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ARCHITECTURAL PHOTOGRAMMETRY APPLIED TO THE CATALOGING OF HISTORICAL HERITAGE. A CASE STUDY OF A BUNKER IN LA LÍNEA DE LA CONCEPCIÓN, SPAIN

Abstract

Photogrammetry is an emerging tool in architecture, conservation, cataloging, and maintenance of heritage, offering a precise and efficient methodology for generating three-dimensional digital models. This work presents a comparative study of photogrammetric methods, focused on a low-cost software application, with the aim of evaluating its effectiveness in capturing and faithfully representing architectural and cultural elements, such as the bunkers located in La Línea de la Concepción (Spain), where the seismic hazard is not neglectable. The results reveal that the method choice depends on the object being digitized. Some programs are more suitable for capturing fine details, while others excel in reconstructing more complex structures.

Keywords: Photogrammetry, bunker, historical heritage, 3D modeling

ПРИМЈЕНА АРХИТЕКТУРНЕ ФОТОГРАМЕТРИЈЕ НА КАТАЛОГИЗАЦИЈУ ИСТОРИЈСКЕ БАШТИНЕ. СТУДИЈА СЛУЧАЈА БУНКЕРА У МЈЕСТУ ЛИНЕА ДЕ КОНСЕПСИОН, ШПАНИЈА

Сажетак

Фотограметрија је нова алатка у архитектури, очувању, каталогизацији и одржавању баштине, која нуди прецизну и ефикасну методологију за генерисање тродимензионалних дигиталних модела. Овај рад представља компаративну студију фотограметријских метода, са фокусом на примјену приступачних софтвера, са циљем процјене његове ефикасности у снимању и вјерном представљању архитектонских и културних објеката, као што су бункери који се налазе у мјесту Линеа де Консепсион (La Línea de la Concepción) у Шпанији, гдје се сеизмичка опасност не може занемарити. Добијени резултати откривају да избор методе зависи од објекта који се дигитализује. Неки програми су погоднији за снимање ситних детаља, док се други истичу у реконструкцији сложенијих објеката.

Кључне ријечи: фотограметрија, бункер, историјска баштина, 3Д моделирање

1. INTRODUCTION

In the advancements of architectural analysis, photogrammetry has emerged as a fundamental tool in a wide range of fields, such as precise data collection and the generation of three-dimensional models. Its application extends from cartography and topography to archaeology and civil engineering, even combined with Light Detection and Ranging (LiDAR) technology for peculiar subjects such as monitoring indigenous settlements [1]. Additionally, it can be used for aerial modeling like the works done with Reality Capture software [2]. This opens up the possibility of investigating and promoting the cataloging of elements that may be forgotten over time and through the degradation of elements.

Indeed, a series of investigations were carried out with aerial photogrammetry using drones and LiDAR, describing the advantages and disadvantages within the framework of architecture and landscape [3]. This provides precise archaeological information, although the method of aerial overflight via airplane requires subsequent orthophotographic restitution. The main studies conducted by Rouco Collazo et al. [4] focused on Órgiva and Poqueira, cities located in Sierra Nevada (Granada, Spain). Similarly, there are applications for the evaluation of archaeological sediments in different historical stages [5].

Therefore, photogrammetry not only plays a fundamental role in the cataloging and documentation of buildings, facilitating efficient management of architectural inventories and tracking changes over time. Furthermore, its application in aerial surveying brings a unique perspective for inspecting large areas and urban planning.

Particularly concerning architecture, it offers innovative solutions to a variety of challenges in the preservation, design, and monitoring of structures [6]. Hence, the importance of historical documentation of architecture is emphasized in a study aimed at recreating historical elements from old photos taken from different angles [7]. For example, the Structure for Motion (SfM) process applied to Caltanissetta Centrale Station consisted of detecting and matching features to result in a three-dimensional virtual model. Kutlu & Soyluk used photogrammetry to support structure calculations through the Finite Element Method (FEM), revealing that photogrammetric use yields similar values to traditional calculation methods [8].

One of the most impressive applications is in the so-called "living architecture". It requires a more complex geometric analysis, as the geometric shapes of trees are more intricate than practically orthogonal ornamentation. This type of element requires multiple 360º photographic shots around the figure. Still, the definition is much more complex, as the point cloud is not as well defined for analyzing specific small-scale details. However, in this regard, Middleton et al. [9] allowed for the evaluation of tree growth in a very interesting way between March 2018 and March 2019, monitoring their behavior and being able to anticipate future interventions.

