A 3D model for architectural analysis, using aerial photogrammetry, for the digital documentation of the convent of Santa Maria da Ínsua,

(Article begins on next page)

Sandro Parrinello
Anna Dell'Amico

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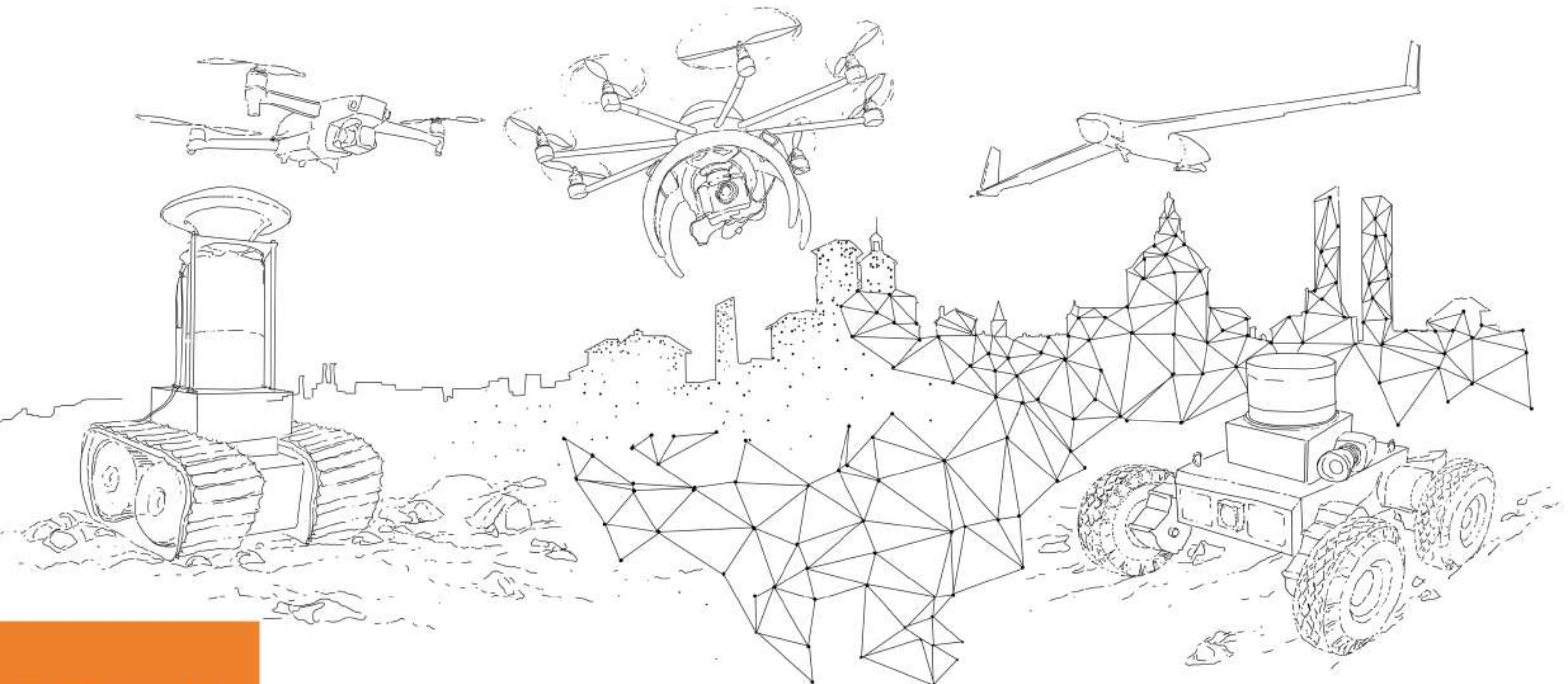
Andrea di Filippo

editors

D-SITE

Drones - Systems of Information on culTural hEritage for a spatial and social investigation

Volume 2



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INDEX

PREFACE

CONFERENCE PAPERS

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UAVs, SfM, Digital documentation, Conventual heritage, Portugal.

ABSTRACT

The convent of Santa Maria da Ínsua, northern of Portugal, was founded in 1392 by the Observant Franciscans. The space has been studied mostly by Historians but an in-depth analysis of its physical evidences is missing. This paper seeks to fill in this gap, in order to contribute to the diffusion of this religious heritage site. This study is even more relevant in this historical moment because it is conducted exactly before the building rehabilitation. Digital photogrammetric surveys through UAVs provide a quick method to obtain a 3D textured mesh model for further studies, online visualization, preservation and sharing.

