

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

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editors

D-SITE

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



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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	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





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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

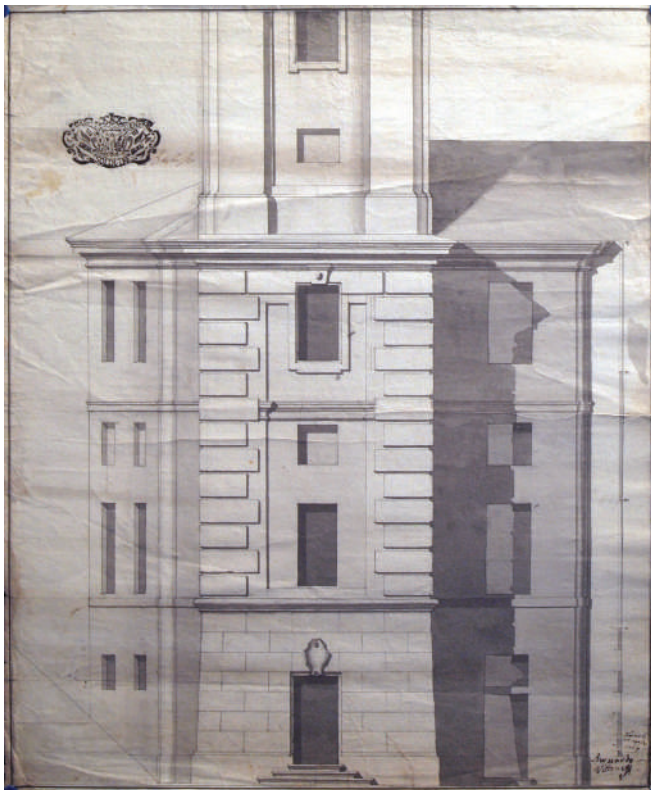


Figure 2. An example of the drawings (Historical Archive of Montanaro) carried out by B. A. Vittone: the main façade (1769-1772).

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 Pro¹ 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 3. UAS acquisition scheme (left) and examples of acquired images (right).

within the ZEB Revo RT². 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

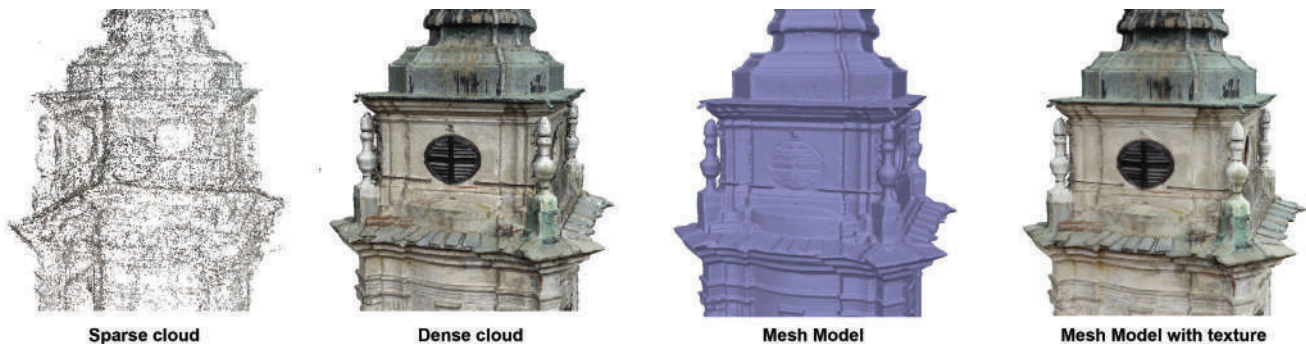


Figure 4. Example of the quality of the 3D models generated by the UAS photogrammetric processing on a portion of the belltower.

