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Large-scale photogrammetry: the case of the Roman baths of Alange, Badajoz (Spain)

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Abstract

Photogrammetry applied to heritage documentation has undergone significant development in recent years. The research objective we present is to synthesise the result of the work carried out by employing and studying the application of large-scale photogrammetric techniques in an integrated manner coherently and exhaustively. This research has been applied in the Roman Baths of Alange case, which was declared a World Heritage Site (UNESCO, 1993). This significant ensemble lacks detailed planimetric documentation and archaeological interventions. This research has established a comprehensive overview of the difficulties affecting the characteristics of the photogrammetric technique and its development in architecturally complex, narrow, enormous, and data collection-challenging places. This has been reflected in a point cloud of the surveyed site. Thus, the aim is to understand the scope of the technique and analyse each of its characteristics.

Keywords: *photogrammetry, heritage, photogrammetric survey, Roman baths of Alange, world heritage.*

1. Introduction

Although photogrammetry is widely used in heritage preservation, such as in historical monuments, culturally significant properties, archaeological remains, small objects, etc, the difficulty of its application in complex natural environments requires extensive knowledge of the technique and instrumentation used.

This work is part of the ongoing themes in the Master's Thesis in Architecture and Historical Heritage at the University of Seville, by David Conejero, supervised by Pablo M. Millán, and conducted with the assistance of Margarita Infante and Concepción Cantillana on fieldwork. It arises from an interest in photogrammetric surveys in exceptionally unusual and complex cases, sometimes successfully employing this technique and simple and low-cost instrumentation to survey locations with difficult access and/or peculiar geometries and characteristics (Conejero, 2023).

In the case at hand, the difficulty lies in the Project's scale and the presence of wáter in the chosen site, the Roman Baths of the Alange Spa, Badajoz (Spain).

1.1. The Photogrammetric Technique in Architectural Heritage

Henri Bonneval defines Photogrammetry as the "...technique for studying and precisely defining the shape, dimensions, and position in space of any object, using measurements taken from one or more photographs…" (Bonneval, 1972, p. 35).

It originated in the 19th century, thanks to the research of Laussedat with Metrophotography. The German architect Meydenbauer, from 1867, carried out numerous interventions in architectural heritage using this technique with the novel photography, henceforth calling it Photogrammetry (Buill, 1997; Herrero, 2006). From its origins, Meydenbauer employed this technology, which was quite novel for preserving historical monuments in his country (Pereira-Uzal, 2016), later expanding and extending his work throughout Europe and abroad (Albertz, 2001).

Over the years, thanks to the technological advances throughout the decades, new instrumentation could be employed in photogrammetry, expanding its working horizons. Currently, with digital technology, photogrammetry employs innovative devices such as UAVs (Unmanned Aerial Vehicles) or drones (Ruiz et al., 2015; Buill et al., 2016; Palacios, 2023), digital cameras or even satellites, as well as the use of fast data processing software, offering a very effective and convenient working method.

Understanding the subtle relationship between the analytical and analogue photogrammetry methods is essential. New technologies and devices that aid data collection are useful and necessary as long as the theoretical foundations and trigonometric principles are understood. It's also crucial to master drawing as a tool to achieve architectural and archaeological details and High-quality representations (Latorre & Cámara, 2010).

In recent works carried out with photogrammetry, it has been used "Close-Range" or "CRP", a technology that consists of closet o surface photogrammetry (around 1.20 m near the surface), which takes around a hundred photographs (Domingo et al., 2024). In heritage dissemination, there are various publications on preserving tangible heritage through virtual models, with works of varying magnitude, some of which involve several hundred photographs taken (Caro & Hansen, 2015; Leija-Román et al., 2022; Sala, 2022) or in some cases, up to a thousand photographs (Conejero, 2023).

1.2. The Roman Baths of the Alange Spa

Declared a World Heritage Site in 1993 (UNESCO, 1993), the Roman baths of the Alange Spa (Badajoz) date back to the 3rd century AD, a period revealed by a Roman inscription found in their vicinity (Álvarez, 1973).

These Roman baths consist of two large elevations with domes, both finished with an oculus that allows sunlight to enter. They are connected by a narrow corridor where natural light barely penetrates, which links on one end to the rest of the spa facilities through a set of stairs and on the other end to the exterior garden.