A 3D model for architectural analysis, using aerial photogrammetry, for the digital documentation of the convent of Santa Maria da Ínsua, on the northern border between Portugal and Spain

1. Introduction

Several scholars, mostly in the historical field, have deepened the diachronic evolution of the Franciscan community settled in the convent of Nossa Senhora da Ínsua (Figueiredo 2008)[1]. However, there is a lack of in-depth studies and documentation of the current physical evidences.

This paper aims to contribute to the knowledge and diffusion of this religious heritage site. This study is even more relevant because it has been conducted exactly before the built structure adaptation into a touristic accommodation. After the literature review, the identification and contact with the buildings' management entities, on-site visits allowed the digital documentation of the whole complex. A photographic and architectural survey of the buildings through SfM techniques, by using data coming mainly from UAVs, has been carried out. Specific constrains, 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 surveys activities. We first analysed the historical framework of the case study. After, we discuss the digital methodology for data collection. Finally, first outputs are displayed and discussed.

2. Historical Frameworks

The convent of Santa Maria da Ínsua was founded in 1392 by a group of Franciscan Observants, coming from the Spanish Galicia (Teixeira 2010; Rodrigues, Fontes and Andrade 2020). It originated by an oratory founded at that time by Frei Diogo Árias (Sousa 2016) on the site of a pagan temple previously dedicated to Saturn (Cepa 1980). Historical, social and economic factors led to a continuous expansion of the conventual structure, so that, in the mid-17th century it was surrounded by a fortress. Franciscans were forced to leave the convent in 1834, due to the Portuguese dissolution of the religious orders. The whole complex was managed by the Ministry of War until the last decade of that century, when it passed to the Navy Ministry. Despite the fortress and the convent have been classified as 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 photographic survey. Since 2000, public access to the interior of the fort has been prohibited. In 2016, the fortress 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 installation of a lodging establishment (equivalent to a four-star hotel). The adaptation work of the built construction is due to start soon. For this reason, the digital documentation is an opportunity to record the physical evidence state before these works.

3. Data collection

Architectural surveying is an evolving field in architecture that has changed significantly over the past decades due to technological advances in the area of 3D data acquisition. Today, several methods and tools are available for data acquisition, namely laser scanning, terrestrial and aerial photogrammetry. These tools make the detection process much more efficient and accurate, when compared with the traditional methodologies and allow the production of a

