the attention of antiquity dealers and thus of forgers [48].

The following points are significant in assessing the vessel's provenance: (1) it is assumed that this vessel was acquired as it is (i.e., with extensive modern overpainting); (2) Manuel de Sousa and Alexandre de Sousa e Holstein died in 1759 and in 1803, respectively; and (3) lead(II)-chromate was not used as a yellow pigment until 1803 or 1804 (and only becoming popular but expensive some years later) (Figure 9). Based on these considerations, it is reasonable to suggest that this vessel could have been acquired by Pedro de Sousa Holstein (who later became the First Duke of Palmela) and not by his ancestors, as previously thought.

Millingen's [35] concept of *perfection dangereuse* in relation to the science of certain "restorations" has become less pervasive as analytical methods and techniques have eventually helped to distinguish ancient from modern interventions. Furthermore, the archaeological and historical interest of this vessel renders it of particular value for critically reflecting on distinct analytical techniques, restoration practices, antiques collecting and the art market, the fashion for the Grand Tour, and their impact on socio-cultural transformations.

Within a conceivable scenario of fakes and copies, what should happen with this vessel? Is it old enough to be protected in its own right, namely, as an object that tells us about antiques collecting? Likewise, one may wonder whether this vessel was originally added to the Palmela collection as a real antique (pseudo-)Panathenaic amphora, as a contemporary restoration, or simply as an imitation or souvenir. Deceived or aware? Whatever its true story, it seems to have been lost in time. Meanwhile, many other archaeological materials from unknown provenance, lacking context or any other valuable data whatsoever, rest quietly in public and private collections all over the world. The work presented here is an attempt to 're-excavate' some of the many stories of MNA 999.1.1.

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Data availability statement

The CT DICOM dataset used for this study is available from IMI-art/Affidea on reasonable request. Larger images and further characterisation of the MNA 999.1.1 vessel are available online as supplementary material [36] to this article at the Zenodo repository, under a CC BY-SA 4.0 license, https://doi.org/10.5281/zenodo.16880854.

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CONSERVAR PATRIMÓNIO

ARTICLE / ARTIGO

Photogrammetry in the conservation of vernacular heritage focusing on the digital preservation of the memory of Algerian ancient ksour: case study of the Kenadsa Ksar

A fotogrametria na conservação do património vernacular com foco na preservação digital da memória dos antigos ksour argelinos: estudo de caso do Kenadsa Ksar

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Abstract

This paper presents the results of our research project KSOUR3D and GIS4D, which aim to explore the use of photogrammetry as an innovative method for the survey, preservation and promotion of the heritage of Algerian Sahara. The adopted approach is based on a methodological strategy and a process model within a global vision of three-dimensional and spatiotemporal modelling (3D/3D+1). Through a case study applied to the Kenadsa ksar, this study underscores the pertinence of establishing a multimodal digital database, which allows the generation of exploitable models for interactive visualisation and scenario planning of heritage interventions. The process is based on data acquisition, processing, and modelling to generate point clouds faithfully representing the buildings studied. The enrichment of models by the incorporation of temporal metadata allows the creation of various 3D model instances usable through augmented and virtual reality visualisation tools, offering immersive animations.

KEYWORDS
Photogrammetry
3D/4D modelling
Digital conservation
Saharan heritage
Restitution

Resumo

Este artigo apresenta os resultados dos nossos projetos de investigação KSOUR3D e GIS4D, que visam explorar a utilização da fotogrametria como um método inovador para o levantamento, preservação e promoção do património do Saara Argelino. A abordagem adoptada baseia-se numa estratégia metodológica e num modelo de processo dentro de uma visão global de modelação tridimensional e espaço-temporal (3D/3D+1). Através de um estudo de caso aplicado ao ksar Kenadsa, este estudo destaca a pertinência de estabelecer uma base de dados digital multimodal, que permita a geração de modelos exploráveis para visualização interativa e planeamento de cenários de intervenções patrimoniais. O processo baseia-se na aquisição, processamento e modelação de dados para gerar nuvens de pontos que representem fielmente os edifícios estudados. O enriquecimento de modelos através da incorporação de metadados temporais permite a criação de várias instâncias de modelos 3D utilizáveis através de ferramentas de visualização de realidade aumentada e virtual, oferecendo animações imersivas.

PALAVRAS-CHAVE
Fotogrametria
Modelação 3D/4D
Conservação digital
Património saariano
Restituição

Introduction

Heritage sites, steeped in history and culture, embody a collective memory and reinforce a sense of belonging [1]. The ksour, real icons of the Sahara, are distinguished by their unique signatures, witnesses of an ancestral heritage [2-3]. They have been recognized as precious territories and historical heritage known for their heritage dimension, namely their identity and cultural value [4]. Some of them have been classified as world heritage sites by UNESCO. Their preservation is crucial to protect the marks of societal identity, in accordance with the provisions of the various international agreements relating to this field.

The rise of digital technologies in cultural heritage has necessitated the establishment of reference frameworks that guarantee a rigorous and ethical use of these tools. In this context that the *London Charter* (2009), with its predominantly methodological and ethical focus, and the *Seville Charter* (2011), which is more practical and normative, were developed. The first defines the principles governing the production and interpretation of digital visualizations, while the second specifies their terms of use, dissemination and evaluation. Both charters highlight the advantages and limitations of digital heritage restitution. The new guidelines emphasize the respect for fundamental values in the virtual restoration applied to the research and enhancement, including authenticity, integrity, and heritage value in its various dimensions (historical, aesthetic, social, spiritual, scientific, etc.).

The *London Charter* is based on six fundamental principles that go beyond technical rules and emphasize ethical and methodological principles. These principles focus on: the scalability of practices, the reasoned choice of the most appropriate methods, anchoring in reliable scientific sources, clear documentation of approaches, the guarantee of the sustainability of results based on data rather than technical supports, and the enhancement of accessibility to strengthen the dissemination of heritage knowledge [5]. Two years later, the *Seville Charter* came into effect to complete and clarify these principles, emphasizing good practices in the visualization of cultural heritage. It extends by adapting them to virtual archaeology and promoting active pedagogy to raise awareness among researchers and the public about the contributions of digital technology in research. Its main principles focus on interdisciplinarity, the link between visualization and scientific objectives, complementarity with traditional approaches, respect for authenticity and historical rigour, the search for sustainable efficiency, scientific transparency, as well as the need to train and evaluate users in order to ensure the quality and relevance of the tools developed [6].

Conservation is based on traditional methods that remain limited in accuracy, speed and representation of fairly complex traditional structures. Digital technologies have revolutionized the way heritage buildings are documented and conserved [7]. The integration of advanced technologies for data acquisition, processing, archiving and analysis is revolutionizing processing methods and results [8]. Several studies show the limitations of traditional methods in heritage documentation and conservation, while 3D digital archiving currently available shows its significant advantages for the documentation, restoration and monitoring of heritage buildings [9]. Photogrammetry has evolved with technological advances to become digital, offering advantages such as automatic orientation and measurements, vector data generation, dense 3D point clouds and surface models [7]. The combination of 3D modelling and information management allows the introduction of the concept of HBIM (Heritage Building Information Modelling) in the documentation of heritage buildings [10-11]. Thus, “digital twins” offer the possibility of monitoring the state of structures in real time, helping to prevent deterioration risks [12]. The integration of the fourth dimension (time) in digital modelling also allows for immersive and emotional experiences in virtual and augmented reality, allowing users to visualise the evolution of buildings and enrich heritage conservation [13-15].

The study aims to enhance the Ksourian heritage, enriched by innovative technologies by integrating the photogrammetry results into global preservation strategies. The initial results presented are the work of two projects, KSOUR3D and GIS4D, by our research team SimulIA which explores the photogrammetry as approach through a study applied to Kenadsa ksar. The objective is to establish a digital database in order to ensure the digital archiving and interactive online accessibility of this city in perpetual degradation. This process stimulates cultural tourism, restoration/education scenarios and promotes enriched interaction with heritage.

Literature review

Research on the virtualization of cultural heritage in Algeria is being developed to contribute to the development of a methodology for the digital restitution of historical monuments and sites, ranging from digital surveys to interpretative restitution. This approach is also part of long-term perspectives, illustrated by the modelling project of the ancient site of Tipasa, led by the 3D platform Archéovision, which uses 3D and digital survey techniques to study and document the architectural remains of Roman city [16].