Throughout history, the Roman baths underwent various transformations and occupations. At the end of the 7th century, they had a monastical use during the Diocese of Aquis in Lusitania in the reign of Wamba (Carmona & Caletero, 2016). It also declined and neglected for almost a millennia (Madoz, 1846). It wasn't until the 16th century that the Roman baths' first interpretations appeared, as Ambrosio de Morales noted in 1575, referring to them as an "ancient temple from Roman times, round like the Pantheon of Rome" (Salas, 2010). Subsequently, other archaeology scholars (De Laborde, 1806; Canto, 2001) and medicine scholars (Colodrón, 1838; De Villaescusa, 1850) highlighted the value of these baths due to their Roman structures and the very rare but beneficial mineral-medicinal properties of the waters. Thus, the Roman baths evolved and transformed into a thermal complex with innovative techniques up to the present day (Carmona & Caletero, 2013).

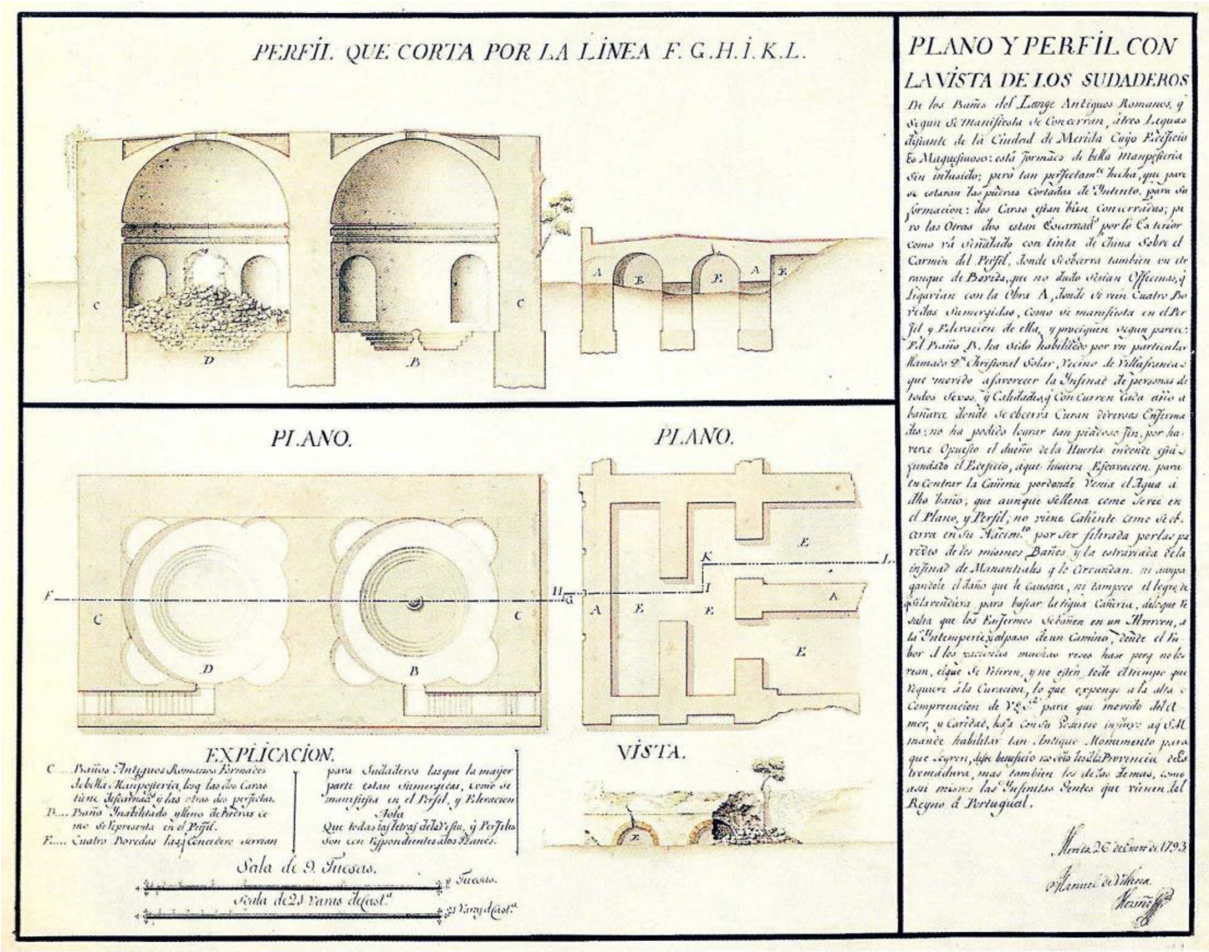

Figure 1. Plate No. 8 - "Baths of Alange" by Manuel de Villena y Moziño, 1793.
Source: Canto and De Gregorio, A.M.. (2001)

2. Objectives

This communication aims to address and develop the complexities and difficulties of using photogrammetric techniques within the surveyed site, explaining the necessary foundations and knowledge required to achieve the best possible result. It aims to understand each necessary step for creating useful and precise documentation, both for characterising the materials of the chosen heritage site and for its dissemination.