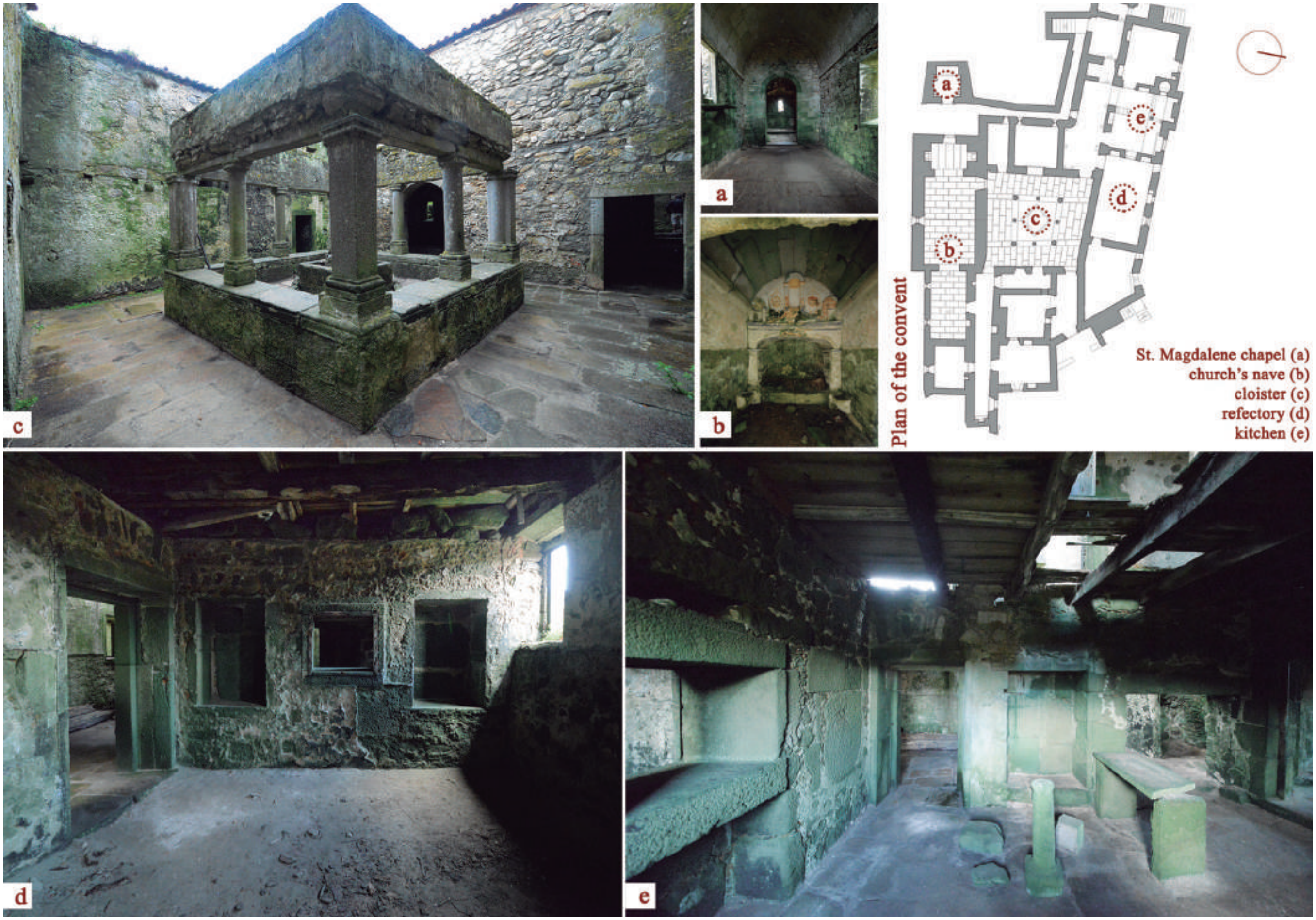

Figure 2. Photographic documentation: Saint Magdalene chapel (a), church's nave (b), cloister (c), refectory (d), kitchen (e). ©Rolando Volzone and Anastasia Cottini, 2021.

valuable three-dimensional database that can be used over time. Digital recording, documentation and preservation are required because our heritage (natural, cultural or mixed) suffers from attrition and ongoing wars, natural disasters, climate change and human neglect.

In particular, the environment and natural heritage received a lot of attention and benefits from recent advances in range sensors and imaging devices. In the last two decades the documentation of Cultural Heritage increased through terrestrial laser scanning techniques (Remondino and Campana 2014). Laser scanning, classified as a non-image-based documentation method, is effective over time as it offers acquisition of up to millions of points per second. However, the weakness of this non-image-based method stands in the low virtualization of edges, colors, and minor surface features, such as cracks, while the combined use of cameras and scanners offers complementary data for a rich and accurate view of objects. Implementing simplified software-hardware solutions that make the challenging task of data collection, data processing and model rendering

