

Sandro Parrinello
Anna Dell'Amico

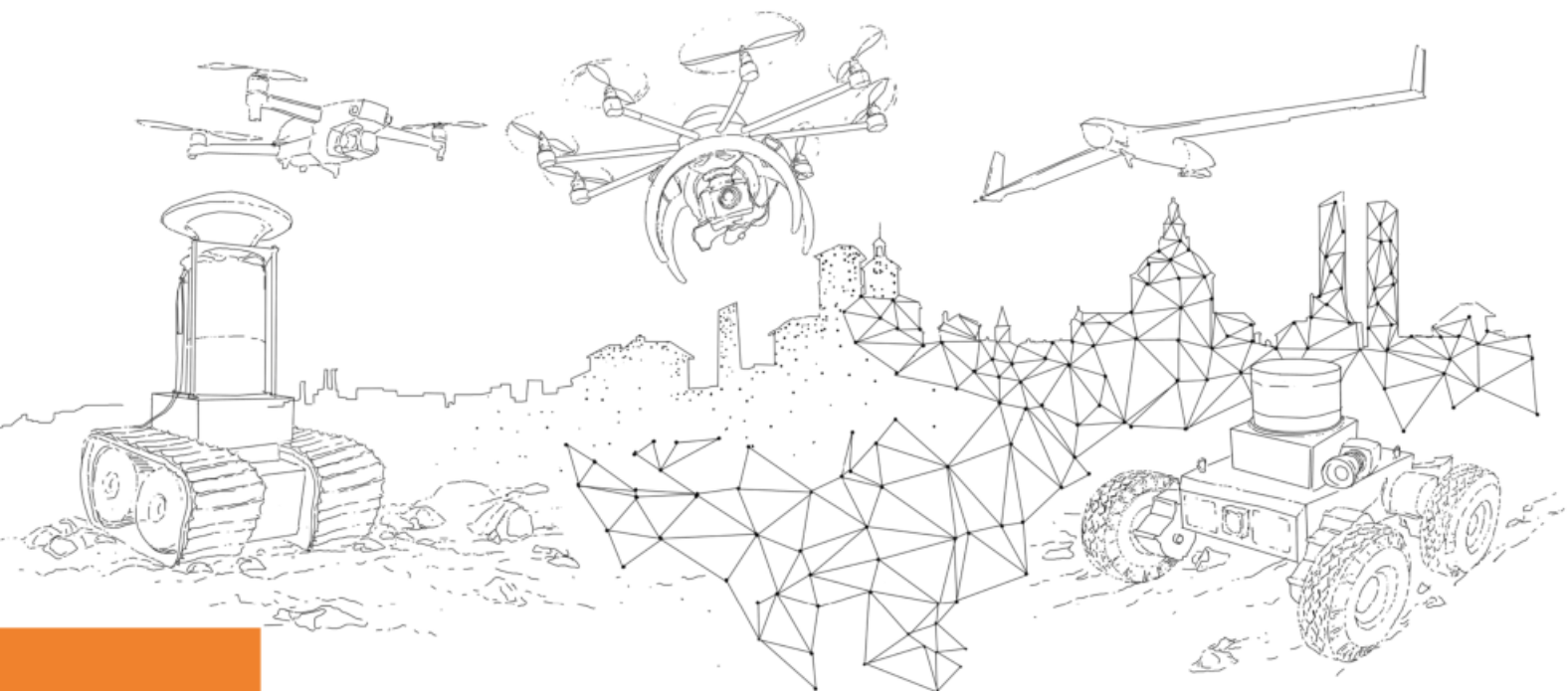
Salvatore Barba
Andrea di Filippo

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.

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

28

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 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	94
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



GIOVANNI PANCANI, MATTEO BIGONGIARI

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

giovanni.pancani@unifi.it
matteo.bigongiari@unifi.it

Keywords:
UAV, photogrammetry, data reliability, point cloud, Verruca fortress.

