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editors

D-SITE

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

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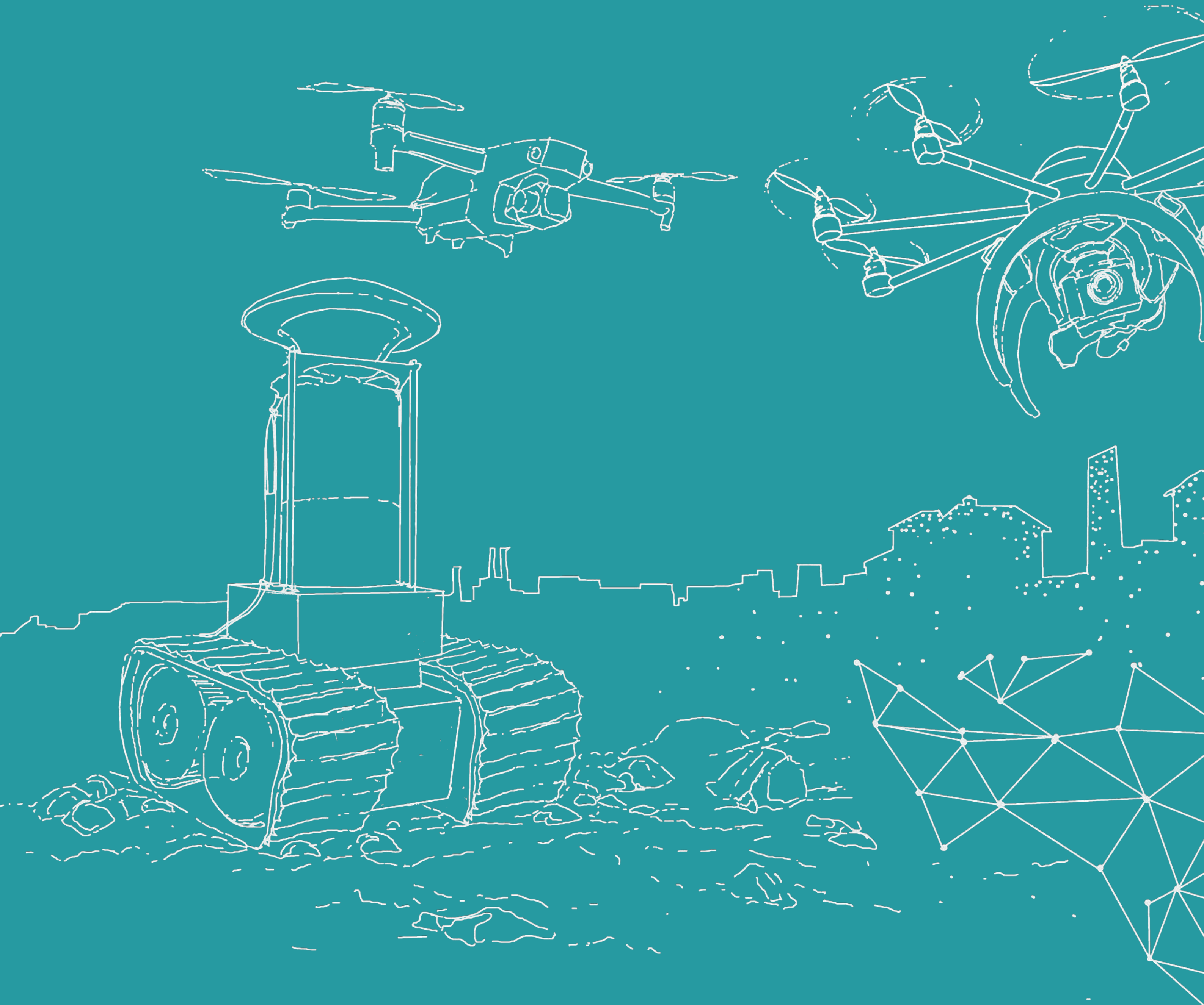

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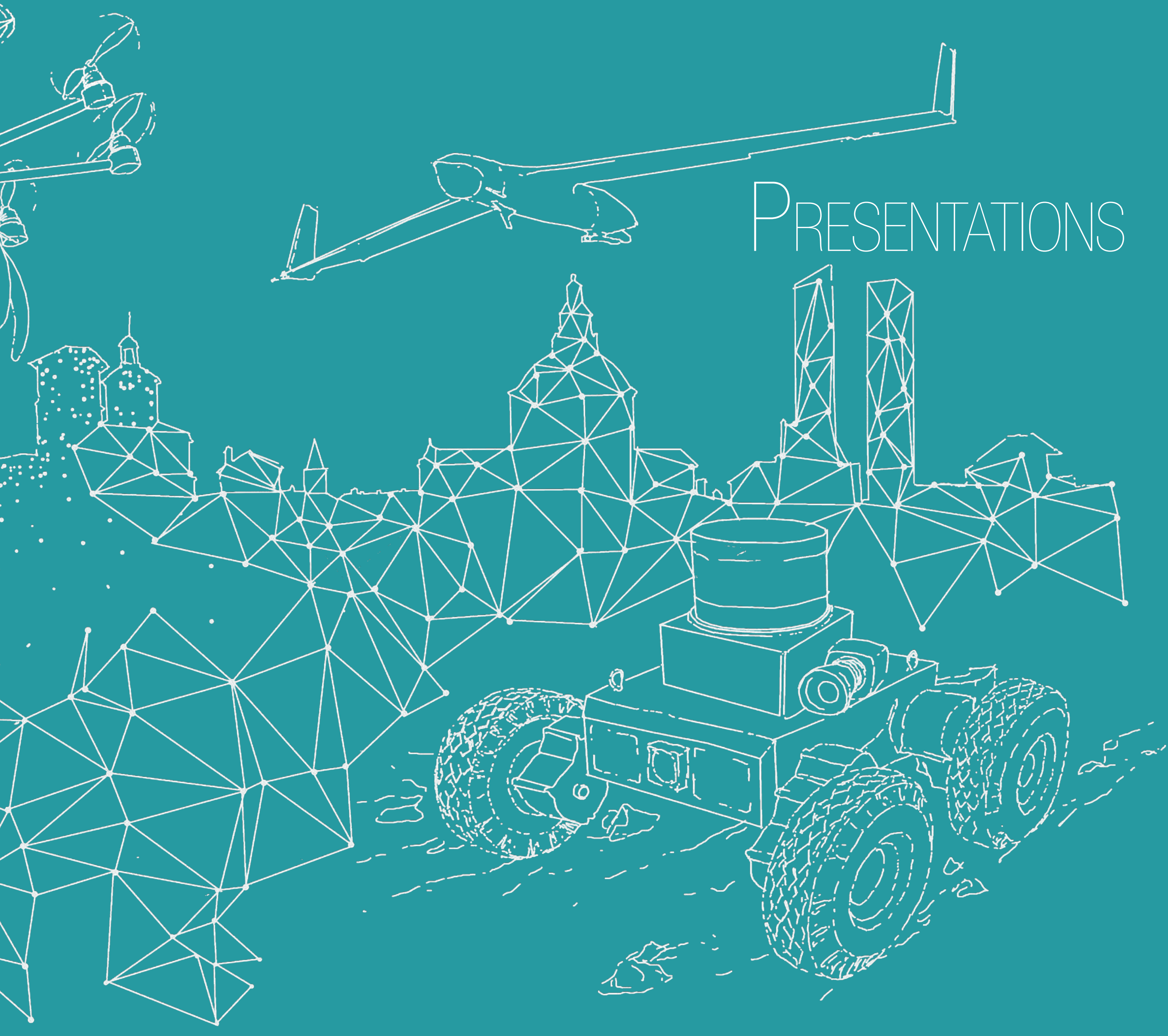






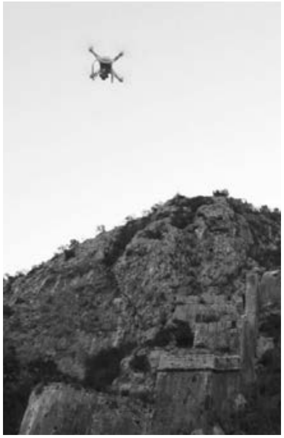



Research activities on the use of drones conducted by the Experimental, Didactic and Research Laboratory DAda-LAB (Drawing and Architecture DocumentAtion), of the Department of Civil Engineering and Architecture of the University of Pavia.

Alessandro Reali
Head DICAr - Department of Civil Engineering and Architecture
University of Pavia

In the past five years, we have witnessed a revolution that has affected the field of digital representation and communication systems. This process has changed the definition of objectives and constantly renewed the offer and requirement for acquisition tools that allow to amplify the possibilities of analysis and inspection at different scales of investigation.
In this sense, remotely controlled UAV technologies that allow us to raise our eyes and reach new horizons of observation to monitor our territory and architectural heritage have increasingly developed.
The use of drones, together with the training of qualified piloting figures, is increasing exponentially, thanks to the different application possibilities involving various areas: from the management of emergencies to the monitoring of agricultural land, to the creation of virtual models in the field of the construction sector.
The theme of the enhancement and conservation of cultural heritage is closely connected to the experimentation of innovative processes of documentation, management, and use of knowledge.
The development of optimized flight control algorithms and sensors and the use of cameras with increasingly high-performance optical lenses make it possible to find high-performance but low-cost machines on the market, offering a wide range of analysis possibilities. Remote pilot systems are part of a relatively "new" generation of tools in the field of cultural heritage, allowing the extensive documentation activities and reducing acquisition times and costs.
The spread of aerial shooting methodologies allows new categories of model development. These outputs can be used as tools for specialist knowledge or for disseminating and preserving the heritage historical memory At this particular moment, a reflection, conducted by national and international research centers, on the study of management and data processing systems for the protection, enhancement, and dissemination of cultural heritage appears to be necessary.
The event "D-SITE - Drones Systems of Information on culTural hEritage", which should have taken place at the headquarters of our Department, has the laudable purpose of being the first point of a global discussion on this issue.
The aim is to define of state of the art on the phenomenon of using UAV devices for the Cultural Heritage sector.
The research actions illustrated in this volume are the result of experiments conducted by excellent research laboratories and constitute a collection of contributions to the different possibilities of applying UAV technologies, which lays the foundations for exciting developments in these disciplines.
The involvement of companies and the development of the so-called "third mission of the University" is of particular interest to the event. In particular, the collaboration between DJI Enterprise and our Department, promoted by a relationship with the DAda-LAB Laboratory, is an example of how these synergies can be of interest to cultural development operations with important aftermaths on applied sciences.
As Director of the Department of Civil Engineering and Architecture of the University of Pavia, I want to thank the editors of the volume. I believe that the release of this publication, after the lockdown period that hit our Country during the first half of 2020, well represents the commitment and constancy of the Department's Research and Didactic Laboratories, as a tangible demonstration of the continuity of the activities planned for the year 2020.
This volume is a concrete sign proving the fact that the University Entities have continued and continued their research and training activities with passion and commitment despite the period of distancing and closing of the offices.





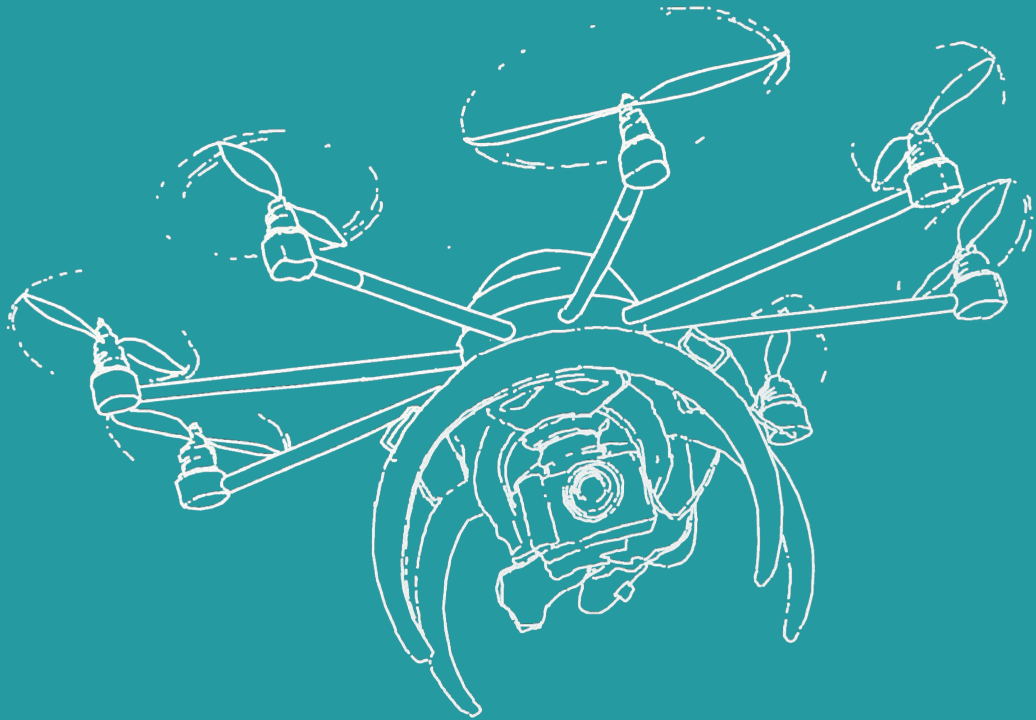


Pierguido Sarti
Scientific and Technological Attaché - Embassy of Italy in Pretoria
South Africa

