



UNIVERSITÀ
DEGLI STUDI
FIRENZE

FLORE

Repository istituzionale dell'Università degli Studi di Firenze

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

Questa è la Versione finale referata (Post print/Accepted manuscript) della seguente pubblicazione:

Original Citation:

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 / ANASTASIA COTTINI, PIETRO BECHERINI, ROLANDO VOLZONE. - STAMPA. - (2022), pp. 94-103. (Intervento presentato al convegno D-SITE - Drones. System of Information on cultural hEritage for a spatial and social investigation tenutosi a Pavia nel 16-18 Giugno 2022).

Availability:

This version is available at: 2158/1301155 since: 2023-03-13T13:22:52Z

Publisher:

Pavia University Press

Terms of use:

Open Access

La pubblicazione è resa disponibile sotto le norme e i termini della licenza di deposito, secondo quanto stabilito dalla Policy per l'accesso aperto dell'Università degli Studi di Firenze (<https://www.sba.unifi.it/upload/policy-oa-2016-1.pdf>)

Publisher copyright claim:

(Article begins on next page)

Sandro Parrinello
Anna Dell'Amico

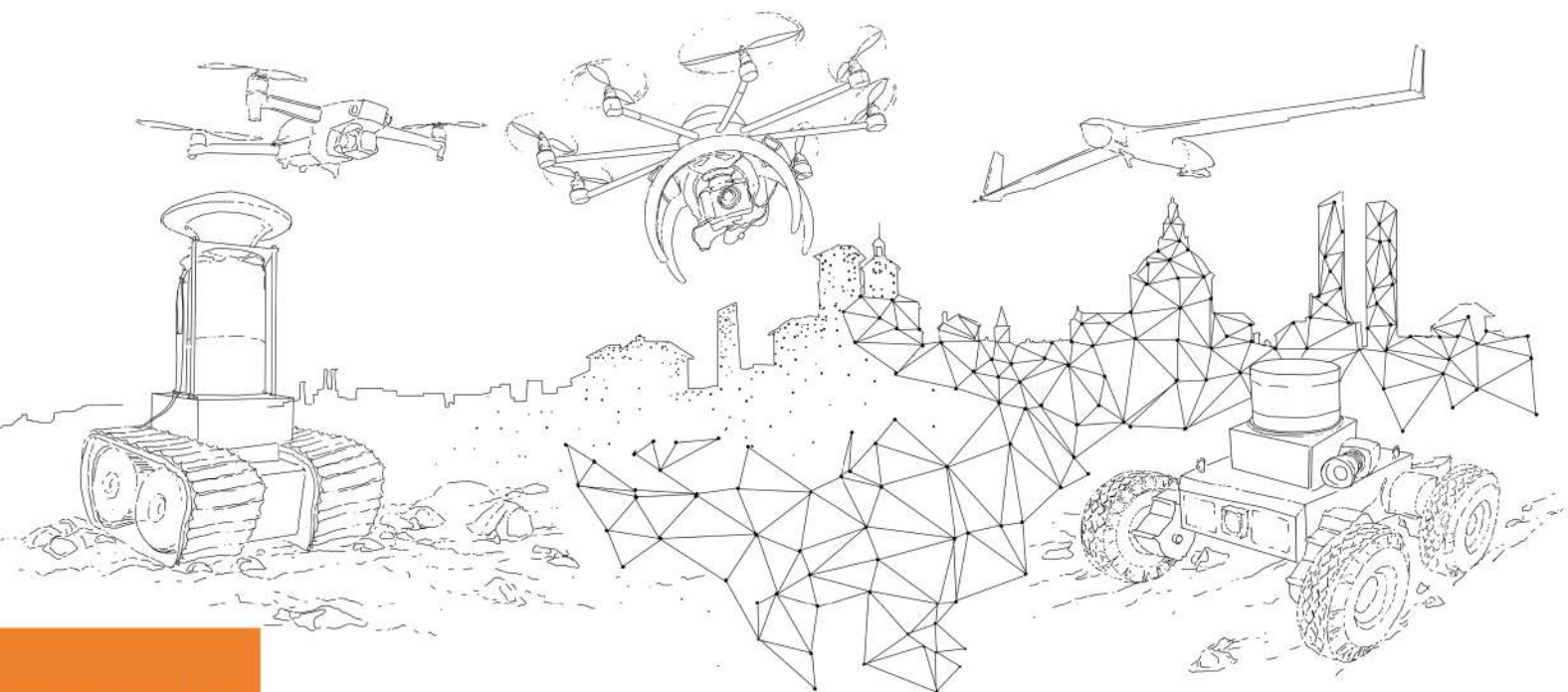
Salvatore Barba
Andrea di Filippo

editors

D-SITE

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

Volume 2



PROSPETTIVE MULTIPLE
STUDI DI INGEGNERIA
ARCHITETTURA E ARTE

Sandro Parrinello
Anna Dell'Amico

Salvatore Barba
Andrea di Filippo

editors

D-SITE

Drones - Systems of Information on Cultural Heritage
for a spatial and social investigation



D-SITE, Drones - Systems of Information on Cultural Heritage for a spatial and social investigation / Sandro Parrinello, Salvatore Barba, Anna Dell'Amico, Andrea di Filippo (edited by) - Pavia: Pavia University Press, 2022. - 684 p.: ill.; 21 cm.

(Prospettive multiple: studi di ingegneria, architettura e arte)

ISBN 978-88-6952-159-1
ebook 978-88-6952-160-7

The present publication is part of the series "Prospettive multiple: studi di ingegneria, architettura e arte", which has an international referee panel. "D-SITE, Drones - Systems of Information on Cultural Heritage for a spatial and social investigation" is a scientific text evaluated and approved by double blind peer review by the Scientific Editorial Board.

Translation of chapters and treatment of citations and bibliography are due to the respective authors.



Pavia University Press
Edizioni dell'Università degli Studi di Pavia
info@paviauniversitypress.it
www.paviauniversitypress.it

Copyright © 2022 EGEA S.p.A.
Via Salasco, 5 - 20136 Milano
Tel. 02/5836.5751 - Fax 02/5836.5753
egea.edizioni@unibocconi.it
www.egeaeditore.it

Editors
Sandro Parrinello, Salvatore Barba, Anna Dell'Amico,
Andrea di Filippo

Graphic project
Anna Dell'Amico, Francesca Picchio, Anna Sanseverino

On cover: Drawing by Francesca Picchio and Sandro Parrinello
First edition: june 2022.