In the field of historical heritage restoration, photogrammetry serves as a valuable tool for the detailed documentation of deteriorated architectural elements, allowing for a precise and faithful reconstruction of them. Additionally, its ability to recreate constructions at any scale opens up new possibilities in the field of architectural design, allowing for the creation of detailed 3D models that can be used for subsequent prints, digital visualizations, and structural analysis [8]. From another point of view, the practice of this technique is being developed in more disciplines similar to traditional architecture, such as interior design. In these cases, the dense point cloud is usually used to recreate the space as realistically as possible [10]. Besides, Firzal conducted a low-cost study to document medium-sized historical buildings, specifically a temple located in Indonesia [11]. The methodology was based on capturing images with appropriate overlap, both from a ground position and through drone shots. Therefore, with close-range photogrammetry (CRP), a three-dimensional model of the actual state can be obtained with the appropriate level of detail according to the final use of that model. Asadpour utilizes photogrammetry to catalog important architectural artworks located in Iran, focusing on simple ornamental elements such as bunkers [12]. They also recreate, based on the obtained model, the arrangement of the construction elements, especially those located on the roofs of mosques. Similarly, Brenner et al. undertook a study on photogrammetry and laser scanning as a method to obtain precise details of special pieces [13]. That study demonstrated that these techniques can take an accurate and realistic image of structural nodes on complex facades to proceed with a more precise intervention. This allows, in the event of having to repair a specific piece, to create a replacement through laser scanning and subsequent 3D printing.

Among the most promising areas of application of photogrammetry in architecture is its ability to assess structural pathologies in buildings [14]. Through the analysis of photogrammetric images, it is possible to identify and evaluate defects in the structure without the need to use continuous monitoring methods, offering an efficient and non-intrusive alternative for assessing the condition of buildings. In the same line, photogrammetry shows great potential in the large-scale determination of macroseismic models, constituting a first step in the automatization of the identification of seismic vulnerability parameters, such as in-plan and vertical irregularities, level of preservation or main dimensions.

To carry out this evaluation, in this research, different low-cost software will be used, such as Meshroom or ReCap Photo. Tests will be conducted in open environments and field situations, using objects of different sizes and shapes to simulate real conditions. Special attention will be paid to the accuracy of the three-dimensional reconstruction, spatial resolution, and the ability to capture specific details. Additionally, a comparative analysis of the results obtained with each software will be carried out in order to identify specific strengths and limitations of each tool in terms of scope and accuracy.

2. STUDY AREA

La Línea de la Concepción is a town located in southern Spain, specifically in the province of Cádiz (Figure 1). It is situated on the coast of the Strait of Gibraltar, on the northern shore of the isthmus that connects the Iberian Peninsula with the African continent, in an area called Campo de Gibraltar. This location grants it considerable historical and commercial importance, as it is one of the main points of connection between Europe and Africa [15].

Figure 1. Location map of La Línea de la Concepción (Spain). EPSG: 25830. Source: www.ign.es

During the Spanish Civil War (1936-1939), La Línea de la Concepción became a key strategic point for the Republican defense due to its proximity to Gibraltar and its military port [16]. To protect this position, bunkers were built along the coast and in the surrounding hills. These constructions, mainly made of reinforced concrete and cement as dictated by the construction boom of the time [17], were designed to withstand aerial and ground attacks [18], providing shelter and firing points for Republican troops. Strategically located, these bunkers had privileged views of the terrain and were equipped with firearms and communication systems to coordinate defense. They represent tangible evidence of the conflict and the military architecture of the time, highlighting the importance of La Línea de la Concepción in the history of the Spanish Civil War. Currently, these remnants form a part of the intrinsic value of the city, being relics of a very important armed conflict for the country's history [19].