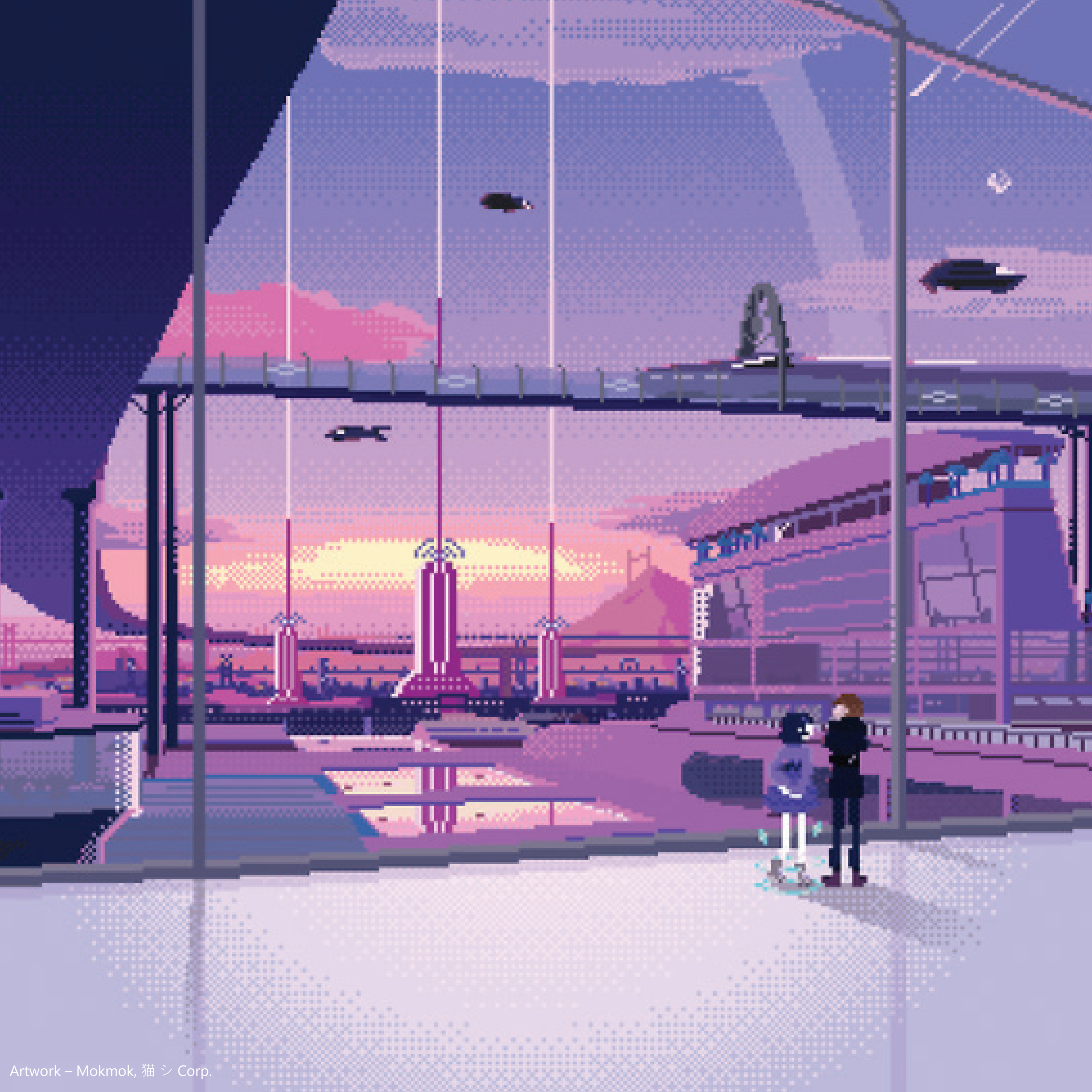
Greetings from beautiful and sunny Pretoria, despite the sunshine, I must say, it is quite cold it is winter here. I am the Scientific and Technological Attaché at the Italian Embassy in Pretoria. When Professor Salvatore Barba asked me to send this message, I immediately said yes. First and foremost, I would like to express my praise to the activities developed, especially towards the once realized throughout the last five years in South Africa with the cooperation of the Italian Ministry of Foreign Affairs and International Cooperation and the Tshwane University of Technology in Pretoria. The activities had indeed involved some Italian Universities and I had the chance to follow the development of their work. The activities are taking place within the framework of the Executive Programme for Scientific and Technological Cooperation between the Italian Republic and the Republic of South Africa for the years 2018-2020, in a Project for exchanging of researches in the thematic area, promoted by myself, in "New Technologies for Social Science". The current Executive Program has been extended by one year, so it will continue up to December 2021, as agreed with the National Research Foundation.

This is due also to the outstanding works and papers. The research presented here are extraordinarily successful, extremely interesting, and very well documented and reported. It is incredibly interesting to me specifically because I have a background in geodesy and topography.
Which means that the activities that are carried out are very close to my heart and scientific interest, in effect I work for the National Institute of Astrophysics.
What I can do now is, wish you the best for your research and I hope we will have a chance to meet soon in South Africa, maybe in Closing Workshop of ISARP - Italy/South Africa joint Research Programme, that will be organized in South Africa (Pretoria) before the end of March 2022.

Dictation of Dr. Pierguido Sarti presentation to the online youth exchanges 2019-20 "The DICIV goes to South Africa", Project co-funded by the Italian Ministry of Foreign Affairs and International Cooperation.



Preface



Artwork – Mokmok, 猫シ Corp.

Cultural Heritage analysis practices conducted through the use of drones: towards a renewed dimension of research

Sandro Parrinello
University of Pavia, Department of Civil Engineering and Architecture

Over the past few years, almost every discipline has been affected by a swirling increase of available technologies, contaminated by digital development, and by a deep-rooted change in productive and social models. In this revolution, certainly, the attention paid to ambitions on certain operating protocols have also contributed to qualify methodologies and tools, increasing the scope of possible actions in each scientific and productive sector. Considering Heritage documentation, drones are just representing a further instrument to acquire extremely advantageous information in a very short time. Due to the undeniable advantage that can be gained from their use, drones immediately found a great diffusion and a multitude of uses, which in turn have produced technical specializations and the development of additional equipment, instruments, and consequent survey methods. Today, the scientific address of this theme refers to the definition of a very huge panorama of applicative possibilities, which is still not well defined and requires a scientific comparison aimed at qualifying its specific characters of application. Moreover, similarly to the other digital tools that have appeared on market in recent years and that have increase the rhythm and speed of knowledge activities, the increase in the action coverage and the ease of interaction with this technology simultaneously produces an effect of detachment from the practice of analysis. A mainly physical detachment, in which the scholar no longer corresponds with the technical operator of the instrument, and where the surveyor, the designer and the project manager are increasingly required as individually specialized figures. In this disjunction from the close contact and study of a certain phenomenon, it is contained a risk of loss of quality, just as the increase in the speed of interaction within a specific context is increasing the risk to cause a detachment from that "processing time" necessary to understand and orient certain information related to a place. These are just some of the reasons that motivated the necessity for an event connected to the documentation of Heritage through the use of drones. It defines a moment of comparison between experts in the sector to gather the experiences that are concerning these technologies at an international level, as it seems necessary to understand what are the changes that this new methodologies of documentation are producing not only in terms of results on research products, but also on the consolidation of operating procedures. Today, considering the international calls, the requests for specialized operations conducted through the use of drones for agriculture, risk management and remote sensing are increasingly frequent. Many of them concern African countries or cities and monuments in the Middle East that are addressed to emergency actions, such as invasions of African locusts, or the development of survey systems in places affected by wars and where the security of an "on-site" operator would be compromised. In this panorama, the perception about the use for drones is changing and it emerges how these tools are increasingly entering the collective imagination in professional activity and beyond. Today, the visit to a touristic site, especially abroad, involves the presence of small drones flying above to take photographs and collecting suggestive moments of the travel experience. Drones, more and more minute and performing, are becoming, like the smartphone before them, a

Figure 1. Runaway (1984) and Back to the Future II (1989) are among the first films in which drones appear. In the first, the drone is the death tool capable of reaching its target anywhere, in the second, the drone has a positive meaning, becoming a useful tool that takes a dog for a walk. From 2010 onwards there are many films featuring drones used in different purposes. In the tragic future of Nolan's Interstellar (2014), where food is lacking because only a few crops resist the "plague", an Indian drone after many years of autonomy, out of human control, lands in the fields describing a prosperity now disappeared. In Spielberg's Ready Player One (2018), drones are an instrument that man has at his disposal, becoming both the means of delivering goods in the vertical slum of the "Columbus stacks", allowing people to live comfortably on Oasis, and the tool for the organization of a terroristic attack.

natural extension of man's action radius, and the user now is not only limited to communicate anywhere by projecting his voice and hearing, but he is also able to reach different viewpoints, until now difficult to be achieved, in a relatively simple way. The ability to observe the world as a bird has always been man's great dream and as Claudio Magris asserts that "the landscape is something similar to archaeology: a stratification of signs where you slowly sink to let stories emerge", so the act of sinking into this landscape of stories and signs is necessary to let man rise and be able to embrace as much information as possible. The collection of a new dimension, relative to a point of view that has a lower altitude than any airplane but high enough to not lose the same references perceived from the ground, represent the main possibility offered by the flying cameras. Within this specific level of distance, there is the possibility of generating wonder, showing those same things observed from the ground, from a different point of view, occupying unusual positions. It is not a coincidence that each drone owner likes to observe the place in which he lives from above.

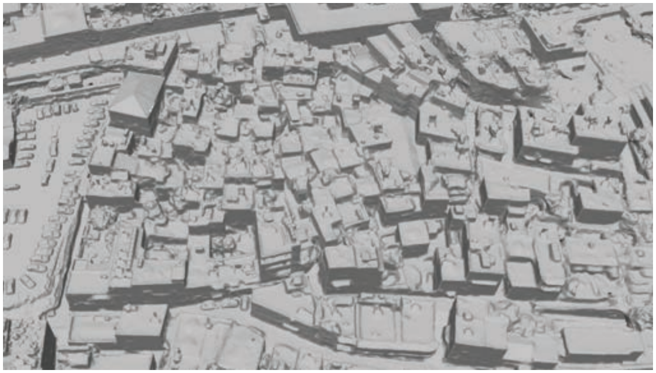
The reasons for this pleasure lie in an increasing knowledge concerning to an already known place, that is daily lived within a certain limit. The drone allows to overcome this limit, occupying different spaces. If on the one hand the specialistic technical aspect is affirmed as the safest of the intervention abilities, which allow these tools to acquire a certain degree of positivity and to be useful to society for a clear purpose, it is the possibility of extending the panorama at this new perspective to define the most important contours of a cultural revolution, another one added to the course of a few years. Thinking about how the cameras integrated into the smartphones have distorted the concept of photographic archive, Big Data and the story of everyday life, in this way the use of drones could, perhaps, extend these same archives with further data concerning "new" points of view. Thus, the collected images will be able to describe, more effectively, the space and morphology of an environment, a place with its characteristics and peculiarities and, even more convincingly, a landscape, understood as a consequence of transformations that determine a cultural identity.

Moreover, it is easy to think that not only photographic archives are possible, but also modelling archives. As the latest mobile phones can generate 3D models of their owners' faces (the recent security control systems of smartphones are based on a facial recognition that integrates chromatic information with three-dimensional information on the physiognomy of those users observing the camera - Face ID), arriving to define an archive that can reproduce a very large number of individuals on our planet, in a similar way the database that today is represented by Google Earth can be implemented, on other platforms perhaps, with an integrated archive of frames capable of defining the spatial identity of a certain environment in a semi-automatic mode. On the other hand, each frame is associated to information relating to the location of the shot, thanks to GPS coordinates, and at the same time of its capture, with the optical specifications of the camera associated with the instrument. Thus, it is possible to define a three-dimensional archive of camera shots from which to reconstruct increasingly performing models that will be able to qualify a high descriptive level of how urban spaces, villages, monumental architectures and inhabited places in general are made. It follows the implementation of that potential already expressed by Google Earth to build a time machine, which today is tied to the quality of the existing shots, but which already aims to become an increasingly detailed dynamic model. It represents an utopia, perhaps a partially dystopian vision of the future of databases, but it shows the development of the last twenty years, since the advent of Facebook, Instagram, WhatsApp, Tik Tok and similar, encouraging to believe that this utopia is not so impossible.

It is not for a coincidence that the first manifestations of these phenomena concern the scope, also in terms of extension, of the documentation and survey projects conducted through the use of drones. The theme of the digital city, which seemed almost a mirage twenty years ago, is now an increasingly frequent protocol. Historic centres digitally acquired with three-dimensional databases consisting of thousands of 3D laser scans and point clouds, which are integrated

Figure 2. Three-dimensional archive of the historic center of Bethlehem, made with over 2,200 laser scans integrated with the point clouds obtained from the photogrammetric survey conducted by high-altitude drones (for part of urban aggregates) and at low altitudes (for each public front and roof).

This is an archive that integrates and is integrated itself during the entire research course (2018-2020/2021). It counts over 24,000 photographs, which describe the complexity of the urban area, collected in three months of on-site work.



between photogrammetry and laser scanners, create information archives that can now be managed by a normal computer. Whole cities can thus be documented by channelling hundreds of thousands of photographs from which to obtain dynamic information.

Similarly to Instagram and Facebook archives, which today represent photo albums of entire nations, or like Spotify's sound databases or many repository systems and devices, it will probably possible to apply a digital memory archive that through the image will be able to reconstruct the space of the past and, just like in science fiction films, also to reconstruct scenarios belonging to other places and other times, with a certain reliability. Several researches that I had the opportunity to coordinate in recent years have been based on the possibility of making multiple measurements over time to evaluate relative displacements, deformations, or the increase in a crack pattern, at a level of detail made possible only thanks to current technologies and presence of a digital survey to refer to. I therefore believe that the possibility of information to persist over time is, as always, the main quality to which a documentation path must aim, in parallel with the possibility of generating information that, in the same processing time, continues to be accessible and decipherable. On the reliability of databases in this sense, it is then easy to imagine that in these large archiving practices the redundancy of data will produce an equally large loss of relevant factors.