Stampa: Logo S.r.l. – Borgoricco (PD)

The rights of translation, electronic storage, reproduction and even partial adaptation, by any means, are reserved for all countries.

The photocopies for personal use of the reader can not exceed 15% of each book and with payment to SIAE of the compensation provided in art. 68, c. 4, of the Law 22 of April of 1941, n. 633 and by agreement of December 18, between SIAE, AIE, SNS and CNA, ConfArtigianato, CASA, CLAAI, ConfComercio, ConfEsercenti. Reproductions for other purposes than those mentioned above may only be made with the express authorization of those who have copyright to the Publisher.

The volume consists of a collection of contributions from the conference "D-SITE, Drones - Systems of Information on Cultural Heritage for a spatial and social investigation". The event, is organized by the experimental laboratory of research and didactics DAda-LAB of DICAr - Department of Civil Engineering and Architecture of University of Pavia, and MODLab of DICIV - Department of Civil Engineering of University of Salerno. The publication co-funded by the the University of Pavia, the University of Salerno, and the Italian Ministry of Foreign Affairs and International Cooperation.

D-SITE CONFERENCE IS ORGANIZED BY:



University of Pavia



DICAr - Department of Civil Engineering and Architecture
University of Pavia



Univeristy of Salerno



DICIV - Department of Civil Engineering
Univeristy of Salerno



DAda LAB - Drawing and Architecture DocumentAction
University of Pavia



PLAY - Photography and 3D Laser for virtual Architecture laboratorY
University of Pavia



LS3D -Joint Laboratory Landscape, Survey & Design
University of Pavia



Laboratorio Modelli - Surveying and Geo-Mapping for Environment and Cultural Heritage
University of Salerno

WITH THE PATRONAGE OF:



Italian Ministry of Foreign Affairs and International Cooperation



UID
Unione Italiana Disegno



APEGA
Scientific Society
Expresión Gráfica Aplicada a la Edificación



SIFET
Società Italiana di Fotogrammetria E Topografia



AIT
Associazione Italiana di Telerilevamento



INGENIA DRON

IN COLLABORATION WITH:



Remote Sensing Laboratory of
the Department of Earth and
Environmental Sciences
University of Pavia



Department of Information
Engineering
University of Pisa



Department of Agricultural,
Food, Environmental and
Forestry Sciences
University of Florence



Institute for
Electromagnetic Sensing
of the Environment
CNR



Museum of Electrical
Technology
University of Pavia



Italian Ministry of Defence
Air Force



Italian National
Council of Engineers



Italian National Council of
Landscape Architects and
Conservators



Order of Engineers
Province of Pavia



Order of Landscape
Architects and Conservators
Province of Pavia

ENTERPRISE SPONSORS:



MEDIA PARTNERS:



ORGANIZER COMMITTEES

Sandro Parrinello
Marco Limongiello

University of Pavia - Italy
University of Salerno - Italy

SCIENTIFIC COMMITTEES

Marcello Balzani
Salvatore Barba
José Antonio Barrera Vera
Stefano Bertocci
Carlo Bianchini
Mirco Boschetti
Enrico Borgogno Mondino
Stefano Campana
Massimiliano Campi
Gabriella Caroti
Filiberto Chiabrando
Gherardo Chirici
Antonio Conte
Krzysztof Cyran
Francesco Fassi
Francesca Fatta
Juan José Fernández Martín
Margherita Fiani
Andreas Fritz
Diego González-Aguilera
Armin Gruen
Pierre Grussenmeyer
Sorin Hermon
Xianfeng Huang
Marinos Ioannides
Falko Kuester
Francesco Mancini
Niccolò Menegoni
Luis M. Palmero Iglesias
Francesca Picchio
Lorenzo Pollini
Fabio Remondino
Fulvio Rinaudo
Mario Santana Quintero
Tesse D. Stek
Lina Tang
Dieter Tengen
Fabio Giulio Tonolo
Kyriacos Themistocleous
Rebeka Vital
Francesco Zucca

University of Ferrara - Italy
University of Salerno - Italy
University of Seville - Spain
University of Florence - Italy
La Sapienza, University of Rome - Italy
IREA, CNR - Italy
University of Turin - Italy
University of Siena - Italy
University of Naples Federico II - Italy
University of Pisa - Italy
Polytechnic of Turin - Italy
University of Florence - Italy
University of Basilicata - Italy
Silesian University of Technology - Poland
Polytechnic of Milan - Italy
University of Reggio Calabria - Italy
University of Valladolid - Spain
University of Salerno - Italy
University of Freiburg - Germany
University of Salamanca - Spain
ETH Zurich Faculty of Architecture - Swiss
Institut National des Sciences Appliquées - France
The Cyprus Institute - Cyprus
Wuhan University - Hubei China
Cyprus University of Technology - Cyprus
University of California - USA
University of Modena and Reggio Emilia - Italy
University of Pavia - Italy
Polytechnic of València - Spain
University of Pavia - Italy
University of Pisa - Italy
Bruno Kessler Foundation - Italy
Polytechnic of Turin - Italy
Carlton University - Canada
Leiden University - Netherlands
Chinese Academy of Sciences - Cina
Technical University Braunschweig - Germany
Polytechnic University of Turin - Italy
Cyprus University of Technology - Cyprus
Shenkar College of Engineering and Design - Israel
University of Pavia - Italy

SCIENTIFIC SECRETARIAT

Anna Dell'Amico (University of Pavia), Andrea di Filippo (University of Salerno), Silvia La Placa (University of Pavia)

INDEX

PREFACE

SANDRO PARRINELLO, ANNA DELL'AMICO

Drones and Digital Innovation: a new scenario in Digital Dimension

16

CONFERENCE PAPERS

CATERINA PALESTINI, ALESSANDRO BASSO, MAURIZIO PERTICARINI

3D modeling from UAV for the reconfiguration of oxidation systems in Abruzzo.

