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Marco Giorgio BEVILACQUA, Denise ULIVIERI (Eds.)

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Vol. XV

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Documentation, understanding and enhancement of Cultural Heritage through integrated digital survey: Ínsua fort in Caminha (Portugal)

Rolando Volzone[a], Pietro Becherini[b], Anastasia Cottini[c]

[a] Dinâmia'CET-Iscte, ISCTE-Instituto Universitário de Lisboa, Lisboa, Portugal, CHAIA, Universidade de Évora, Évora, Portugal, rveoo@iscte-iul.pt, [b] Università degli Studi di Firenze, Firenze, Italy, Pietro.becherini@unifi.it, [c] Università degli Studi di Firenze, Firenze, Italy, anastasia.cottini@unifi.it

Abstract

The Ínsua fort is located on a small island, south of the Minho River mouth (north of Portugal, at the border with Spain). The construction of the fort took place in the mid-17th century (during the Portuguese Restoration War) and surrounded the pre-existing convent of Santa Maria da Ínsua, founded in 1392 by the first observant Franciscans. This fort allowed the protection of the entrance via the Minho River, integrating a defensive system formed by a network of small coastal forts and other fortresses already standing along this river. During the first French Invasion (1807), the space was invaded by Spanish troops. Moreover, the Franciscan community was forced to abandon the convent, due to the Portuguese dissolution of religious orders (1834). Ínsua was managed and occupied by the Army until 1970's. However, despite its classification as a National Monument (1910), the abandonment and degradation of the last decades, as well as the lack of alternative reuse, led to the on-going conversion into a tourist accommodation. Scholars, mostly in the historical and architectural fields, have deepened the diachronic evolution of both the convent and the fort. However, there is a lack of studies that analyse the physical evidence through the elaboration of digital documentation. This study seeks to fill in this gap, and it is even more relevant, because it was conducted before the building rehabilitation. The digital documentation of the whole complex was carried out through integrated digital survey methodologies, with TLS and photographic instruments, combining terrestrial and aerial data. First results of the digital survey operation allow the creation of a digital model for further studies on the historical and architectural evolution of the complex. Moreover, different outputs for the visualisation, the preservation and sharing of this historical cultural heritage can be enabled.

Keywords: digital documentation, cultural heritage, Portugal, TLS and SfM photogrammetry.

1. Introduction

This research has been developed within the European Project F-ATLAS, which aims to study the conventual complexes of the Franciscan Observance and their landscape context between Italy, Spain, and Portugal. The Minho River defines the border between Alto Minho (Northern Portugal) and Galicia (Spain). For this reason, it is a strategic point to ensure the defence of both the territories. The Ínsua fort, in Portugal, represents an exceptional case in the context of the Portuguese-Spanish border, as it is built around an observant Franciscan convent on an islet. In this way, a combination between a religious and a military space takes place. The fort and, mostly, the convent of Ínsua have been recently deepened from the historical and architecture point of view (Figueiredo, 2008; Ferreira & Neto, 2019; Becherini et al. 2022). However, a 3D survey for its documentation, understanding and valorisation was still missing.

This research aims to fill-in this gap. From the methodological point of view, after a literature review, the owners of the built structure have been identified and contacted, in order to permit on-site visits, aimed at the 3D digital documentation of the fort and convent. Terrestrial Laser Scanning and both Aerial and Terrestrial Photogrammetry have been useful for the 3D virtual reconstruction of the building.

Specific constraints, due to the location on an uninhabited island, the climatic conditions and the time limitations, led to the definition of a specific workflow for the survey's activities. In this paper, we first analysed the historical framework and the spatial features of the case study. After, we discuss the applied digital methodology for data collection. Finally, results are displayed and discussed.