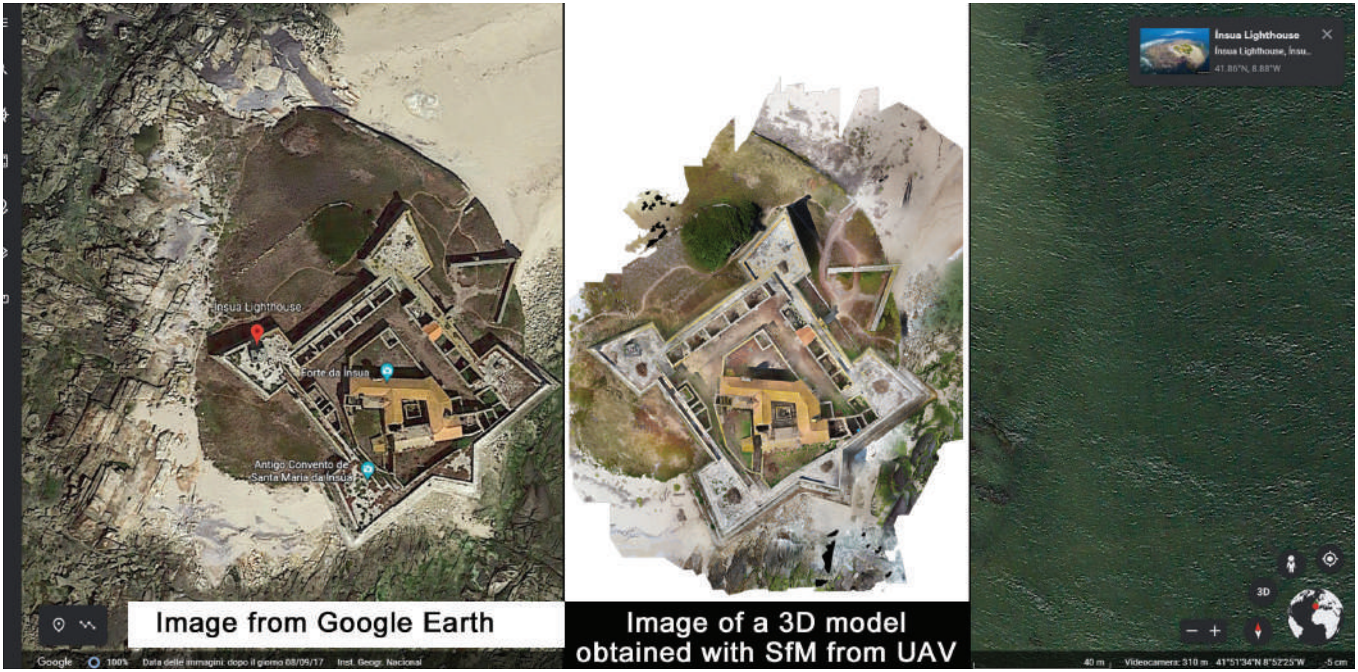

Figure 3. Aerial view of Santa Maria da Ínsua: picture by Google Maps (left), image obtained by processing pictures captured by drone (right). ©Pietro Becherini, 2022.

is a challenge that can be addressed with intelligent, can provide a large amount of accurate 3D data at various scales and resolutions, texture and georeferenced data, metadata and stereo visualization capabilities (Stylianidis and Remondino 2017). The value that the photogrammetric acquisition from drone has given to this work can be seen in the final product obtained, where each portion of the photographed structure is well defined both chromatically and physically thanks to the recording from GPS and the possibility of verification with the point cloud obtained by a laser scanner.

3.1 Historical Frameworks

Flight planning is an important step in completing a successful UAV flight mission and meeting the objectives and requirements of the mapping project. Different flight planning models can be applied depending on the activity and area of interest. For example, the flight plan for pinging the road map and power line is different from the ones required for mapping a ground area or tower.

In our case, a DJI Mini 2 was used which has a 12 MP camera (24mm lens), which can capture images with different photo modes, from single shot, to burst (3 frames), HDR, auto exposure, bracketing2 with different intervals, obtaining images of 4 dimensions: 4/3 - 4000 × 3000, 16/9 - 4000 × 2250. For the type of context, the burst of frames every 3/5 seconds allows to recover a good part of the totality of the photos acquired for this campaign, in the absence of a flight plan. The drone structure weighs less than 250g (dimensions of 245 × 290 × 55mm) and the battery life lasts about 30 minutes with a maximum operating ceiling above sea level of 4000m. Unlike previous models, hovering accuracy with a Vertical: ± 0.1m (with visual positioning), ± 0.5m (with GPS positioning) and Horizontal: ± 0.1m (with visual positioning), ± 1.5 m (with GPS positioning)

Figure 4. View from the Metashape program of the 3D model, the result of processing 1300 aerial photographs.

made it possible to obtain excellent photographs even with the annoying presence of the wind (the considerable presence of wind affected the battery life).
The GSD - Ground sample distance is another important parameter to be considered. In order to get a lower (better) GSD and a more accurate map, it is necessary to fly at a lower height than the camera's resolution and take more photos with higher resolution.
This means more time spent on a project due to longer flights and more data to process. In the case we analyzed, a maximum height of around 20 meters was set with respect to the data to be analyzed, of 1 cm instead of 3 cm; in this way an amount of data up to ten times was acquired and stored for the same covered area but with a much better detail.
Within this photogrammetric survey campaign, the evaluation of the weather conditions before each raising of the instrument was very important, because in addition to greater ease of management of the same, it is possible to make the most of the battery life, which otherwise, for the sole maintenance of the position, could undergo a drastic lowering. Flight plans were then defined for each type of front to be documented, in order not to have any

