POLITECNICO DI TORINO
Repository ISTITUZIONALE

UAS photogrammetry and SLAM for the HBIM model of the Montanaro Belltower

Original
UAS photogrammetry and SLAM for the HBIM model of the Montanaro Belltower / TEPPATI LOSE', Lorenzo; Chiabrando, Filiberto; Pellegrino, Eleonora - In: D-SITE, Drones - Systems of Information on Cultural Heritage for a spatial and social investigation / Parrinello S., Barba S., Dell'Amico A., Di Filippo A.. - STAMPA. - Pavia : Pavia University Press, 2022. - ISBN 978-88-6952-159-1. - pp. 202-211

Availability:
This version is available at: 11583/2973314 since: 2022-11-23T10:56:39Z

Publisher:
Pavia University Press

Published
DOI:

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

19 April 2024

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

PaviaUniversityPress

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 Engeenering 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 Engeenering and Architecture
University of Pavia

Univeristy of Salerno

DICIV - Department of Civil Engeenering
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	University of Pavia - Italy
Marco Limongiello	University of Salerno - Italy

Scientific Committees

Marcello Balzani	University of Ferrara - Italy
Salvatore Barba	University of Salerno - Italy
José Antonio Barrera Vera	University of Seville - Spain
Stefano Bertocci	University of Florence - Italy
Carlo Bianchini	La Sapienza, University of Rome - Italy
Mirco Boschetti	IREA, CNR - Italy
Enrico Borgogno Mondino	University of Turin - Italy
Stefano Campana	University of Siena - Italy
Massimiliano Campi	University of Naples Federico II - Italy
Gabriella Caroti	University of Pisa - Italy
Filiberto Chiabrando	Polytechnic of Turin - Italy
Gherardo Chirici	University of Florence - Italy
Antonio Conte	University of Basilicata - Italy
Krzysztof Cyran	Silesian University of Technology - Poland
Francesco Fassi	Polytechnic of Milan - Italy
Francesca Fatta	University of Reggio Calabria - Italy
Juan José Fernández Martín	University of Valladolid - Spain
Margherita Fiani	University of Salerno - Italy
Andreas Fritz	University of Freiburg - Germany
Diego González-Aguilera	University of Salamanca - Spain
Armin Gruen	ETH Zurich Faculty of Architecture - Swiss
Pierre Grussenmeyer	Institut National des Sciences Appliquées - France
Sorin Hermon	The Cyprus Institute - Cyrus
Xianfeng Huang	Wuhan University - Hubei China
Marinos Ioannides	Cyprus University of Technology - Cyprus
Falko Kuester	University of California - USA
Francesco Mancini	University of Modena and Reggio Emilia - Italy
Niccolò Menegoni	University of Pavia - Italy
Luis M. Palmero Iglesias	Polytechnic of València - Spain
Francesca Picchio	University of Pavia - Italy
Lorenzo Pollini	University of Pisa - Italy
Fabio Remondino	Bruno Kessler Foundation - Italy
Fulvio Rinaudo	Polytechnic of Turin - Italy
Mario Santana Quintero	Carlton University - Canada
Tesse D. Stek	Leiden University - Netherlands
Lina Tang	Chinese Academy of Sciences - Cina
Dieter Tengen	Technical University Braunschweig - Germany
Fabio Giulio Tonolo	Polytechnic University of Turin - Italy
Kyriacos Themistocleous	Cyprus University of Technology - Cyprus
Rebeka Vital	Shenkar College of Engineering and Design - Israel
Francesco Zucca	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 Argiolas, 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 Canciani, 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.
Comparative analysis of photogrammetric data obtained from UAV systems 468

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.
The case study of sculpturing elements of Donatello's Pulpit 518

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: retracting 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 Engeenering

SPONSOR 664

Lorenzo Teppati Losè, Filiberto Chiabrando, Eleonora Pellegrino

Department of Architecture and Design (DAD), Polytechnic of Turin
Laboratory of Geomatics for Cultural Heritage (Lab G4CH), Polytechnic of Turin
Turin, Italy

lorenzo.teppati@polito.it
filiberto.chiabrando@polito.it

Keywords:

UAS, HBIM, SLAM, SfM.

ABSTRACT

Uncrewed Aerial Systems (UAS) are nowadays a consolidated technique for the 3D metric documentation of Built Heritage. Nevertheless, a complete survey of complex heritage assets still requires the integration of different techniques, using a multisensor and multiscale approach. The research presented in this contribution relates a documentation experience achieved on a complex heritage asset, from multisensor data acquisition, through data processing and validation to the phase of 3D modeling and HBIM creation.