Therefore, a state of the art on the applied methods becomes truly important, because it makes possible a specific reflection necessary in this field of application, regarding the different factors that characterize the practice of documentation conducted with these technologies. This reflection concerns: first of all the equipment, for which the continuous updates of models, prototypes and accessories, now risk to confuse less experienced people on the actual potential of use; secondly, the different methodologies adopted, the specificities of which are well described in the many research projects collected in the pages of these proceedings. This set of experiences effectively expresses a wide range of working possibilities as a basis to define

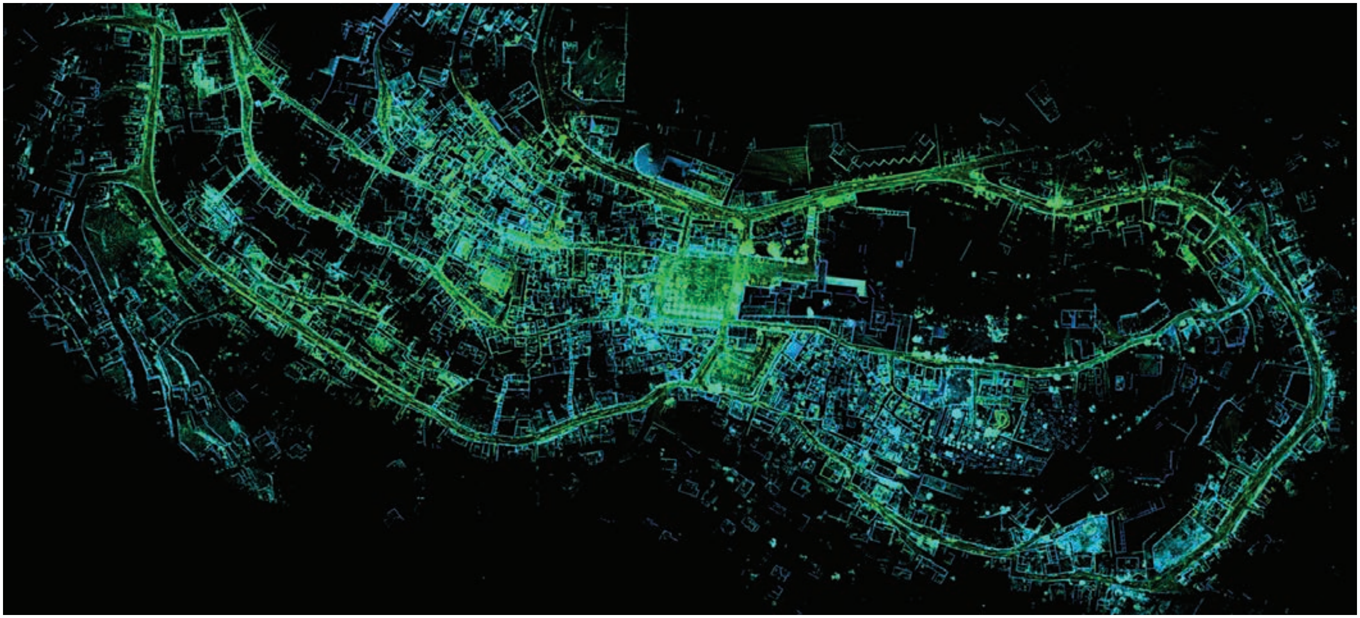


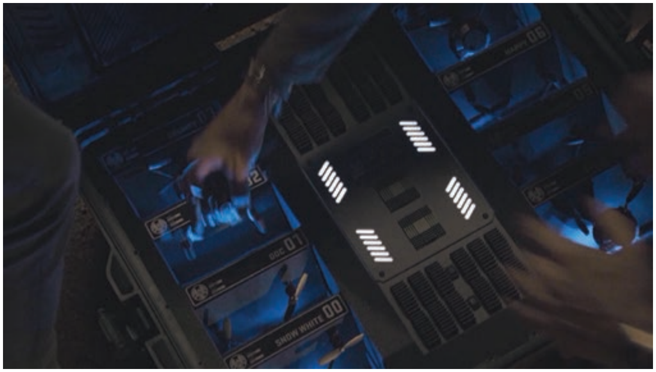
Figure 3. Training activities for students and researchers for drone piloting aimed at building reliable models using SfM photogrammetry.
Moments of practice lessons in Santo Domingo, Cartagena, Colombia and near Cherdyn, in Perm Territory in Russia.

action plans and active programs concerning to a hypothetical research project. Moreover, as doctors can consider PubMed as a term of comparison on procedural and technological innovations, in the other fields of science there is not a corresponding dissemination system of scientific practices that constitutes a unique reference of shared knowledge. It becomes appropriate to build experiences, such as the one proposed here, which constitutes the necessary corpus of information to generate moments of synthesis. It is not a coincidence that during this same year, three different scientific conferences are launched simultaneously in Europe with the same focus theme. We extended our purposes to these parallel events, looking for future sharing and program, imagining that one of the fundamental objectives of these experiences is the possibility to connect the different networks of scholars. For those who work in this sector, across multiple scientific realities, it is essential to be able to determine standards, and sharing practices as the most effective way of reaching their univocal definition. These aspects are then linked as a specific consequence to an important reflection on the data acquired and its archiving, also about certain issues of rights regarding images, properties and the protection of privacy rights. Finally, and perhaps at this moment with a priority aspect over the rest, a critical comparison on the quality of the models produced and on the different variations that these models may have to describe and represent a certain phenomenon becomes necessary. Whenever a "new" tool is applied with such frequent experiments that generate interesting results, it makes sense to define standards, as happening for the parametric modelling, useful for defining the accuracy levels of the three-dimensional databases produced. In this way, it becomes possible to guarantee quality standards for the benefit of the correct

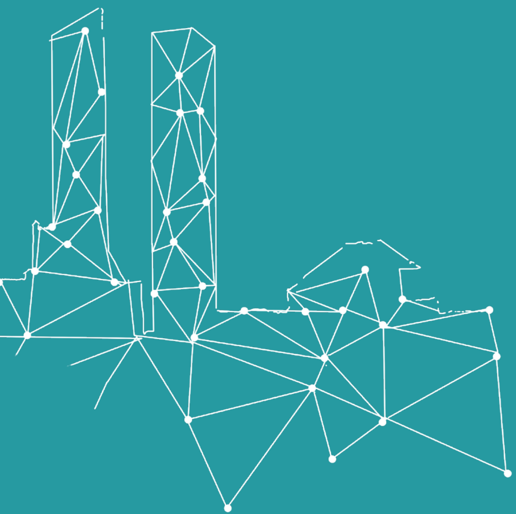
Figure 4. The D.W.A.R.F.s - Drones Wirelessly Automated to Retrieve Forensics, are the small drones used in the science fiction of Agents of Shield during a laser scanner detection of an internal environment.

execution of a professional service that concerns this type of specialist intervention. For example, this characterization of standards took a long time to be defined in some way for laser scanner surveys, so that it is perhaps possible to say that certain requirements have never really come into force in common practices. In any case, as a function of these correct protocols, universities have been moving for some time within important training actions which are added to the practical training of pilots in the case of surveys with UAV. At the didactic level, the university research laboratories are equipping themselves with numerous tools to make these experiences more and more connected with the framework of technical and professional training. To this effort from institutions and individual research laboratories, it is also to be considered a trend that characterizes many young people studying in the faculty of Engineering: a spontaneous approach and interest in these issues. The student first starts to approach these experiments in a self-education form, and then finds a specific characterization in the more specialized practices.

A similar phenomenon is affecting 3D printing, and it is not coincidence that in many universities in Central and South America these instruments are collected in common laboratories where the entire production process of the data is developed, from the acquisition of information for the construction of reliable reality-based models, till to reach to the management of reverse modelling, reverse engineering and prototyping processes. This reality testifies a trend that is very well received and that concerns the insertion of the latest production and analysis technologies towards operational models involving both artistic experiences and more exquisitely technical and technological abilities. Considering how the operation of drones is shown in the study courses, seeking the involvement of students in the development of analysis practices, it should however be highlighted that the potential of these tools, especially for civil practices and Cultural Heritage, is still enormously reduced and contained. Only considering to the potential of involving drone swarms and to the research in this field to coordinate multiple action profiles



on associated tool sets, it is possible to imagine how in the short future the actions of architectural, landscape and city documentation will further change in favour of these technologies.
The science fiction of Agents of Shield's Drones Wirelessly Automated to Retrieve Forensics D.W.A.R.F.s is not so far from being plausible, imagining that multiple cameras work simultaneously in the reception and reconfiguration of metric reliable three-dimensional scenarios. Regardless the interactivity of recovery systems and the possibility of coordinating data flows, it is certain that a redefinition of the analysis schemes and the configuration of the databases on Heritage is already underway.This renewed form of storing information, which then resides in the construction of digital spaces, generates an additional level of complexity which is, however, at the same time an opportunity for the use of information and updating about the possibilities of digital projection of Cultural Heritage.
Today more than ever, following the events related to these last months and the health emergencies, we have understood the importance of a digital projection of Heritage, and the construction of digital dissemination tools. Drones, engaged in projects of the Red Cross and the Civil Protection, aimed at integrating man's ability in the places of greatest risk, are an opportunity for the development of a digital projection of complex spaces. It is therefore with this sense of responsibility that the promoted research activities help to define development scenarios not only for Cultural Heritage, but for entire communities and societies.
The society of tomorrow already begins to look at digital cultural assets with completely different attention than the scepticism that governed this sector a few years ago and therefore the use of drones is to be considered a resource for achieving ever more performing objectives to produce a widespread knowledge for the benefit of all.



Conference Papers

TOPIC

3D Models from UAVs for the visualization and conservation of Cultural Heritage

Salvatore Barba, Andrea di Filippo, Carla Ferreyra, Marco Limongiello

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Keywords:
Cultural Heritage, Simultaneous Localization and Mapping, Unmanned Aerial Vehicle.

ABSTRACT

This paper presents an efficient solution, based on the integration of different survey systems, for the digitalization and modelling of a complex cultural heritage building. A pipeline of procedures for the acquisition of data, processing and generation of 3D products over a medieval structure located in Ravello, Italy is formalized. Multidimensional topographic techniques have been implemented. The exterior was acquired by an UAV photogrammetric technique, while for the intricate interior space, the wearable mobile laser system has been the most suitable solution for the design of restoration actions. The results obtained from this integration are corroborated by the robustness and precision of the digitalization strategy, which allows the generation of products with a high level of quality promptly. This multidisciplinary and technological vision of heritage protection aims to be the key digital tool in current efforts to conserve, study and promote Cultural Heritage.

A pipeline for the integration of 3D data on aerophotogrammetric frameworks. The case study of Villa Rufolo

1. Introduction

1.1. Digital Documentation

Cultural Heritage can be defined as a living memory of our society, an irreplaceable testimony of a particular moment in the history and it is an essential but non-renewable resource (Niglio 2012). In order to promote its specialized knowledge, the aim is to encourage a widespread appropriation by the community and thus transmit its value and duty of protection (Letellier & Eppich 2015; Whelan 2016). Digital survey plays a key role in its documentation; it provides an interesting and innovative scientific basis for study and research, in addition to ensuring an effective dissemination approach even for a non-technical audience (Torres-Martínez et al. 2016). The output facilitates historical interpretations and is a tool for designing strategies for the and preservation of Heritage. This paper collects the survey experiences matured during a collaboration between the University of Salerno, in particular the "Laboratorio Modelli, Surveying and Geo-Mapping for Environment and Cultural Heritage" of the Department of Civil Engineering, and the direzione di Villa Rufolo, creating a multidisciplinary team. The data acquisition and processing are carried out as part of this laboratory project, born with the aim of experimenting with new integrated survey techniques as a basis for a critical analysis, focused on a site study with scientific rigor and precise knowledge. The methodology, applied to a case study of medieval Italy, today a world heritage site, provides a database for academic purposes that will be used for successive recovery projects.

Villa Rufolo, recognized as a cultural symbol of the city of Ravello, for its immense landscape, and its historical and cultural value, is one of the greatest exponents of Arab-Byzantine architecture on the Amalfi coast, in southern Italy. This monument dates from the XII century and has undergone numerous alterations over the centuries. From its construction, the property was fragmented and divided among several owners until the 19th century, with the arrival of a Scottish lord who, with an architectural recovery project, turned the monument into a centre of international cultural fervour. A space that then and even today is a source of inspiration for writers, musicians, poets, artists or simply art lovers.

1.2. Strategies of Conservation

The laboratory activities have been developed, implementing a critical approach of surveying and documentation, to discover, document and disseminate the acquired information.

With the aim of contributing to the correct reading of the architectural object by applying the rules of scientific rigor, as well as new technologies for the dissemination of heritage. To create digital models for a better analysis of the object that serves as a basis for possible restoration projects or documentation for the dissemination of Heritage. Through an extensive documentary research integrated with innovative data collection and processing techniques, a critical approach to heritage analysis and documentation has been implemented.

Digital technologies, instruments and techniques not only facilitate and improve the technical-scientific processes traditionally used for the protection of heritage, but also modify how it is understood, perceived and transmitted, offering a new horizon of strategies to make decision-making on its conservation more sustainable over time.

2. Material and methods

The main goal of this benchmark is the generation of an accurate 3D model with the integration of active and passive sensors for the documentation and subsequent conservation of complex architectural heritage. Obviously considering the compatible and integrative workflow within the panorama of range-based and image-based methodological processes, and analysing the nature of the output obtained from this data integration by comparing models in terms of quality and detail. The section briefly introduces the instrumentation used during the acquisition phase, specifying the technical characteristics and technological principles underlying its operation, and describes in detail procedures and algorithms for the processing of raw data from the acquisition phase, detailing the contents for the different sources.

2.1 UAV-based Photogrammetry

The need to acquire and manage accurate and geo-referenced three-dimensional data is a common factor in many cultural heritage disciplines, from engineering to archaeology.

Figure 2. Entrance tower and central courtyard that reflects Villa Rufolo historical and artistic value.

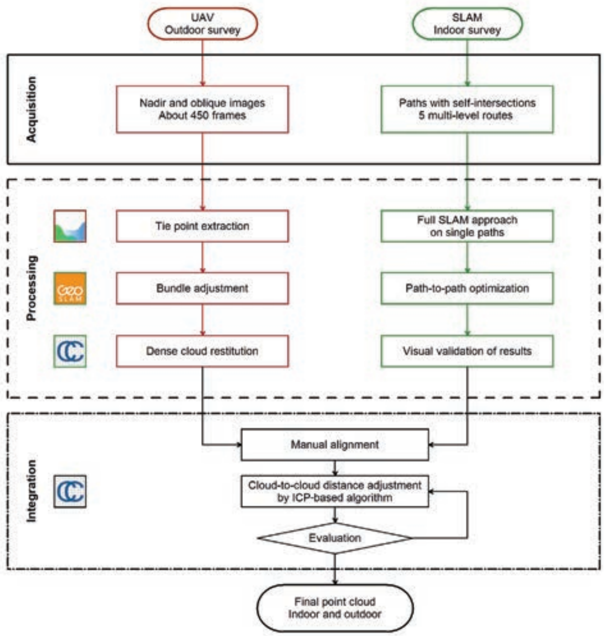

Figure 3. Block diagram of the proposed methodology.

The Phantom 4 is an aircraft that weighs approximately 1400 g, capable of shooting video in 4K and streaming HD videos on smartphones, tablets and external devices through a special App (DJI Go). The camera is equipped with a 12 MPixel Sony Exmor sensor (size 6.3 x 4.7 mm sensor, pixel size 1.56 μm), which has a wide-angle lens with focal length 4 mm and FOV (Field of View) of 94°. The camera is integrated in the gimbal to maximize the stability of the images during the movements. In order to control the metric error, 14 GCP are detected on the arena floor by a Geomax Zenith 25 used in RTK mod. The accuracy of planimetry is below 1 cm and 2.5 cm for altimetry. For the acquisition of the frames, two flight are prepared, both automatic and with double grid: a first one for the acquisition of nadir photogrammetric images and a second one, with the optical axis tilted about 45 degrees, to survey the vertical walls and any shadow cones.

The flight lines are designed using the DJI Ground-Station software package.

For all the grids, the UAV is set to a target al.titude of 16 m above take off point - Torre Maggiore - (46 m from Duomo Square) and horizontal ground speed of 4.0 m·s−1. The height is calculated in the DJI Ground-Station software using elevation data derived from Google Earth.