From the rediscovery and analysis, using 3D laser scanning and digital modelling, of a marble model of Hadrian's Villa, researchers demonstrate that it is an unfinished amphitheater project. The metrological interpretation reveals a design designed according to rules of proportion, while revealing parallels with the amphitheater of Caesarea of Mauretania (Cherchell in Algeria). This underlines the existence of a coherence between the architecture of spectacles buildings and the urban layout of Roman cities, planned according to modular principles. This study thus illustrates how digital technologies make it possible to reconstruct and decipher ancient constructive logics and to highlight the value of models as supports for communication and experimentation in Roman architecture [17].

In the same vein, the introduction of new digital survey methods has enriched the technical and morphological interpretation of ancient monuments. Indeed, the application of photogrammetry to the documentation of three access doors of the nameless temple of Tipasa has allowed the development of a virtual anastylosis protocol based on the modelling of 2D and 3D models of architectonic fragments, supplemented by the contributions of classical architectural treaties to fill the gaps. This method, which combines metrical survey, hypothetical restitution and digital dissemination, guarantees both the material preservation of the remains and the scientific transparency of reconstructions, while always meeting the ethical principles defined by international charters [18].

As an extension of this approach, the digital reconstruction of the fragmentary statue of Hercules highlights the critical dimension of virtual archaeology. Far from being a static restitution, 3D modelling functions as a laboratory of hypotheses, based on material indices and typological analogies, where the management of uncertainty, the transparency of interpretative choices and the reproducibility of the process ensure both scientific rigour and heritage enhancement. This approach gives 3D an epistemological and heritage role, simultaneously affirming it as a cognitive, critical and mediation tool [19].

Materials and methods

Photogrammetry is the technique adopted to study and document the Ksourian heritage in order to preserve the memory of space. Indeed, several studies show the theoretical bases, procedures and tools of architectural photogrammetry [8]. In fact, the "3×3- Rules" provides a practical directive framework for photogrammetric documentation based on three major criteria: geometric, photographic and organizational, each comprising three distinct directives [20]. Following the work of previous research, we propose a summarised methodological process developed in the form of a mind map grouping five important phases: data acquisition, 3D photogrammetry, 3D model instances, 4D photogrammetry and finally interactive visualisation (AR/VR). Each phase consists of a set of successive steps specifying the tools used and the product obtained (Figure 1b).

It should be noted that the penultimate and final step aims to explore other limits of the context, around which the central problem focuses. In this context, the collection of data relating to the past physical state of the ksar's buildings will increase the added value of our knowledge and our appreciation of the tangible (possibly intangible) heritage of the region. The technical question, in this sense, is based on the adoption of methodological strategies capable of taking charge, under the terms of a global vision (3D/3D+1) of the heritage of our ROI (Region Of Interest).

The interest sought is characterized by three facets (Figure 1a), the first concerning the present state (reported with current photogrammetric data on site subsequently processed), the second facet concerns the past of the heritage in ROI (Work by survey, poll and collection of sensitive data in relation, step followed by adequate processing – Photogrammetric assembly and processing of incompleteness such as Gaussian Splatting (advanced 3D processing technique). The third facet touches on in-depth study, using predictive photogrammetric methods by assembling trend models.

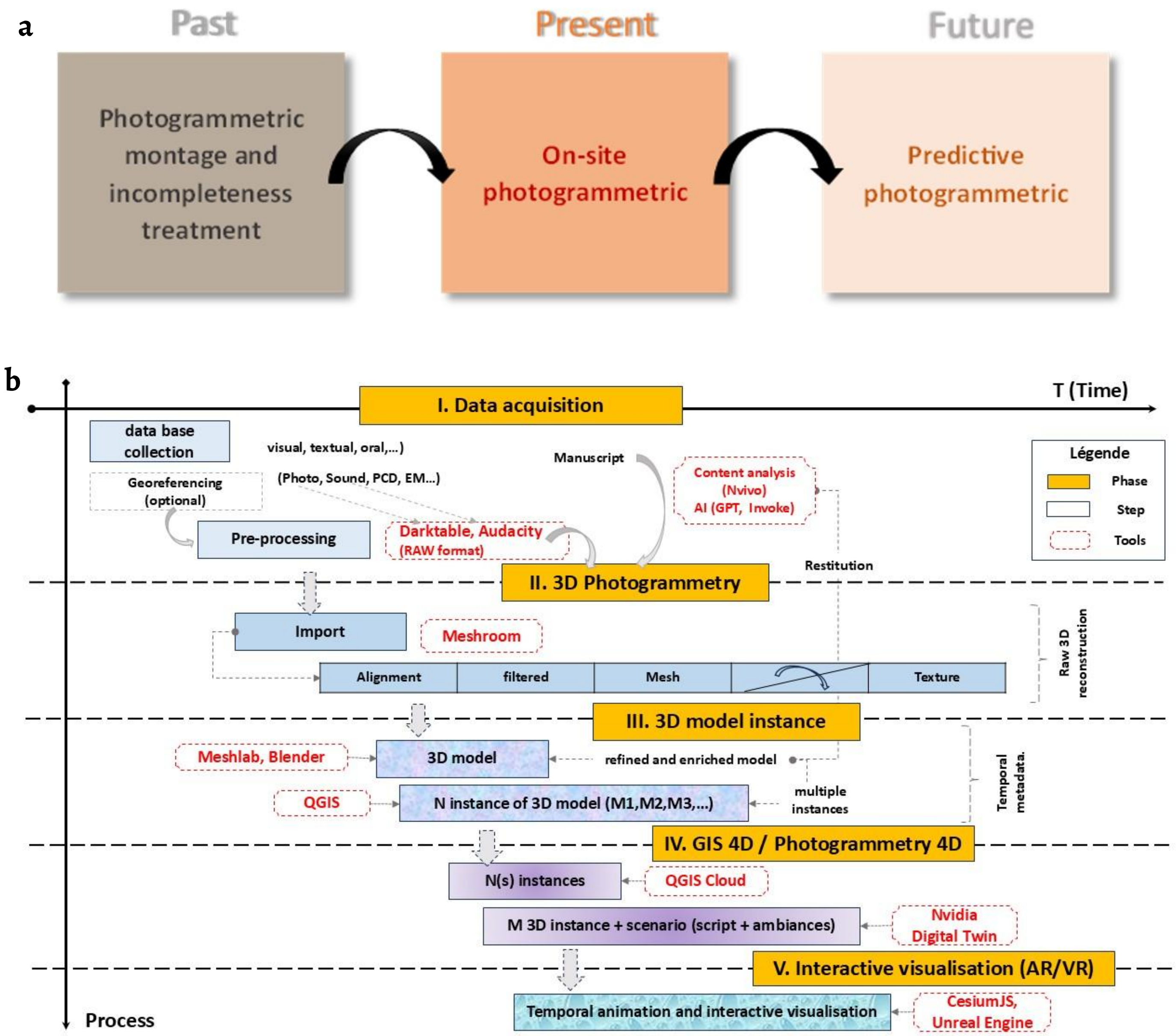

Figure 1. Research methodology and process: *a)* steps of study strategy; *b)* methodology process.

Steps of the overall study strategy:

- On-site photogrammetric (present)
- Photogrammetric montage and treatment of Multimodal incompleteness (past): a reconstruction process combining various data sources to fill in gaps and to obtain the most faithful digital representation possible of a former state of building.
- Predictive photogrammetric (future)

Presentation of the case study “Kenadsa ksar”: heritage values and advanced degradations

Over the past three centuries, Kenadsa has exerted a spiritual, cultural, and economic influence in the region. The city is organized around two cores: the ksar, a religious and cultural center and the colonial city. The discovery of coal at the beginning of the twentieth century profoundly transformed the spatial and social structure, transforming Kenadsa from a religious oasis to a cosmopolitan mining city. The ksar has an undeniable heritage value, loaded with cultural, symbolic and architectural wealth. With its specific historical features and buildings with a very special connotation, the ksar is recognised as a common heritage and has been classified as a "historical monument" and national heritage to be preserved since 1999. The ksar’s image refers to a structure that is at once complex, labyrinthine and hierarchical, while being perfectly homogeneous and coherent (Figure 2c). The fabric covers a variety of architectural forms and spatial arrangements [17].

The Kenadsa ksar stands out from the other ksour in the region by its type of dwelling commonly called *dwiriyâ* which is characterised by its high-quality architecture, endowed with an undeniable symbolic and cultural value [23]. They have been described as "veritable palaces" [24]. The Riad, seat of the *zawiya*, is described as "..., a beautiful Arab residence in the middle of gardens" [25]. In fact, "the residential complex is formed of small, precious palaces faced with the ambient Saharan bareness” [26]. These residences, of particular symbolic value, are distinguished by the richness of their decoration, the refinement of the doors, courtyards, columns and arches, and are part of the Andalo-Maghreb architectural tradition (Figure 2a-g).