UAS photogrammetry and SLAM for the HBIM model of the Montanaro Belltower

1. Introduction and case study

The documentation of Built Heritage is a complex task that requires to be carefully planned and executed (Letellier, 2015; Patias, 2007; Remondino & Stylianidis, 2016). The developments of Uncrewed Aerial Systems (UAS) over the last decade allowed to speed up and simplify the overall documentation process in different fields of applications and specifically also in the one of Built Heritage. A rich scientific literature is available regarding the different approaches that can be adopted with these platforms and the operative guidelines for implementing data acquisition and processing (e.g., Adami et al., 2019; Chiabrando et al., 2017; Nex & Remondino, 2014; Remondino et al., 2012; Russo et al., 2018). Nevertheless, a complete survey of complex heritage assets still requires the integration of different techniques, using a multisensor and multiscale approach (Achille et al., 2018; Georgopoulos, 2018; Remondino & Stylianidis, 2016).

Furthermore, while the acquisition and processing phases are generally managed with consolidated strategies, the phase of 3D models generation and data interpretation still presents some major challenges. This aspect is particularly evident in Heritage Building Information Modeling (HBIM) workflows where the data collected and processed need to be further interpreted, validated, modeled, and enriched (e.g., Banfi, 2020; Brumana et al., 2013; Yang et al., 2020). This phase presents a series of challenges that need to be faced, new solutions that need to be researched, and new approaches yet to be validated and studied.

The research presented in this paper relates a comprehensive and thorough experience completed on a complex heritage asset: the Santa Marta Belltower designed by Bernardo Antonio Vittone between 1769-1772 A.C. for the municipality of Montanaro (Figure 1), a little town close to Torino (Northwest of Italy). This asset was designed and built together with other structures with which it forms a unique heritage palimpsest. The belltower is indeed the fulcrum of the architectural composition, while the other structures are: the town hall, the brotherhood of S. Marta, and the parish church. This project represents the integration between the secular community and the sacred space in the XVIII century municipality of Montanaro (Battaglio, 2000) and was carefully designed by the architect (Figure 2). The belltower is approximately 48 m high; it becomes slender in the progression toward the top and has a peculiar internal spiral stairway made of stone. Considering that this asset should be part of a new requalification project in the next years, a complete metric documentation of the tower and the surroundings was necessary.

2. Data acquisition, processing, and validation

A detailed 3D model of the belltower was completed combining different techniques: in particular UAS photogrammetry was used for the exterior part of the belltower while Simultaneous Localization And Mapping (SLAM) based solutions were adopted for the

On the cover: aerial view (from south) of the Santa Marta Belltower and the buildings around.

interior. All the different acquisitions were referred to the same coordinate system thanks to a set of ground control points measured with traditional topographic techniques (Global Navigation Satellite System -GNSS and Total Station surveys) that were used also for evaluating the accuracy of the different processing approaches. The final products of the documentation project were requested to meet the nominal map scale accuracy of 1:100 (precision under 0.02 m with an accuracy of 0.04 m). The topographic network was constituted of a total number of 8 vertices (five in the square facing the tower and three in some intermediate floor in the indoor). All the vertices were measured by mean of Total Station and, moreover, two of the vertices outside the belltower were measured with GNSS static technique, to georeference the network with respect to WGS84 Datum (UTM Zone 32N coordinates). Secondly, UAS acquisitions were performed to achieve a complete 3D reconstruction of the exterior part of the belltower. The UAS deployed in the field was a DJI Phantom 4 Pro[1] and, considering the urban conformation of the area and the proximity of other buildings it was decided to perform manual flights, to guarantee a better control of the platform during the operation. Images were acquired starting from the ground to the upper limit of the tower and to ensure the desired Ground Sample Distance (GSD) of 3 mm, a mean distance of 5 meters was maintained between sensor and object. For each façade both nadiral and oblique images (with respect to the façade average plane) were acquired for a total number of 543 images (Figure 3). This acquisition solution was preferred to the Point of Interest (PoI) flight scheme for two main reasons: i) to avoid flying over the nearby building and ii) to guarantee a lower acquisition distance from the tower with a consequent lower GSD and higher detail. To document the interior part of the tower a rangebased approach was used exploiting the SLAM algorithm