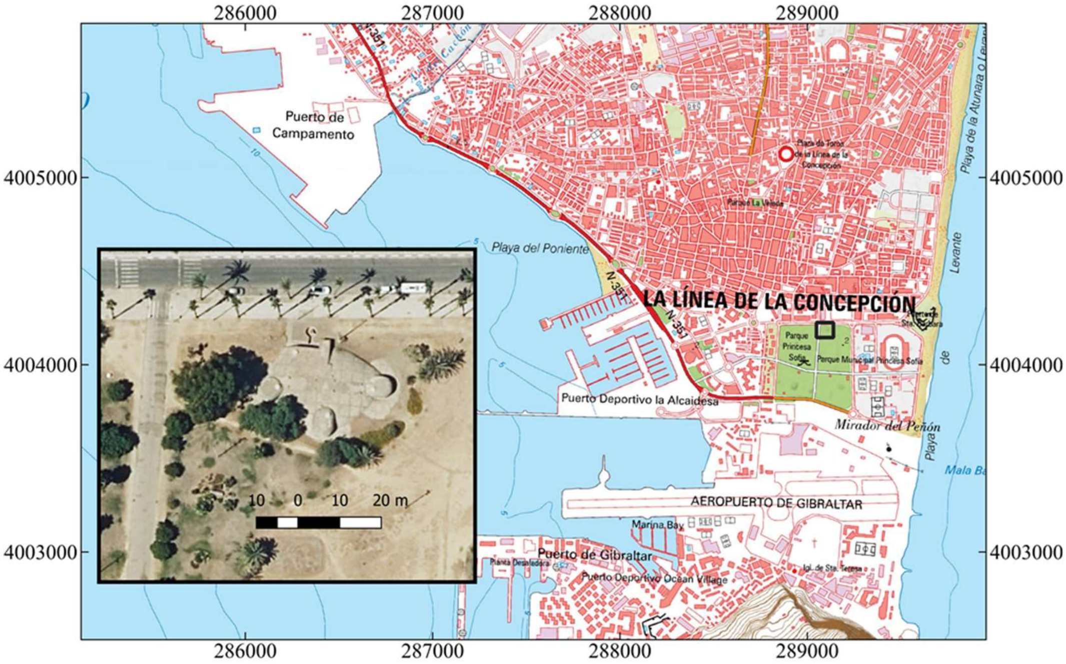

Figure 2. Site map of the bunker in La Línea de la Concepción (Spain). EPSG: 25830. Source: www.ign.es

The bunkers built during the Spanish Civil War are an important historical and architectural legacy that, in many cases, is unprotected and in a state of decay. These structures, also located in other places in the Campo de Gibraltar, face challenges in terms of conservation due to exposure to climatic and chemical elements such as environmental salinity. This reveals a lack of resources for their maintenance. However, the application of photogrammetry can offer a viable solution for documenting, evaluating, and planning the conservation of these historical sites.

The use of photogrammetric applications, as a method for obtaining three-dimensional models, has revolutionized the way we understand and preserve architectural heritage. Its ability to accurately recreate elements of different dimensions and shapes has found applications in the restoration and conservation of historic structures. Particularly in this case where one of the abandoned bunkers located in La Línea de la Concepción is being analyzed (Figure 2). Architectural restoration is a complex process that requires a precise understanding of the original structure and the damages suffered over time [20]. Therefore, these types of techniques offer an efficient and precise solution for capturing the geometry and characteristics of historical buildings. This technology streamlines the documentation process and provides a basis for restoration planning, minimizing the loss of important details and ensuring the authenticity of the intervention.

Hence, the conservation of the historical architecture of bunkers is important for cultural and heritage reasons, as well as for its value in preserving historical memory. These sites bear witness to significant events that are part of the collective identity of a society [21], and their loss or degradation represents an impoverishment of historical narrative. Additionally, early intervention in the conservation of these structures can result in significant long-term savings. Photogrammetry is a precise and cost-effective tool for documenting and evaluating damages, allowing for the identification of structural problems and the establishment of conservation strategies before they become more expensive to remedy. Drap et al. [22] developed a study combining laser scanning techniques, short-range photogrammetry, and field analysis, for the cataloging of archaeological objects, reducing the cost of intervention.

Another essential aspect in the current era for the conservation of military and defensive architectural heritage is access to affordable technologies. Low-cost photogrammetry has enabled access to the creation of realistic three-dimensional models for professionals who need its support. This has allowed conservators and local communities to document and study their heritage in a cost-effective manner [23]. This form of photogrammetry, which uses consumer cameras and open-source software, has expanded the possibilities for heritage conservation in environments with limited resources [24].

Therefore, photogrammetry has established itself as a highly useful tool in the recreation and conservation of heritage, especially in contexts of those forgotten elements that suffer degradation over time, such as climatic agents or natural actions like earthquakes. In fact, in terms of seismic hazard, La Línea de la Concepción (Spain) is estimated to experience a peak ground acceleration (PGA) of 0.10 g for a return period of 475 years. This implies that the maximum expected intensity according to EMS-98 scale is VII (Damaging) [25].