2. Historical Frameworks

The foundation of Santa Maria da Ínsua convent dates to 1392. A group of Franciscan Observants from Galicia, in Spain, (Rodrigues et al. 2020; Teixeira, 2010), founded an oratory on the site of a pagan temple which was dedicated to Saturn. Historical, social and economic factors led to a continuous expansion of the conventual structure. A fort was built in the mid-17th century, as part of the reformation of the coastal line of defence on the banks of the Minho River (Fig. 1), due to the Restoration War (1640-1668). It was built on the initiative of D. João IV, supervised by D. Diogo de Lima, aiming at the protection of the Minho river mouth and the northern border of the Portuguese territory. Simultaneously, the fort protected the Franciscans friars, living in the convent, from pirates and the convent itself from the bad weather. In 1834, due to the Portuguese dissolution of the religious orders, Franciscans were forced to leave the convent. Since this time, the fort and the convent were managed by the Ministry of War until the last decade of the 19th century, passing to the Navy Ministry. In 1886, a lighthouse was placed on the northwest bastion and, years later, a small lighthouse was installed on the southeast one. Despite the fort and the convent having been classified as a National Monument in 1910, important movable assets have been lost, most of all since the 1940's.

The worsening situation led to the building's complete state of abandonment, still evident in the recent survey. Since 2000, public access to the interior of the fort has been prohibited. Rehabilitation work for the adaptation to the designed Centre for Marine Studies was never accomplished. So, in 2016, the fort and the convent were included in the list of properties to be leased by the Portuguese state to private individuals, through the Revive program, with the aim of its conversion for touristic purposes. The selected project foresees the adaptation of the structure into a lodging establishment (equivalent to a four-star hotel). It is due to start soon. For this reason, the digital documentation is an opportunity to record the physical evidence state before these works.

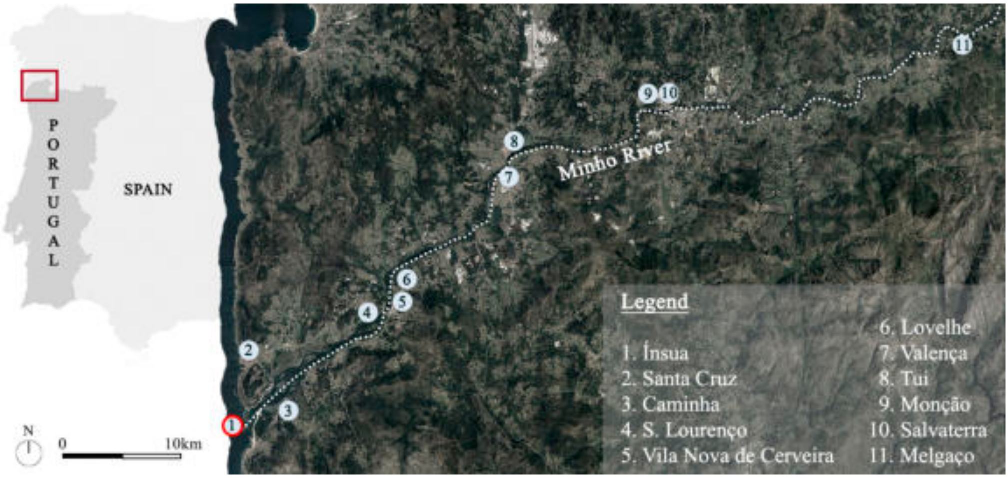

Fig. 1 - Geographical distribution of permanent fortifications along the Minho River, between Melgaço and Caminha (graphic elaboration by Rolando Volzone, 2022)

Fig. 2 - Spatial organisation and defensive system components of the Fort of Ínsua. Military lodging (A), external tenaille (B), western bastion (C), eastern half-bastion (D) (graphic elaboration by Rolando Volzone, 2022)

3. Architectural Description and function/ space organisation

The fort of Ínsua has a non-regular five-pointed shape, with bastions at north-east and north-west corners, and half-bastions at the south-east and south-west corners, with a tenaille among them (Fig. 2).