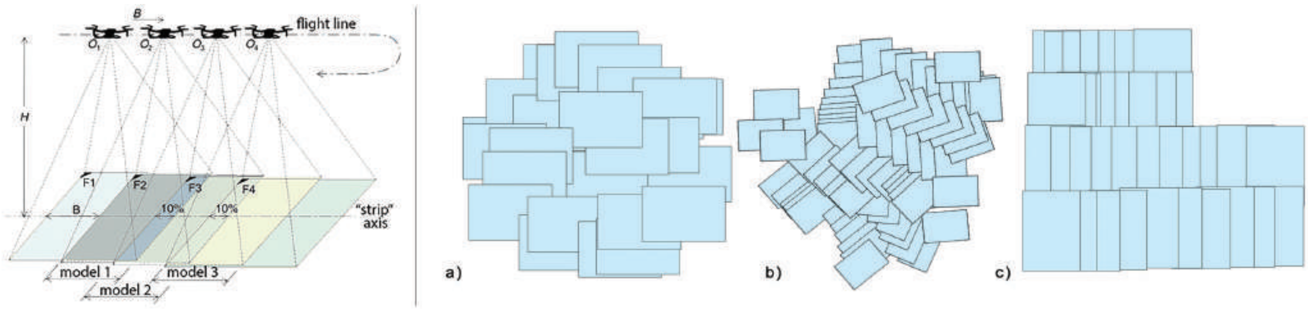

Figure 5. Verification, by entering the coordinates of the object of the aerial photogrammetric survey in the DSPace site, of any flight restrictions using UAV.

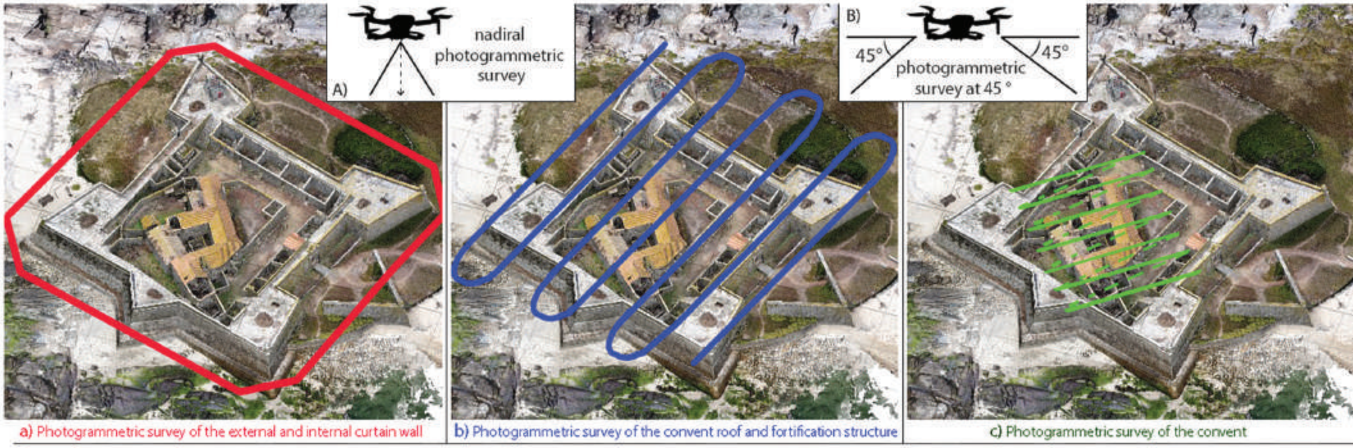

Figure 6. Methodology applied for the acquisition of the territory with a photogrammetric flight organized in rectilinear trajectories (a, b, c) with a nadiral and 45° (A, B) camera during which it is taken a certain number of frames called "streak".

lack in the post-production phase. The timetable was an additional value to be taken into consideration.

Avoiding shaded areas is important to obtain a color scheme of the structure common to all fronts. 1300 photographs were captured with planned routes and spiral or ellipsoidal shots, in order to cover specific architectural elements in more detail.

These geo-referenced images were used to define each quadrant of the grid created in the pre-acquisition phase, in order to cover the entire surface involved in the survey study.

3.2 Terrestrial Photogrammetry

In parallel with photogrammetric drone acquisitions, Nikon D610 digital camera photo sets with 24-120 mm lens were captured. A careful planning of work steps has been crucial to obtain photographic sequences that guarantee good results in data processing. The photographs must not have too sharp shadows and must be taken using appropriate parameters: low ISO, low focal ratio, short exposure time (Mosbrucker et al. 2017). Since the weather conditions were erratic and rapidly changing, we tried as much as possible to coordinate the photographic acquisitions from