28

The case of the tower of Forca di Penne, an immersive archival resource for the lost Historical Heritage

RAMONA QUATTRINI, RENATO ANGELONI, BENEDETTA DI LEO

Data integration and optimization for Cultural Heritage fruition. The case study of the Rail to Land Project

38

ANDREA PIRINU, RAFFAELE ARGOLAS, NICOLA PABA

Design models and landscape form of Sardinian IIWW Heritage. The Simbirizzi Lake in territory of Quartu Sant'Elena

48

MARCO SACCUCCI, VIRGINIA MIELE, ASSUNTA PELLICCIO

UAVs for the analysis of geometrical deformation of fortresses and castles. The case study of Sora Castle

58

RITA VALENTI, EMANUELA PATERNÒ, GRAZIELLA CUSMANO

UAS applications for the protection of archaeological heritage. From the interpretative complexity of the absence to 3D visualization of euryalus castle

66

GIOVANNI PANCANI, MATTEO BIGONGIARI

The aerial photogrammetric survey for the documentation of the Cultural Heritage:
the Verruca fortress on the Pisan Mountains

76

ELENA MADALINA CANTEA, ANNA DELL'AMICO	
Application of fast survey technologies for knowledge, valorization and conservation: the case study of Rondella delle Boccare	84
PIETRO BECHERINI, ROLANDO VOLZONE, ANASTASIA COTTINI	94
A 3D model for architectural analysis, using aerial photogrammetry, for the digital documentation of the convent of Santa Maria da Insua, on the northern boarder between Portugal and Spain	
ALBERTO PETTINEO	
Videogrammetry for the virtual philological reconstruction of the Scaliger fortifications in the territory of Verona. The case study of Montorio Castle	104
GIULIA PORCHEDDU, FRANCESCA PICCHIO	
Close-Range photogrammetry for the production of models and 3D GIS platform useful for the documentation of archaeological rescue excavations	112
FABRIZIO AGNELLO, MIRCO CANNELLA	
Multi sensor photogrammetric techniques for the documentation of the ruins of Temple G in Selinunte	122
GIANLUCA FENILI, GIORGIO GHELFI	
Conservation and enhancement of Cultural Heritage using UAVs. New perspectives for the preservation of some case studies	130
CATERINA GRASSI, DIEGO RONCHI, DANIELE FERDANI, GIORGIO FRANCO POCOBELLI, RACHELE MANGANELLI DEL FA'	
A 3D survey in archaeology. Comparison among software for image and range-based data integration	138
GIORGIA POTESTÀ, VINCENZO GELSOMINO	
Experience of integrated survey by drone for archaeological sites. Documentation, study, and enhancement of the Italic Sanctuary of Pietrabbondante	146
CÈLIA MALLAFRÈ-BALSELLS, DAVID MORENO-GARCIA, JORDI CANELA-RION	
Photogrammetric comparison between different drone survey methodologies: dry stone as a case study	156
DIEGO MARTÍN DE TORRES, JULIÁN DE LA FUENTE PRIETO, ENRIQUE CASTAÑO PEREA	
Scars in the landscape: photogrammetry and analysis of the trenches of the Spanish Civil War	168
SALVATORE BARBA, ALESSANDRO DI BENEDETTO, MARGHERITA FIANI, LUCAS GUJSK, MARCO LIMONGIELLO	
Automatic point cloud editing from UAV aerial images: applications in archaeology and Cultural Heritage	176
CORRADO CASTAGNARO, DOMENICO CRISPINO	
Drone flight as a knowledge tool for Cultural Heritage	184
ELENA GÓMEZ BERNAL, PABLO ALEJANDRO CRUZ FRANCO, ADELA RUEDA MÁRQUEZ DE LA PLATA	
Drones in architecture research: methodological application of the use of drones for the accessible intervention in a roman house in the Alcazaba of Mérida (Spain)	192

LORENZO TEPPATI LOSÈ, FILIBERTO CHIABRANDO, ELEONORA PELLEGRINO UAS photogrammetry and SLAM for the HBIM model of the Montanaro Belltower	202
FABIANA GUERRIERO Methodologies for the protection of the Portuguese architectural heritage	212
CARLO COSTANTINO, ANNA CHIARA BENEDETTI, GIORGIA PREDARI UAV photogrammetric survey as a fast and low-cost tool to foster the conservation of small villages. The case study of San Giovanni Lipioni	220
LUCA VESPASIANO, LUCA CETRA, STEFANO BRUSAPORCI Experience of Indoor Droning for Cultural Heritage Documentation	232
RICCARDO FLORIO, RAFFAELE CATUOGNO, TERESA DELLA CORTE, VICTORIA COTELLA, MARCO APREA Multi-source data framework: integrated survey for 3D texture mapping on archaeological sites	240
VALERIA CERA, MASSIMILIANO CAMPI Evaluation of unconventional sensors for the photogrammetric survey of underwater historical sites	250
DJORDJE DJORDJEVIC, MIRJANA DEVETAKOVIC, DJORDJE MITROVIC Regulatory and controlling mechanisms on UAV/UAS that influence efficient architectural heritage praxis: actual situation in Serbia	260
ANTONIO CONTE, ANTONIO BIXIO Privileged documentary observations of surveying of "fragile heritage" in emergency conditions: the case studies of Pomarico landslide and of Montescaglioso abbey	270
MARCO CANCELI, MARCO D'ANGELICO A methodology for survey, documentation and virtual reconstruction of historical centers in a seismic area: the case study of Arquata del Tronto	280
RAISSA GAROZZO, DAVIDE CALIÒ, MARIATERESA GALIZIA, GIOVANNA PAPPALARDO, CETTINA SANTAGATI Integration of remote surveying methodologies for geological risk assessment of masonry arch bridges	294
FAUSTA FIORILLO, LUCA PERFETTI, GIULIANA CARDANI Aerial-photogrammetric survey for supervised classification and mapping of roof damages	304
RAFFAELLA DE MARCO, ELISABETTA DORIA The processing of UAV 3D models for the recognition of coverages at the technological scale: opportunities for a strategy of conservation monitoring	314
QIUYAN ZHU, SHANSHAN SONG, LINGYUN LIAO, MARIANNA CALIA, XIN WU UAV survey for documentation and conservation of Han City in the UNESCO mixed heritage site of Mount Wuyi, China	324