The ksar, a reflection of society and culture, is in a state of alarming decline due to advanced degradation, abandonment, and past inadequate restoration attempts that have compromised their authenticity (Figure 2h-k). This deterioration threatens their identity and cultural memory, highlighting an urgent need for preservation in line with international standards. To address this, the KSOUR3D Project was initiated to use innovative digital technologies, such as photogrammetry and AI sketching/modelling, as a new approach to survey and preserve the Algerian Sahara's ksour. The project's central hypothesis is that these digital tools are effective for documenting, preserving, and promoting this vulnerable heritage for future generations.

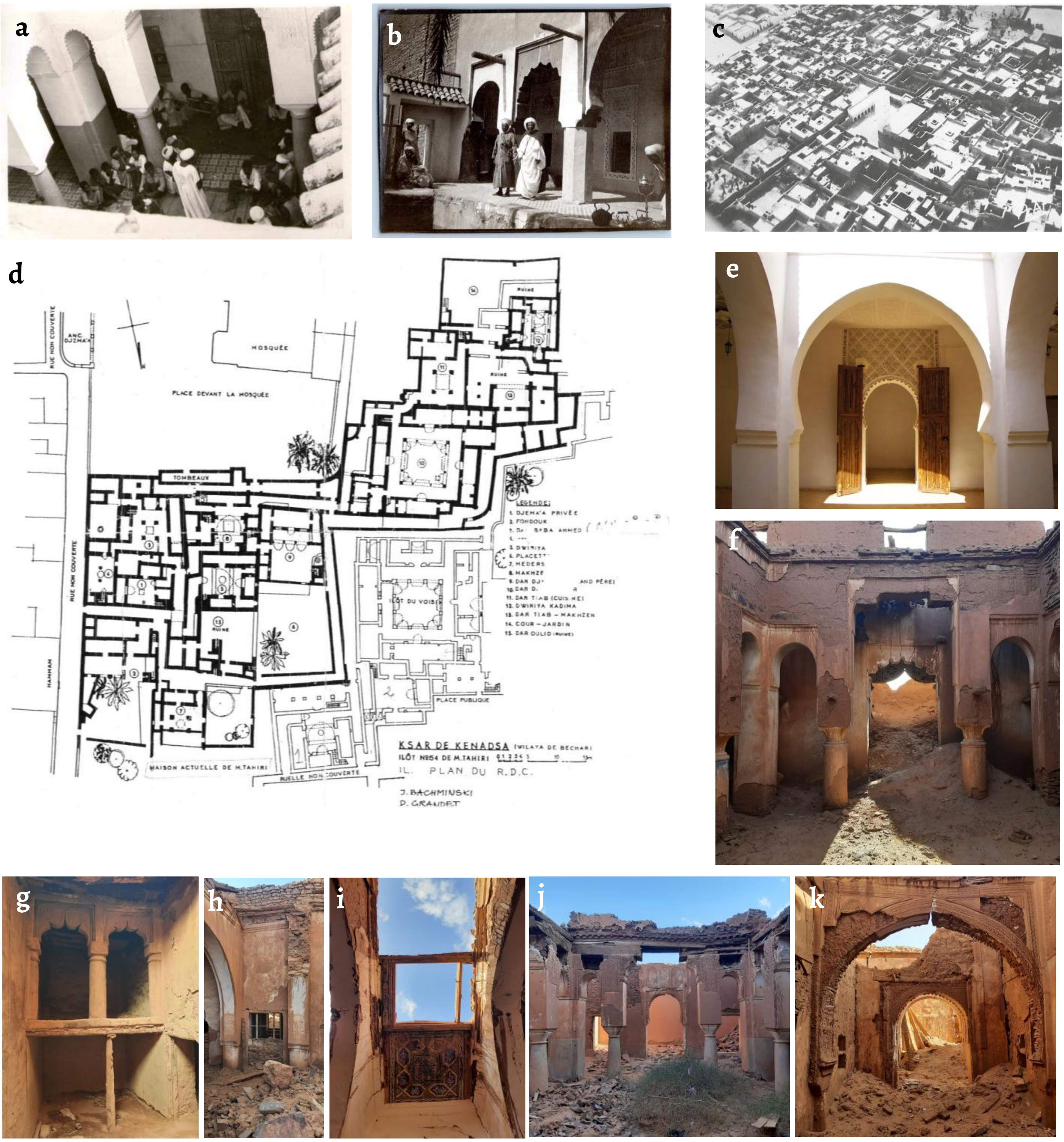

Figure 2. The architectural heritage of Kenadsa Ksar between ancient heritage and current state: old image of: *a)* courtyard house; *b)* portico of the Riad; *c)* aerial view ksar (Houillères Sud-Oranais HSO Archive); *d)* Plan of part of the ksar (Bachminski & Grandet, 1985); *e)* decorated of interior space; *f-g)*-architectural, decorative and technical elements. The current degraded state of: *h)* structural element column; *i)* ceiling; *j)* courtyard and gallery; *k)* keystone and decoration of the arcade.

Analysis and results

From two-dimensional survey to three-dimensional modelling

The digital restitution of the ksar is based on a progressive methodology that gives space to the two-dimensional approach as a preliminary step for three-dimensional modelling. In this work, all the buildings studied were first the subject of precise architectural surveys in two dimensions (more than twenty houses). These include plans, elevations and cross-sections, as well as detailed representations of architectural elements and ornamental components.

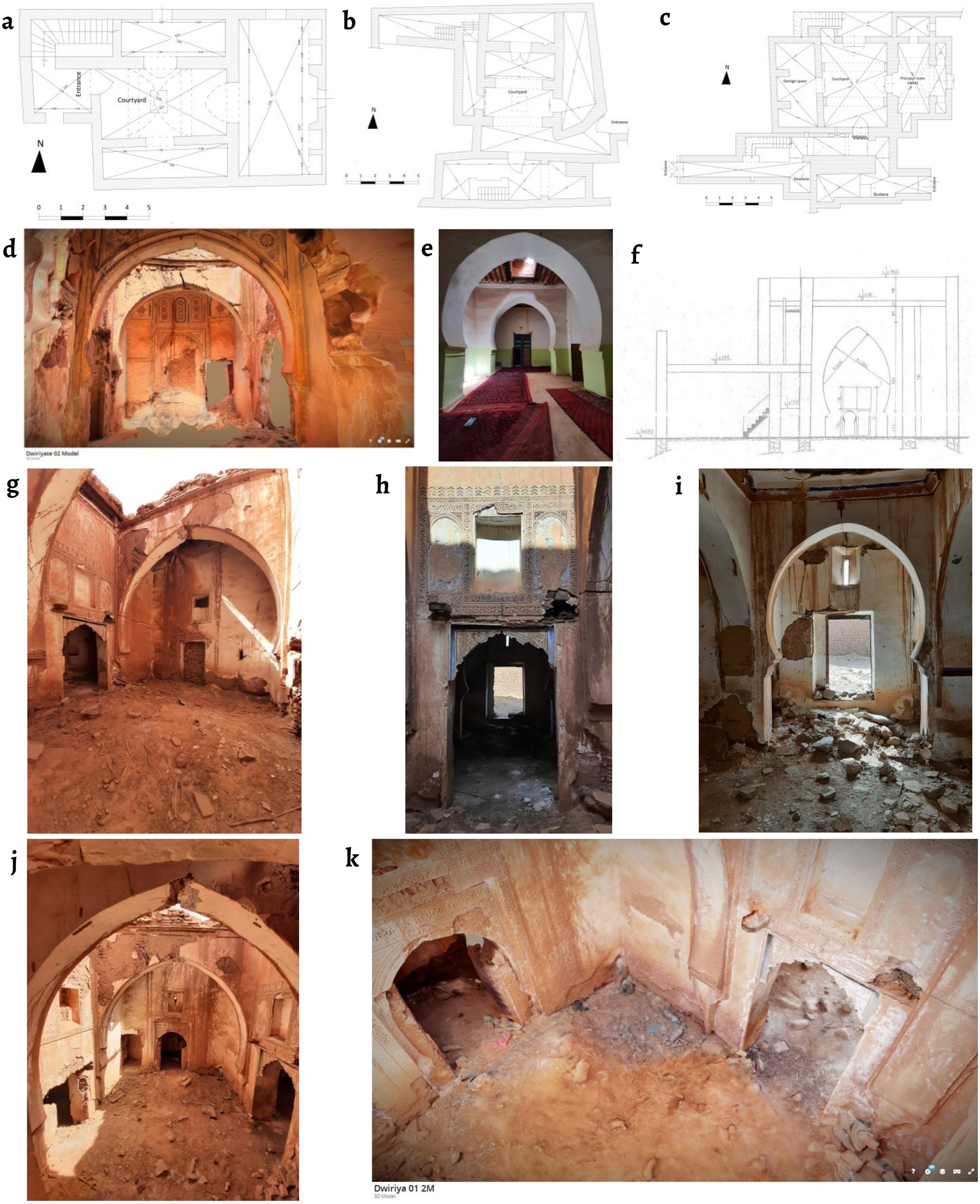

Figure 3. 2D restitution, produced from in situ metric and photographic surveys: *a-c)* various typology houses; *d)* 3D model photogrammetry; *e)* 2D image of courtyard; *f)* section of old house; *g-j)* different 2D views of various interior space; *k)* 3D model in Sketchfab.