Parallel flights lines are programmed to have an image overlap of 60% and sidelap of 60%, setting the proper camera parameters (dimensions of the sensor, focal length and flight height). In the nadir flights, 93 and 94 images are acquired for the first (from North to South) and second (from West to East) grid, respectively. Two other flights, with the camera tilted at 45° on the horizontal plan, are carried out acquiring, respectively, other 92 and 163 photos. The image acquisition is planned bearing in mind the project requirements - a Ground Sampling Distance (GSD) of about 1 cm - and, at the same time, with the aim of guaranteeing a high level of automation in the following phases. Data treatment is performed by Agisoft Metashape, 1.5.3 build 8469 version. Its workflow is based on four steps: Align Photos, Build Dense Cloud, Build Mesh and Build Texture.

At the first step an algorithm evaluates the camera internal parameters (Focal Length, position of the principal point, radial and tangential distortions), the camera positions for each photo and the Sparse Cloud.

In the next phase, a greater pixel number is re-projected for each aligned camera, creating the Dense Cloud. In the Build Mesh step, it is possible to generate polygonal mesh model based on the dense cloud data.

Finally, the polygon model is textured in the Build Texture step. The outputs of the photogrammetric model, necessary for further documentation studies and data integration with active sensors, are a nadir orthophoto of the entire villa and the dense point cloud. The extracted point cloud has more than 48 million points, with average GCPs errors of about 2.8 cm.

2.2 SLAM-based Mobile Mapping

Besides, in order to obtain a complete model of the object of study, the data captured by the UAV must be integrated with other techniques, differing in terms of resolution, which will depend on the instrument used, but also on the characteristics of the object that is digitally proposed for the survey. The mobile mapping systems are a solution characterized by speed, flexibility and high quality of the results. These tools, combining motion sensors with observation sensors, can integrate and merge heterogeneous data streams through special algorithms, ensuring three-dimensional digital reconstruction of an object of study. Villa Rufolo, characterized by its articulated and complex spatial structure, due to its numerous temporal stratifications, becomes a benchmark to test the capabilities of this system.

The ZEB-ONE is the first mobile mapping system produced by GeoSLAM. It is a solution for the three-dimensional survey of environments that develop over several levels, able to acquire 43,000 points per second that will form a fully recorded cloud. This tool, combining motion sensors with observation sensors, can integrate and merge heterogeneous data flows through special algorithms, ensuring the three-dimensional digital reconstruction of areas of focus. It is equipped with a class one 2D laser profilometer, by a manual raw alignment. The maximum value of the RMS for the discrepancies between matching points on all the registration pairs is about 1.95 cm.

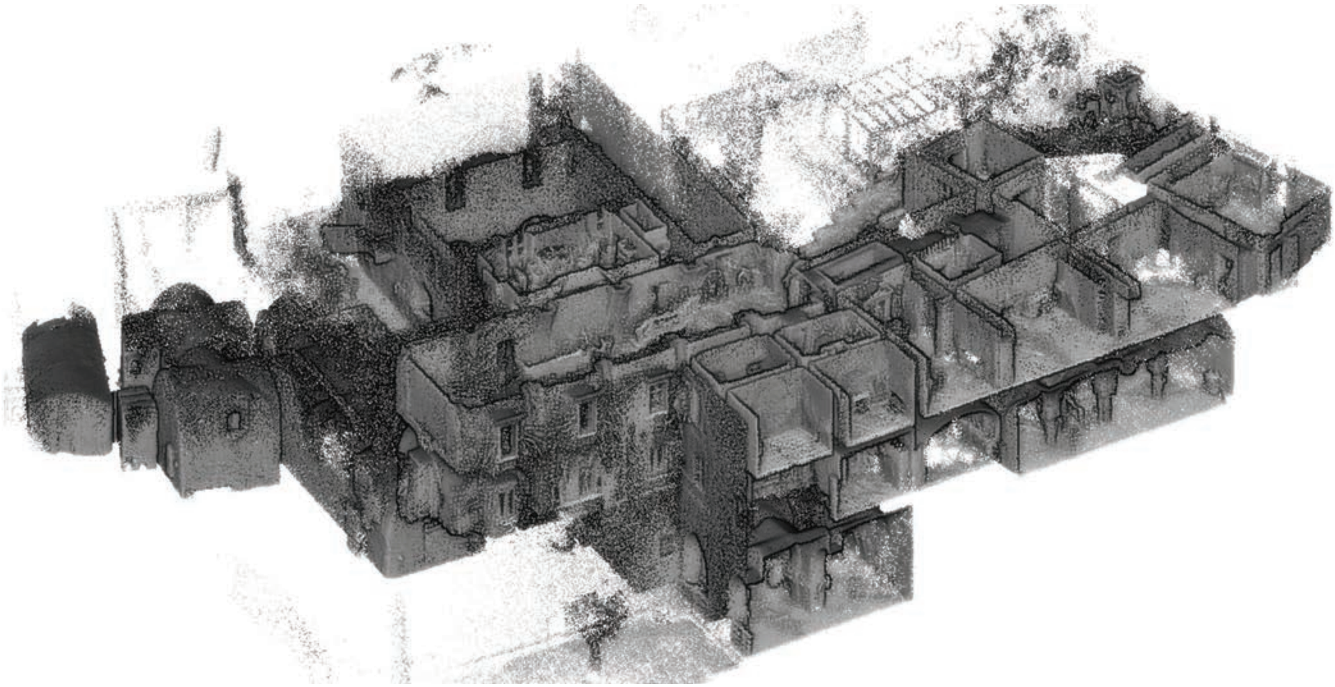

Figure 4. Orthographic projection view from a cross-section of the SLAM point cloud.

2.3 UAV dataset as a framework for SLAM point cloud registration

The application of active and passive optical sensors for the digitization and documentation of Villa Rufolo highlights a fundamental point: each instrument or method is defined by peculiarities that make it unique both in the acquisition mode and in the type of data returned. This strong characterization limits its exclusive use, even more so if we consider the complexity of the relevant conditions of the case study (Guidi et al. 2008). This requires an analysis about the range of performances that the single instrument can reach. For this reason, the integration between different systems is appropriate, in order to obtain the best result in terms of single data precision, global accuracy and process optimization. The model produced is characterized to have a variable resolution, a multi-resolution point cloud, where the metric data is consistent with the geometry contained in the context of interest. In the case study, the UAV system allows the photogrammetric reconstruction of the exteriors, also ensuring the urban and territorial contextualization of the building, with a high accuracy guaranteed by the integration of GNSS data.

Otherwise, for interiors, due to the presence of articulated and narrow paths, the range based technique was chosen, in particular, the SLAM approach was preferred to stationary TLS systems, allowing a significant reduction in acquisition times, while ensuring an compatible accuracy with the purposes of the survey

Figure 5. Cross-section of the point cloud, obtained through integration of SLAM and UAV data.

provided by a performance of a proper planning phase of acquisition.
The methodology of alignment of the UAV and SLAM point clouds has provided the identification of homologous points on the external facades, common of both surveys. The first solution can be found in the 3D point cloud with x, y, and z coordinates measured as references. The evaluation of the metric quality of the alignment can be expressed by means of the value of RMS on many homologues point. A more effective solution for aligning point clouds is generally the control of deviation errors by means of the ICP algorithm, between a reference surface, UAV-based photogrammetry cloud point and the comparative surface, the SLAM-based point cloud (Sammartano & Spanò 2018). From the manual alignment procedure for homologous points and subsequent ICP between the clouds, the estimated RMS is approx. 4 cm. Another parameter taken as a reference is the comparison of the distance between the cloud points using the CloudCompare C2C algorithm (Lague et al. 2013). The most significant discrepancies > 5 cm are recognizable on the edges and sides of the columns. The mean values of deviation, 2-5 cm, are spread on the entire façade. The generation of an accurate 3D model with the integration of active and passive sensors is an infographic product for the development of documentation potentially sustainable for the restoration of architectural heritages. This tool allows to reveal to specialists in the sector (architects, engineers, archaeologists), as well as the world at large, what is still hidden, even though in the form of virtual model. This is a different way of representing the space, even for those who do not know them, and an efficient plan of cultural promotion.

3. Conclusion. Compatibility and integration of survey techniques

The project seeks a broad understanding of the object of study, with a survey that is not limited only to the knowledge of geometry and dimensions but consists

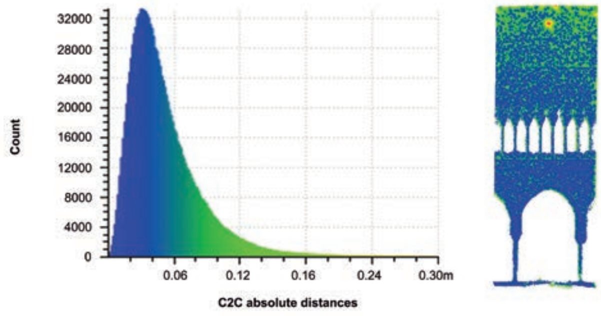

Figure 6. Histogram and spatial distribution of absolute distances between homologous models.

of a process of extended knowledge where formal, compositional, constructive, structural and historical information is acquired.
The opportunities offered by the integration of modern digital surveying techniques, such as aerial photogrammetry with dynamic active laser scanning systems, allow to obtain new products that not only improve metric data, but are also effective for purposes of representation and visualization (Lerma et al. 2011). This integration makes it possible to virtually reconstruct sites of artistic interest to document and, at the same time, provide a tool for interpreting the dynamics of transformation of architectural objects. The digital treatment of the acquired data with different survey techniques will update information of architectural interest, proposing possible interventions for the enhancement.
The innovation will be in terms of: documentation -with the generation of engineering plans-, visualization -all the information about the monument would now be shown in a 3D virtual space-, and diffusion, through the creation of online material that will allow generalized virtual visits.
This multidisciplinary and technological vision of heritage protection aims to be the digital key tool in current efforts to conserve, study and promote Cultural Heritage.

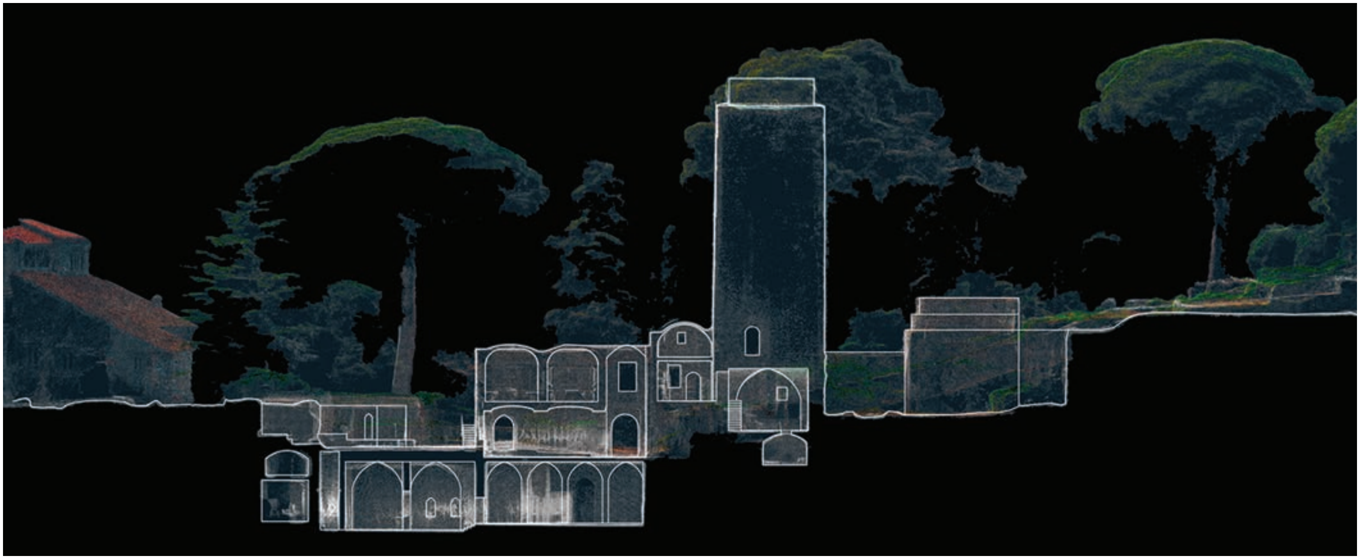

Figure 7. Vectorized section from the unified point cloud.

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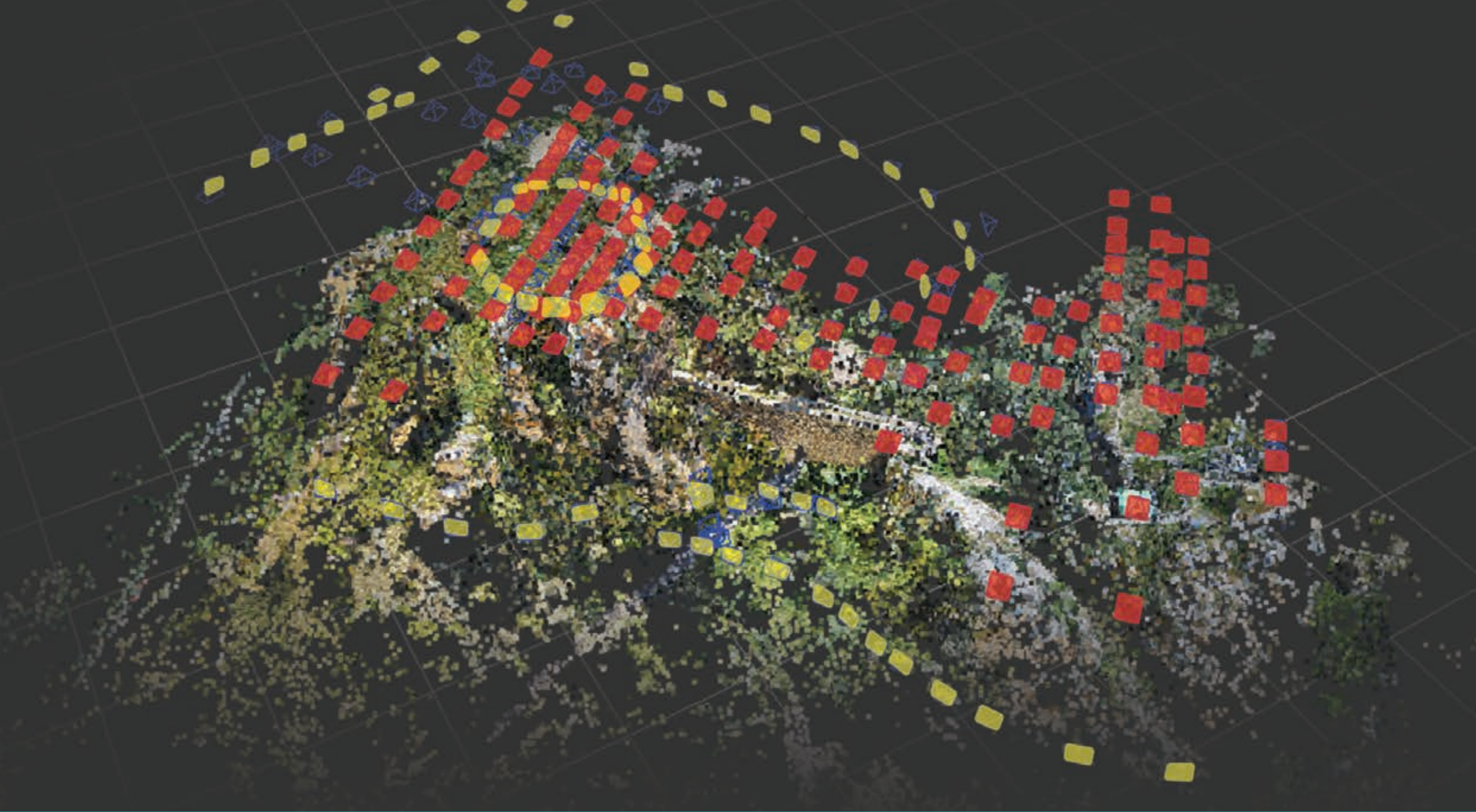

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ABSTRACT

The study looks at the numerous ruined fortified medieval sites throughout the Sicilian territory. Their value in terms of landscape and historical memory are significant, yet unfortunately, they are not very usable and quite often, a metrically reliable graphic representation does not exist for them.The methodology chosen required a primarily image-based drone survey and an elaboration of data aimed at obtaining both 2D and 3D drawings as well as a virtual reality application to provide an instrument of knowledge and a virtual use of the sites. The paper presents the results of a case study carried out on the Castleof Nicosia (Enna).