ABSTRACT

The paper describes the digital survey project of the Verruca fortress, which is located on the summit of Monte Serra, in the Pisan mountains. Today the fortress is in a state of ruin, and recently a summer fire caused the loss of the vegetation that had massified around the building, thus allowing to program the analysis of the walls of the fortress to deepen its construction history and state of material and structural conservation.

the fortress survey project integrates range based, image based and UAV technologies, focusing attention on the methodologies used to ensure the high morphological reliability of the data obtained from the survey, in a very complex area to reach.

The results of the survey made it possible to reconstruct a whole series of graphical drawings that made it possible to deepen the architectural and historical analyzes on the fortress.

THE AERIAL PHOTOGRAMMETRIC SURVEY FOR THE DOCUMENTATION OF THE CULTURAL HERITAGE: THE VERRUCA FORTRESS ON THE PISAN MOUNTAINS

1. INTRODUCTION

The paper describes the digital survey project of the Verruca fortress, which integrates range-based, image-based and UAV technologies, focusing attention on the methodologies used to ensure the high morphological reliability of the data obtained from the survey in an area that is very difficult to reach. (Figure 0)

The fortress is located on the summit of Mount Serra, in the Pisan mountains with the aim of controlling the valley of the Arno river, near its outlet to the sea. It was built by the Pisans in the 10th century and has always been considered of great strategic importance for the maintenance of power (Francovich, Gelichi 2003). Florence and Pisa in the 15th century fought over the possessions and strategic points on the Pisan mountains for a long time until the fortress was definitively taken in 1503, the year in which it was visited by the great Florentine military architects, Sangallo and Leonardo, at the behest of Machiavelli (Pedretti 1972); immediately afterwards the defenses are modernized, in such a way as to be able to defend itself from the shooting of firearms. A few years, due to the loss of strategic importance of these lookout points, the fortress was slowly abandoned. Today it is in a state of ruin, and recently a summer fire caused the loss of the vegetation that had massified around the building, thus allowing to program the analysis of the walls of the fortress to deepen its construction history and state of material and structural conservation. (Figure 1)

In May 2019, a collaboration began between the municipality of Vicopisano, on which part of the fortress

property stands, and the Department of Architecture of the University of Florence to carry out the architectural surveys of the fortification; the fortress survey project involved the experimental use of the most up-to-date laser scanner, drone and GPS digital survey tools, to create a highly reliable digital model; the fortress had already been partially surveyed in the past finding great difficulties in measuring the external parts, along the steep slopes, where it is possible to see how the building rests directly on the rocks that characterize the Serra mountain and make it derive its name. The 3d models deriving from laser scanner survey and drone photogrammetry have been joined together in a single highly reliable textured model. To ensure the reliability of the digital models reconstructed with the different acquisition techniques, particular attention was paid to the comparison between the morphologies of the point clouds obtained and to the simultaneous verification



Figure 1. View of the mountain top from the remains of the nearby convent of San Michele alla Verruca.

of significant points measured both in local and geo-referenced coordinates; to ensure the reliability of the individual models, it was also necessary to pay attention to the data registration phase.

The results of the survey made it possible to reconstruct two-dimensional and three-dimensional graphs that allowed to deepen the architectural and historical analyzes of the fortress; it raises a lot of interest in the study of the evolution of fortresses at the end of the 15th century and in the activity as a military architect both by Sangallo and by Leonardo da Vinci.

2. ARCHITECTURAL SURVEY

The position of the Verruca fortress does not present optimal conditions to be able to plan the measurement operations: the survey of the areas inside the walls is not so complex, as the outside, which is arranged on a steep slope with thick vegetation that does not facilitate the passage of operators, instruments and measurements. Despite this, some instrumental surveys have been carried out in recent decades, which did not however allow the detailed description of the walls, and presented some approximations as regards the morphologically more complex parts of the structures: the need for a detailed survey to interpret, following a scientific method, the state of conservation and the evolution of the building led to the design of a more modern and accurate survey campaign.