This 2D restitution phase, carried out from in situ surveys complemented by photogrammetric processing, constitutes a scientific validation step. It ensures both the metric accuracy and fidelity to the current state of structures, while also verifying the typological and constructive coherence of the built ensembles. The documents produced provide a stable and shareable reference base, ensuring data traceability and scientific reproducibility, while constituting a detailed graphic corpus illustrated by surveys and photographs (Figure 3). Following this two-dimensional restitution, designed as an essential foundation, 3D modelling was undertaken in order to reconstruct the volumes, integrate architectural and decorative details, and simulate various restoration scenarios. The 2D survey provides a cognitive and analytical foundation, while 3D modelling opens the way to a technical, spatial, volumetric and prospective reading of buildings.

The process and steps of 3D photogrammetric modelling

Photogrammetric terrestrial modelling is a methodical process that allows to create three-dimensional models from 2D photographic images. The process includes essential steps, each contributing to the accuracy and quality of the generated models [8, 27].

Acquisition of photos

The first step involves taking 2D photos of the building sequentially [27]. The images were taken from different angles with sufficient overlap (Figure 4e). Additional photos are taken of areas containing important details. The choice of photographic equipment and the acquisition method are crucial to ensure the results quality (Figure 4a-c). A high-quality digital camera (Canon EOS 4000) was used to capture the images, taking care to correctly define the position and the number of shots required to cover all building faces.

Pre-processing and analysis of* "Darktable" *images

Once the images have been taken, pre-processing is performed to optimise their quality. The photos are first processed using Darktable in RAW format, which preserves a wide dynamic range and corrects imperfections in the images (Figure 4f). This software is based on two main features: the "light table", which enables exposure and white balance settings to be viewed, selected and adjusted, and the "dark room", where each image is finely retouched in terms of brightness, contrast, and exposure to ensure optimal quality. Then, the images are georeferenced to associate them with spatial coordinates, ensuring their accurate integration into the 3D reconstruction (Figure 4d).

Importing and generating the 3D model

After this initial processing, the images are then imported into the Meshroom software (open source) / Agisoft Metashape (licensed version), which performs the necessary processing to generate a 3D model (Figure 5a-c). This software analyses the images to identify common points between them and to determine the camera position at the time of each shot. Each point detected is associated with precise spatial coordinates (longitude, latitude, altitude), generating a dense point cloud. By aligning the images and detecting correspondences between the photos, triangulation algorithms can be used to reconstruct the geometry of the building. The perspective dimension is detached from the movement during elementary shots. A point belonging to the scanned space is seen by the moving camera (SFM – Structure From Motion), which allows the depth value to be determined. The triangulation forms the basis of the process, where an initial raw 3D reconstruction is produced, which is then refined by meshing and texturing to produce a complete three-dimensional model. This model generally requires additional processing to improve accuracy and eliminate errors.

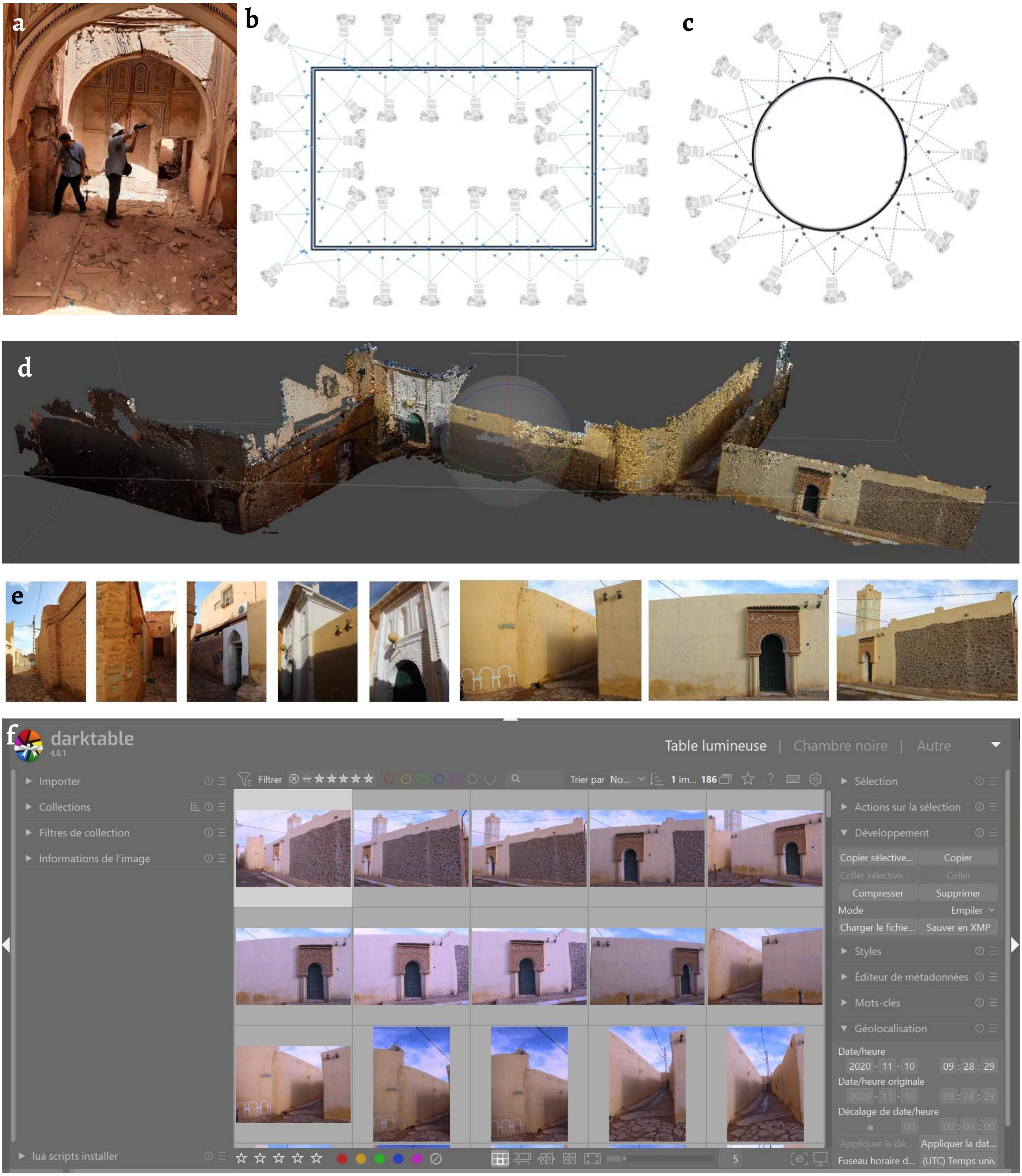

Figure 4. Image acquisition techniques: *a)* Team taking photos; *b)* Map of the captures from different angles; *c)* Photographing key circular architectural elements; *d)* 3D Photogrammetry; *e)* a series of 2D images; *f)* Pre-processing.

Post-processing

After the initial generation of the 3D model, a post-processing phase is essential to improve its quality and accuracy. This step includes cleaning the model to remove unwanted artefacts, correcting irregularities, and adjusting the scale to ensure a faithful match with the real dimensions of the building. Once these adjustments have been made, the model is ready to be used for various applications, such as restoration/education scenarios or realistic visualisations.