Keywords:
Ruined Places, Integrated Survey, Uav, 3D Modeling, Virtual Reality.

From the integrated survey to the virtual enjoyment of the ruined, fortified sites. The case study of the Castle of Nicosia (Enna)

1. Introduction

The wealth of castles and fortified systems within the Sicilian territory pay testimony to its strategic position and the challenging events that marked the island's history through the centuries.

There are numerous examples of medieval castles that have survived over time. They are no longer used as fortification or residential palaces, yet they continue to be relevant and affect the local communities by acquiring new functions.

Unfortunately, there are even more examples of fortified systems that in time have seen their physical structures compromised and that today are neglected ruins dispersed in abandoned areas. Nevertheless, these ruins continue to carry the value of the memory and the symbolic characteristic of the territory and community to which they belong.

Our research looks at documenting these systems that are spread throughout the territory to activate new knowledge processes, use and enhancement of the territories in which they are located. We now present the results of the study on one of these fortified systems, the Castle of Nicosia[1].

2. The fortified system of Nicosia (Enna)

In the centre of Sicily, at the top of the cliffs that overlook Nicosia, immersed within nature the remains of an ancient defence system can be found.

Its current state of decay makes it only possible to hypothesise on a planimetric layout closely linked to the area's topography.

Nicosia is located along the route that from ancient times up to today has connected Palermo to the Eastern part of Sicily. This historically strategic position explains the reason for the fortification system, which consisted of a "*castrum magnum*" and a "*castrum parvum*"[2] positioned at the top of two rocky peaks that overlooked the village. The passage between the two peaks was guaranteed by a stretch of fortified wall, equipped with a crenelated walkway with a large arched opening. Several sections of the wall that must have surrounded the area still exist.

The origins of the monument are not fully known, although thought to originate initially as a Byzantine structure[3].

In 1081 Nicosia was added to the list of "*civitates e castra*"[4] and during the thirteenth century, the Castle

Figure 1. View of the Castle of Nicosia.

Figure 2. The town of Nicosia and the castle above, hanging in the wooden choir of the Cathedral of Nicosia, Li Volsi 1622.

of Nicosia and its surrounding territory become part of the property of the royal state, confirming the strategic value recognised of the site. By the mid-1700s, the castle was considered to be "nearly useless"[5]. Between approximately 1700 and 1866 the castle was used as a prison by the Bourbons, and then eventually abandoned. The planting of a wooded area near the remains of the castle dates back to 1963. Today the park is in a state of abandon for various reasons. Firstly, the area around the castle is not usable, and the roads that lead to it are difficult to locate and thus quite dangerous. Furthermore, there is an absolute lack of services as well as the presence of items that do not belong, such as a network of antennas that damage the location's historical and landscape value.

3. Methodological approach

The choice of which methodological approach to adopt was driven by the dual need to document ruined, fortified sites, such as the one in Nicosia, for which there is not often a valid graphic representation, and also to develop digital instruments that can give new life to these abandoned sites. The entangled identity connection between fortified monument, *topos* and landscape dictated the choice to use integrated survey techniques and digital representations that are capable of not limiting themselves to the ancient walled structures but to also include the surrounding territory and its multiple components with the same metric precision and representative capability. The goal of wanting to develop a procedure that could be easily replicated and with reduced time and cost is one of the factors that went into favouring an image-based survey by drone. Other factors include the limited accessibility to the site due to the rocky nature of the cliffs on which it is located. 3D laser scanning technology was used to integrate 3D data of the monuments and areas that were not detectable by the drone. The most extensive spatial data which was fundamental in reconstructing the surrounding landscape was provided by lidar data and orthophotos taken by the Region of Sicily of the entire regional territory (FLIGHT ATA 2007 - 2008) and by spherical photos taken by our drone. The processing of all the data acquired was geared towards reaching two results: obtaining for the first time, metrically accurate 2D and 3D graphic representations - that included all of the anthropic and natural components of the investigated site - and also proceed with a virtual reality application that would permit for the virtual enjoyment of the site. The site could be virtually experienced in its current state, guaranteeing a complete vision of the entire surrounding landscape together with the ruins, but also critically mediating between the need to create a complete scene that facilitates the immersive experience and the desire to not insert useless elements for purely scenic reasons.

3.1 Integrated survey of the site

The survey campaign was conducted in two separate phases using different techniques because of the morphological complexity of the site and the final objective of the study. The territorial survey was primarily carried out with aerial photogrammetry thanks to the use of a drone equipped with a high-definition photo camera[6]. The image acquisition was performed during two phases, following precise criteria. The flight plan required an initial flyover of the entire site following a'grid' plan at a constant altitude of roughly 30 meters and a subsequent "orbital" flight around the perimeter of the site and the historical - monumental structures of particular interest. The lens inclination during the "grid" flight was set at -90° in order to capture

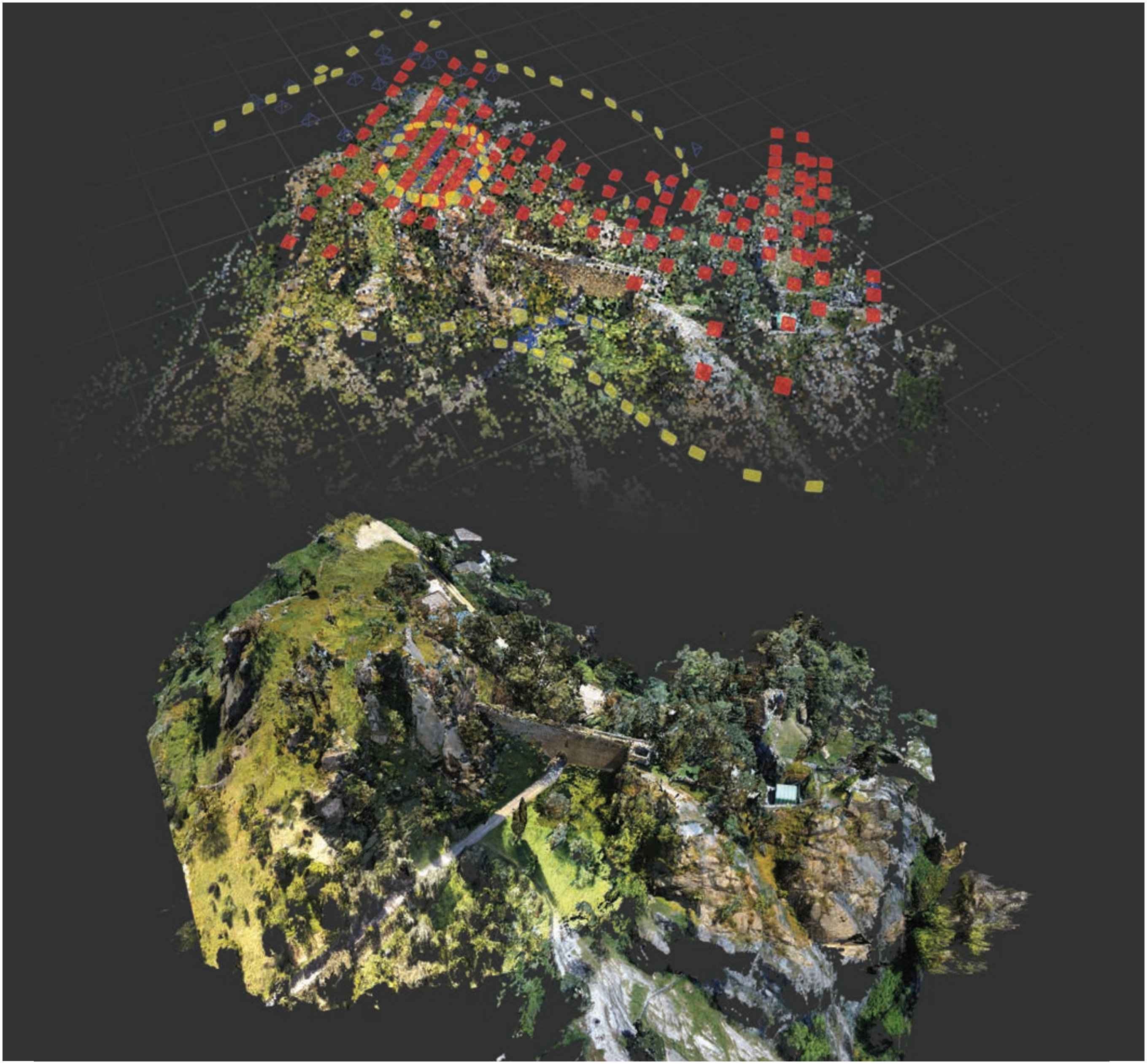

Figure 3. The photo-modelling process. Above: sparse point cloud generated by the pre-alignment of the photos; bottom: dense point cloud.

zenithal pictures, while the "orbital" flight required a different and more adaptive approach because of the changing characteristics of the area photographed. It was necessary to set the camera inclination to vary between -45° and -20°. Special attention was placed during both flight phases on providing a significant overlap (both frontal and side) of the images, never less than 80%. The drones were manually operated in order to provide the best acquisition conditions. A subsequent survey phase was necessary to compensate for the gaps in information following the acquisition of the photogrammetric data phase due mostly to the dense vegetation within the areas of interest and interference to the drone's GPS from cell phone and television antennas. This second survey campaign was conducted by combining surveys from both GPS and 3D laser scanning technology[7]. The scans were carefully planned to close the information gaps and to gather geometrically accurate data of the surviving fortified structures. The laser scanner survey was indispensable also in providing coherent geo-referencing (in UTM-WGS84) for the photo-modelling data. Compared to the standard photogrammetric surveys where GPS measurements from markers placed around the site are used, this survey, considering the particular difficulties previously discussed, was planned out so that positioning information could be extracted from the geo-referenced point cloud generated from the 3D laser scanner.

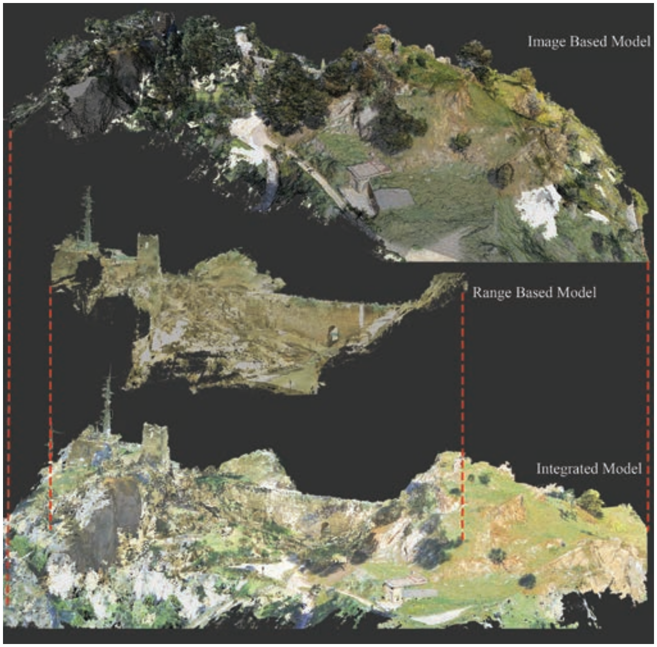

Figure 4. The integrated 3D model.

3.2 Data Processing phase

The elaboration of the acquired data required a preliminary comparative analysis between the set of aerial images and comprehensive point cloud model, obtained from the registration and cloud to cloud optimisation of all the laser scans into a single geo-referenced positioning system[8]. This operation allowed for the selection of control points that were spread throughout the entire investigated area with the following characteristics: able to be clearly identified within the aerial photographs and to be part of a geometrical shape that is clear and can easily be selected within the point cloud (edges, ashlar, etc.) The coordinates of these control points were taken into equal consideration along with the physical markers located throughout the site and it was, therefore, possible to introduce this metric information into the photo-modelling process.The photo-modelling process required a preliminary estimate of the quality of the photos loaded into the software. Thus it was possible to identify a very good quality index for each aerial image. Several steps were subsequently taken, including aligning both photo cameras, geo-referencing the sparse point cloud through the identification of the control points on the photographs and producing a dense cloud. The point cloud originating from the photo-modelling were combined with those originating from the 3D laser scans during the final phase of data elaboration.

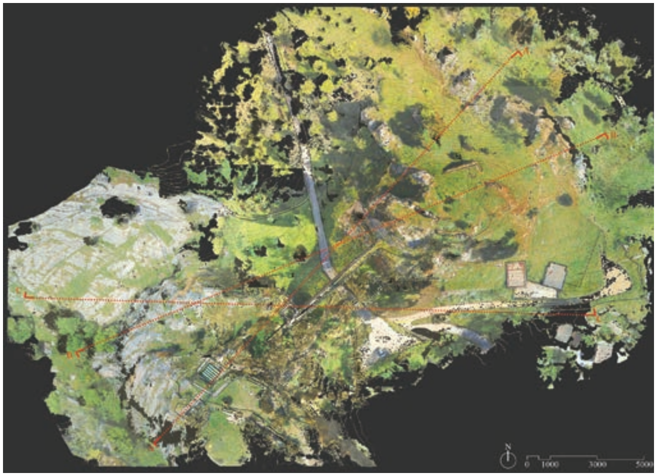

Figure 5. Fortress of Nicosia. View from top of the point cloud model.