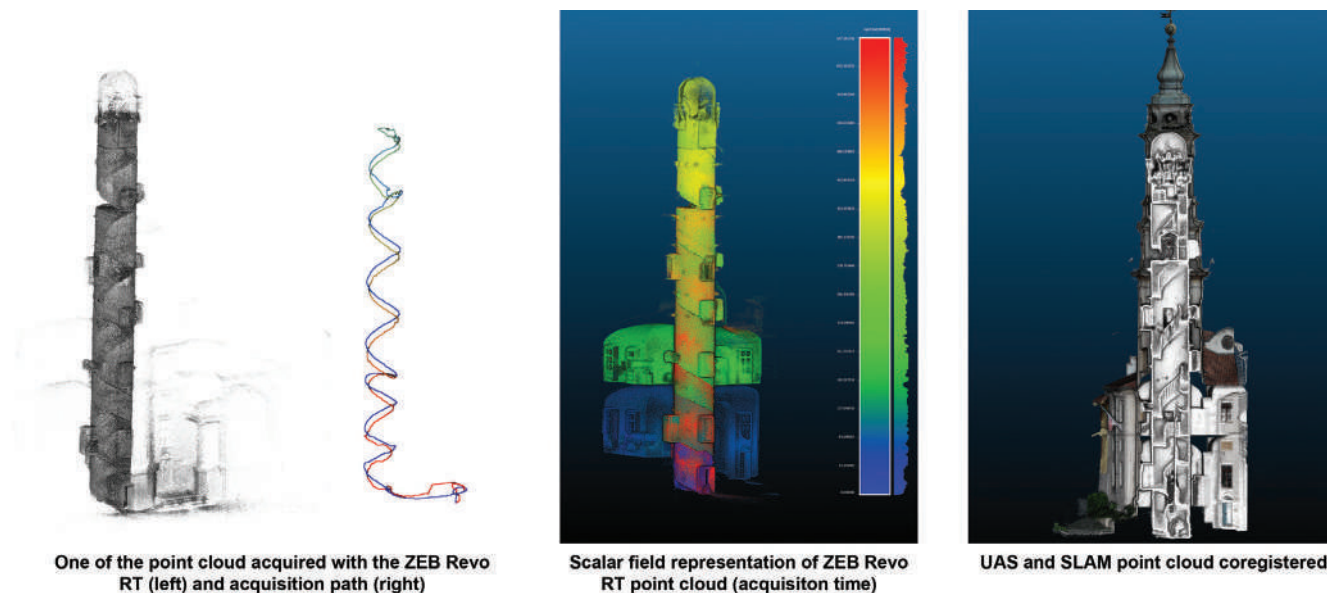


Figure 5. Workflow of the on the field survey (left), schema of the GNSS network and the position of the ground marker used for the photogrammetric UAV processing (center). Topographic measurements total station (right).

images and the reduced sensor/object 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 CloudCompare³. 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, Chiabrand, & Tonolo, 2021; Teppati Losè, Chiabrand, 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, Chiabrand, & 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).