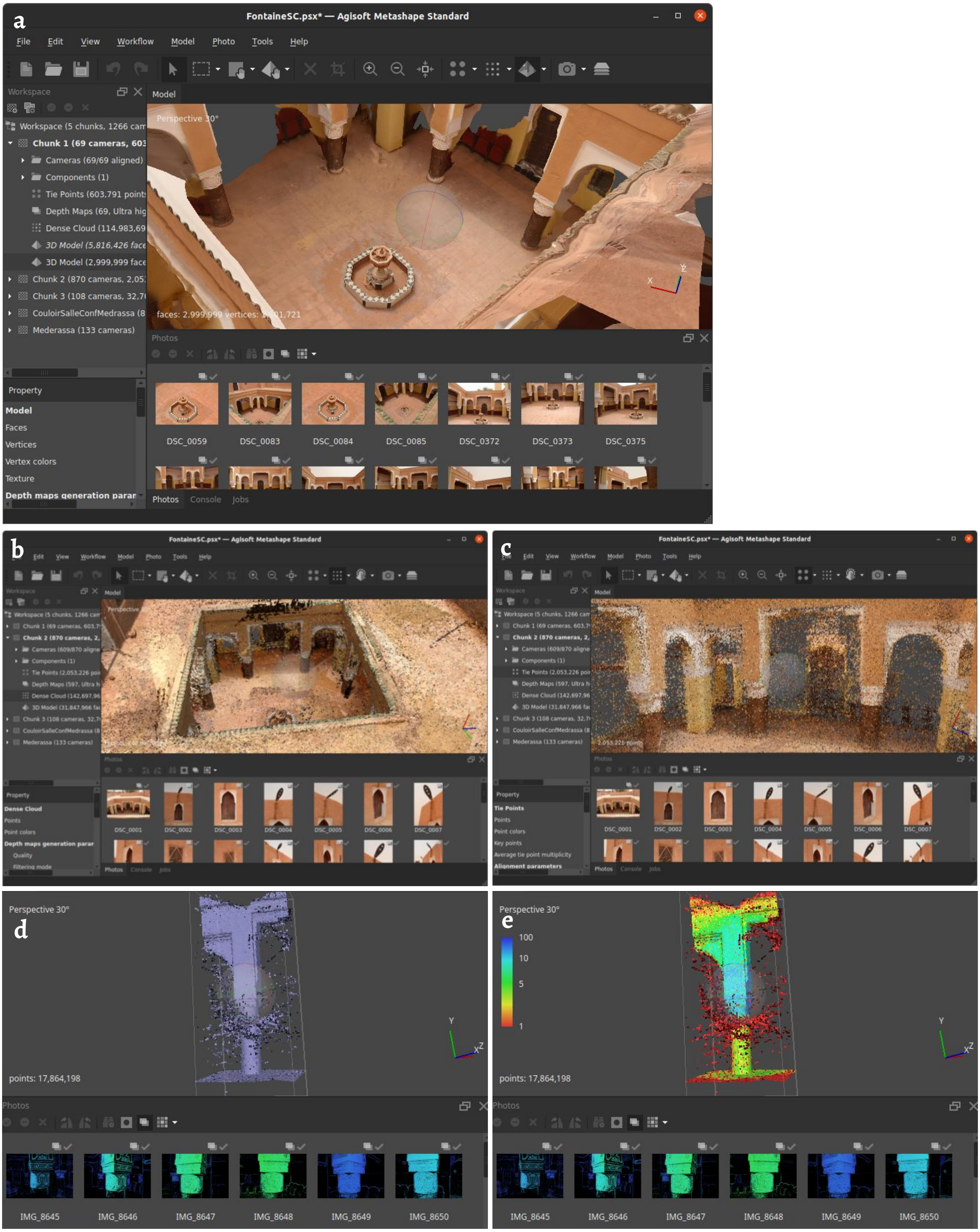

Figure 5. The 3D model of house and column: *a)* 3D model; *b-c)* dense 3D point cloud; *d)* solid model of column; *e)* Point Cloud and structure confidence.

Figure 5d-e show the photogrammetric modelling of the column, a key structural element among the 12 posts of the house, allowing for the accurate restoration of its geometry and architectural characteristics. This column defines the gallery and supports the patio, while integrating capitals and arches that enrich its architectural expression. Different renderings of the 3D model were generated to analyse and validate the reconstruction quality.

The true-colour model represents the most detailed and realistic version, integrating the textures from the captured images. In addition, an untextured model, without colours, was produced to verify the consistency of the overall form of the 3D model. In addition, a rendering based on depth parameters allows a differentiated visualisation according to the depth. Finally, the point cloud offers a raw and precise reading of the acquired spatial data.

From 3D photogrammetry to GIS4D

Beyond 3D modelling, 4D photogrammetry involves the fourth dimension "time", allowing for the analysis of changes in the building and the simulation of dynamic scenarios. The technique involves several steps in which the data acquisition phases are enriched by the incorporation of temporal metadata.

Data collection and pre-processing

This phase combines several types of data (MMD). The visual data (old photographs) is essential to restoring the past state of the building. These images are processed with specialised software to improve their quality. Tools for restoring old items, such as PhotoGlory, are used to remove scratches, creases and stains. The historical textual data (manuscripts, narratives, novels, newspaper articles) are analyzed by software such as NVivo, which can detect which detect manifest and latent content. This analysis involves structuring the corpus, categorising it thematically and defining the variables to be analysed. Then, the sound data, where oral testimonies and sound environments are processed with software such as Audacity to eliminate unwanted noise and improve clarity, ensuring a faithful restitution of past sensitive atmospheres. The specialised data surveys can reveal hidden details or structural features that are not visible (Point Clouds Data PCD) is obtained using LiDAR equipment, measurements with electromagnetic radiation (EM, Echography) (Figure 6). All these different data form a rich and diverse base, essential to trace the temporal evolution of the building and ensure a precise and faithful 4D restitution.

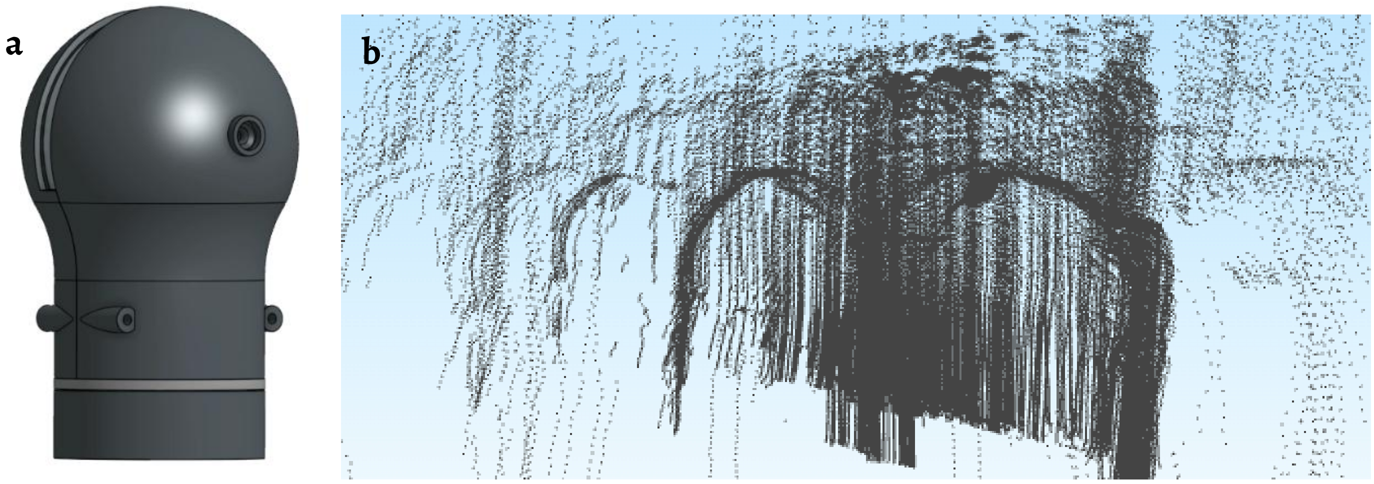

Figure 6. Digitalization of the Mosque Kenadsa Ksar's using laser beam acquisition: *a)* used LiDAR developed by our team; *b)* screenshot of the Point-Cloud, Reduced density.

Integrating the time dimension

This phase aims to enrich the 3D models by generating multiple variants, each corresponds to a particular period or state of the building, modelled in the form of a mathematical equation. This is followed by the constitution of a temporal Metadata where each instance is attributed to specific temporal data in order to trace the chronological mutations of the building.

$$M(t) = \sum mi\ (t)$$

M: model; Σ= some; Mi= ith M instance

These various temporal instances of the models are then structured and examined with QGIS, offering the possibility of integrating temporal data for each model. Thus, the use of QGIS Cloud simplifies the management, analysis and visualization of the building. The steps are as follows:

Firstly, the fields are populated by organizing the temporal and attribute metadata of each 3D model in a structured table where each entry corresponds to a specific instance. This table is then imported into QGIS via a vector layer, ensuring proper georeferencing and recognition of temporal attributes. Then, the temporal parameters are configured to visualize the evolution of the 3D models using the temporal panel. Finally, QGIS allows for realistic 4D visualization, offering the analysis of changes and evolutions of the modelled building.