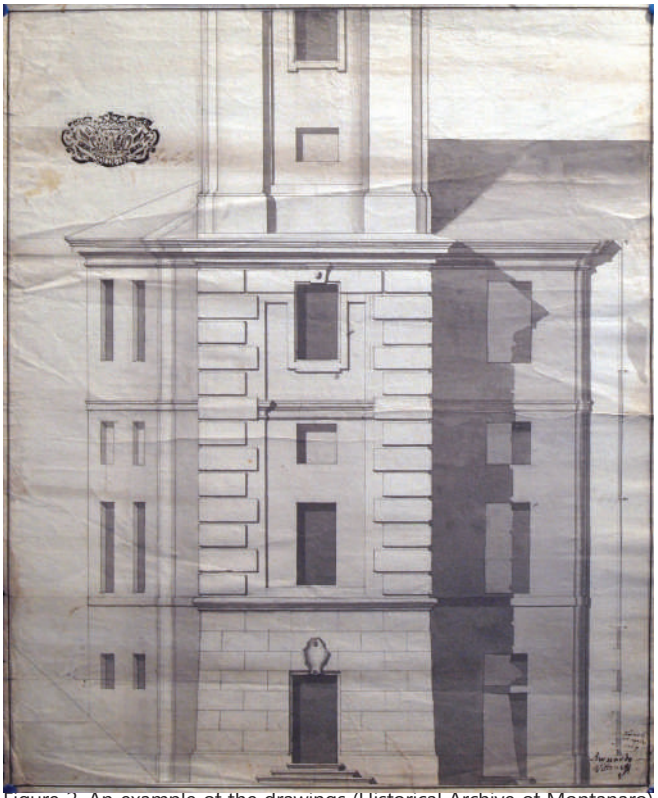

Figure 2. An example of the drawings (Historical Archive of Montanaro) carried out by B. A. Vittone: the main façade (1769-1772).

Figure 3. UAS acquisition scheme (left) and examples of acquired images (right).

within the ZEB Revo RT[2]. This approach is sustained by a recently new technology that however has proved to be suitable also for heritage documentation under certain conditions (Barba et al., 2021; Chiabrando et al., 2018; Malinverni et al., 2018; Sammartano & Spanò, 2018). During fieldwork, the operative and wellknown procedures for acquiring data with this system were followed (Riisgaard & Blas, 2004), and specifically, closedloop acquisitions were achieved. The acquisition with the Zeb Revo RT started and ended outside the belltower entrance and the operator reached the higher accessible area inside the belltower, a total number of four scans was acquired. The acquisitions with TLS were not conceived to cover all the volume of the belltower, and thus only few scans were achieved to serve as ground reference. A Faro Focus3D X 330 TLS was used for data acquisition and a total of eighteen scans were acquired covering part of the exterior of the tower and part of the indoor areas. The processing and the final products derived from the acquisitions were metrically and geometrically validated following two approaches: the use of Ground Control Points (GCPs) and Check Points (CPs) and the comparison with a Terrestrial Laser Scanner (TLS) dataset that can be considered a more consolidated technique and can thus be used as a ground reference.

Both artificial papercoded targets and natural features were used as GCPs and CPs and were measured by mean of a Total Station in the interior and exterior part of the belltower. The points measured on the exterior were mainly used for the UAS data processing and validation, while the ones in the interior were crucial to ensure a reliable connection between indoor and outdoor and to control the interior acquisitions. In the exterior part, it was possible to measure 67 points while 32 were measured in the interior. Concerning data processing, it was decided to follow consolidated strategies for all the different acquired data. Images acquired during the photogrammetric flights were processed in a commercial solution (Agisoft Metashape) exploiting the standard pipeline: from image matching, via the Bundle Block Adjustment (BBA), metric validation through GCPs and CPs (Table 1), point cloud densification, and generation of added value products such as Digital Surface Models (DSM) and orthophotos. Due to the high number of

Table 1. Main processing results of the photogrammetric processing.

Images	N° GCPs	3D RMSe GCPs (m)	N° CPs	3D RMSe CPs (m)	GSD (m)
543	27	0.009	8	0.008	0.003

Figure 4. Example of the quality of the 3D models generated by the UAS photogrammetric processing on a portion of the belltower.