The reinforced south-facing curtains underline the need for greater protection of this side, at the direct defence of the Portuguese coast. Bastions have a bartizan in the corner, for the guardians, and are interconnected by a patrol path that runs along the inner perimeter. This is accessed by stairs located next to the north-east and north-west bastions and at the middle of the east one. Externally, regular curtains enclose the structure. Moreover, another tenaille, north-east oriented, formed by two curtains external to the structure of the fort, protected the fort by a frontal attack and allowed a counter-attack before returning inside it. All these elements were already visible in the cartography developed by the military engineer Manuel Pinto de Vilalobos (Fig. 3). On this map it is also possible to identify a wall that surrounded the north-eastern bastion and a spring located north of the structure, protecting the passage between the spring and the gate of the fort.

The fort is accessed northeast, through a monumental entrance, topped by three heraldic symbols: the coat of arms of D. João IV, in the middle, flanked by two identical ones of the family Lima. A secondary access is located northwest. The former garrison quarters are leaning against the interior side of the door, on the northwest side. These are formed by five dependencies, accessed by a door, through a few steps. Each one also has a window, and the end ones have chimneys. The governor's barracks and the main guard structure are located northeast, respectively at right and left of the main entrance. An armoury is placed on the southwest interior facade of the fort. In terms of its constructive system, the fort is made of granite masonry, a material extracted directly *in loco*. The built structures, despite the lack of roofs, doors, windows - due, mostly, to its abandonment - are in a moderate state of conservation. The walls have no significant structural damages. However, some areas are more degraded, needing a sustainable conservation project. The 3D survey operations, carried out on this structure, will certainly support its implementation.

4. Data acquisition with integrated digital survey techniques

F-ATLAS project provides accurate digital surveying operations to understand the connection between the conventual complexes and the surrounding landscape. The methodology foresees the integration of aerial and terrestrial instruments such as laser scanners (TLS instruments), drones and reflex cameras (for

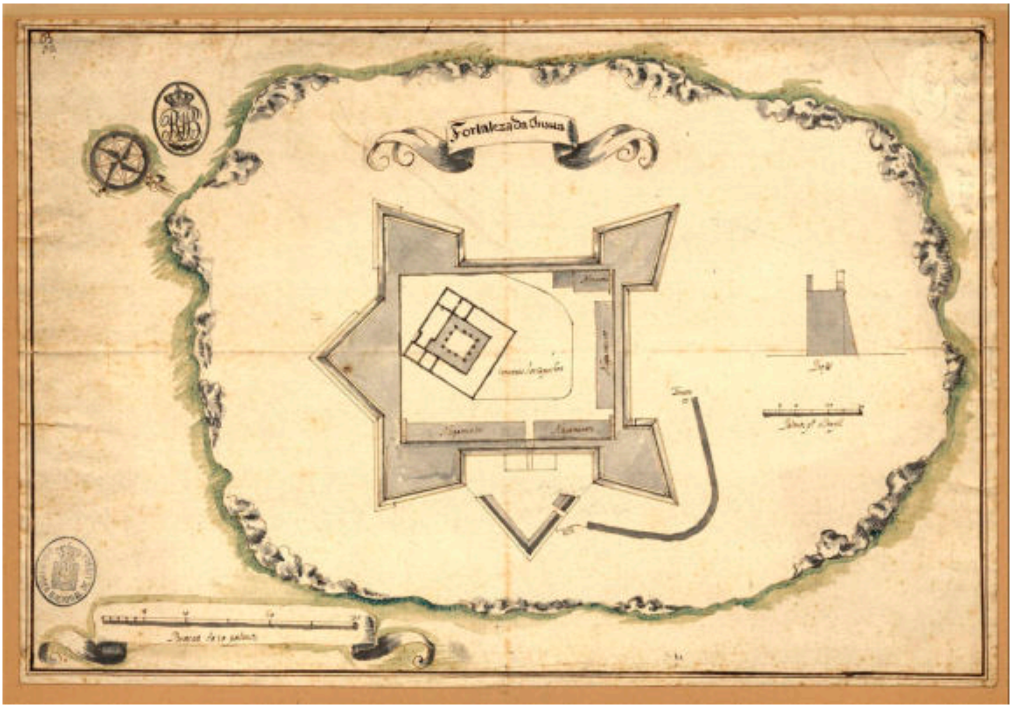

Fig. 3 - Drawing of the Fort of Ínsua by Manuel Pinto de Vilalobos, 1734 (National Library of Portugal, D.246.V)