The other objective of this project is to reflect the qualities of data collection in photogrammetric surveys and topographic work in a point cloud. This aims to raise awareness about the value of the work done with this technique and its professional rigour in research projects or any other type of work.

3. Methods

3.1. Planning

The work plan was devised during several preliminary inspection visits to the site, during which the geometric and architectural complexities of the building were analysed.

Due to their archaeological significance, it was decided to focus the survey not only on the interior of the two baths and the stairwell and corridor area providing access to them but also on their roofs and exterior walls. Given the scale of the task, simultaneous data capture of the spaces was proposed using two cameras with different characteristics.

Fieldwork begins with selecting camera parameters based on the dimensions and lighting conditions of the different work areas. Firstly, the focal length must be decided, which is the ratio between the distance from the focus to the optical centre of the camera lens. For data capture of the oculi of both domes, the cameras are set to their maximum focal distance, 32 mm, to allow for greater precision in the information from photographs near this area and to optimise the connection between exterior and interior data. The rest of the photographs are taken with a focal length of 12 mm to achieve a wider field of view and capture as much data as possible with minimal photographs, to obtain a thorough understanding of the interior of the domes and the connecting corridor and stairs, which are very narrow (some áreas are less than 1m in width), making image capture challenging.

Before taking the photographs, the ISO speed parameter must also be configured. This determines the amount of light the digital camera sensor is sensitive to. Lower values, around ISO 100-200, are used in well-lit places, while higher values, ISO-400 or more, capture as much light as possible in poorly-lit areas. In this case, since tripods were available, very low ISO values of 100 and 200 were chosen to avoid digital noise in photographs and enable data capture even in areas with dim lighting conditions, such as the interiors of the domes, shaded areas, and corridors.

Another consideration is the Aperture Priority Mode, in which the Automatic option is chosen to regulate the amount of light entering the digital camera sensor when the surrounding light is constantly changing and moving. This is crucial because the fieldwork extends for many hours, during which natural light, entering only through the domes' oculi, undergoes slow but constant changes over time, resulting in moving shadows and changes in lighting and colours.

Finally, the Aperture setting is selected, closely related to the depth of field when obtaining information. A higher aperture setting results in a greater depth of field. Despite the walls being mostly smooth and lacking pictographic or archaeological information in most cases, the aim is to capture as much data as possible. It was considered that an aperture of F8 was the optimal working value, as it represented an intermediate aperture that provided good depth of field for the available light both indoors and outdoors, achieving good sharpness and quality in the shots taken.

Regarding topographic data collection, the work environment was thoroughly inspected, and the required number of stations and suitable locations were determined based on visibility between stations and between these stations and the selected control points. A series of coded targets were placed on these control points, forming a network of points that would facilitate the orientation of different parts of the future 3D model and provide it with good geometric rigidity and scaling. The targets used are marked with geometric patterns automatically recognisable by the chosen software for subsequent office work. These targets are numbered and captured using a total station along a necessarily open itinerary. In pursuit of maximum reliability and precision, the itinerary is repeated several times, verifying its validity and averaging errors.

3.2. Procedure

Once the processes and working characteristics are understood, data collection begins. Walkable areas surround the Roman baths, as each centre has a circular pool. Data is collected from the oculus areas with focal distances of 12 and 32mm alternately, while the rest of the domes and rooms are captured only with a 12mm focal length.

Before starting the survey, photographs were taken in various locations in the surveyed area using white balance cards. This is done to calibrate the white colour in the digital images that will be taken, considering the various lights produced in the areas depending on solar incisions and shadows present in the property at different times. This helps to balance the light for photographic exposure.

The survey should be conducted to capture data where the photographs overlap by a minimum of 60%. This means that when taking a photograph, the next one should have at least 60% of the information from the previous photograph so that later, the computer software can correctly align the photographs.