3. METHODOLOGY

The methodology followed for the study involves the use of various low-cost photogrammetry software with the aim of creating a detailed model of the composition of the remains of the aforementioned bunker, specifically number 162 according to the La Línea de la Concepción City Council's cataloging. Different techniques and tools were used to capture images from various angles and heights, ensuring complete coverage of the object.

In order to graphically reconstruct a historical object or building using photogrammetry with software, a general process combining image capture techniques and digital processing is followed. First, a series of photographs of the building are taken from multiple angles using a digital camera with sufficient resolution. These images serve as input data for the software. Next, the images are imported into the software, which utilizes computer vision algorithms to reconstruct the three-dimensional geometry of the building from the photographs. The reconstruction process involves identifying common points in the images (matching), estimating the camera position in each image, and triangulating points in three-dimensional space.

The software to be used in this study is Meshroom and ReCap. These programs employ spatial data structure techniques and optimization algorithms to produce a detailed three-dimensional model of the building, including its shape and textures. The final result is a 3D digital model that can be visualized and manipulated in Computer-Aided Design (CAD) software or 3D visualization applications.

Firstly, Meshroom is an open-source software that facilitates the 3D reconstruction of scenes and objects from photographic images [23]. Its intuitive graphical interface and automated process simplify the workflow, while it has the ability to leverage CPU processing. Meshroom can be combined with other modeling programs such as MeshLab and the non-free Agisoft software [24].

On the other hand, ReCap Photo is an Autodesk software that offers solutions for reality capture and modeling for architectural projects. Using images captured with standard cameras, it generates accurate 3D models with dense point clouds [26], which can be used for visualization, analysis, and design in architecture. This tool allows obtaining a realistic image of the architectural shape of an element.

Meshroom, offering advanced features such as SfM and Multi View Stereo (MVS), requires a deeper technical knowledge and may be more suitable for experienced users focused on virtual reality tasks, supporting more than 1000 images. On the other hand, ReCap, part of the Autodesk suite, provides a more intuitive interface and is optimized for large amounts of data, although its free version supports up to 100 images. The final quality of the models depends on various factors, including the quality of the input images and the software configuration. Processing time may vary, with Meshroom being slower due to its processing from the computer itself. Whereas ReCap can be faster thanks to its optimization and cloud processing.

For the creation of the virtual model, photographs have been captured following the provided scheme (Figure 3). Each image has been selected and processed with appropriate overlap to ensure the accuracy and fidelity of the model and environment. Different angles and perspectives have been used according to the scheme, thus achieving every detail necessary to accurately recreate the object.

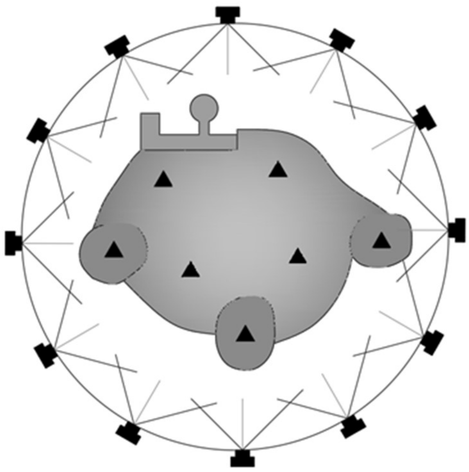

Figure 3. Camera position around the bunker with image capture angles.

Initially, the Meshroom software version 2023.23.0 was used to generate an initial model of the bunker. A total of 336 photographic shots were captured from the entire perimeter of the bunker, with an approximate minimum overlap of 30% between the photographs. This coverage ensures the capture of hidden details and creates a representation of the structure as a whole. These images were taken with a Xiaomi mobile device model 2201113PG, with an estimated focal distance of 5.948 m, which was determined from the metadata procured by Meshroom.

Subsequently, an additional survey was conducted using the ReCap Photo program. At this stage, 100 photographs were captured with an approximate minimum overlap of 30%, focusing especially on the top part of the bunker (Figure 4). For these shots, a pole was used, and photos were taken from different angles, even climbing onto the bunker's roof, in order to obtain a complete and detailed perspective of this area. In the scheme of the Figure 3, areas where the photos were taken from high points are marked with a triangle.