The recent arson attacks, which hit the top of Mount Verruca, have at the same time partly favored the design and implementation of new measurement campaigns, adopting in this case digital data acquisition systems. In particular, three different acquisition campaigns were carried out:

- laser scanner equipment to create a model that describes the morphology of the building in detail;
- SfM photographic acquisitions from the ground to create three-dimensional models that describe the materiality of the walls;
- aerial photogrammetry with the use of drones, to create a mapped model of the whole complex.

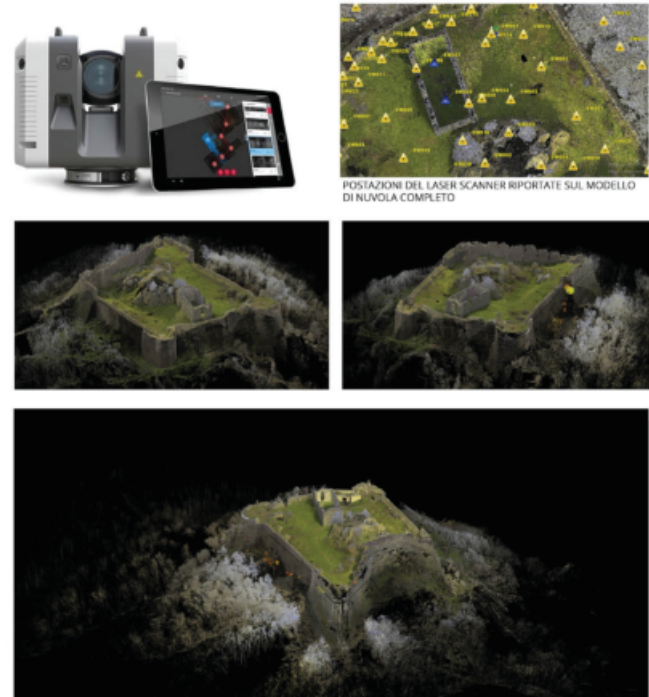


Figure 2. Range-based survey methodologies, used for the reconstruction of the fortress.

In this article we will not go into the acquisition methodology used for each acquisition campaign, which will be further explored elsewhere, but in particular we will deal with the photogrammetric survey from drone and the integration with the other acquisition systems.

3. METHODOLOGIES

The laser scanner survey of the Verruca fortress was designed to describe all the surfaces of the architecture with a definition that would allow the graphic rendering of the drawings necessary for the preparation of the diagnostic investigations (Bigongiari, Pancani 2020).

The scans were carried out with the Leica RTC360 instrument, whose characteristics allowed the rapid completion of highly reliable measurements: the scanner



Figure 3. Image based and UAV survey methodologies, used for the reconstruction of the fortress.

in fact is able to measure over two million points per second, creating hd panoramic photographs; the 5 cameras positioned on the edges of the instrument also allow the recognition of the scene in which the scanner is located and its movements, allowing the alignment of the scans directly on the field. The result of the acquisitions produced a point-cloud in local coordinates

resulting from the alignment of 145 scans. (Figure 2) The 3d photogrammetric survey was carried out with the main purpose of producing rectified images of the architectural surfaces to be used for diagnostic investigations; to obtain this result it was useful to combine acquisitions from the ground with the acquisitions obtained from drone flights to solve some problems.

The photographic survey of the Verruca was particularly complex due to a series of environmental conditions that made shooting difficult: the greatest difficulties were encountered along the outer perimeter of the fortification, which, being on the top of a particularly rocky mountain, did not allow move easily around it to build a three-dimensional model; moreover, the vegetation around it, even if not particularly luxuriant after the fires, forced constant movements and changes of framing and definition on the wall surfaces, as well as causing considerable differences in lighting due to the filtering of light through branches and trunks. Beyond this, in some areas it was impossible to resume the wall texture due to the degradation caused by spontaneous vegetation. The photographic shooting campaigns were therefore organized to solve these difficulties and to obtain a

textured model that could describe the surfaces with a definition at least on a 1:50 scale.