Three types of photographic shots were considered based on the angle formed between the camera's optical axis and the photographed surface:

The first pass is as orthogonal as possible, aiming to obtain the highest possible quality in texture and colours.

The second pass is at an approximate angle of 45º to the surfaces. This is to capture depths and points that are less visible from an orthogonal view.

The third pass is also at an approximate angle of 45º, but in the opposite direction to the previous one, to gather maximum information about the relief.

Finally, data is collected in the corridor and stairs in one direction and then in the opposite direction. This is due to the barrel vaults, arches, and skylights found in the high areas, which need to be considered for a complete survey due to the reflection of light on the digital camera and the architectural complexity.

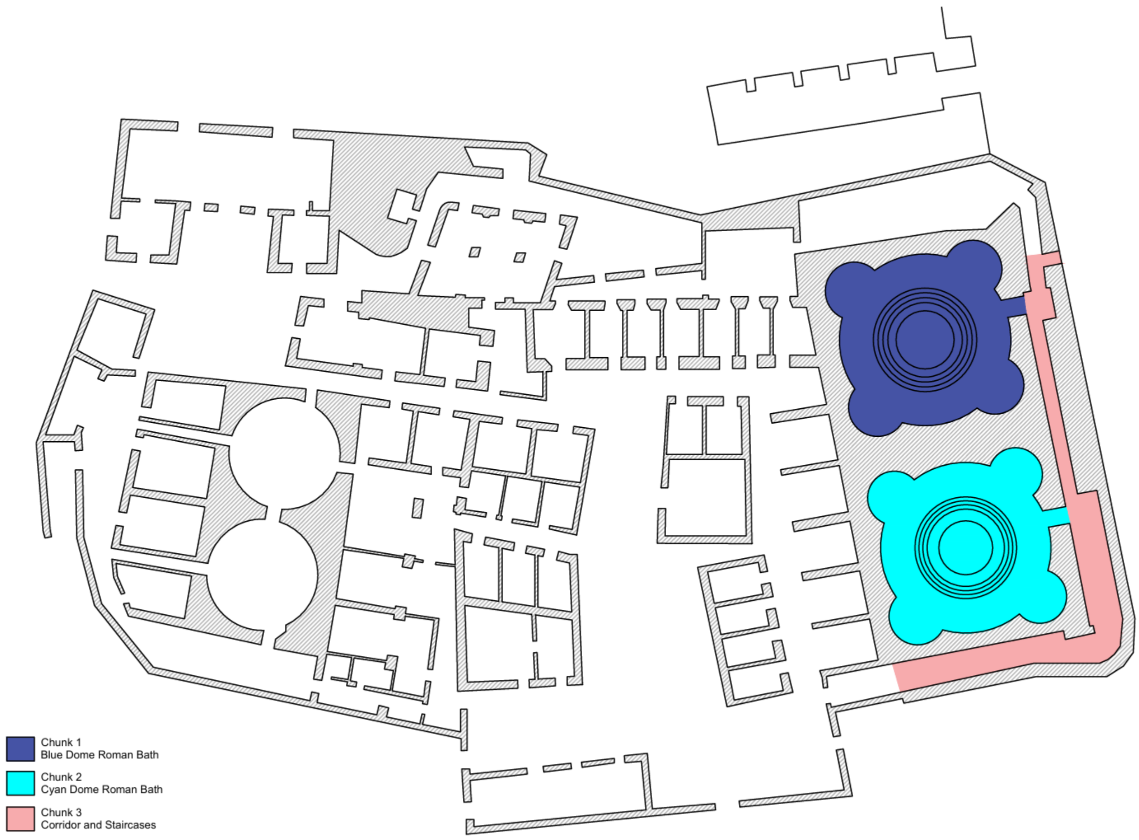

Figure 2. Areas of Action in a Sketch of the Alange Spa. Author's work.

3.3. Instrumentation

The instrumentation used in this project consists of equipment that does not require a large initial budget. The aim is to present photogrammetric techniques as an accessible working method that provides professional and rigorous results with affordable instrumentation.

Most of the field equipment used belongs to the authors of this research, while some were provided for this work by the Department of Graphic Engineering at the University of Seville.