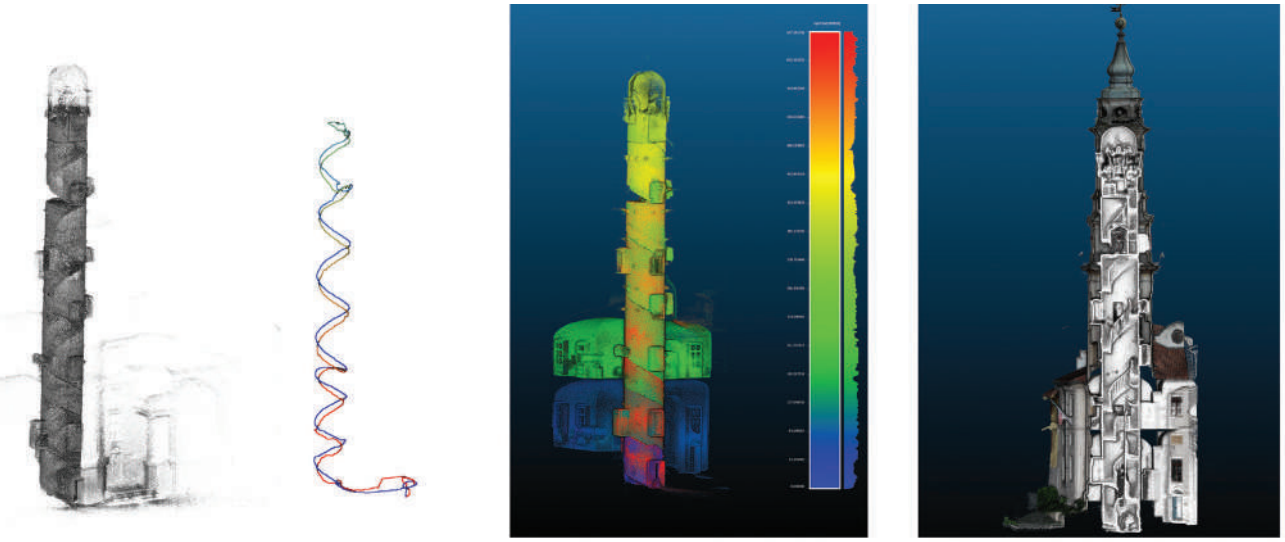

Figure 5. Workflow of the on the field survey (left), schema of the GNSS network and the position of the ground marker used for the photogrammetric UAV processing (center)). Topographic measurements total station (right).

images and the reduced sensorobject distance, it was possible to generate a high detailed 3D model, as shown in Figure 4. The TLS dataset was processed using its dedicated solution: the Faro SCENE software and two different approaches were followed for the outdoor and indoor dataset. The outdoor scans were firstly registered using an Iterative Closest Points (ICP) algorithm and then georeferenced using the ground control points measured during the fieldwork. For the indoor dataset, the control points were used for both the registration and georeferencing phase, due to the different and more complex geometry of the scan positions influenced by the environmental constraints. The accuracy of the targetbased registration was 1 cm for the outdoor dataset and 0.5 cm for the indoor dataset. The first step of the ZEB Revo RT processing (Figure 5) foresees an optimization of the acquired point cloud thanks to the SLAM-based algorithms and is then followed by a registration of the SLAM point cloud in the same reference system of the other acquisitions. The first step is performed in GeoSLAM hub and the operator's possibility of processing customization is quite limited.

In the second step inside GeoSLAM hub, the different point clouds are roughly aligned and then registered by the software via the "merge" function. During this second step the SLAM scans were then coregistered with the TLS dataset using an ICP registration in the open-source solution CloudCompare[3]. The RMSE (Root mean square error) resulted from this operation was approximately around 4 cm. A more detailed description of the acquisition and processing phases can be found in (Teppati Losè, Chiabrando, & Tonolo, 2021; Teppati Losè, Chiabrando, Novelli, et al., 2021) while more information about some tests connected to Spherical Photogrammetry approaches completed using the belltower as test sites can be found in (Teppati Losè, Chiabrando, & Tonolo, 2021).

3. From point clouds to HBIM

Two main products were generated starting from the point cloud derived from the metric survey: traditional 2D drawings and a first HBIM model. The creation of an HBIM "as-built" model represents a further step of the documentation project of the belltower.

As is well known, the use of this type of data (point clouds) in the BIM software solutions is still not fully implemented and different challenges need to be addressed when adopting this approach, especially when dealing with a complex architectural object.

Different solutions were tested in the BIM software used (Autodesk Revit), both using built-in tools and external plugins or software.

The first approach tested for the creation of the HBIM model consisted in a more consolidated solution, that started with the import of the point cloud in the Autodesk Revit software and the subdivision of the belltower in different main portions. For each of the eight portions created a series of sections was then extracted to serve as the geometrical base for the creation of the main volumes constituting the belltower. Thereafter, the sections were manually vectorialized and served as core elements to create the main volumes of the belltower (Figure 6). After this first phase of modeling, each face of the new volumes created was converted into wall elements, and information derived from the joint use of indoor and outdoor data was applied (e.g., thickness, stratigraphy, etc.). Concluded this initial modelling phase, it was necessary to refine the details of the belltower (decorative elements, windows, niches, etc.) that needed to be individually modeled exploiting different tools provided by Revit (e.g. cutting geometry using solids) and using as reference the different point clouds. It was particularly challenging to model the molding and the decorative bands for which three different strategies were tested: i) sweeping a 2D profile along a path, ii)using AutoCAD and Rhinoceros to create more complex NURBS and, iii) increasing the number of sections on the element to be modeled (Figure 7).