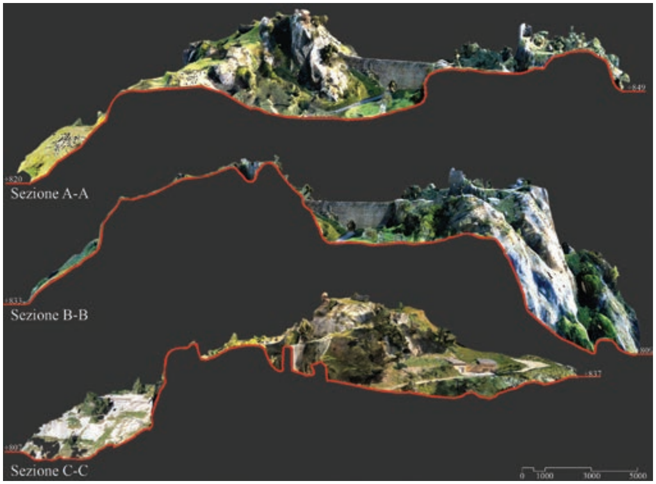

Figure 6. Fortress of Nicosia. Territorial sections of the point cloud model.

The combining of data - which were already elaborated within the same referencing system (UTM-WGS84, with geodetic altitudes) - was conducted with the same photo modelling software by importing the point cloud from the laser scanner (in ply format).
It was then possible to optimise cloud to cloud and, using a specific command, recalculate the colours of the point cloud from the laser scanner based on the chromatism of the aerial photos.
The three data acquisition technologies used: GNSS, Photogrammetry and 3D laser scanning, all have increasing levels of precision.
The integrated use of these methodologies compensates for the centimetric margin of error of the photogrammetry by readapting its 3D data to the laser scanner point cloud model. In this way, the margin of error becomes millimetric within the registration of the comprehensive point cloud model. The error related to the geographic positioning, though, continues to remain centimetric as it is tied to the precision of the GPS data.
Once the integrated point cloud were obtained, it was then possible to proceed to the 3D modelling phase.

3.3 3D MODELLING PHASE

The 3D modelling phase was set up with the aim of creating a final product compatible with virtual reality (VR) applications. The 3D modelling methodologies are distinctly different from each other based on their scope and purpose. For example, a 3D model that is developed for additive prototyping must have a mathematical and geometric precision that is not necessarily needed for one aimed at VR. Similarly, a model developed for monitoring or documenting the conditions of various locations does not need to be enhanced or cleaned from anthropic or natural elements.
The point cloud model of the site was reworked throughout various phases for a semi-automatic development of the 3D mesh model[9]. The software used makes it possible to take advantage of the dense point cloud to automatically triangulate a mesh with such similar parameters to the cloud that it is possible to identify and recognise the most minute details perfectly.
With this type of automatism, recorded data is treated all the same, even those obtained from vegetation which was very diffused in this case study.

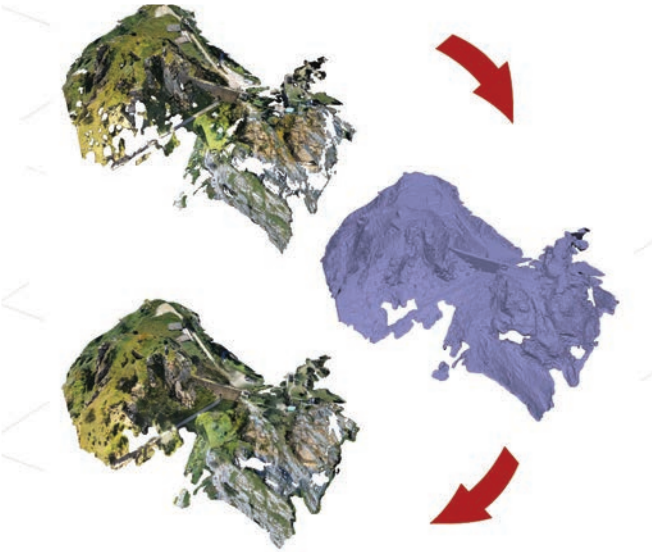

Figure 7. The steps of the modelling, from the clean-up of the point cloud to the production of the textured mesh.

Figure 8. Details of the mesh model. Above: the wall viewed from the north-west; bottom-left: the ruins of the palazzo; bottom-right: the ruins of the north tower.

For this reason, the dense cloud was cleaned up and the points were classified in an attempt to lighten and optimise the model. This last step made it possible to identify, during the generation phase of the mesh, the quantity and the quality of detail for the various classes of dense cloud. A 3D deviation map between the mesh model and the original point cloud model reveals two various precision levels. The variance is sub-centimetric for the architectural portions of the model. The variance for the rest of the model reaches nearly 10 centimeters of precision. This precision level was caused by filtering the model by trees and bushes but not by lower vegetation such as grass. Another fundamental step was the interpolation of the areas where data was missing. Once the vegetation was eliminated, it was immediately evident that some areas were missing data, as they had been covered up, such as the case of the data obtained from UAV or in the case of the 3D laser scans where bushes were attached to the buildings. An interpolation algorithm was able to average the data from an area with limited information and reconstruct a mesh surface similar to the model even with a lack of points, avoiding the formation of holes within the final model for VR. This last step was carefully examined because of the elevated risk of producing results that were less than reliable. The last step of the 3D modelling phase was the creation of high-resolution texture photographs[10].

3.4 Virtual reality phase

Before implementing a system of virtual reality for the area of the Castle of Nicosia, it was necessary to carry out a critical analysis of possible alternatives tied to the type of experience that we wanted the final user to have. In fact, in a VR situation that is completely immersive, the users no longer sense their own physical presence within the real world. Alternatives exist that are easier to obtain but only provide a partial immersive experience, where the user only makes use of a device. These devices can allow the user a dynamic or static experience within the real and virtual worlds.

Figure 9. 3D model in the VR environment.

Figure 10. Views of the fortified structure in the virtual environment.

Wanting to provide an outline of the VR available, we have: VR with complete mobility within both the real and the virtual worlds; VR with static mobility within the real world and total mobility within the virtual world; VR with static mobility within the real world and partial mobility within the virtual world. The first option allows for total freedom when moving around through the use of a visor and sensor devices positioned around the room which produce the same movements within the virtual environment.

The second and third options make it possible to access the virtual space by means of a keyboard, a JoyPad, a mouse or set actions recognised by the visor, for example staring at a specific tag[11]. The user though, maintains a sense of mobility within the real world. The methodology that we chose for this study called for the development of a VR with static mobility within the real world and total mobility within the virtual world. This in fact offers an immersive experience without sacrificing its widespread use.

Any user through an average computer can reproduce the VR experience without necessarily needing any other device such as a visor, sensors or empty room. The textured mesh was imported onto selected software to obtain the VR[12] and appropriately enriched with useful details to create the right environment such as natural lighting, vegetation, and the landscape.

A hierarchy was also created around the collider objects useful in creating a realistic 'walking' and 'listening' experience[13]. The VR model was exported in stand-alone.exe format so to be run without needing to install specific software.

4. Conclusion

The experiments done on the fortified site of Nicosia made it possible, for the first time, to obtain a complete 3D documentation of the area, triggering interesting considerations.

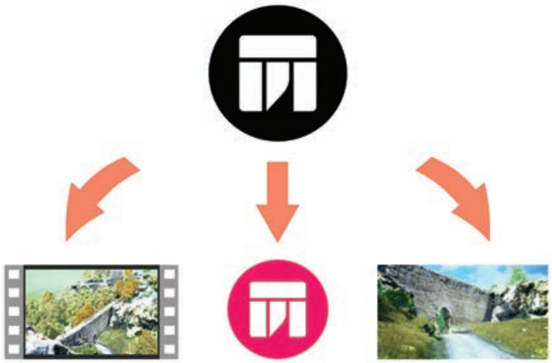

Figure 11. Output hierarchy of Twinmotion 2019 for the virtual enjoyment of the site.

In this paper we have made reference not to the possibility of more accurately hypothesising on the original configuration of the monumental complex, but to the desire to give new life to the site, understanding its elevated identity, landscape and environmental value. Moving forward, the application of a virtual reality should be seen as a possibility of widespread virtual enjoyment of the area, regardless of the limited accessibility that exists, as well as an analytical instrument to identify the site's potentiality and fragility on which to verify hypothetical interventions in order to guarantee its future and perhaps a real widespread enjoyment of the park. The operational protocol used, which has already been experimented on other fortified sites on the island, is characterised by the use of advanced technologies that require limited resources in terms of time and money. This makes it a useful instrument for the authorities responsible for these monumental and natural resources who have to tackle enormous difficulties in terms of management and security and who have not been able to guarantee the effective actions of revivification and enhancement that the local communities request.

Note

1 The study was conducted by the Survey and Representation Laboratory of Kore University of Enna, by Mariangela Liuzzo (project leader), Egidio Di Maggio, Dario Caraccio and Federica Alessandra. CREDITS: M. Liuzzo: sections 1, 3 and 4; F. Alessandra: section 2; D. Caraccio: sections 3.1 and 3.2; E. Di Maggio: sections 3.3 and 3.4.

2 See *Archivio di Stato di Palermo, Regia Cancelleria,* reg. 51, c. 238, cited in Vv.Aa. (2001) *Castelli medievali di Sicilia. Guida agli itinerari castellani dell'isola*. Palermo: Regione Siciliana Centro Regionale per l'Inventario la Catalogazione e la Documentazione dei Beni Culturali e Ambientali. Palermo, p. 205.

3 For the historical sources, also see: Gioco S. (1972) *Nicosia diocesi*. Catania: Libreria editrice Musumeci, p. 359; Beritelli La Via G. (1852) *Notizie storiche di Nicosia, riordinate e continuate per A. Narbone*. Palermo: Stamperia di Giovanni Pedone; Campione A. (2003) Itinerari di civiltà rupestre a Nicosia. Leonforte: Lancillotto e Ginevra. ISBN 978-8887464146, p. 12; La Motta G. (1963) *Nicosia.* Palermo: Editoriali Ibis, p. 36; Stamher E. (1995) *L'amministrazione dei castelli nel Regno di Sicilia sotto Federico II e Carlo I d'Angiò*. Bari: Adda Editore, Bari 1995.

4 Vv.Aa. (2001) Cit. Op., p. 205.

5 Amico V. (1859) *Dizionario topografico della Sicilia di Vito Amico, tradotto dal latino e continuato sino ai nostri giorni per Gioacchino di Marzo.* Palermo: Salvatore di Marzo Editore, 2 ed., vol. II, p. 198.

6 A Parrot Anafi drone was used, provided by the Survey and Representation Laboratory of the Kore University of Enna.

7 A time of flight laser scanner, Leica ScanStation C10 and a GNNS system, Leica Viva Gs15 in RTK modality were used and were provided by the Survey and Representation Laboratory of Kore University of Enna.

8 The registration and optimisation of the laser scanning data was conducted within the Cyclone Leica software.

9 Elaboration was done with Zephir Aerial software.

10 The software used made it possible to extrapolate 4 photos with a resolution of 4096x4096 px, 67 Mpx in size of a portion of 20,000 square meters of land.

11 Virtual objects located within the room which make it possible to'jump' from one point to another or to obtain added information

12 Twinmotion 2019 software was used.

13 Twinmotion 2019 provides a series of scripts during the import phase of the mesh model which give the user suggestions on how to interact with the model (hit it, walk on top of it or sink into it); it is however necessary to fine-tune these settings, implementing for example the type of sound or collision in order to prove the best VR experience possible.

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Multirotor drone, architectural heritage, surveying, documentation.

ABSTRACT

The diffusion of multirotor drones, together with Structure from Motion applications, has favoured their use in architectural survey, study and enhancement. In particular, drones allow the free navigation of the space and the observation from new points of view. The movement takes place in a 3D space, perceptively similar to the virtual one. Therefore, the tangible heritage becomes a 1:1 scale model of itself, and as such it is observed, surveyed, modelled and narrated. Similarly, point clouds and 3D models permit analogous experiences that favour interpretation and presentation processes.

The gaze of the flying avatar: multirotor drones experiences for architectural heritage surveying, study and enhancement

1. Introduction

The growth of automatic control technologies has allowed the development of drones, both for recreational purposes and scientific research. In particular, the functions of flight control and planning, stabilization and handling, automatic return, collision prevention, the equipment with cameras, as well as the cost-effectiveness have boosted the diffusion of drones. In heritage fields, photography has always played a leading role. Especially in architectural and archaeological studies, the application of digital photogrammetry to aerial images has been very important, from aerial photogrammetry solutions combined with the use of balloons for surveying at the architectural scale (Angelini et al. 2008; Tsingas et al. 2008).

Therefore, the possibility of providing multirotor drones (from now in this paper simply called "*drones*" for the sake of brevity) – that is small helicopters – with cameras, even with a high resolution, has favoured their use for documentation, survey and monitoring of architectural heritage. In particular, the procedures of Structure from Motion (SFM) have increased the use of drones for the study of historic buildings and of their particulars, their characteristics, and degradation. In fact, the SFM allows the automatic orientation of digital images, even taken from videos, and therefore the generation of point clouds and 3D models.

Based on some case studies related to the use of multirotor drones, aim of the paper is to present a reflection on their use at the architectural scale, both for documentation, historical critical study, and enhancement of historical buildings. The purpose of the paper is not to focus on measurement issues, data processing and accuracy – although they are important aspects –, but to understand how multirotor drones could influence the critical process of architectural study and the approach to built heritage. Therefore, the paper relates to the fields of digital culture (Gere 2002), also in relation to cultural heritage and digital heritage from real contents (Murray 1997; Bolter, Grusin, 2000; Berry, Dieter 2015), and to the line of visual culture studies (Pinotti, Somaini 2016). In particular, the possibility of drones to take images moving freely and with great stability in three-dimensional space, near the facades, even inside the buildings, plays an essential role, and favours a remediation in the mutual relationship between the scholar and the monument.

2. The architectural surveying as critical interpretation

As it is well known, the traditional process of architectural surveying roots on the following phases (Docci, Maestri 2009): the preliminary study of the building; the surveying project (with the realization of sketches to discretize the architectural continuum and to highlight significant elements that will be measured, and defining the surveying methodology); the measurement; the restitution with interpretive drawings and models. The diffusion of laser scanners and of digital photogrammetry software has produced a partial alteration of the process, anticipating the measurement phase, and postponing the critical-interpretative act in the post-processing (Bianchini 2014; Gaiani 2012).

In a certain way, the spread of drones in the architectural survey has in part brought back the surveyor closer to the building, inviting him/her to look at it closely, forcing him/her to reflect if the shots are useful for documentation and photogrammetric survey, especially of architectural and constructive details.

The first aspect that has favoured the spread of digital photogrammetry applications is the possibility of creating point clouds with SFM processes far cheaper than using laser scanners (Stathopoulou et al. 2019).