In choosing the correct instrumentation to use for shooting, the condition of poor lighting was considered, which causes dazzling points of light where the sun's rays enter. For this reason, it was necessary to provide for the use of tools that were able to create high quality frames despite the light present being significantly unfavorable for photographic shooting. A full frame Sony A 7R II camera (42.4 MP CMOS sensor) mirrorless was used, in order to guarantee a high level of definition, which was able to describe the walls in its details, and a frame of good quality at the level of exposure: this camera is able to return high quality frames even by setting a rather high sensitivity, in such a way as to encourage shooting without a tripod; the same camera body was mounted for drone shooting, on the Leica Aibot AX20 model. (Figure 3)



Figure 4. Three-dimensional model after the reconstruction integrated by laser scanner and photogrammetry.

To best reconstruct the surfaces of the fortress, it was decided to shoot frames following three levels of investigation: a first from the ground moving around the object at close range, a second plane shooting zenith images, a third still aerial but tilting the camera to shoot at best the elevations.

Each of these photographic sequences, shooting objects from different distances, required the use of lenses with different focal lengths. For the first sequence, from the ground, a Sony FE 28mm f / 2.8 was used, ideal for moving around objects even at close distances, less than 2 meters: with this lens all the external and internal surfaces of the fortification were acquired. A Sony Zeiss Sonnar T * FE 55mm f1.8 ZA 50mm was used for the second and third sequence, rotating around the fortress at a more or less fixed distance.

The choice of the focal length was based on the study of the resolution that must be guaranteed to the frames in order to fall within the definition scales of the three-dimensional model; if, in the case of the laser scanner survey which is directly acquired in metric scale, it is possible to evaluate the definition on the basis of the set point grid, as regards the photographic survey, the evaluation of the definition values must be designed on the basis of the pixels with which the surfaces are defined. The photographic acquisitions maintained a ratio of at least 6px / cm with a minimum margin of overlap between contiguous frames of 50%.

9 targets were also positioned on the ground and the corresponding GPS coordinates were obtained, useful for scaling and georeferencing the point clouds.

At the end of the data collection phase, 682 final images were imported and oriented in the 3DF Zephyr software during the 3D reconstruction process. The photogrammetric point cloud was then joined to the laser scanner point cloud to obtain an even more detailed model, as well as scaled and georeferenced. (Figure 4)

Before proceeding with the data processing for the reconstruction of the three-dimensional scene, a careful quality control was made on the frames: although we had always tried to keep within the safety shutter speeds



Figure 5. Drawing of the plan of the fortress.

to avoid the blur effect in the photographic shots (Forti 2006), especially with regard to acquisitions from close distances in which, moving around the object, one incurs repeated changes in light exposure, the risk of having frames out of focus or with incorrect exposure had to be avoided. For this reason the frames in raw format have been imported into a special software with the aim of verifying their correct focus and adjusting their parameters. In this way, the white balance was equalized for all the shots so as to have a color as uniform as possible. Due to the different light exposures of the surfaces, it was also decided to limit the presence of over-lit and shaded areas to a minimum, reducing the Highlights and Shadow parameters to a minimum. Finally, we tried to make the exposure of the surfaces as homogeneous as possible by varying the parameter according to the shutter speed of the frame. The data from different acquisition systems were used to create the technical drawings (plans and sections) according to the traditional system that involves the extraction of the geometries from the laser scanner point clouds, the materiality of the surfaces from the photogrammetric acquisitions: both databases have been suitably subjected to data certification protocols in order to verify



Figure 6. Drawing of the access elevation to the fortress.