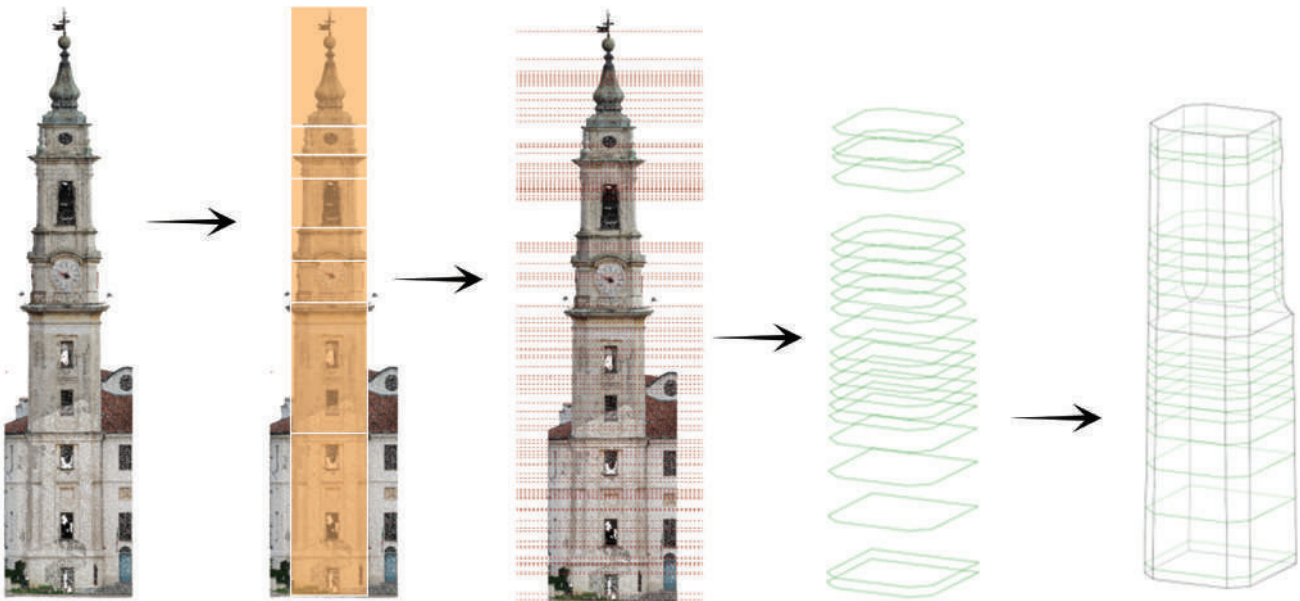


Figure 6. Standard approach from point cloud to solid geometry.

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

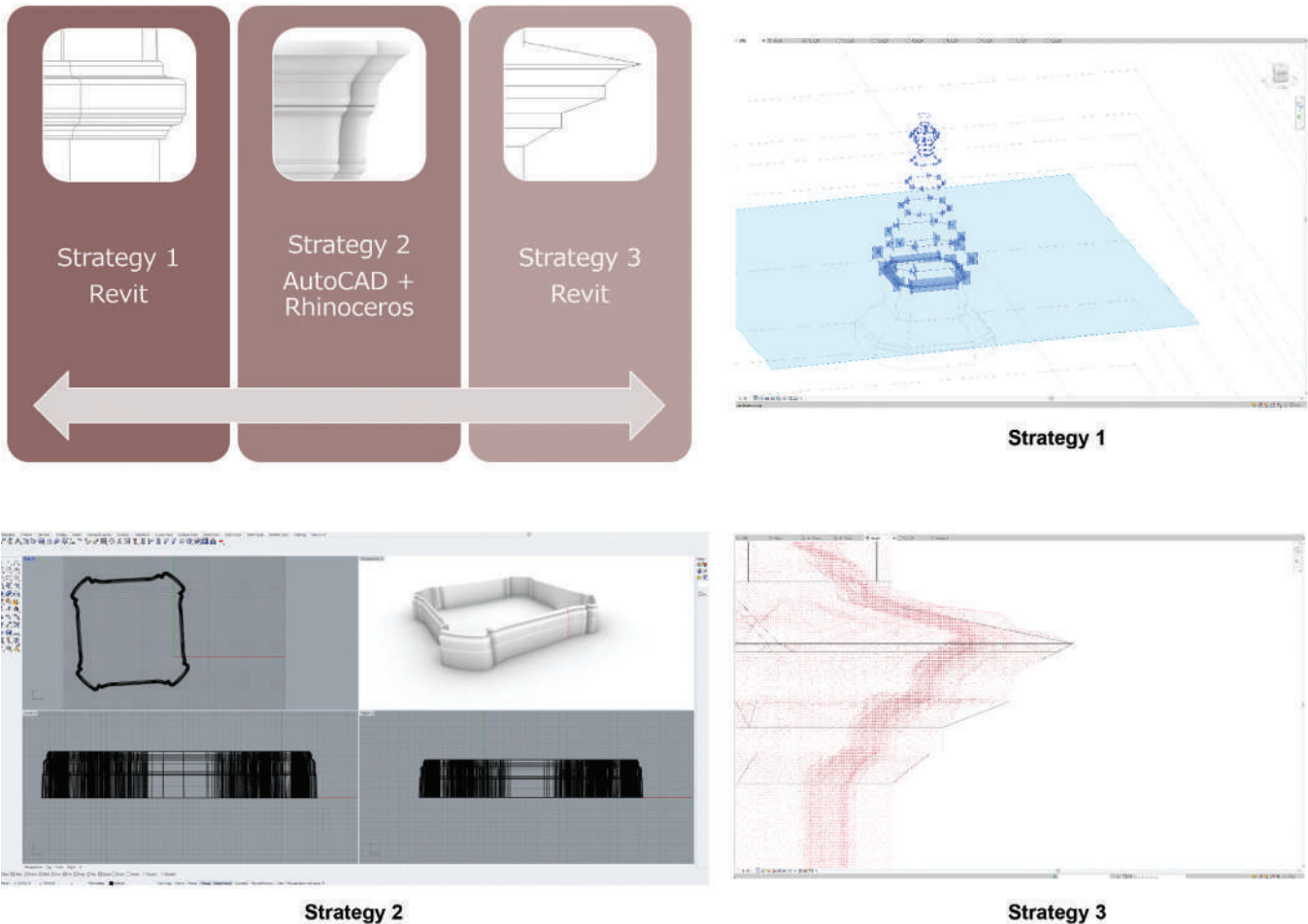


Figure 7. Example of the different modeling approaches tested.