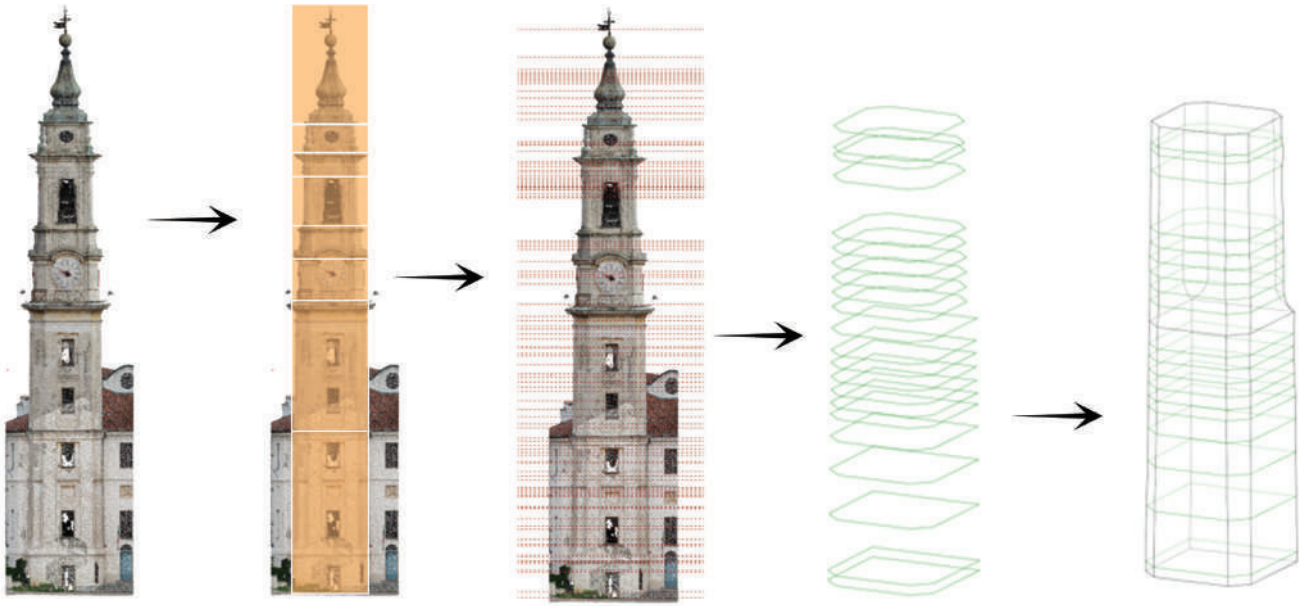

Figure 6. Standard approach from point cloud to solid geometry.

Furthermore, considering that some decorative elements are repeated on the four facades it was possible to create specific families inside Revit and to customize all the related parameters.
A final step of this process was connected with the enrichment of the HBIM models with a series of information. Data derived from historical sources and in situ inspections concerning the wall stratigraphy and materials were added to the model. Moreover, extracts of the orthoimages of each facade were connected as image parameters where it was necessary to underline specific features such as state of decay, missing elements, etc. The generated HBIM model was finally validated using an M2C (Model to Cloud) analysis thanks to the plugin FARO As-Built for Revit; results from this analysis are reported in Figure 8. It needs to be reported that the plugin failed to analyze the portions modeled inside Rhinoceros and thus further analyses are needed on these elements. The image reports the analyses conducted using the point clouds as a ground