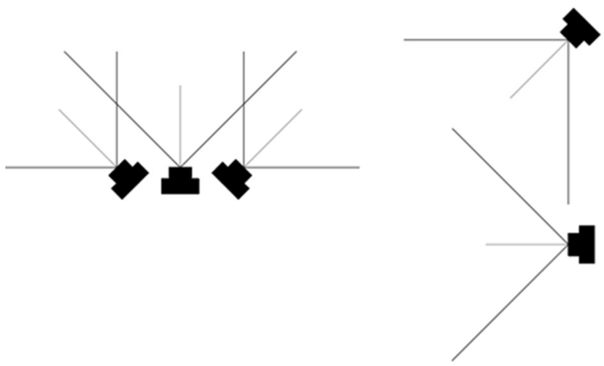

Figure 4. Camera position from image capture angles. Left: plan view position, Right: vertical position.

Finally, a specific survey of particular parts of the bunker was carried out. 94 photographs were captured for one of the main faces, and 26 photographs were taken concentrically around two upper vents. The first vent shows advanced wear, while the second one is in a more preserved state. In both cases, the interior reinforcement is rusted, and the metal elements supporting it have broken.

4. RESULTS

The results of the photogrammetric study reveal several important observations:

Meshroom produces a dense point cloud but fails to fully define the element (Figure 5 and Figrure 6). It places elements in incorrect positions, which may compromise the accuracy of the model.

Figure 5. High correspondence of the photos taken with the points obtained by Meshroom.

Figure 6. Low correspondence of the photos taken with the points obtained by Meshroom.

ReCap provides a more complete survey of the bunker as a whole compared to Meshroom (Figure 7 and Figure 8). Despite this, it still fails to define much of the element, indicating limitations in its ability to capture details.

Figure 7. Realistic representation of the entire bunker. Aerial view of the South face.

Figure 8. *Realistic representation of the entire bunker. Aerial view of the North face.*

A much more complete image of one of the bunker faces is obtained compared to the other technology. Although the definition improves, some errors are still found at the top of the element (Figure 9), suggesting possible difficulties in the accuracy of certain areas. This fact is more evident in the mesh (Figure 10).

Figure 9. *Realistic representation of a bunker dome.*

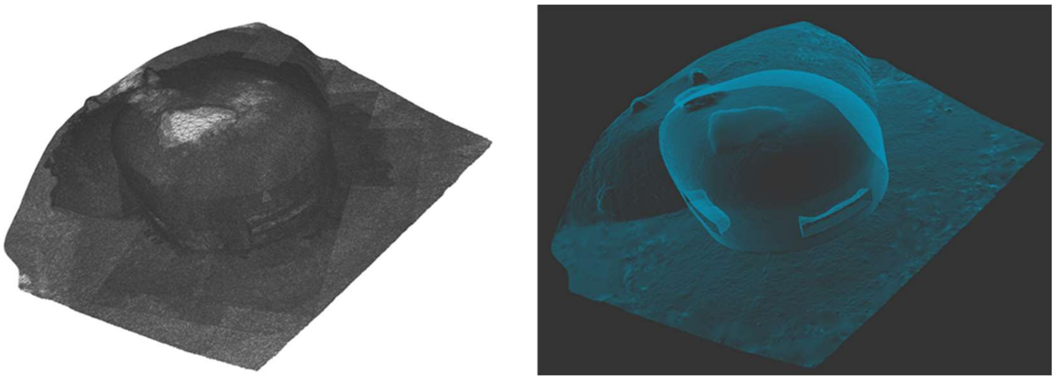

Figure 10. *Mesh representation of a dome. Left: point correlation version, Right: laser-type meshing.*

The survey of two vents is carried out with total detail and precise definition (Figure 11 and Figure 12), indicating that ReCap can be especially effective in capturing smaller or detailed objects.