Interactive visualisation (AR/VR)

To enrich the results of QGIS 4D modelling, interactive visualisation tools in augmented and virtual reality are used, offering immersive temporal animations. Platforms such as Sketchfab [28] (Figure 7a), CesiumJS, Unity and Unreal Engine are used to generate interactive 3D environments in which the user can explore the temporal evolution of the building. These tools cover advanced features to incorporate 3D models with enriched temporal metadata, thus facilitating the development of dynamic and immersive scenarios.

These virtual replicas of buildings are used to simulate, analyse and anticipate their behaviour (Metahuman model) in various scenarios. Their creation allows for the dynamic scenarios simulation by incorporating temporal and contextual data to reproduce historical events based on acquired historical data. Moreover, it also allows for the prediction of the building's state based on extracted profile techniques at a given moment to simulate its dynamic evolution. This enables people to have immersive experiences and to explore the building history in an interactive way, enriching their understanding and engagement. The Figure 7b shows the 3D model results, composed of 3 million triangles and 1.5 million points, with high-resolution textures (8000 × 8000), a specular PBR, an activated UV layer and integrated point coloring.

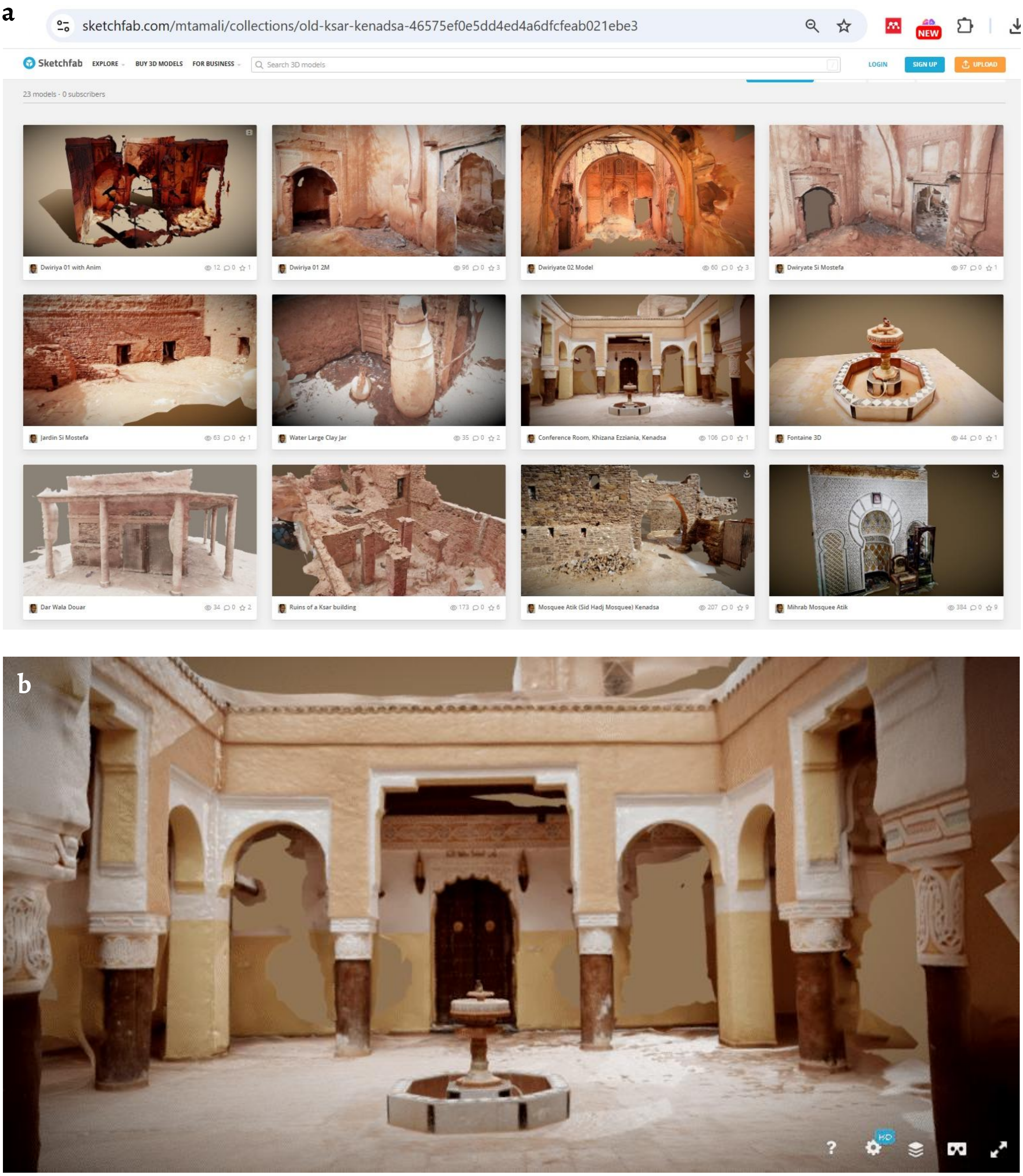

Figure 7. Animated 3D and AR models diffuse on: *a)* the platform which that allows to upload, view, share, and embed 3D models interactively of Kenadsa ksar, Algeria; *b)* courtyard house 3D.

Final product and uses

The definitive 4D model is an exhaustive instrument, designed to be used in scientific research, analysing the structural or aesthetic transformations of the building. In heritage preservation, through the planning of heritage intervention strategies, as well as in cultural mediation offers interactive visualisations intended for the public or educational tools. Using MCP based AI

(Model Context Protocol) tools, along with software such as Blender (Figure 8a-d), Mixamo, and MMD, reduce costs while increasing the efficiency of building a heritage-oriented scene.