close-range photogrammetry), obtaining metric and morphological data. These tools make the detection process efficient and accurate and allow the production of a valuable three-dimensional database that can be used and updated over time. In the specific case, this data acquisition is important also because it has been conducted before the foreseen structural adaptation into a tourist accommodation.

Terrestrial laser scanning (TLS) instruments use light detection and ranging (LiDAR) for range measurements and an optical beam deflection mechanism to record angle measurements. They enable dense measurements, capturing in accurate and fast manners, and are sometimes integrated with a digital camera that provides colour information to the measured point cloud. Aerial and terrestrial close-range photogrammetry involves techniques for retrieving 3D information from two-dimensional digital images, allowing the generation of dense point clouds, textured models, and high-resolution orthomosaics from large datasets (Adamopoulos & Rinaudo, 2021). The integration between TLS and SfM (Structure from Motion) photogrammetric surveys is the standard approach for modelling historical structures, benefiting from the complementary characteristics of both datasets and ensuring that density, accuracy, and texture-resolution predefined specifications are met. It is essential to plan the survey operations in the initial phase of the campaign: in this specific case, the time available for carrying out the activities was four days. It was therefore necessary to coordinate the TLS survey with the ground and aerial photographic ones. To do so, it was crucial to consider the adverse and rapidly changing climatic conditions and the fact that access to the island, through a taxi boat service, was only possible at certain times and depending on the tide.

4.1. Data acquisition with TLS (Terrestrial Laser Scanner)

A campaign was carried out with terrestrial laser scanner instrumentation. The instrument used is a FARO Focus M70, a phase-based laser scanner with an integrated camera, a range of approximately 70 metres and an accuracy of 3 millimetres. The 215 laser scanner acquisitions were concentrated in the internal and external

Fig. 4 - Digital survey with TLS. Scan stations (left) and some examples of point cloud data elaboration - cross-sections of the fort and the convent (right) (graphic elaboration by Anastasia Cottini, 2022)

spaces of the convent and the fortress, to obtain a complete and metrically reliable point-cloud of the entire complex. A first acquisition was made around the external perimeter of the fort (approx. 35 scan stations) and a second acquisition along the walkways (approx. 30 scan stations): both follow a closed polygonal line and have common connecting points (Fig. 4).

These two polygons have been linked to the scans acquired in the external spaces surrounding the fortress and in the internal spaces (military lodgings, conventual spaces). Regarding the conventual space, acquisitions in the upper floor were hampered, due to the mostly collapsed pavements. The external ones have RGB colour, acquired with the laser scanner integrated camera, allowing textures displaying. Contrarily, the lighting conditions of the interior spaces did not allow to capture the colour data. The planning of data acquisition campaigns aimed at identifying the elements or surfaces to be covered, defining the optimal number and location for scanning positions and targets. Scanning positions are selected to maximise covered and incidence angles, achieving the required resolution specifications, while decreasing occlusions and, if possible, the number of scans/scanning time. Particular attention was paid along the southwest and northwest perimeter of the fort, as the route was not always accessible due to the rise of the water level at high tide. A rather complete point cloud was acquired, because of the particular conformation of the fort and the convent. The conventual complex is located at a lower altitude than the walkways of the fort walls, enabling the operator to acquire data about the buildings' roofs - when still intact.

4.2. Data acquisition with SfM (Structure from Motion) photogrammetry

Fast remote survey technologies represent an increasingly central issue in the documentation and inspection of historic buildings' state of conservation. Photogrammetry is now a well-established method for 3D recording in building documentation and analysis.