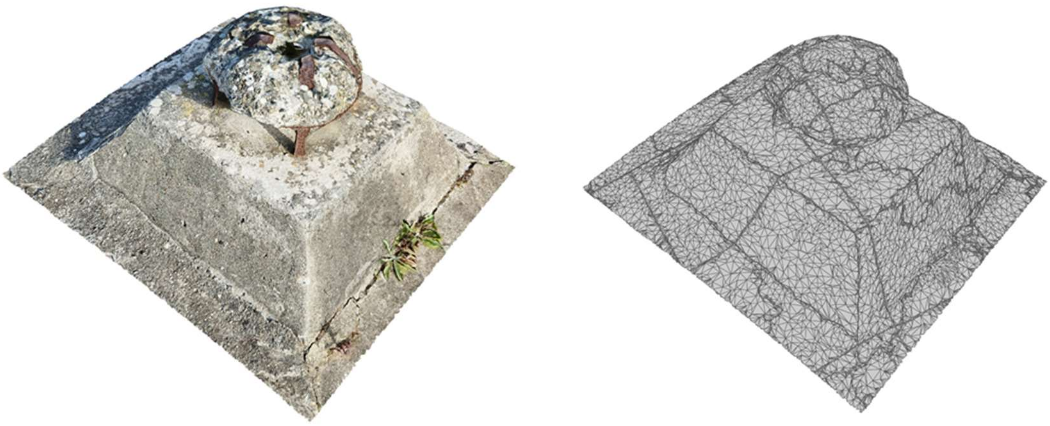

Figure 11. *Representation of a poorly preserved vent. Left: realistic version, Right: point correlation version.*

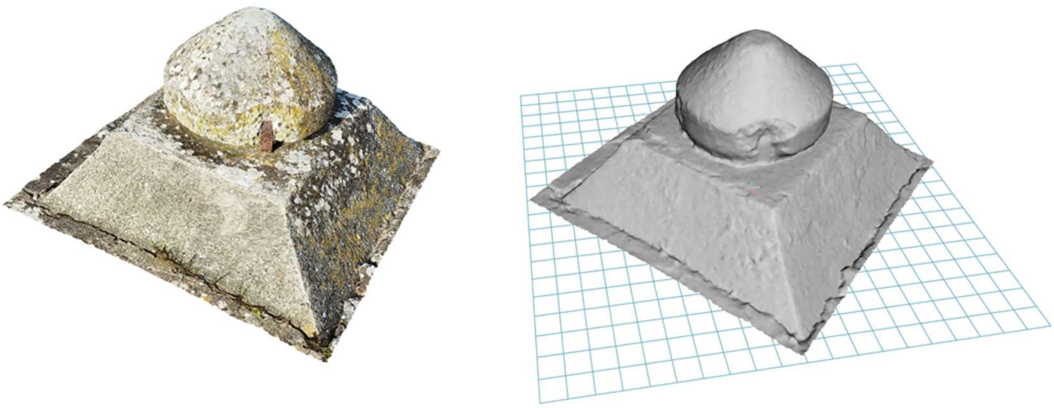

Figure 12. *Representation of well-preserved vent. Left: realistic version, Right: extruded version.*

5. DISCUSSION AND CONCLUSIONS

Although photogrammetric methods are considered extremely useful in generating three-dimensional models, it is important to consider some limitations, especially regarding the size of the elements to be developed. It is recommended to focus the analysis on objects of medium size, as the difficulty of precision increases significantly with larger elements. By focusing on medium-sized objects, the precision and definition capabilities of these methods can be maximized, thus optimizing the obtained results and rendering time. In this way, a balance between the utility of photogrammetry and the inherent limitations of its application in large objects and low-cost programs can be achieved.

The results obtained through various photogrammetric methods have demonstrated the ability to create high-quality three-dimensional models for small-sized objects. However, when attempting to reproduce larger elements, significant problems arise in low-cost methods. Despite this, it has been shown that these techniques are very useful in the field of cataloging, especially for the conservation of forgotten architectures within cities.

During the research development, it has been found that the Meshroom program is capable of generating a dense point cloud, although it fails to fully define large elements. On the other hand, ReCap, while improving precision compared to Meshroom, still faces difficulties in clearly defining such elements. However, for specific parts of the construction, ReCap demonstrates considerable ability to accurately define details.

In the photogrammetric tests carried out on the bunker vents, being small but valuable elements, remarkably precise definition has been observed. Additionally, they provide an interesting perspective on the pathologies presented by the vents, such as oxidation and elevation, as well as other information for their cataloging and possible restoration processes. Similarly, as in this case study, photogrammetry applied to small ornamental objects of historical value can greatly assist in their recreation and restoration. In the study by Triviño-Tarradas et al., pieces were recreated through computer numerical control (CNC), which yielded excellent and very precise results [27].

As a final reflection, according to Shults, these systems should be used in engineering and architecture faculties to improve education and digital visualization for students [28], allowing them to handle different tools and promoting their utility for the preservation of heritage.

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