Secondly, drones are useful for the surveying of roofs and facades (Carnevali et al. 2018), in particular of buildings with peculiar characteristics, such as for example towers (Centofanti et al. 2018).

The practice highlights the useful combination of drones and laser scanners. For example, in terrestrial laser scanning a recurrent problem is the integration of gaps in the point clouds caused by ledges and cornices. Certainly, the greater precision and certainty of the measurements offered by the laser remains, but drones allow station points that are often impossible for laser scanners (Mateus 2019). Moreover, laser scanners can be useful in the registration of photogrammetric models made in subsequent campaigns, sometimes even at a great distance of time. In the process of architectural surveying, after the phase of taking the measurements, necessarily the "*restitution*" through critical interpretative models follows. They can be 2D drawings, discontinuous or numerical models (point clouds and mesh models), mathematical models (for example CGS or NURBS models), or HBIM models (Migliari 2003; Chiavoni, Filippa 2007; Maiezza 2019; Rodríguez-Gonzálvez et al. 2019; Brusaporci et al. 2019). The role and skills of the user plays a leading role, also in taking images (De Luca 2011). 3D modeling requires a critical work, made by expert connoisseur of traditional geometries and construction systems.

Figure 2. Facade of the Basilica of Collemaggio. View of the point cloud inside the Agisoft software.

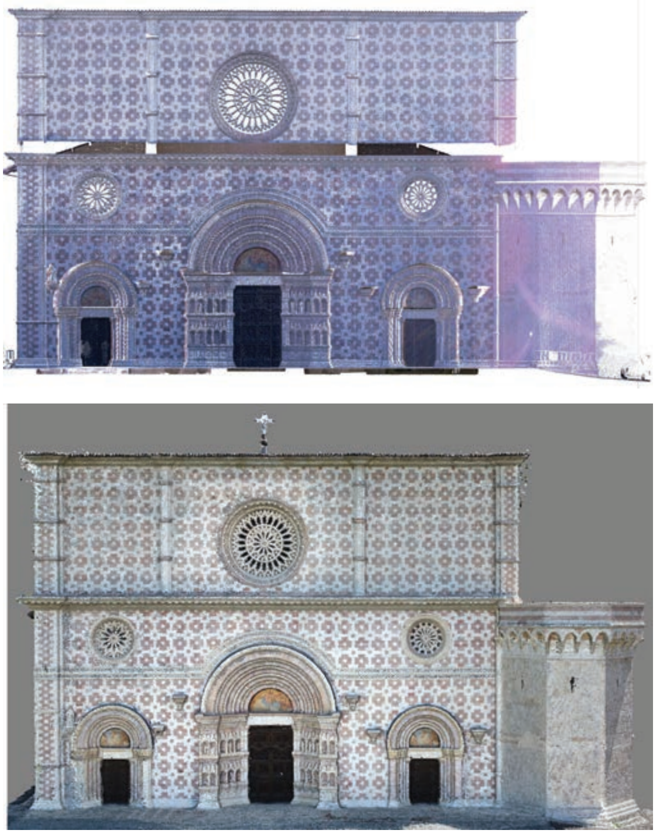

Figure 3. Comparison between the point cloud acquired by laser scanner to the left and by drone to the right.

Certainly, the question concerning the relationship between the architectural characteristics, the scale of restitution and the purpose of the knowledge remains essential (Docci, Maestri 2009). Last but not least, 3D models – through their visualization – can play an important role in telling the story of architectural heritage and therefore in enhancing cultural heritage (Brusaporci et al. 2017).

3. Documentation, Communication, Enhancement

The spread of digital photography has favoured, also in the field of drones, the use of images for the documentation of cultural heritage. More and more are the videos made with drones for the enhancement and publicity of places and architectural heritage. This goes hand in hand with the diffusion of digital photography using smartphones, which allows anyone at any time to acquire photos, tag, georeferenced, and share them on social media. In general, it is a process of "democratization" of documentation, survey and modeling, boosted by economic applications and repositories such as Sketchfab (https://sketchfab.com/) o Potree (http://potree.org/) which allow the diffusion and sharing of 3D models in the form of point clouds or meshes (Brusaporci et al. 2018). Project as "*Google Arts & Culture*", "*Open Heritage*", or "*Google Earth*" – even considering the opportunity to insert pictures by users – support processes of Participatory Heritage (Roued-Cunliffe, Japzon 2017): "*The innovation that is digital photography, and its spinouts, in the realm of social media operate not only in the service of heritage, but are complicit in its definition*" (Coyne 2012). Point clouds – if sufficiently dense – can be intended as discontinuous digital models and represent the buildings as if they are a spatial picture, providing a navigable three-dimensional cast. An issue is related to the colour of the points, heavily influenced by lighting conditions, especially for indoor images, where HDR can greatly support the post-processing (Trizio et al. 2019). Photorealistic meshes with a high degree of detail can offer extremely interesting Virtual Reality experiences, with the vision at close range and from unthinkable points of view of complex architectural details, and favoring the narrative and understanding of architectural heritage.

4. The case studies

For some time now, our research group from L'Aquila University, also within the INCIPICT project (http://incipict.univaq.it), experiments the use of drones for

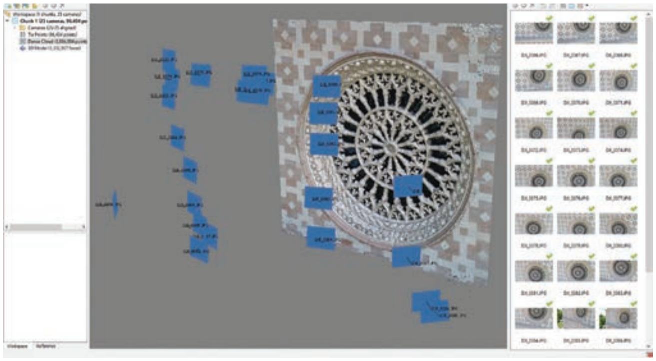

Figure 4. Point cloud screenshot of the Collemaggio rose window obtained by drone photogrammetry.

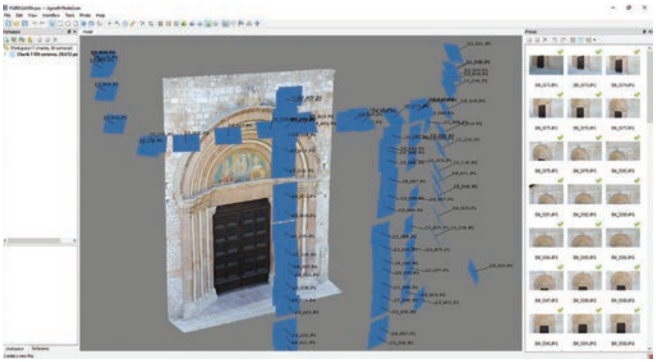

Figure 5. Point cloud screenshot of the Collemaggio Holy Entrance obtained by drone photogrammetry.

Figure 6. Mesh models of the rose window and Holy Entrances of the Basilica.

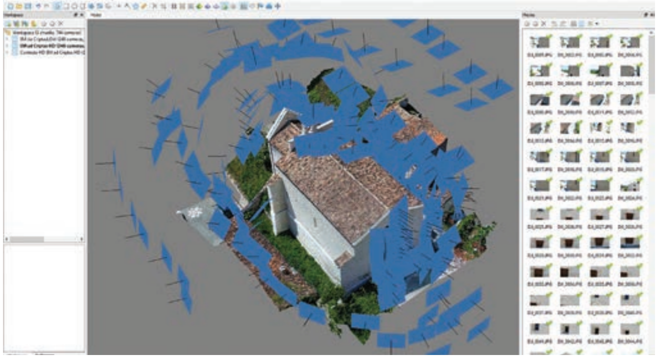

Figure 7. Point cloud of St. Maria ad Cryptas in Fossa (L'Aquila). Screenshot of the Agisoft software.

the study, survey and enhancement of architectural heritage. The reflections presented in the previous paragraphs and in conclusions rises from these works. In particular, in this paper we refer to two case studies: the survey of St. Maria ad Cryptas church in Fossa, near L'Aquila (IT), and of the Collemaggio Basilica in L'Aquila. In both cases, drones and laser scanner were used. St. Maria ad Cryptas (14th century) is a Cistercian church with one-nave and a less width square presbytery. The photogrammetric survey of the building was carried out with the help of the DJI Phantom 4 drone. The 248 photographs acquired by the integrated camera were processed with Agisoft PhotoScan Professional 1.4.3 software, thus obtaining the point cloud and the textured mesh of the exterior of the church. Moreover, the digital survey was performed by integrating drone photogrammetry applications and laser scans. In particular, the Faro Focus S70 laser scanner was used to realize 17 scans, of which: 6 outside the church, with a resolution corresponding to a distance between the points of 6.1 mm at 10 meters; 9 scans inside, with a resolution of 3.1 mm at 10 meters; 2 in the crypt, with a resolution level of 6.1 mm at 10 meters. For the acquisition of photographic images, necessary to associate the RGB value to the points, the HDR mode was set, choosing three exposures for the exterior and the crypt, and 5 for the interior of the church.

The point cloud was then used to allow the virtual visit of the church that, damaged by the 2009 earthquake, remained closed until April 2019. In particular, the use of a VR viewer, combined with the point cloud processing software Scene, offered the possibility to virtually explore the church, allowing an immersive visit experience in which the user has the perception of moving within the scanned architectural space.

The Collemaggio *Basilica* has a medieval settlement and a Renaissance facade. It has three-naves, transept in line with the fabric, flat terminated apses. The architectural surveying of the *Basilica* was realized with the integration of Leica BLK360 laser scanner and digital photogrammetry applied to pictures taken by a DJI Phantom 4 drone. The laser scanning campaign was realized with 37 station points into the church and 13 outside. The instrumental resolution between two points at 10 meters is of 20 mm. The 50 scans have been recorded by using Autodesk ReCap software. UAV technology have been necessary to realize the point cloud of the external parts of the building that cannot be measured by the terrestrial scanner, such as the roofs, the façade and the related architectural details. By using the drone, 4 datasets of photos were acquired, consisting of 159 images for the exterior of the *Basilica*, 86 images for the so-called Holy Entrance, 219 for the main façade and 25 for the main rose window.

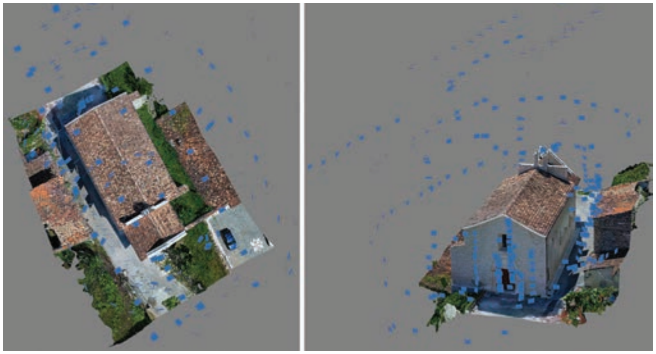

Figure 8. Maria ad Cryptas: point cloud obtained by drone with indication of the photos position.

Figure 9. Navigation of the point cloud of St. Maria ad Cryptas through the use of a VR viewer and Scene software.

According to Structure from Motion technology, the images have been elaborated with the Agisoft PhotoScan Professional 1.4.3 software, realizing a point cloud and a textured mesh.

In order to allow the navigation of the numerical model, the mesh of the exterior of the *Basilica* was exported in.obj format, for the surfaces, and.jpg for the texture; subsequently, the exported model was loaded on the website Sketchfab.

This web platform, also available on mobile devices, makes it possible to enjoy the asset in a completely original way compared to the traditional visit. In fact, the architectural elements placed even at high altitudes, such as the rose window, can be observed from privileged points of view and at close range, thus promoting their knowledge and the understanding of their architectural values.

5. Conclusion: The space of the observer

The stability and handling of drone movement in the internal and external space of buildings, and the possibility of viewing in real time what is framed make these tools a sort of avatar of the observer: through the digital screen, he/she can freely navigate the real space and look at the monument from new points of view. With specific reference to the scale and spaces of build ings, from a perceptive point of view, the scholar was traditionally confined into an anthropometric and anthropocentric perspective space. Certainly, with stairs, scaffolding, and elevators different and closer points of view are possible, but these systems are extraordinary, and the points of view exceptional but static.

The drone allows you to change the viewing and perception modes, because the eye of the viewer – through the drone camera – is able to see like the one of a bird, or rather of a bee, assuming positions allowed both by a free flight ability and by small drone size.

The movement of the drone takes place in a three-dimensional space controlled by the user, in many ways similar, also in perceptive characteristics, to the virtual one to which surveyors and modelers are used in the digital age. Conceptually, the real building immerses into a sort of digital space – in the sense of a space that is experienced with digital tools and in the manners of digitality –, where the drone takes on the role of user's physical avatar.

In this way, the tangible heritage becomes a 1:1 scale model of itself, and as such it is observed, detected, modeled and narrated. Similarly, but in the virtuality, point clouds and 3D models allow similar experiences that favor interpretation and enhancement processes (ICOMOS 2008) In the post-digital age, there is a union between real architectural heritage and digital heritage (from real content), overcoming the traditional opposition, with an explicit and reciprocal possibility of favoring the study and enhancement of historic buildings (Brusaporci 2017).