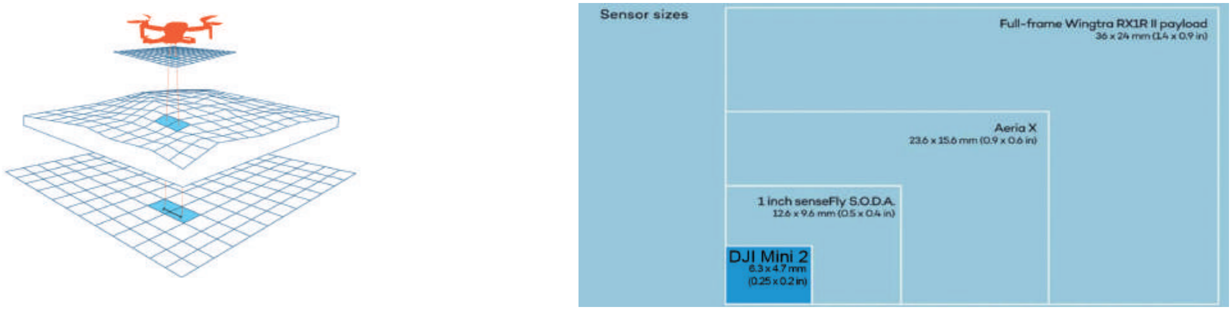

Figure 7. GSD is the amount of ground captured by the distance between the central point of two adjacent pixels. On the right, the size of a payload's sensor influences the quality of the pictures, especially those taken at lower altitude and at high speed. By comparing the real resolution of images with the same GSD, it is evident that a high-quality payload improves the final result.

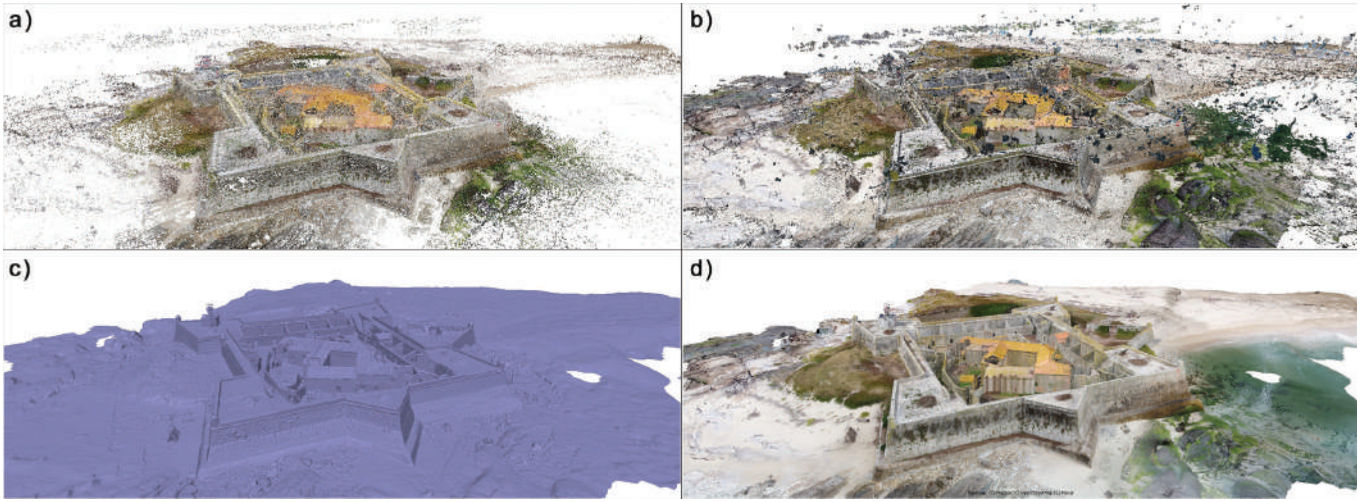

Figure 8. Modeling steps from aerial photographs processed in Agisoft Metashape. a) sparse cloud, b) dense cloud c) mesh, d) tex-tured model.

the ground with those aerials, in the hours of the day when the global lighting was sufficient and widespread. In this way, it was possible to acquire photographs that have similar characteristics in terms of exposure and color. The photographic acquisitions from the ground were concentrated inside the cloister of the convent, along the outer perimeter walls and inside the military accommodation along the perimeter of the fortress. The purpose was to integrate the data collected by drone to fill any gaps in acquisition. In the planning phase of the survey campaign the impossibility of flying with the drone at low altitudes was highlighted in order to avoid accidental collisions against the walls, also considering the presence of strong wind. The photographs from the ground are therefore particularly useful to obtain a greater definition of the areas that, from the point of view of the drone, are not very visible or hidden (Luhmann et al. 2020).

3.3 Laser-scanner survey

In addition to the photogrammetric survey, a campaign was carried out with laser-scanner instrumentation. The instrument used is a FARO Focus M70, a laser-scanner phase-based with integrated camera. The 215 laser acquisitions were concentrated in the internal and external spaces of the convent and the fortress, to obtain a metrically reliable data of the entire complex. The particular conformation of the buildings of the convent has allowed to acquire a rather complete point cloud, including the roofs of the buildings (when still intact) and the surrounding environmental context[2]. The conventual complex is located at a lower altitude than the walkways of the fortress walls, allowing the operator to position the laser-scanner instrument in order to easily acquire a data that has few gaps. The integrated camera of the instrument, moreover, has allowed to associate to the point-cloud a realistic color, which allows to appreciate the colors and textures of the walls.