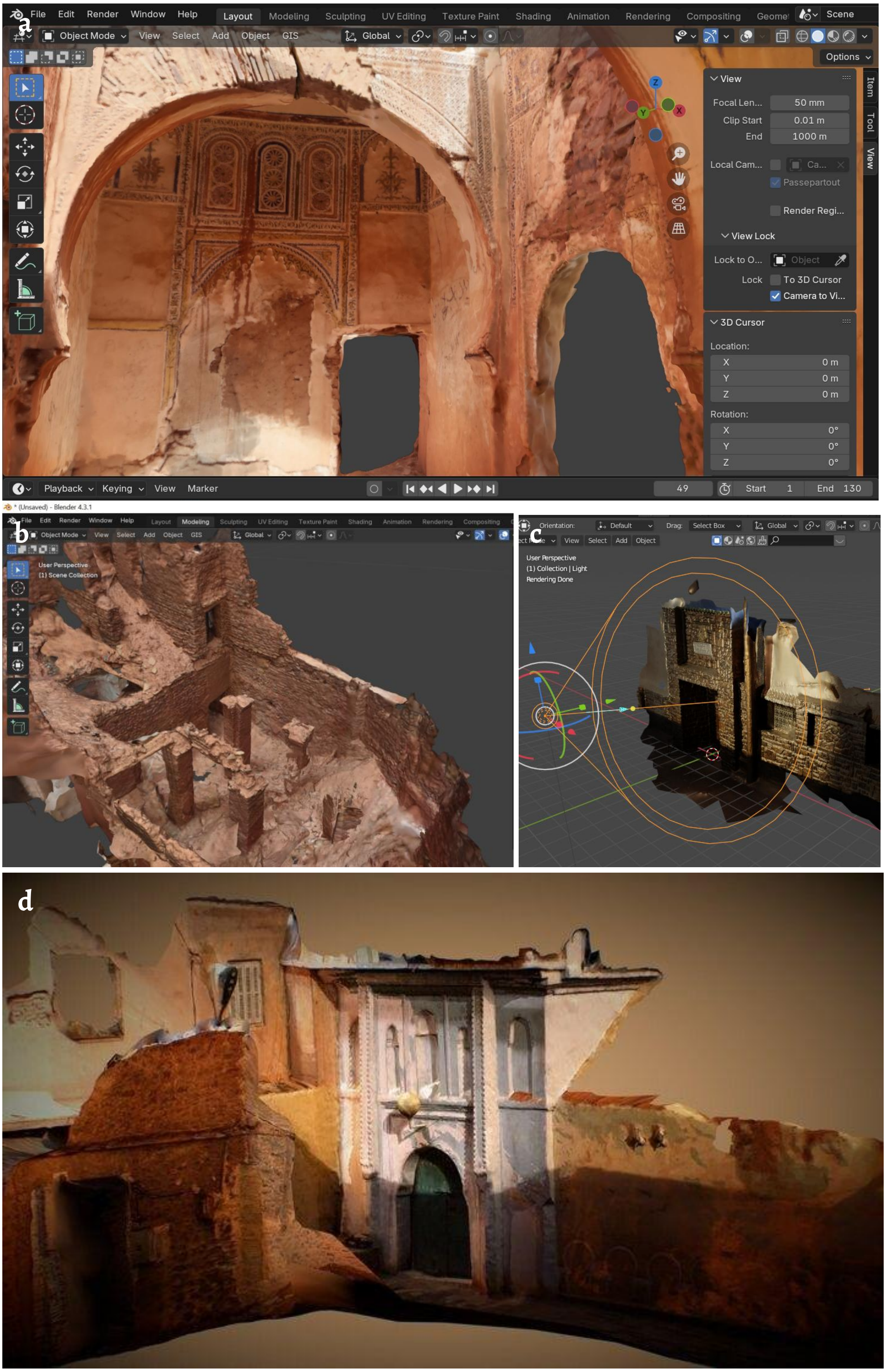

Figure 8. Refined and enriched model by Blender: *a)* house with decorative richness; *b)* old house; *c)* entrance of *Khizana*; *d)* the entrance of the mosque.

Architectural comparative analysis for predicting photogrammetric restitution

In his study, J.C Echallier highlights a series of formal and decorative clues that allow to specify the architectural stratigraphy and guide the restitutions. He emphasizes that the Kenadsa Ksar "has a completely different appearance [...], a city of old culture and established architecture" [29], and clearly distinguishes between ancient phases, close to Mauritanian traditions, and later influences from the Maghreb and especially Morocco (Figure 9). The oldest cores, built in dressed stone in polychrome shades, have sharp edges, carefully treated frames and sometimes decorations in "fish bone", showing technical affinities with Mauritanian models (Tichite, Akreijit). Conversely, the Moroccan influence is manifested in later layers, notably through the decoration of the facades coated with an ochre coating. Thus, the facade of the mosque, adorned with niches and clumsy polylobate arches, and decorated with rosettes carved in plaster, pilasters and cornices, glazed tile awnings or portals embellished with low-sprung arches. In some of the most prestigious residences, the portal is distinguished by pointed arches, enriched with colonnettes and surmounted by partial canopies covered with glazed tiles.

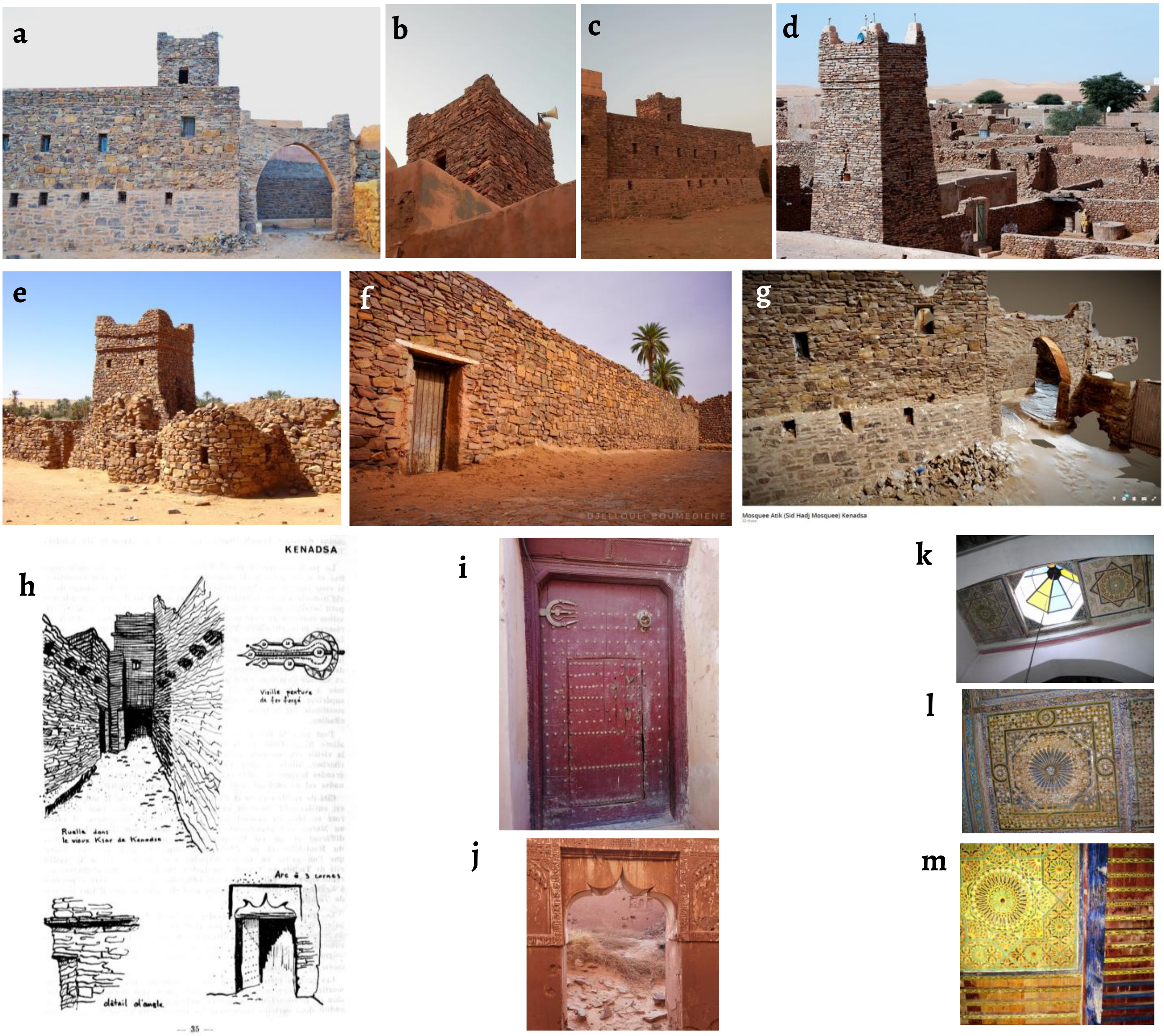

Figure 9. Architectural typology between Mauritanian traditions and Maghreb influences: *a-c)* stone architecture in Kenadsa ksar*; d-e)* stone architecture in Mauritania (Chinguetti)*; f)* stone wall in Kenadsa; *g)* 3D restitution of Kenadsa fortification wall; *h)* Kenadsa details elements by Bachminski and Grandet; *i)* traditional door; *j)* arcade type*; k-l)* decorated ceilings Kenadsa*; m)* ceilings in Fez.

Echallier also pays particular attention to the ornamentation of the doors, some elements of which seem directly imported from the Maghreb. They are indeed framed with wooden mouldings carved in "cable", studded leaves combining large leaf and small wicket, and especially wrought iron hinges with three parallel branches whose birth draws concentric circles. Thus, there are motifs (triangular rafters and internal metal twists) identical to those of hinges in Meknes in the eighteenth century, not only in general form but also in the geometric decoration of the main branches. He also points out singular morphological elements such as the three-horned arch created by a breach of the tympanum coating, also found on the great mosque of Tamelhat near Touggourt, as well as arches in recticurvilinear accolade, which complete the local formal repertoire (Figure 9h-j). The mihrab of the B. Bûziyân mosque bears a strong resemblance to those of the mosques of Fez, particulary in its polylobed arcature pediment [24].

For their part, the work carried out by Bachminski and Grandet highlights the process of gradual assimilation of new architectural forms, linked to interactions with the outside: “frequent contact with foreigners influenced them to assimilation and the use of new, more attractive architectural forms” [30]. Their work and the old photographs collected constitute a valuable reference for the reconstruction of parts that have now been demolished or completely disappeared (Figure 10). This historical database, combined with recent photogrammetric surveys, allows for a faithful reconstruction of the initial state of the building. It also proves to be indispensable in the framework of the adopted methodology, based on architectural analogy and the reconstitution of incompleteness, with a view to proposing scientifically argued hypotheses of restitution consistent with the original constructive logic

As part of our research conducted in 2011, strong similarities were revealed between the great houses of Kenadsa and those of the Maghreb. These similarities are based on both field surveys and data from oral and written archives, as well as on the work of J. Reveault and A. Paccard devoted to the architecture of Fez and decorative craftsmanship, confirming that the architecture of Kenadsa, is fully inscribed in the Andalusian continuum-Moorish and shares many common features. They concern the vegetal and epigraphic ornamentation in sculpted plaster, the coatings in *Zellij* (mosaic), as well as the decorated ceilings, made of sculpted wood and painted with natural pigments, and adorned with finely crafted floral motifs (Figure 9k-m). These elements clearly reflect Andalou-Maghrebin influences. To these decorations are added calligraphic inscriptions such as *al-ʿāfiya; al-bāqiya*, which are also found in Marrakech and even in the Alhambra.