Due to its many advantages, such as its flexibility and low cost, this method has seen a wide appeal in cultural heritage as a recording tool and for virtual reconstructions.

4.2.1. Terrestrial photogrammetry

A camera placed in front of an object cannot capture more than half of its diameter (Bisson-Larriv'ee & LeMoine, 2022). For this reason, a careful planning of the work phases was essential to obtain photographic sequences that guarantee good results in data processing.

Photo sets for Nikon D610 digital cameras with 24-120mm lens were acquired: photographs should not have too sharp shadows and should be taken using appropriate parameters: low ISO, low focal ratio, short exposure time (Mosbrucker et al. 2017).

Since the weather conditions were irregular and rapidly changing, photographic acquisitions from the ground with the aerial ones were carried out when the global illumination was sufficient and widespread.

In this way, it was possible to acquire homogeneous photos, in terms of exposure and colour. The acquisitions from the ground were

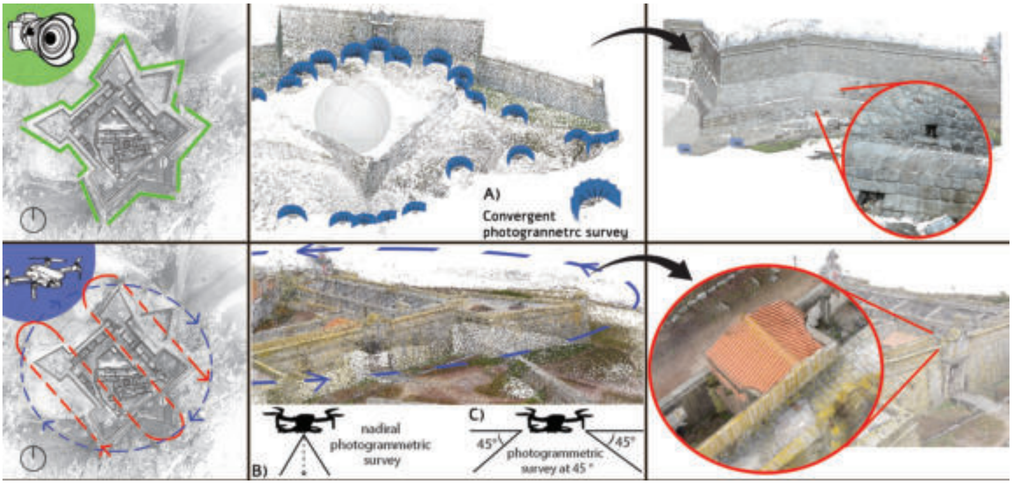

Fig. 5 - Different photogrammetric methods of acquisition. Reflex (A), UAV (B and C). On the right are the details of the point cloud definition (graphic elaboration by Pietro Becherini, 2022)

concentrated along the external perimeter walls and the military lodgings inside the fort, with 800 photos. The aim was to integrate the data collected by the drone (hard-to-reach side covers) to fill any gaps in the acquisition phase (Fig. 5).

During the design phase of the survey campaign, it was evident the difficulty of low-altitude flights with the drone, to avoid accidental collisions with the walls, also due to the presence of strong wind. So, ground photos have been useful for a better data of unreachable areas by drone (Luhmann et al. 2020).

4.2.2. Aerial photogrammetry

Unmanned Aircraft Systems (UAS), commonly known as drones, have become increasingly popular tools for the collection of aerial data. Through monitoring and detection activities, this equipment allows photogrammetric acquisition for increasingly efficient and fast environmental management.