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,

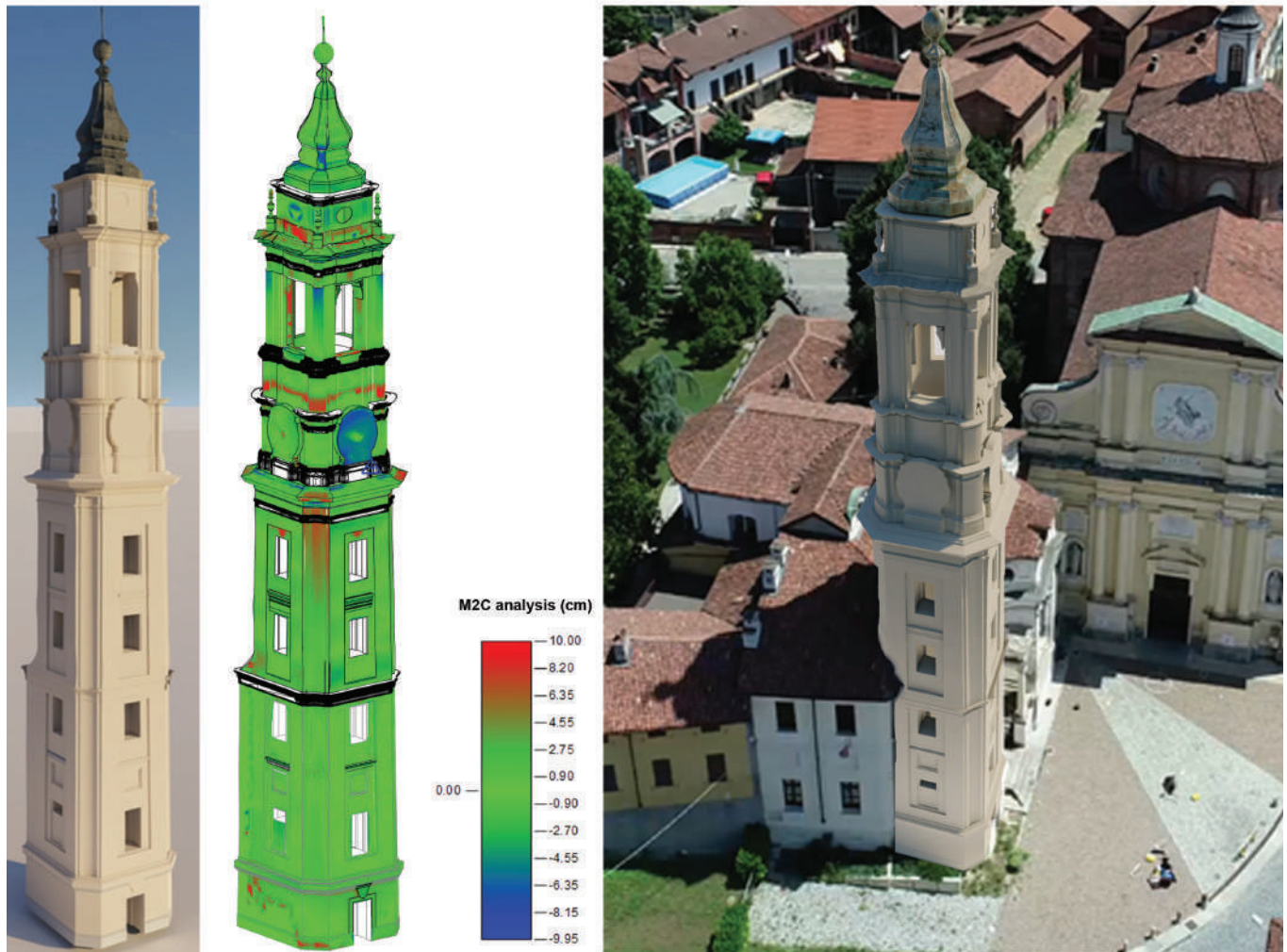


Figure 8. The final HBIM model and the results of the M2C analysis.

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/>

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