the reliability of both the registration of the scans and the calibration of the photoplanes on the point cloud (Pancani 2017). (Figure 5, Figure 6) The verification of the reliability of the reconstructions took place by comparing the different three-dimensional survey systems: the survey integrated different methodologies, producing multiple digital copies of the Verruca with different levels of reliability. We can synthesize the acquisitions in three different reconstruction systems: laser scanner, SfM and satellite. Two of these measurement methods are able to provide a measurement within certain error parameters: the single laser scan in fact, depending on the model of instrument, guarantees high reliability, in our case millimetric; in the same way, the GPS has guaranteed centimetric measurements on the xy plane; 1.2 cm on the vertical axis. Unfortunately, it is not possible to say the same about photogrammetric reconstructions, although the positioning of the trigger

point is supported by the presence on the drone of a high-precision GPS: in fact, the positioning of the trigger point does not guarantee the correct reconstruction of the point clouds that are influenced. from numerous and different problems related to the light source (Pancani, Bigongiari 2019). For this reason, after an accurate control of the registration process, the laser scanner survey was taken as the morphological basis, whose polar coordinates were used to verify the control points of the photogrammetric survey, both from the ground and from the drone. At the same time, the union between laser scanner alignment and photogrammetry was experimented, obtaining interesting results in terms of reliability of the mesh model: together with the developers of 3d FLOW with whom a collaboration has been active since 2019, there is the intention to improve these algorithms for make the photogrammetric survey even more an integrated survey.

4. CONCLUSIONS

The Verruca survey made it possible to experiment with numerous data acquisition systems in order to integrate the results from the different instruments.

The three-dimensional model obtained by the drone, necessary for the reconstruction of reliable textures, has been verified to be reliable per cm compared to the laser scanner model. Highly reliable drawings were obtained which are useful for analyzing the state of conservation of the architecture; thanks to the use of the drone it was possible to measure points that were not accessible until now. The research on methodologies by the research group in collaboration with the software house 3d FLOW will be increasingly directed to the study of rapid systems that integrate the use of laser scanner and drone acquisitions to obtain increasingly reliable data.

BIBLIOGRAPHY

<https://www.3dflow.net/it/casi-di-studio/la-fortezza-della-verruca>

Bigongiari M., Pancani G., (2020) *Digital survey for the structural analysis of the Verruca fortress*, in *PROCEDIA STRUCTURAL INTEGRITY*, v.29, DOI 10.1016/j.prostr.2020.11.151

Colomina I., Molina P. (2014). *Unmanned aerial systems for photogrammetry and remote sensing: a review. ISPRS J Photogramm Remote Sens*, 92, 2014, pp. 79–97

Forti G. (2006). *Fotografia, teoria e pratica della reflex*, Roma, Editrice reflex

Francovich R., Gelichi S., (2003). *Monasteri e castelli fra X e XII secolo. Il caso di San Michele alla Verruca e le altre ricerche storico-archeologiche nella Tuscia occidentale*. Firenze all'insegna del Giglio.

Gaiani M., (Ed.), *I portici di Bologna, Architetture, modelli 3D e ricerche tecnologiche*, Bologna: Bononia University press, 2015.

Multiuroso A., Grussenmeyer P. (2017). *Documentation of Heritage Buildings using Close-Range UAV images: dense matching issues, comparison and case studies. The photogrammetric Record*. Vol. 32 (159), 2017, pp. 206-229.

Pancani G., (2017). *Rilievo delle lastre tombali del Camposanto Monumentale di Piazza dei Miracoli a Pisa*, in *"Restauro archeologico"*, n°2, Firenze University Press, Firenze.

Pancani G., Bigongiari M. (2019). *The Integrated Survey of the Pergamum by Nicola Pisano in the Cathedral of Pisa*, in *Digital Cultural Heritage*, Springer Nature, Switzerland AG, pp. 373-388, doi 10.1007/978-3-030-15200-0_25

Pedretti C. (1972). *La Verruca*, in *R.Q.*, vol. XXV, 4, pp. 417-425



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.