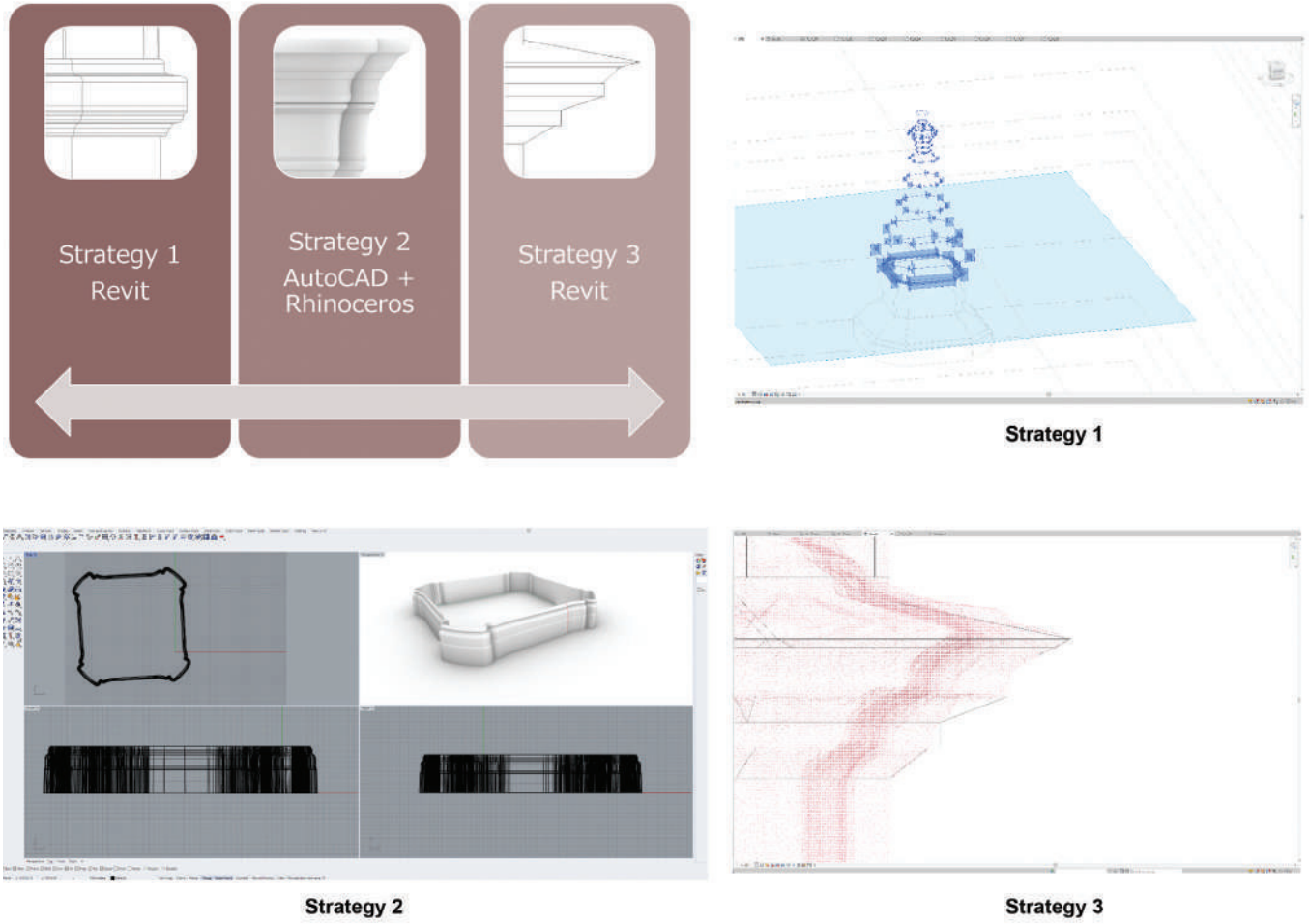

Figure 7. Example of the different modeling approaches tested.

reference and shows the deviation of the HBIM model. As is possible to notice results can be considered satisfying, especially for a complex asset like the Santa Marta Belltower and are in a range of few centimeters. Results are under 2 cm in areas constituted from the more simple geometries of the belltower, while a bigger deviation can be observed in the more complex parts where the modelling phase was more challenging (mainly in the higher moldings of the structure).

4. Conclusion and further perspectives

The documentation project of the Santa Marta Belltower allowed tailoring several issues connected with the different phases of the documentation work,