ZHUOWEI LIN, MARIANNA CALIA, LINGYUN LIAO, XIN WU	
Digital survey of the Cliff-Burial sites with consumer-level UAV photogrammetry: a case study of Mt. Wuyi	334
ANNA SANSEVERINO, CATERINA GABRIELLA GUIDA, CARLA FERREYRA, VICTORIA FERRARIS	
Image-based georeferenced urban context reconstruction in a BIM environment: the case of the Crotone Fortress	344
ANDREA ARRIGHETTI, ALFONSO FORGIONE, ANDREA LUMINI	
The Church of San Silvestro in L'Aquila. An integrated approach through TLS and UAV technologies for the architectural and archaeological documentation	356
SILVIA LA PLACA, FRANCESCA PICCHIO	
Fast survey technologies for the documentation of canalization systems. The case study of the settlement "Il Cassinino" in the Naviglio Pavese surrounding	366
TOMMASO EMPLER, ADRIANA CALDARONE, MARIA LAURA ROSSI	
Fast assessment survey for protected architectural and environmental site	376
MASSIMO LESERRI, GABRIELE ROSSI	
Salento baroque spires survey. Integrating TLS and UAV photogrammetry	386
SARA ANTINOZZI, ANDREA DI FILIPPO, ANGELO LORUSSO, MARCO LIMONGIELLO	
Toward a virtual library experience based on UAV and TLS survey data	396
GENNARO PIO LENTO	
UAS applications for the survey of monumental architecture. The case study of the Royal Residence of Aranjuez in Spain	404
ORNELLA ZERLENGA, GIANFRANCO DE MATTEIS, SERGIO SIBILIO, GIOVANNI CIAMPI, VINCENZO CIRILLO, ET AL.	
Open source procedure for UAV-based photogrammetry and infrared thermography in the survey of masonry bell towers	412
TOMÁS ENRIQUE MARTÍNEZ CHAO, GIUSEPPE ANTUONO, PEDRO GABRIEL VINDROLA, PIERPAOLO D'AGOSTINO	
Image-based segmentation and modelling of terraced landscapes	422
ALESSIO CARDACI, PIETRO AZZOLA, ANTONELLA VERSACI	
The Astino Valley in Bergamo: multispectral aerial photogrammetry for the survey and conservation of the cultural landscape and biodiversity	432

RAFFAELA FIORILLO, ANGELO DE CICCO	
The Port of Fiskardo: architecture, history and innovation	442
GUIYE LIN, PABLO ANGEL RUFFINO, LU XU, ANDREA GIORDANO, LUIGI STENDARDO, RACHELE A. BERNARDELLO	
Application of UAV photogrammetry technology in the process of architectural heritage preservation	450
EMANUELE GARBIN	
On phenomenology of remote vision: the panoramas of the first lunar probes	458
FRANCESCA GALASSO, ALESSIA MICELI	
The documentation of the decorative system of the Ark of Mastino II in Verona.	468
Comparative analysis of photogrammetric data obtained from UAV systems	
VALENTINA CASTAGNOLO, ANNA CHRISTIANA MAIORANO, REMO PAVONE	
Immersive environments and heritage digitization. The virtual image of a medieval cathedral	478
LUCA FORMIGARI, VERONICA VONA, MARCO ZUPPIROLI	
Towards an “allround” control of the restoration project: 3D modelling as a real-time monitoring system for the design outcome	488
DAVIDE CARLEO, MARTINA GARGIULO, GIOVANNI CIAMPI, MICHELANGELO SCORPIO, PILAR CHIAS NAVARRO	
Immersive virtual model accuracy and user perception: preliminary results of a case study with low cost photogrammetric survey method by drone	500
HANGJUN FU	
UAV survey for 3D printing digital modeling for the representation and enhancement of Nativity Church on the urban and architectural scales	510
CHIARA RIVELLINO, MARCO RICCIARINI	
Testing the reliability of mini-UAVs acquisition campaign on detailed bas-reliefs.	518
The case study of sculpturing elements of Donatello’s Pulpit	
ANDREA CAMPOTARO	
Documenting the evolution of a Lilong neighborhood in contemporary Shanghai through mini-UAV-based photogrammetry surveys	528
CRISTIANA BARTOLOMEI, CECILIA MAZZOLI, CATERINA MORGANTI	
The Woodpecker: virtual reconstruction of an abandoned discotheque in the Adriatic Coast	536
YLENIA RICCI, ANDREA PASQUALI	
From UAV photogrammetry to digital restitution, new process for the preservation of Cultural Heritage	544

REMOTE SENSING IN AGRICULTURE AND FORESTRY	556
CLAUDIO SPADAVECCHIA, ELENA BELCORE, MARCO PIRAS, MILAN KOBAL Forest change detection using multi-temporal aerial point clouds	558
RAMIN HEIDARIAN DEHKORDI, MIRCO BOSCHETTI Exploring the relationship between soil organic carbon and crop water stress across century-old biochar patches within agricultural fields by combining UAV thermal, multispectral, and RGB images	564
GIORGIO IMPOLLONIA, MICHELE CROCI, ANDREA MARCONE, GIULIA ANTONUCCI, HENRI BLANDINIÈRES, STEFANO AMADUCCI UAV-based remote sensing to evaluate nitrogen and irrigation effects on LAI and LCC dynamics combining PROSAIL model and GAM	570
CARLOS CARBONE, MULHAM FAWAKERJI, VITO TRIANNI, DANIELE NARDI Photorealistic simulations of crop fields for remote sensing with UAV swarms	576
BIANCA ORTUANI, ALICE MAYER, GIOVANNA SONA, ARIANNA FACCHI Use of vegetation indices from Sentinel2 and UAV in precision viticulture applications	582
FILIPPO SARVIA, SAMUELE DE PETRIS, ALESSANDRO FARBO, ENRICO BORGOGNO MONDINO Geometric vs Spectral content of RPAS images in the precision agriculture context	588
GIOVANNA SCARDAPANE, FEDERICA MASTRACCI, ANTONELLO CEDRONE, LILIAN VALETTE T-DROMES®, Drone-as-a-Service solutions for Smart Farming	596
FRANCESCA GIANNETTI, GIOVANNI D'AMICO, FRANCESCO CHIANUCCI, GHERARDO CHIRICI UAV forest application supporting sustainable forest management	602
GEOLOGY AND UAV: RESEARCH, EXPERIENCES AND FUTURE PERSPECTIVES	608
ALBERTO BOSINO, NICCOLÒ MENEGONI, ELISA FERRARI, CLAUDIA LUPI, CESARE PEROTTI Art and Drones: retracing the paths of Torquato Taramelli 100 years later	610
NICCOLÒ MENEGONI, DANIELE GIORDAN, CESARE PEROTTI, ENRICO ARESE Uncrafted Aerial Vehicle-based rock slope stability analysis of Baveno granite quarry area: the tailing and waste rock extractive site of Ciana-Tane Pilastretto (Montorfano)	614
DAVIDE FUGAZZA, MARCO SCAIONI, VALERIA BELLONI, MARTINA DI RITA, FABIANO VENTURA, FABRIZIO TROILO, GUGLIELMINA ADELE DIOLAIUTI UAVs in cryospheric studies: experiences from Alpine glaciers	620