In order to accomplish the objectives and requirements of the mapping project, different planning models can be applied depending, mostly, on the activity and area to be surveyed. In the analysed case, a DJI Mini 2 has been used. This is equipped with a 12 MP camera (24 mm lens), capable of capturing images with different photo modes. Due to the peculiarity of the site and the atmospheric conditions, a manual acquisition was chosen, without pre-set flight plan programs. It was therefore possible to obtain a rigorous definition of the structure by means of the burst of frames every 3/5 seconds. It is equally important to consider the Ground Sampling Distance (GSD). To get a lower, therefore better, GSD and a more accurate map, it is important to fly lower (than the camera's resolution) and take more photos at a higher resolution. This means more time spent on a project due to longer flights and more data to be processed.

In this study, in order to have a better GSD, a maximum height of 20 metres was set with respect to the structure to be analysed, passing from a detail of 3 cm to one of 1 cm; in this way, up to ten times more data were acquired and stored for the same covered area but with much better detail. Within this photogrammetric survey campaign, the evaluation of the weather conditions before each lifting of the instrument was very important. Flight plans were then defined for each type of front to be documented, to avoid any shortcomings in the post-production phase. The acquisitions were made through nadiral and inclined circular trajectory views, depending on the situation.

Shaded areas have been avoided, in order to obtain a homogeneous colour scheme of the structure in all the surfaces. 1100 photographs were taken with planned routes and spiral or ellipsoidal shots, with specific architectural elements in more detail. These georeferenced images were used to define each structural part of the fort in the pre-acquisition phase, so as to cover the entire surface involved in the survey study.

5. Data elaboration and output

The data collected with the laser scanner was processed with Leica Cyclone software. The 215 individual scans of the whole built structure were registered together in a single complete point cloud, with a final error of about 2 cm. The point cloud can be visualised in grayscale, RGB colours or intensity map, depending on the operator's needs and on the survey purpose. Data collected with drone and digital camera were processed with Agisoft Metashape software, obtaining a 3D model of textured mesh. The model was subsequently scaled taking as a reference the point-cloud obtained from laser-scanner, so that they have the same scale and orientation in space. Three well recognisable points are identified on the mesh model, to which are assigned "markers", whose coordinates are modified in order to be equal to those of the three homologous points belonging to the laser-scanner point-cloud (Cioli & Lumini, 2021).

The obtained three-dimensional models, characterised by a high metric-morphological reliability, are a valid support to carry out further analysis on the buildings, combining studies of historical and archival sources (Volzone et al. 2022). Technical drawings, such as plans, elevations and sections, perspective views, axonometric splits, are produced from the 3D models.

These allow study of the represented architectures and provide metric and morphological information, including the materiality and chromatic appearance of the surfaces. This will serve as a support for the analyses concerning the distributive aspects of the architectural complexes, those relating to the decorative apparatus, the state of conservation of the wall surfaces and the evolutionary phases of the buildings.

6. Discussion and Conclusions

The singularity of the convent of Santa Maria da Ínsua, due to its strategic location – an islet in the Minho River at the Spanish border – and to its double function, with the coexistence of a religious building (the convent) and a military one (the fort), makes this complex a unique case study.

The 3D survey operations enabled the creation of digital documentation, both 3D and 2D. Future studies should foresee an exhaustive digital survey or to update the ones already carried out, as in the case of the project CADIVAFOR, aimed at cataloguing, digitisation and enhancement of these structures along the Minho River. This could enable a comparative analysis with other military architecture at local, regional, national and international level, once this territory is bordering with Spanish Galicia. Historical factors, morphological analysis, and construction techniques can be the starting point of this analysis.

In the scope of this research, the concern lies also in the identification of new uses, once the spaces lose their military function. Indeed, these structures are an important part of the historical, cultural and social identity. Moreover, they represent a distinctive element for regional attractiveness and tourism and territorial development. It is therefore crucial to ensure its preservation, enhancement and dissemination, as well as an inclusive and sustainable access to a broader local (or not) community.

Author contributions

Paragraphs 1, 2, and 3 are attributed to Rolando Volzone. Paragraphs 4, 4.1 and 5 are attributed to Anastasia Cottini. Paragraphs 4.2, 4.2, 4.2.1, 4.2.2 and 6 are attributed to Pietro Becherini.

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