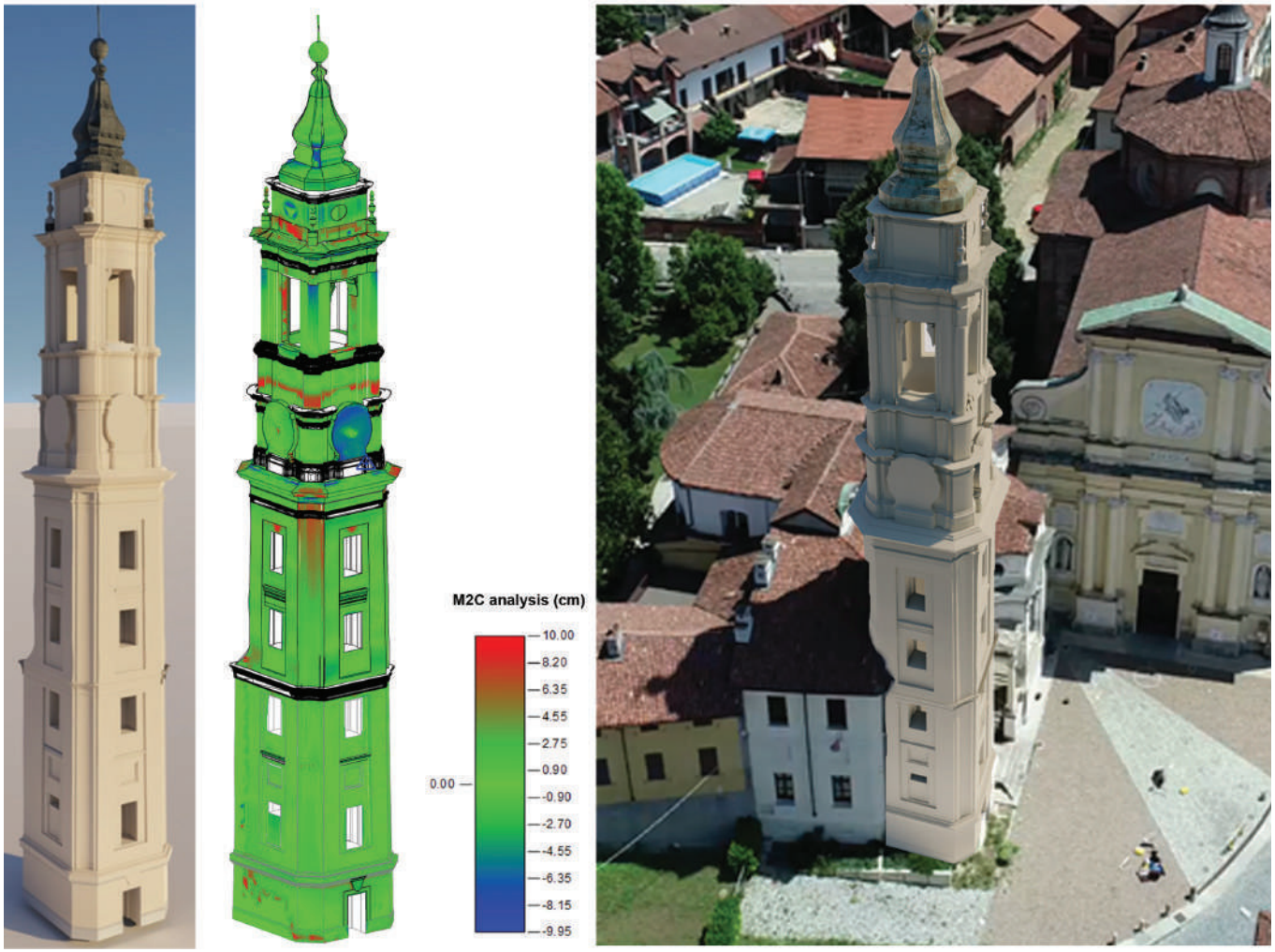

Figure 8. The final HBIM model and the results of the M2C analysis.

exploiting all the survey pipeline from survey design, via data acquisition, processing and validation, to the generation of addedvalue products including the HBIM model. In this contribution, the focus was on the modelling phase. After data acquisition and processing, for the creation of an as-built parametric model. It is clear from the experience conducted and from the result presented that, despite the advancement of the last years, this phase is still the most time-consuming and the one that requires a high effort from the involved operators. Automatization is still missing, or at least is at its initial phase of development, and the use of point clouds in the modelling requires expertise and experience. Different strategies have been tested for the management of survey products in the phase of 3D modelling, both inside the Revit software, both using external solutions or ad hoc plugins. Nevertheless, every strategy has its own pros and cons and needs to be selected mainly considering the characteristics of the asset. This is particularly evident when dealing with Built Heritage which lacks the possibility of standardization and still requires the research of new solutions for enhancing this phase of work. A contribution in this sense can be provided by the recent development of AI (Artificial Intelligence) approaches applied to Cultural Heritage, which is a hot research topic continuously evolving.

Notes

1 https://www.dji.com/uk/phantom-4-pro/info#specs

2 https://geoslam.com/solutions/zeb-revo-rt/

3 https://www.cloudcompare.org/

Bibliography

Achille C., Fassi F., Mandelli A., & Fiorillo F. (2018). *Surveying Cultural Heritage: summer school for conservation activities*. Applied Geomatics. https://doi.org/10.1007/s12518-018-0225-3.

Adami A., Fregonese, L., Gallo, M., Helder, J., Pepe, M., & Treccani, D. (2019). *ULTRA LIGHT UAV SYSTEMS FOR THE METRICAL DOCUMENTATION OF Cultural Heritage: APPLICATIONS FOR ARCHITECTURE AND ARCHAEOLOGY.* ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Infor-mation Sciences, XLII-2/W17, 15–21. https://doi.org/10.5194/isprs-archives-XLII-2-W17-15-2019.

Banfi F. (2020). HBIM, 3D drawing and virtual reality for archaeological sites and ancient ruins. Virtual Archaeology Review, 11(23), 16–33. https://doi.org/10.4995/VAR.2020.12416.

Barba S., Ferreyra, C., Cotella V. A., Filippo A. di, & Amalfitano S. (2021). A SLAM *Integrated Approach for Digital Heritage Documentation*. Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 12794 LNCS, 27–39. https://doi.org/10.1007/978-3-030-77411-0_3.

Battaglio M. (2000). *L'ultimo Vittone. Il campanile di Montanaro nuovi rilievi e fonti d'archivio*. (E. Litoart, Ed.)