4 Data elaboration and outputs

The data collected with the laser scanner were processed with Leica Cyclone software, to register together individual scans and obtain a complete point cloud, managed in a database and upgradable over time. The 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

Figure 9. a) Perspective view of the point cloud of the fortress entrance, obtained from the SfM processing of 256 photos taken with a digital camera. On the right 3D, model obtained from 108 aerial photos (b – dense cloud, c – model 3D textured).

from laser-scanner, following operational methodologies already consolidated within the research team (Cioli, Lumini 2021). Mesh models are referenced based on the laser-scanner point-cloud, so that they have the same scale and orientation in space. Several 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. Mesh models are then combined into a single overall model.

The obtained three-dimensional elaborates, characterized by a high metric-morphological reliability, allow to carry out further analysis on the architectures, also with the support of the study of historical and archival sources. From the three-dimensional models, technical drawings, such as plants, elevations and sections, perspective views, axonometric splits, can be produced. These allow to study the represented architectures and provide metric and morphological information, including the materiality and chromatic appearance of the surfaces. This constitutes a valid support, for example, 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. 3D models also offer different opportunities in terms of materials supporting accessibility. They can be processed in such a way that they are navigable, exploiting the applications of immersive reality both for touristic purposes and enhancement of the Cultural Heritage (Argyriou, et al. 2020, Häkkilä, et al. 2019) and educational purposes (Bekele, Champion 2019). They can also be 3D printed and used by visually impaired people (Volzone, et al. 2021).