Table 1. Instrumentation Used in Photographic Work

Instrumentation	Models and Features
2 Digital Cameras	-Panasonic DMC-GX80KEGK with 4K Ultra HD quality and 16 MP resolution -Panasonic DMC-GX80K LUMIX G VARIO with 4K quality and 16 MP resolution
2 Photographic Tripods	-Manfrotto Compact Advanced (44 – 165cm) with a three-way head -Cullman Primax 380 (62 – 160cm) with a three-way head and quick-release coupling system
2 White Balance Cards	Calibrated white reference card for light balance and photographic exposure
2 Memory Cards	128 GB SD Cards

Table 2. Instrumentation Used in Topographic Work

Instrumentation	Models and Features
1 Total Station	Leica Flexline TS02 with FIRMWARE v.2.31 software and leveling base
1 Tripod	Leica GST20-9 Heavy Wooden with a maximum height of 180cm
Targets	Circular targets of 12 bits

Table 3. Instrumentation Used in Informatic Work

Instrumentation	Models and Features
1 Computer	OMEN by HP Laptop 15-duplex: -Operating System: Windows 11 Home 64 Bits -Intel Core i7-9750H processor -CPU 2.60GHz (12 CPUs) -BIOS F.19 -DirectX12 -16 GB RAM -NVIDIA GeForce GTX 1650 graphics card
Specific Software for Photogrammetric Data Processing	AGISOFT METASHAPE 2.0.1. PROFESSIONAL EDITION

4. Results

After data collection in the field, a fairly accurate point cloud of the study object is obtained using AGISOFT METASHAPE PROFESSIONAL software. Given the extensive nature of the work, these point clouds are divided into three different sets, as over 2,000 photographs are processed in the software. This divided working mode is referred to as *chunks*.

The photo-alignment process is conducted with maximum precision, using 40,000 key points per frame and 4,000 tie points per photo, resulting in a sparse point cloud of 362,409 points in the blue dome chunk, 228,634 points in the cyan dome chunk, and 514,595 points in the corridors and staircases chunk. These point clouds are then aligned and merged using the topographic work performed, thanks to the itinerary taking the targets as scaling and orientation points for the model. This allows for creating a complete model, generating the mesh using depth maps and an 8K RGB texture map, ultimately resulting in a virtual 3D model of the ensemble.

Regarding the captured images, they are also of great value as a result of the photographic dating of the property. This work, 2,244 photographs are processed, each with a quality of 4592 x 3448 pixels. Additionally, each photograph generates two files, one in JPG format and another in RAW format. The RAW format is particularly useful for photographic editing tasks, as it contains many uncompressed and unprocessed data and details from the digital image.

Figure 3. Dense Cloud in Agisoft Metashape Professional of Blue Dome Bath. Author's work.

Figure 4. Point Cloud in Agisoft Metashape Professional of Cyan Dome Bath. Autor's work.

Figure 5. Point Cloud of Corridor and Stairs. Author's work.

5. Conclusions

This project has had a steady but slow process due to the enormous amount of data that needs processing, the hours, and dedication in the fieldwork since each photograph was taken carefully. However, the significant effort in project data planning greatly sped up the work.

Overall, the time required for surveying such a large ensemble with photogrammetry is a disadvantage compared to other surveying methods, which offer more agility in work time, such as 3D scanning. On the other hand, the photogrammetric technique offers greater economic accessibility; it can be performed with lower-cost instrumentation, providing a professional-quality product if used correctly. It's essential to emphasise the explanations and actions outlined in this article to address the architectural complexities and photogrammetric technique challenges. Having all these factors addressed in this article is crucial to starting a photogrammetric survey project in heritage buildings of similar scale, complexity, and technical challenges.

This is an ambitious project, and even though we've obtained the point cloud, future lines of work are left open to create a complete model of all the Roman baths, indoors and outdoors, and to form a complete 3D virtual model.

Regarding heritage, photogrammetry offers many possibilities for any type of research. Some of its utilities include, for example, gaining a better understanding of its geometric and architectural characteristics, helping to date heritage assets or parts of them, monitoring the state of conservation through the comparison of point clouds and virtual models to detect defects or deterioration in the asset over time; facilitating multidisciplinary and international work teams thanks to the possibility of sharing the 3D model with specialists from different fields via the internet; likewise, the 3D model serves to disseminate our architectural heritage and enhance its value to tourism and society.

Finally, the quality obtained from the work is very satisfactory, despite the disadvantage in working speed. The set objectives are achieved, and we look forward to further developing this well-studied property's survey, archaeological, and research studies.

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