MARCO LA SALANDRA	
Application of UAV system and SfM techniques to address the hydro-geomorphological hazard in a fluvial system	622
DANIELE GIORDAN, MARTINA CIGNETTI, DANILO GODONE, ALEKSANDRA WRZESNIAK	
Structure from motion multi-source application for landslide characterization and monitoring	626
FABRIZIO TROILO, NICCOLÒ DEMATTEIS, DANIELE GIORDAN, FRANCESCO ZUCCA	
UAV observation of the recent evolution of the Planpincieux glacier (Mont Blanc)	628
MARCO DUBBINI, CORRADO LUCENTE, GIACOMO UGUCCIONI	
Photogrammetric monitoring by drone of San Leo landslide (Rimini)	630
AERIAL, GROUND AND UNDERWATER ROBOTICS FOR CULTURAL HERITAGE	632
MATHEW JOSE POLLAYIL, FRANCO ANGELINI, MANOLO GARABINI	
UAV for environmental monitoring	634
DANILA GERMANESE, DAVIDE MORONI, MARIA ANTONIETTA PASCALI, MARCO TAMPUCCI, ANDREA BERTON	
Exploring UAVs for structural health monitoring	640
BENEDETTO ALLOTTA, ALESSANDRO RIDOLFI, NICOLA SECCIANI	
Autonomous Underwater Vehicles for Underwater Cultural Heritage: some experiences from the University of Florence	644
FABIO BRUNO, ANTONIO LAGUDI, UMBERTO SEVERINO	
Autonomous Surface Vehicles to support underwater archaeologists in survey and documentation	648
FABRIZIO GIULIETTI, EMANUELE LUIGI DE ANGELIS, GIANLUCA ROSSETTI, MATTEO TURCI	
High-range/high endurance rotary wing aircraft for environmental protection and Cultural Heritage valorisation	652
AFTERWORD	658
SALVATORE BARBA, ANDREA DI FILIPPO	
DICIV - Department of Civil Engineering	
SPONSOR	664



PIETRO BECHERINI¹, ROLANDO VOLZONE², ANASTASIA COTTINI¹

¹ DIDA, Department of Architecture, University of Florence, Florence, Italy

² ISCTE-Instituto Universitário de Lisboa, Lisbon, Portugal

pietro.becherini@unifi.it

rveoo@iscte-iul.pt

anastasia.cottini@unifi.it

Keywords:

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 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 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