Brumana R., Georgopoulos A., Oreni D., Raimondi A., & Bregianni A. (2013). *HBIM for Documentation, Dissemination and Management of Built Heritage. The Case Study of St. Maria in Scaria d'Intelvi*. International Journal of Heritage in the Digital Era, 2(3), 433–452. https://doi.org/10.1260/2047-4970.2.3.433.

Chiabrando F., della Coletta C., Sammartano G., Spanò A. T., & Spreafico A. (2018). *"TORINO 1911" project: A contribution of a SLAM-based survey to extensive 3D heritage modeling*. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 42(2), 225–234. https://doi.org/10.5194/isprs-archives-XLII-2-225-2018.

Chiabrando F., Lingua A., Maschio P., & Teppati Losè, L. (2017). *The influence of flight planning and camera orientation in UAVs photogrammetry. A test in the area of rocca San Silvestro (LI), Tuscany*. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 42(2W3). https://doi.org/10.5194/isprs-archives-XLII-2-W3-163-2017.

Georgopoulos A. (2018). *Contemporary digital technologies at the service of Cultural Heritage*. In Heritage Preservation: A Computational Approach (pp. 1–20). Springer, Singapore. https://doi.org/10.1007/978-981-10-7221-5_1.

Letellier Robin (2015). *Recording, Documentation and Information Management for the Conservation of Heritage Places. In Recording, Documentation and Information Management for the Conservation of Heritage Places*. Donhead Pub. https://doi.org/10.4324/9781315793917.

Malinverni E. S., Pierdicca R., Bozzi C. A., & Bartolucci D. (2018). *Evaluating a Slam-Based Mobile Mapping System: A Methodological Comparison for 3D Heritage Scene Real-Time Reconstruction*. 2018 IEEE International Conference on Metrology for Archaeology and Cultural Heritage, MetroArchaeo 2018 - Proceedings, 265–270. https://doi.org/10.1109/MetroArchaeo43810.2018.13684.

Nex F., & Remondino F. (2014). *UAV for 3D mapping applications: A review. Applied Geomatics*. 6(1), 1–15. https://doi.org/10.1007/s12518-013-0120-x.

Patias P. (2007). *Cultural Heritage documentation*. In J. Fryer, H. Mitchell, & J. Chandler (Eds.), Applications of 3D Measurement from Images. Whittles Publishing.

Remondino F., Barazzetti L., Nex F., Scaioni M., & Sarazzi D. (2012). *Uav Photogrammetry for Mapping and 3D Modeling – Current Status and Future Perspectives*. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Infor-mation Sciences, XXXVIII-1/(September), 25–31. https://doi.org/10.5194/isprsarchives-XXXVIII-1-C22-25-2011.

Remondino F., & Stylianidis E. (Eds.). (2016). *3D Recording, Documentation and Management of Cultural Heritage*. Whittles Publishing.

Riisgaard S., & Blas M. R. (2004). *SLAM for Dummies*. Massachusetts Institute OfTechnology Projects, 1–127.

Russo M., Carnevali L., Russo V., Savastano D., & Taddia Y. (2018). *Modeling and deterioration mapping of façades in historical urban context by close-range ultra-lightweight UAVs photogrammetry*. International Journal of Architectural Heritage, 00(00), 1–20. https://doi.org/10.1080/15583058.2018.1440030.

Sammartano G., & Spanò A. (2018). *Point clouds by SLAM-based mobile mapping systems: accuracy and geometric content validation in multisensor survey and standalone acquisition*. Applied Geomatics, 10(4), 317–339. https://doi.org/10.1007/s12518-018-0221-7.

Teppati Losè L., Chiabrando F., Novelli F., Patrucco G. & Perri S. (2021, April 26). *DOCUMENTATION OF A COMPLEX Cultural Heritage ASSET WITH INTEGRATED GEOMATIC SURVEY: THE MONTANARO BELL TOWER*. ARQUEOLÓGICA 2.0 - 9th International Congress & 3rd GEORES - GEOmatics and PREServation. https://doi.org/10.4995/arqueologica9.2021.12107.

Teppati Losè L., Chiabrando F., & Tonolo F. G. (2021). *Documentation of Complex Environments Using 360° Cameras. The Santa Marta Belltower in Montanaro*. Remote Sensing 2021, Vol. 13, Page 3633, 13(18), 3633. https://doi.org/10.3390/RS13183633.

Yang X., Grussenmeyer P., Koehl M., Macher H., Murtiyoso A., & Landes T. (2020). *Review of built heritage modelling: Integration of HBIM and other information techniques*. In Journal of Cultural Heritage (Vol. 46, pp. 350–360). Elsevier Masson. https://doi.org/10.1016/j.culher.2020.05.008.