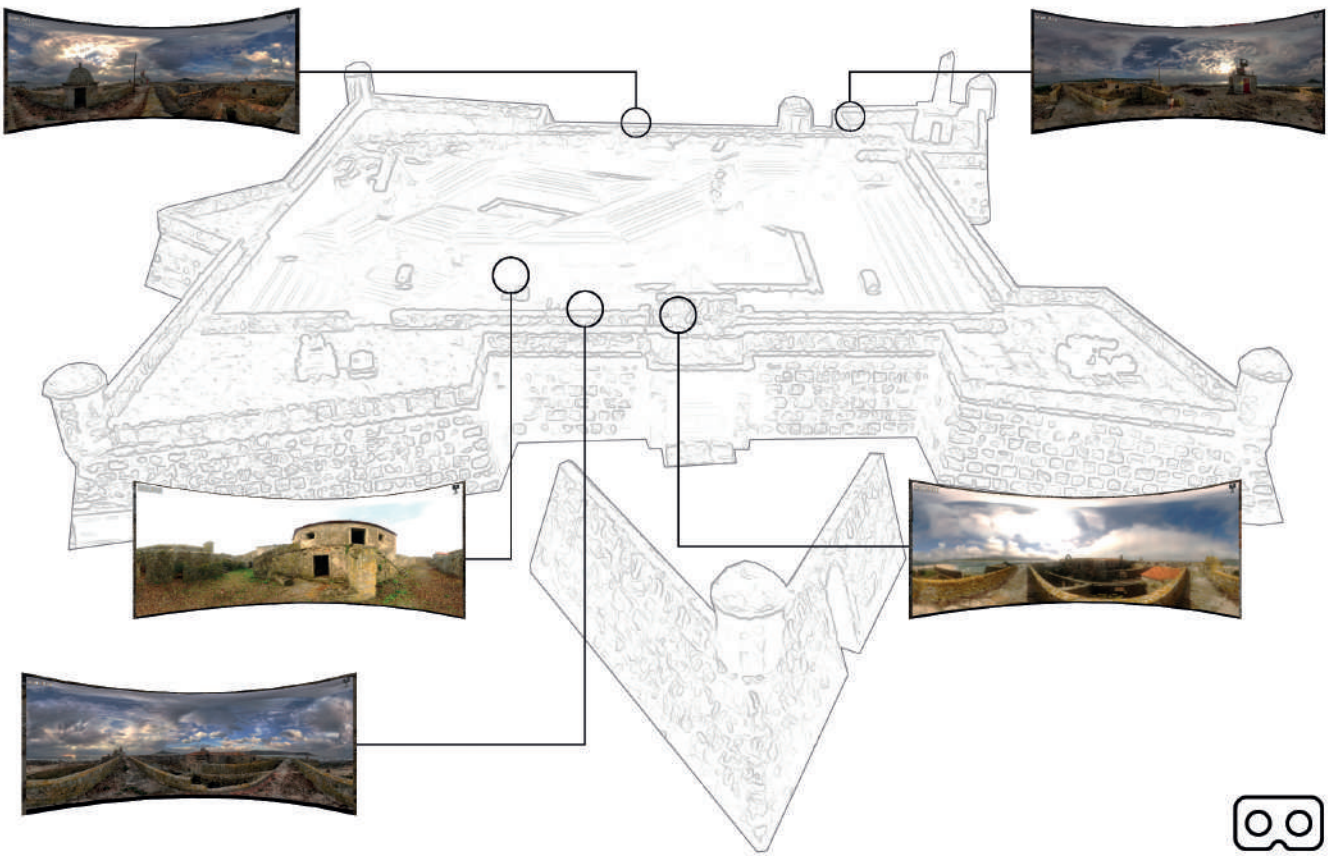

Figure 10. Virtual tour of the external and internal spaces of the conventual complex and fortress.

5. Discussion and conclusion

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 fortress), makes this complex a unique case study. This is being delved deeper within the European project F-ATLAS, and integrates a cluster of convents founded in the same region (Alto Minho) and with origin in the same year (1392). The 3D survey operations enabled the creation of a digital documentation including 3D and 2D documentation. Future studies should focus on a typological comparison among these case studies, and with the others that are examined in Spain and Italy, belonging to the Franciscan Observance. Finally, once the survey campaign has been carried out exactly before the adaptation works of the space into a tourist accommodation, strategies of heritage communications will allow a universal and digital access to the conventual complex by local (or not) communities, even after its privatisation.

Notes

1 In the last years, Master's degree students have carried theses focusing on the valorization of the convent. See: Neto, J. L. G. S. 2019. "[Re]thinking the Fort of Ínsua. The meeting between the Sea, History and Belief". MSc thesis in Architecture. Coimbra: Faculdade de Ciências e Tecnologia da Universidade de Coimbra; Lima, S. M. M. N. 2015. "Intervenções de conservação e restauro do património edificado: o Forte da Ínsua". MSc thesis in Architecture and Urbanism. Porto: Universidade Fernando Pessoa; Loução, C. S. C. P. 2021. "O património conventual do concelho de Caminha e o seu percurso após a extinção das ordens religiosas, em 1834". MSc thesis in Heritage Studies. Universidade Aberta. In addition, results of a study carried out by students of University of Porto, have been presented in a book. See: Ferreira, Teresa Cunha, and Neto, Rui. 2019. Património na Paisagem. Santa Maria da Ínsua/ Heritage on the Landscape. Santa Maria da Ínsua. Guimarães, Portugal: EAUM/Lab 2PT/IPVC.

2 The laser-scanner instrument, having a range of about 70m, has produced a figure in which the rocks and the sandy beach surrounding the fortress walls are clearly visible. On the contrary, the surface of the water is not legible, since the laser is not able to correctly acquire the data of the reflective surfaces (https://shop.leica-geosystems.com/ca/it-IT/leica-blk/blog/video/scanning-dark-or-reflective-surfaces).

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The use of UAVs is increasingly widespread in activities related to Heritage documentation. In recent years the development of methodologies of data integration, obtained through surveys that exploits drones to reach privileged observation points, has been witnessed by the numerous computation platforms, software and tools, that populate the exchange.
The definition of increasingly reliable methodologies and procedures of close-range photogrammetry has produced considerable results in the survey of Architectural Heritage.
Nowadays, several Universities and Research Centres, together with enterprises, are working to optimize documentation services whose goal is, in any case, the representativeness of technical data aimed at the project development. Parallel to aerial documentation, even the applications of remote-controlled terrestrial drone systems is renewing the inspection and survey practices in architecture and on territory, overtaking barriers and access dimensions to sites and emergency contexts otherwise impractical for human operators.
Surface rovers and submarine robotics, equipped with controlled cameras and implemented survey devices, in terms of stability and compartment, contribute to complete an extremely scientific and innovative field, where the central theme of robotics applied to Cultural Heritage documentation is expanded and consolidated in correspondence to the international categories of UAS (Unmanned Aerial Systems), USV (Unmanned Surface Vehicles) and UUV (Unmanned Underwater Vehicles). Drones, in the wider terms of their definition, are now used for documentation, management, protection, maintenance, and monitoring, integrating imaging systems and measuring instruments that contribute to define three-dimensional databases on Cultural Heritage. This conference is promoted with the aim of collecting recent experiences on that topic and of providing a moment of reflection between academic and enterprise realities for the promotion of updated frameworks for the development of research in the architectural survey field.

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