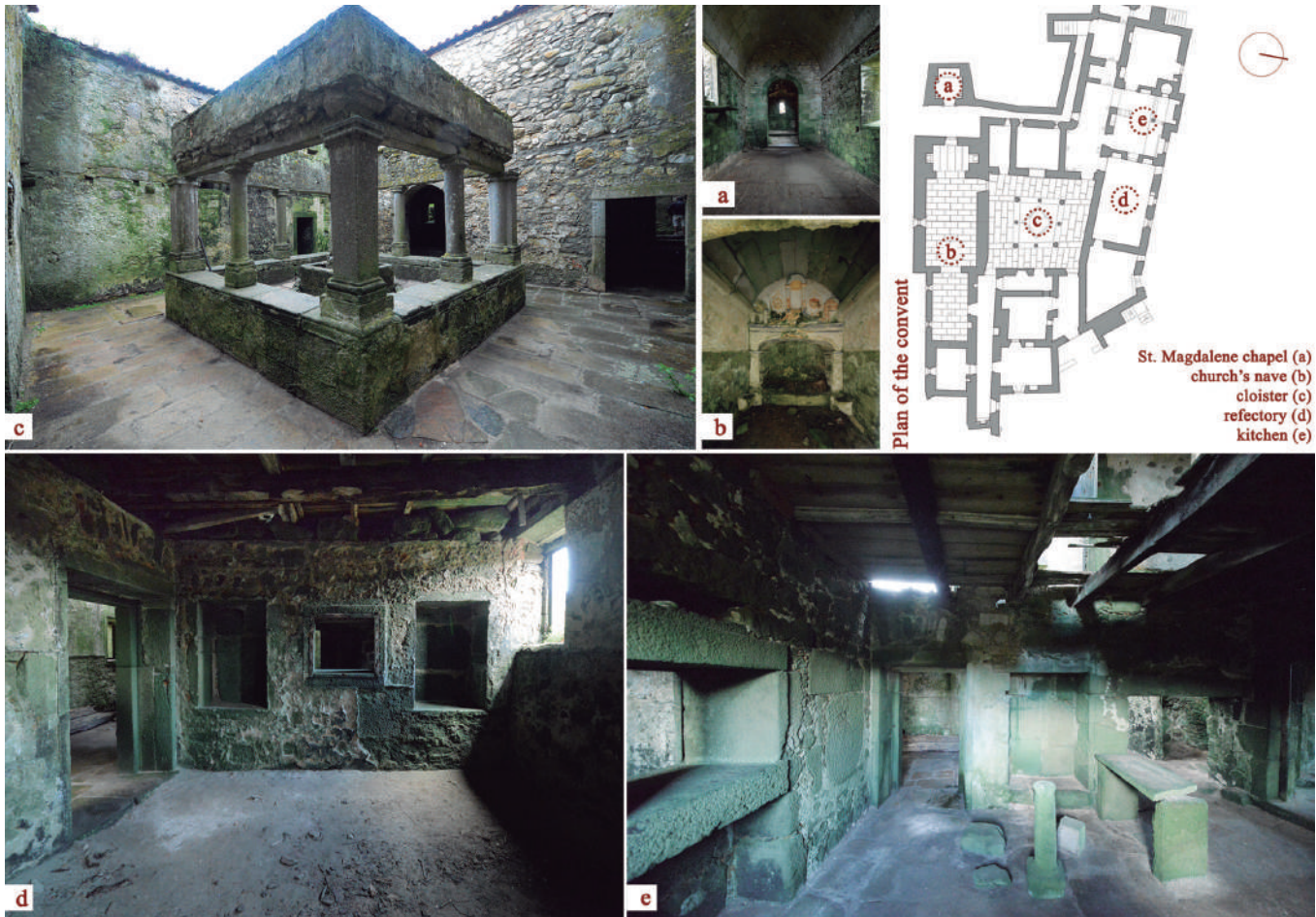


Figure 2. Photographic documentation: Saint Magdalene chapel (a), church's nave (b), cloister (c), refectory (d), kitchen (e). ©Rolando Volzone and Anastasia Cottini, 2021.

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

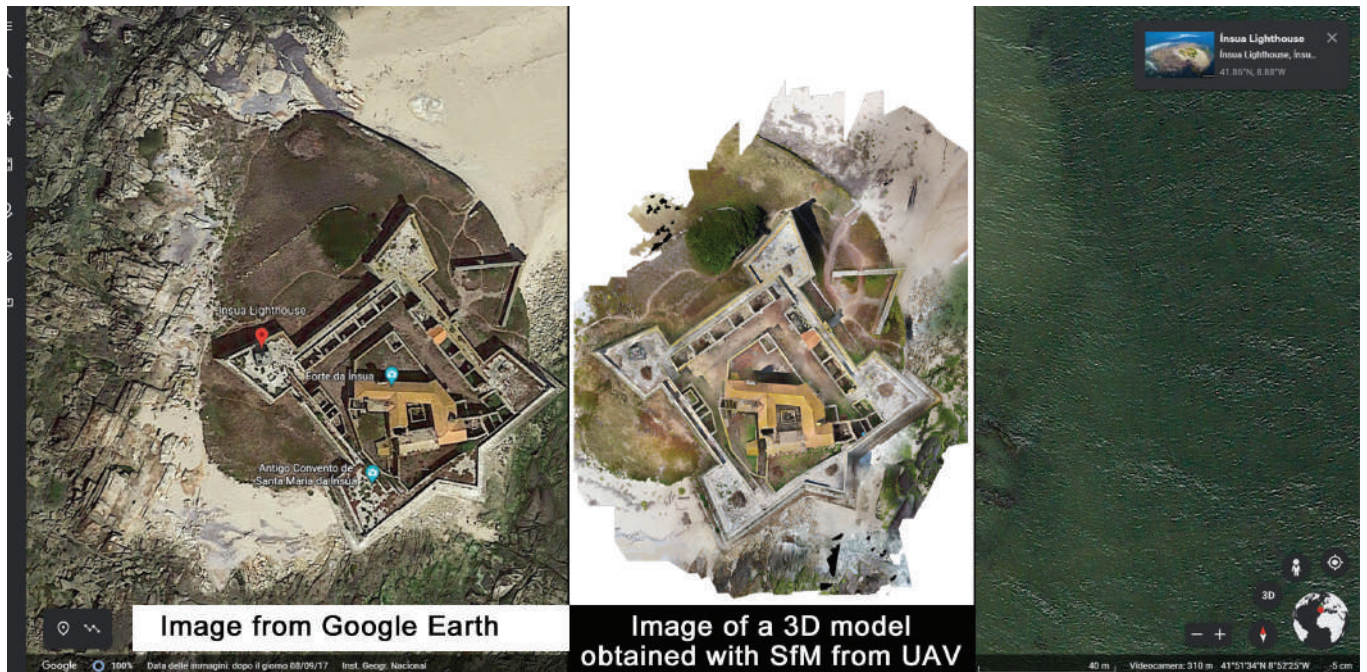


Figure 3. Aerial view of Santa Maria da Ínsua: picture by Google Maps (left), image obtained by processing pictures captured by drone (right). ©Pietro Becherini, 2022.

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

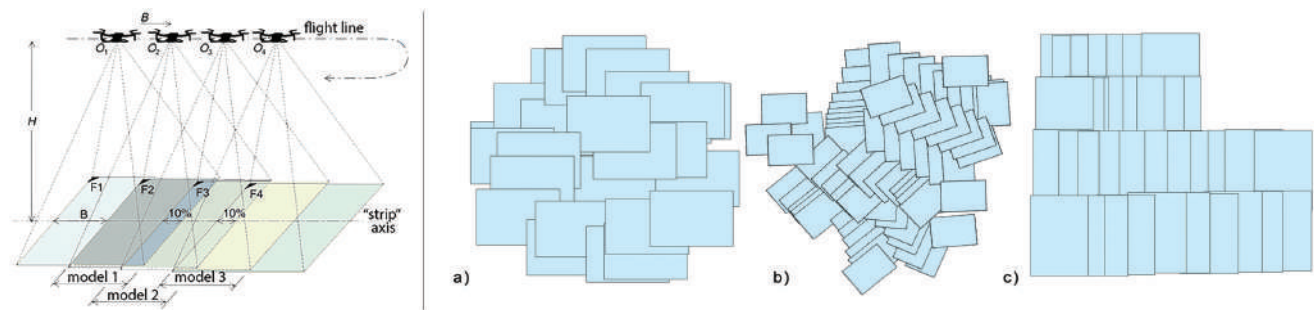


Figure 5. Verification, by entering the coordinates of the object of the aerial photogrammetric survey in the DSPace site, of any flight restrictions using UAV.