This analogy grid plays a decisive role in the interpretation of gaps and in the mitigation of uncertainties inherent to digital restitution. The metric attributes provide objective benchmarks to complete the degraded parts of the building, while the decorative attributes allow to assign with more precision a chronological phase or a cultural area to the reconstructed elements. Thus, the combination of material indices recorded in situ and typological analogies from regional corpora contributes to validate photogrammetric restitution hypotheses, reducing the margin of arbitrariness and ensuring the scientific rigor of the models produced.

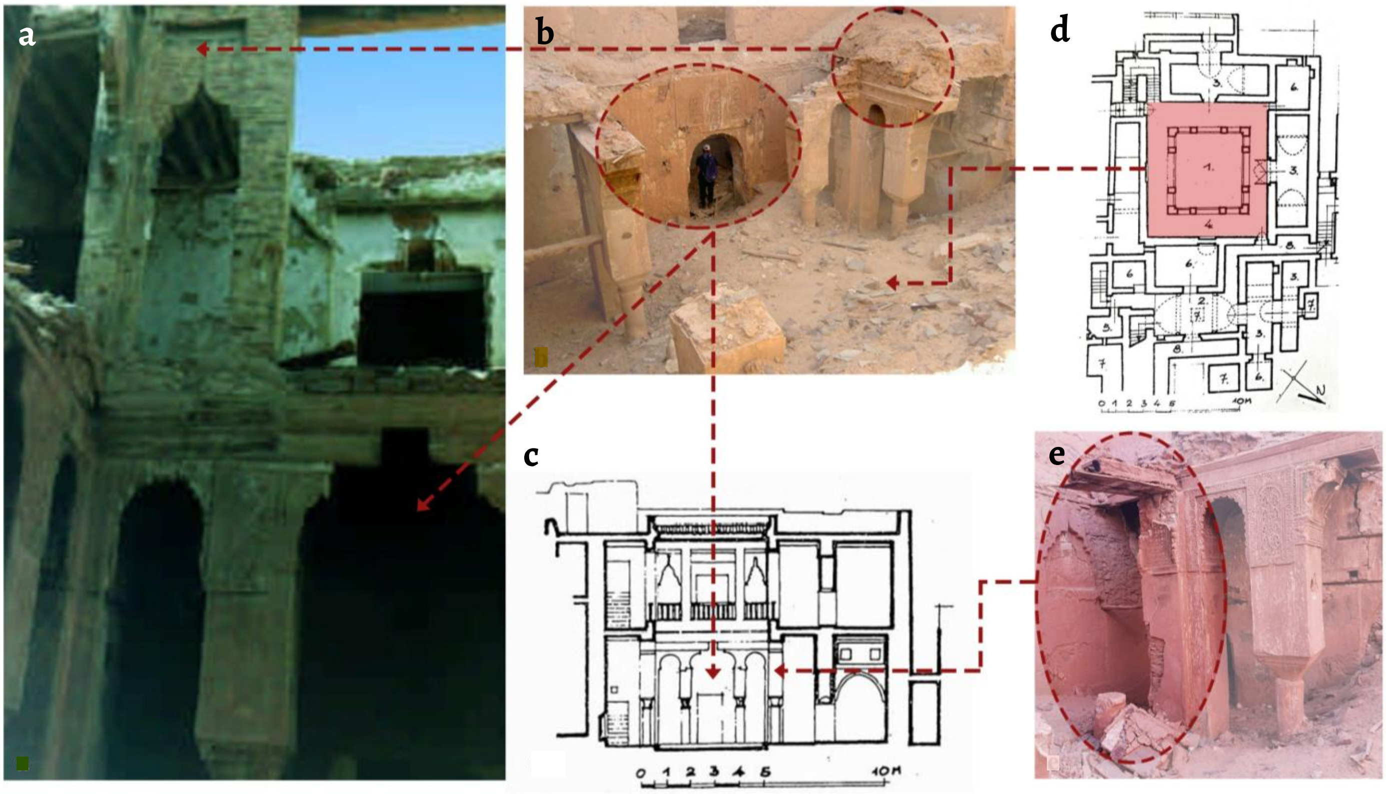

Figure 10. 2D restitution, produced from in situ metric and photographic surveys before 3D modelling: *a)* old photos of parts now disappeared; *b-e)* recent photos show parts completely disappeared; *c-d)* sectional and plan survey.

Discussion and conclusion

This paper addresses methodological approaches used to digitalize the Kenadsa Ksar's damaged building using well-known photogrammetry (for acquiring *Dwiryates*) and Laser beam acquisition for LiDAR (for acquiring *Sidi Mhmed Abi Zyan* Mosque (Figure 6b)). Data acquisition involved processing over 3 000 photographs (all phases combined) taken with EOS professional camera (Electro-Optical System) renowned for its optical performance suitable for photogrammetric surveys. This metadata was processed using ExifTool to determine the general parameters of the acquired images. The resulting point cloud achieved subcentimeter metric accuracy (less than 1 cm), confirmed by control points measured on-site, attesting the reliability of the method and the geometric accuracy of restitution. The retopology in Blender allowed for "texture baking", recentring the model on the reference (0,0,0); and then uploading the final model to Sketchfab (specialized collection). For the RPLIDAR A1M8, the point cloud "density" is best understood through its angular resolution and how the sample frequency is distributed across each scan. With an angular resolution of ≤1°, the LiDAR can theoretically capture one data point at least every degree in its 360° rotation, and up to 8000 points per scan at 10 Hz. This indicates a trade-off, where a higher scan rate (Hz) can lead to more scans per second but potentially fewer points per individual scan if the sample frequency is fixed. This defines the fineness of the environmental outline it can perceive in a single scan. The number of points in one full 360° scan is not fixed. The search results mention different values under various configurations: 1450 points per scan at 5.5 Hz.

Owing to its precision, digital restitution improves stakeholder decision-making for the sustainable management of built heritage and offers an effective way to reduce intervention costs. This study is in line with approaches that consider photogrammetry not only as a documentation tool, but also as a methodological support for restoration operations. This methodology provides a reliable and adaptable framework, using photogrammetry to create 3D digital models that aid in decision-making and ensure the conservation of traditional forms. The process addresses current conditions, past data gaps, and future predictions, with the resulting models supporting heritage popularization, digital archiving, and cultural tourism. The photogrammetry allows for rigorous documentation of the current state of buildings, identification of deformations, as well as anticipation of conservation interventions and simulation restoration scenarios in an experimental setting that respects the material integrity of buildings. Our work has focuses on collecting history of the available data relevant to the studied building (attached to the studied culture) and through architectural analogy in order to propose scientifically reconstruction hypotheses. By reverse-engineering the observed facts, process of restoration can be guided and then achieved.

Several challenges are encountered during the project advancement in order to ensure optimal data acquisition. Some of these have been overcome through the use of appropriate measures using several documentation's type, while others require digitalization techniques and tools that offer high precision of complex architectural structures and areas that are difficult to access. In addition, photogrammetry has more than one method for digitization, but other generalizations such as the use of Max Range LiDAR or aerial scanning, using a UAV, or even acoustics (a method using sound to scan obscure sites). If the data comes from a multitude of sources and methodologies, the result of processing the artifact could yield significant observations and details.

Moreover, the methodology implemented is adaptable to other ksour and similar vernacular settlements, by offering a reproducible framework that respects local architectural and cultural specificities while generalizing good practices of documentation and rehabilitation (Unified framework). The methodology steps vary depending on the details level to reach or observations requested. The experimental application on Kenedsa Ksar concretely illustrates the global approach: photogrammetry allowed to record with a great precision the existing structures, to restore virtually degraded parts and to simulate several restoration situations and scenarios. This experience shows the scientific method's value as well as its ability to constitute an operational basis for developing coherent rehabilitation interventions that respect traditional materials and structural procedures. Our aim is to unify considerations in aspects organization of Tangible and Intangible heritage, this by introducing a unified classification for both types.

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