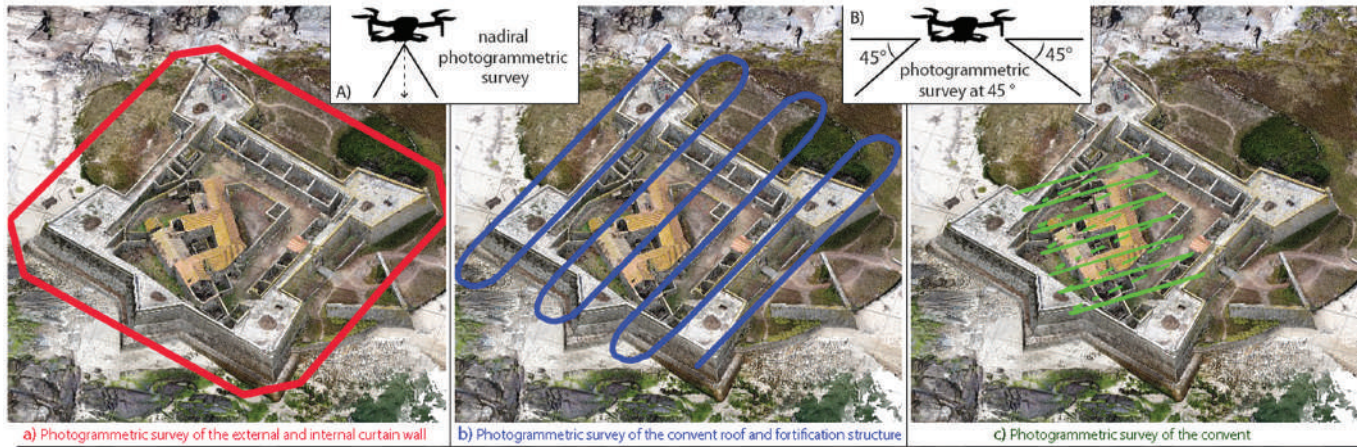


Figure 6. Methodology applied for the acquisition of the territory with a photogrammetric flight organized in rectilinear trajectories (a, b, c) with a nadir and 45° (A, B) camera during which it is taken a certain number of frames called “streak”.

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.

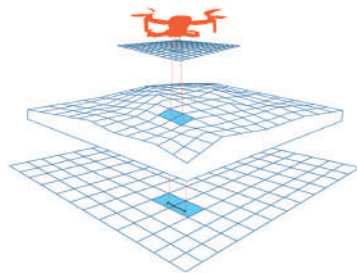


Figure 7. GSD is the amount of ground captured by the distance between the central point of two adjacent pixels. On the right, the size of a payload's sensor influences the quality of the pictures, especially those taken at lower altitude and at high speed. By comparing the real resolution of images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

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

Sensor sizes	Full-frame Wingtra RX1R II payload 36 x 24 mm (1.4 x 0.9 in)
	Aeria X 23.6 x 35.6 mm (0.9 x 0.6 in)
	1 inch senseFly S.O.D.A. 12.6 x 9.6 mm (0.5 x 0.4 in)
	DJI Mini 2 8.3 x 4.7 mm (0.25 x 0.2 in)

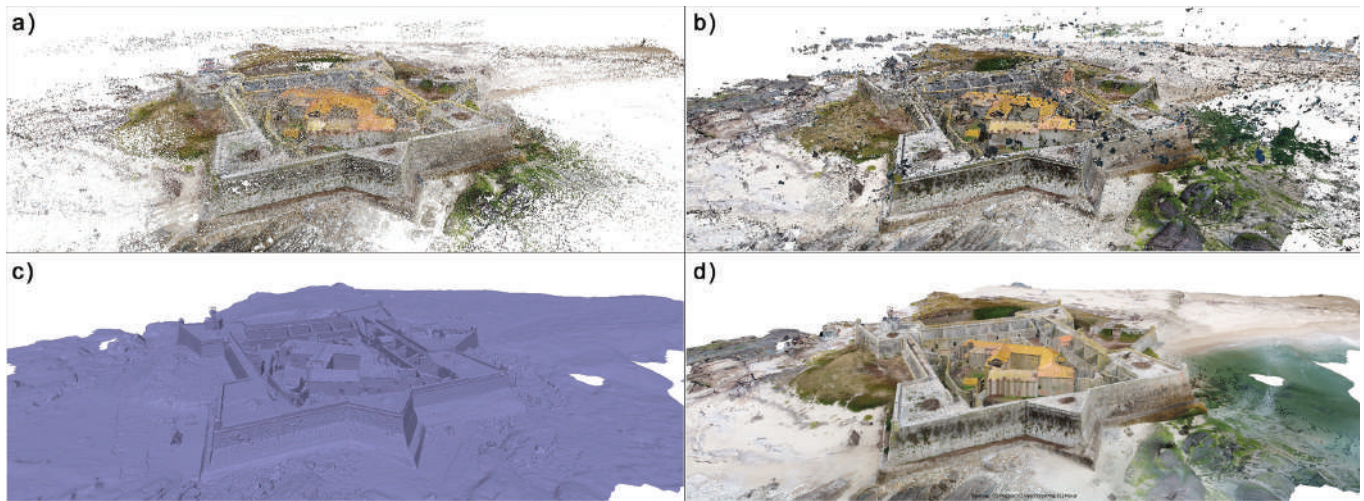


Figure 8. Modeling steps from aerial photographs processed in Agisoft Metashape. a) sparse cloud, b) dense cloud c) mesh, d) tex-tured model.

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 context². 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, Häkkinä, 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).

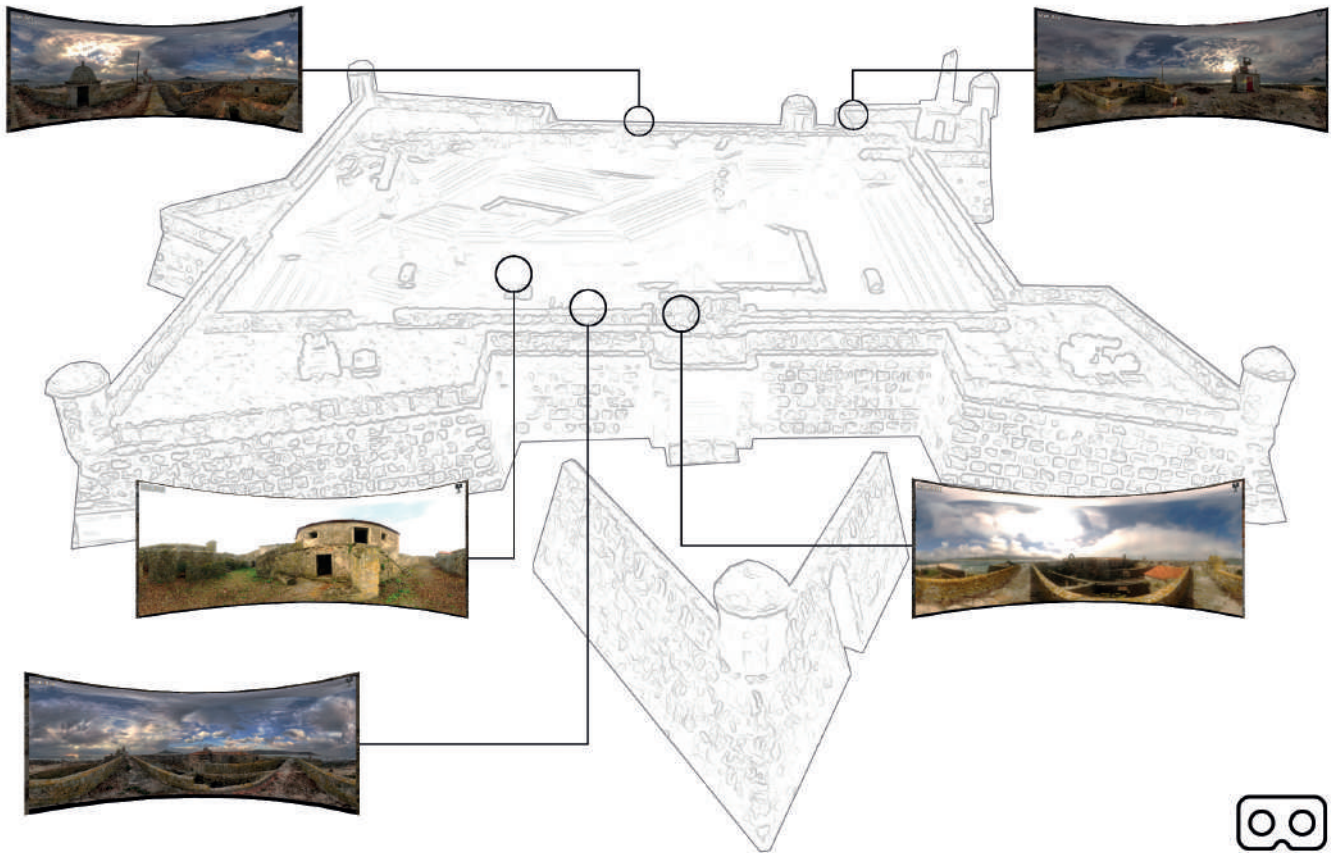


Figure 10. Virtual tour of the external and internal spaces of the conventual complex and fortress.

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>).

BIBLIOGRAPHY

Argyriou L., Economou D., and Bouki V. (2020). "Design methodology for 360° immersive video applications: the case study of a Cultural Heritage virtual tour". In *Personal and Ubiquitous Computing*, 24(9), pp. 843-859

Bekele M. K., and Champion E. (2019). "A Comparison of Immersive Realities and Interaction Methods: Cultural Learning in Virtual Heritage". In *Front. Robot. AI*, 6:91. doi: 10.3389/frobt.2019.00091

Cepa A. (1980). *Caminiana: Revista de Cultura Histórica, Literária, Artística, Etnográfica e Numismática*, n. 2 (June): 148–59.

Cioli F., and Lumini A. (2021). "Il Santuario del Sacro Speco di San Francesco a Narni. Rilievo architettonico e ambientale per la comprensione dei rapporti tra architettura e paesaggio". In Bellanca, C., and Alonso-Munoyerro, S. Roma, capitale d'Italia 150 anni dopo. Volume I, pp. 405-420. Roma: Artemide.

Figueiredo A. P. V. (2008). "Os Conventos Franciscanos Da Real Província Da Conceição : Análise Histórica, Tipológica, Artística e Iconográfica". PhD Thesis in História (Arte, Património e Restauro), Faculdade de Letras - Universidade de Lisboa.

Häkklä J., Hannula P., Luiro E., Launne E., Mustonen S., Westerlund T., and Colley A. (2019). "Visiting a virtual graveyard: designing virtual reality

Cultural Heritage experiences". In *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia (MUM '19)*. Association for Computing Machinery, New York, NY, USA, Article 56, 1–4. DOI: <https://doi.org/10.1145/3365610.3368425>

Luhmann T., Chizhova M., and Gorkovchuk D. (2020). "Fusion of UAV and Terrestrial Photogrammetry with Laser Scanning for 3D Reconstruction of Historic Churches in Georgia". In *Drones*, 2020, 4, 53. <https://doi.org/10.3390/drones4030053>.

Mosbrucker A. R., Major J. J., Spicer K. R., and Pitlick J. (2017). "Camera system considerations for geomorphic applications of SfM photogrammetry". In *Earth Surface Processes and Landforms*, 42, pp. 969-986. Wiley Online Library. <https://doi.org/10.1002/esp.4066>.

Remondino F., and Campana S. (2014). *3D Recording and Modelling in Archaeology and Cultural Heritage - Theory and Best Practices*. Oxford: Archeopress BAR. ISBN: 9781407312309.

Rodrigues A. M., Fontes J. L., and Andrade M. F. (2020). "La(s) Reformas En El Franciscanismo Português En La Edad Media". In *Hispania Sacra LXXII* (145): 51–63. <https://doi.org/10.3989/hs.2020.004>.

Stylianidis E., Remondino F. (2016). "3D recording, documentation and management of Cultural Heritage". In *International Journal of Heritage Studies*, 23, 1-3.

Sousa B. V. (ed.). (2016). *Ordens Religiosas Em Portugal Das Origens a Trento - Guia Histórico*. 3rd ed. Lisboa: Livros Horizonte.

Teixeira V. G. (2010). *O Movimento Da Observância Franciscana Em Portugal, 1392-1517: História, Património e Cultura de Uma Experiência de Reforma Religiosa*. Porto: Editorial Franciscana.

Volzone R., Niglio O., and Becherini P. (2022). "Integration of knowledge-based documentation methodologies and digital information for the study of religious complex heritage sites in the south of Portugal". In *Digital Applications in Archaeology and Cultural Heritage*, Volume 24, e00208, ISSN 2212-0548, <https://doi.org/10.1016/j.daach.2021.e00208>.



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.