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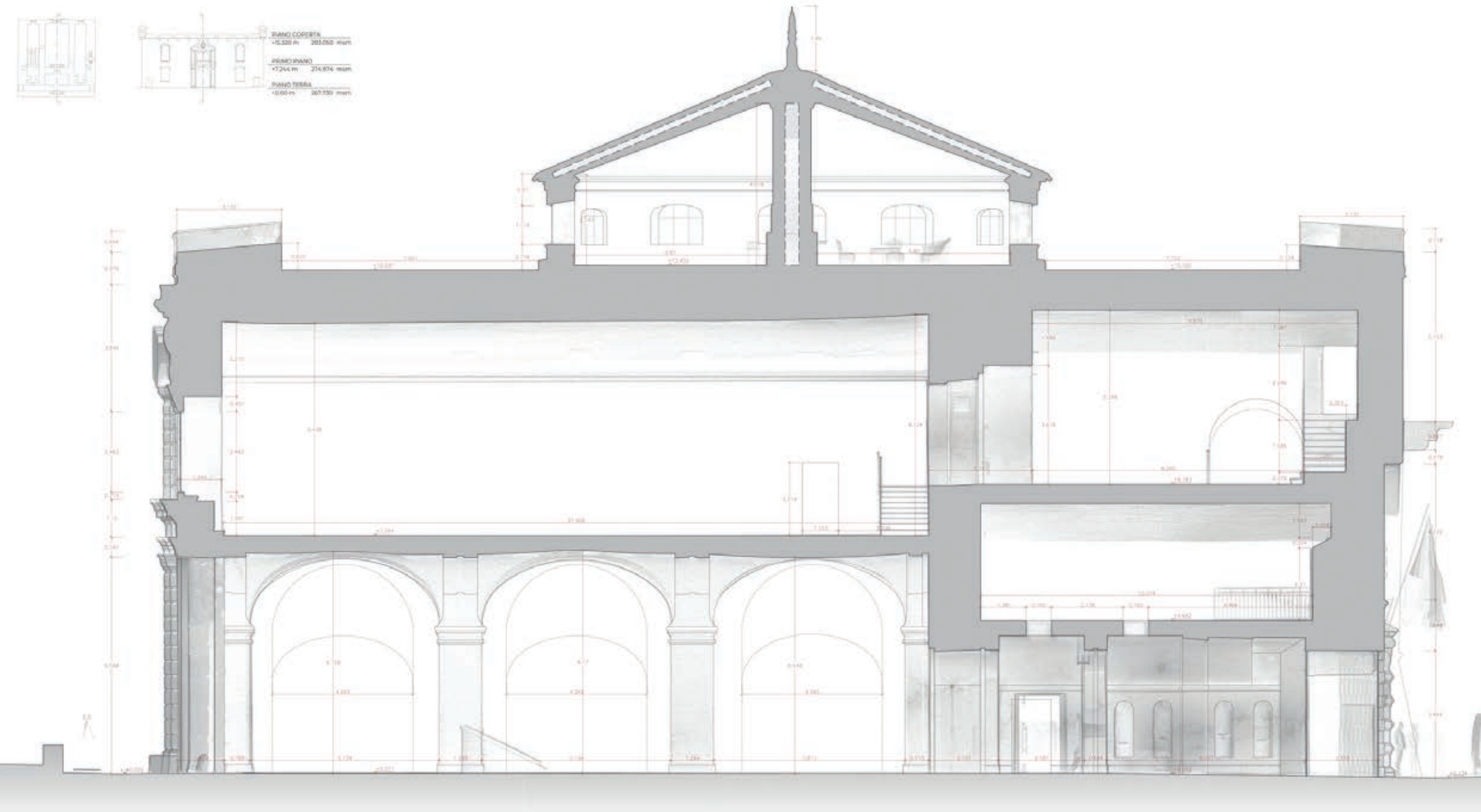

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Small UAVs, SfM, Cultural Heritage, data integration, SLAM.

ABSTRACT

Even more the 3D documentation of the Built Heritage is requested for several metric purposes and digitization objectives. In the last years according to the evolution of the recording and processing techniques producing a 3D model become quite straightforward and is important to understand how the process could be managed and controlled. With this aim, starting from 2008 in the architecture master's course of the Politecnico di Torino a Geomatics workshop is offered to the students. The paper deal with the experience carried out during the a.y. 2018-2019 with the aim of integrating data acquired by a very light UAV and different range-based sensors for documenting an historical and stratified fortified architecture. The problems related with the flight authorization and the followed strategies for data acquisition using the UAV and the employed range-based sensors are discussed. In conclusion the achieved metric products and the analyses are reported.

Very light UAV data and ranging methods for heritage documentation. The teaching activities of a master's degree course

1. Introduction

3D imaging and ranging methods have become in the last years a best practice in Heritage documentation (Georgopoulos et al. 2014; Lo Brutto et al. 2014; Patias, 2006; Stylianidis et al. 2016) since the continuous improvement of instruments and methodologies used for 3D data recording opened the usability of this tools to an increasing number of different actors, not specifically connected to the geomatics fields (Remondino et al. 2010). In this scenario even more is important to drive the community that works on the digitalization of the Built Heritage in a "conscious" use of the acquired and processed data in terms of metric value of information. This use is strictly related to the precision and the accuracy of the followed process and to the final metric products, such as 3D models, DEM/DSM, orthophotos or traditional 2D drawings (plans, sections and facades).

With this objective, the Politecnico di Torino offered to the master's students of Architecture the workshop "*3D Imaging and ranging methods for Heritage Documentation*" with the specific aims of presenting the panorama of the most up-to-date digital methodologies for performing a 3D survey and carrying out metric representation of Built Heritage.

The main objective of the course, whose results are presented in the next sections, is to analyse and exploit the use of photogrammetry (UAV-Unmanned aerial system and close-range) integrated with terrestrial laser scanning methods (static and mobile) and to test their use in a real application.

The use of these approaches highlights the opportunity of successfully deploy them it in the context of Built Heritage, in relation with the urban or natural environment in which the heritage is located. During the class of the current a.y. 2018-2019, the students will be able to acquire skills in data acquisition related to a stratified architectural heritage (The Mastio della Cittadella): topographic measurement (total station and GNSS-Global Navigation Satellite System), UAV and close-range photogrammetry, terrestrial laser scanners (both static and portable mobile scanning based on SLAM - Simultaneously Localization and Mapping approach). Moreover the processing phase is analysed adopting the consolidated Geomatics

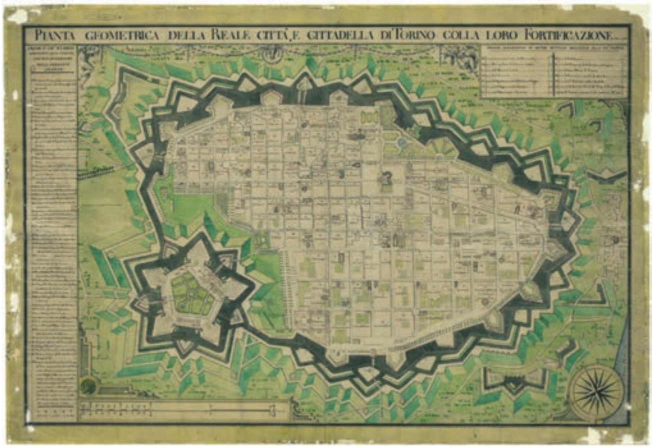


Figure 1. "Pianta geometrica della reale città, e cittadella di Torino colla loro fortificazione" (Galletti, 1790). Historical Archive of the Torino Municipality (Tipi e Disegni 64.2.13). http://www.museotorino.it.

workflow that consist in the use of several measured Ground Control Points (GCPs) and Check Points (CPs) both for the photogrammetric process (mainly based on Structure from Motion - SfM software) and for the laser scanner data processing. Their use is connected to the georeferencing of data and for analysing the accuracy of the processing steps that is strictly related to the final 3D or 2D products. The work reported in the paper deal with the approach followed in the course organized in line with the current state of art according to the workflows proposed by the scientific community for documenting and improving the knowledge of the Built Heritage using the so called approach of Learning by Doing.

2. The case study: the mastio of Cittadella of Turin

The Mastio is what remains today of the Cittadella di Torino, an impressive fortification complex built between 1564 and 1573. The Cittadella was committed by Emanuele Filiberto di Savoia, based on the project of Francesco Paciotto and built under the direction of general Robilant (Spallone, 2017). This complex of fortifications was the cornerstone of the military defensive system of the city in the centuries after its construction and represented a reason of pride for the Savoy monarchy, a later representation of the Cittadella and its surrounding is reported in the Galletti's map (Figure 1) at the end of XVIII century (Bevilacqua & Zannoni, 2006). The Cittadella was located in the western part of the city and undergone several damages and transformation during centuries until its partial dismantling during the French occupation at the beginning of the XIX century. Today the Mastio (Figure 2), re-opened in September 2019 after an important and time-consuming requalification project, host the National Historical Museum Museo of Artillery and other temporary exhibitions.

3. Law and regulation connected to the use of UAVs in urban area. The survey of cultural heritage assets

Since the Mastio is in the city centre of Torino, one of the most critical issue for data acquisition was related to the use of drones. In this area the employed platform was an inoffensive one (under a weight of 300g) that is allowed nowadays, according to the Italian regulations, to perform flights in urban areas (as is reported below, the European regulation will change this standard). Before the flights, in accordance with the Italian rules, a flight authorization was requested to the Italian civil authority (https://www.enac.gov.it/). Unmanned Aerial Vehicles (UAVs) have definitely been a theme of great interest in the last years and their use and diffusion faced an impressive growth. In first place the commercial drone industry is growing at an

Figure 2. Aerial view (left), main entrance (centre) and rear entrance (right) of the Mastio.

impressive rate and is estimated to reach $120 billion by 2020 (Giones et al. 2019), leading to a massive diffusion of these systems between professional and non-professional users. Considering the growing number of people possessing a drone it is clear that also the regulations connected with their use need to be transformed and adapted to the new everyday reality. Several issues need to be considered when dealing with the themes connected with the use of drones: where you can fly, how, with which typology of platform, at which conditions, what can be recorded (privacy issues), etc. An exhaustive overview of UAVs regulations, on a global scale, can be found in (Stöcker et al. 2017), updated until 2017; this contribute contains also some interesting reflections on how the different systems of laws and regulations can affects the developments of the research connected with UAVs and also the works of professionals. Concerning the Italian scenario, the regulation for UAVs are in charge to the Italian Civil Aviation Authority – ENAC[1] with a regulation that have been updated seven times in the last six years, as further proof of the fact that is not always straightforward to deal with the rapidity of evolution of this technology and in these scenarios.Finally, it needs to be reported that a great effort was carried out by the European Union Aviation Safety Agency (EASA) in the last years to harmonise the regulations of the different European States. The new European UAVs regulation will probably enter into force in early 2020 and the member states will have a 2 years' time to adapt their local regulation to the new norms[2].Two topics that were particularly stressed, first from the Italian regulation and then from the European one, are related with the achievement of flights in urban area and the use of very light platforms. Following the Italian directions drones can be considered inoffensive under a weight of 300g and can thus be deployed also in urban areas (with some limitations such as the prohibition of flying over people), while for the new European regulation the limit is lowered to 250g. It is interesting to notice how in this case the trend of the market and the regulations are influencing each other, the release of the last DJI platform (30th of October 2019) that weights 249g is a clear proof of that. In the present work according to the actual regulation a platform under 300g was employed for performing the flights. A very light UAV system (DJI Spark – Figure3) was employed in connection with other techniques to achieve a complete metric survey of the analysed Built Heritage complex.

4. The acquisition in the field: instruments, techniques and best practices

The acquisition phase for the Mastio was completed in one day with the participation of the students of the course that worked in different groups under the supervision of the teaching staff following the schema reported in Figure 4 (left). As usual when a metric survey is performed the first phase was connected with the creation and measurement of a network of vertices using traditional topographic techniques (total station and/or GNSS); in this case each vertex was measured using a GNSS receiver in static mode (with a measurement time for each base-line of at least 45 minutes). The network was then calculated and adjusted with Leica Geo Office Suite. In order to assign a common reference system to the new vertices, three points of the inter-regional Piedmont-Lombardy-Aosta Valley permanent GNSS network (http://www.spingnss.it) were used (Torino Gravere and Asti). This phase allowed to reach a centimetric accuracy on the vertices coordinates (Table

Camera model	DJI FC1102
Sensor	CMOS 6,17×4,55 mm
Effective pixels	12 MP
Lens	FOV 81.9° 4,5 mm f/2.6 (25 mm in 35 mm format equivalent)
ISO Range	100-1600
Shutter Speed	2-1/8000 s
Max image Size	3968×2976
Photo Format	JPG
Weight	300 g[1]
Size	143×143×55 mm[2]

[1] Take-off Weight
[2] Size of the entire drone

Figure 3. The DJI Spark (left) with the technical specification (right).

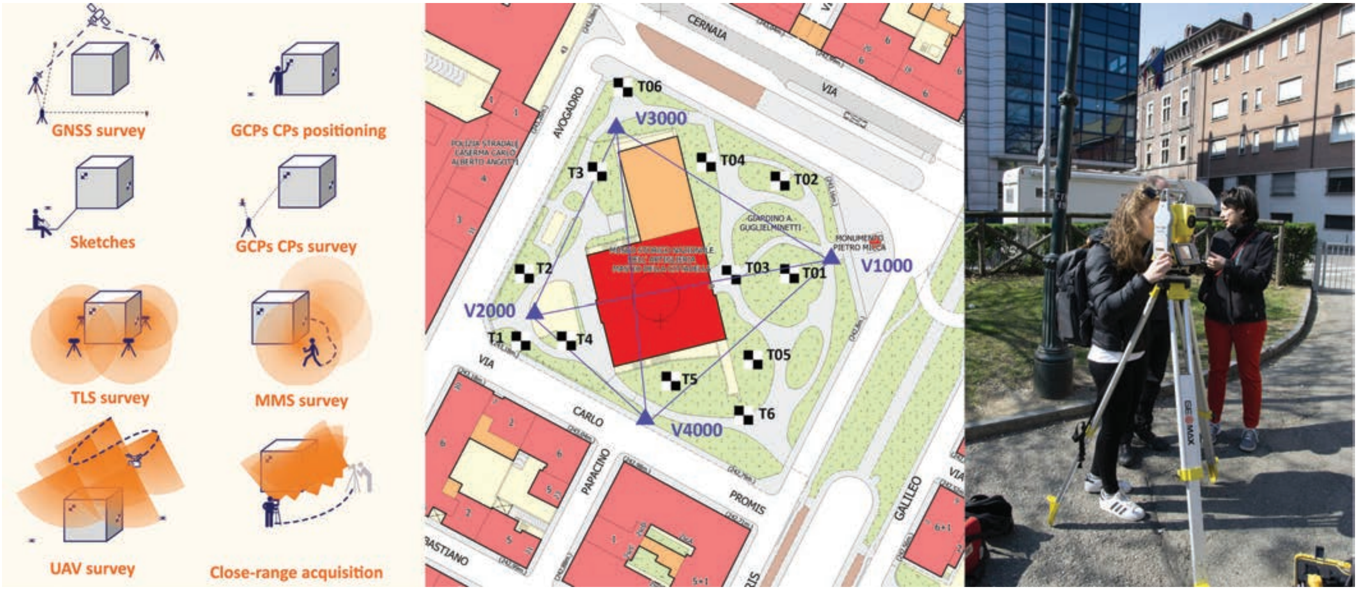


Figure 4. Workflow of the on the field survey (left), schema of the GNSS network and the position of the ground marker used for the photogrammetric UAV processing (center)). Topographic measurements total station (right).

Point id	RMS_x [m]	RMS_y [m]	RMS_z [m]
1000	0.002	0.003	0.007
2000	0.004	0.005	0.012
3000	0.007	0.012	0.022
4000	0.007	0.007	0.024

Table 1. Coordinate RMS of the achieved GNSS network.

1) and the georeferencing of all the data collected in the field to the UTM WGS 84 coordinate system.
The definition of new vertexes in a common coordinate system in the area of the survey is the starting point for the next survey operation that are related to the measurement of several targets or markers that will be used to correctly perform the orientation phases using photogrammetric or/and laser scanner data.
That points called GCPs or CPs, were measured by a Total Station (Geomax Zoom 35) using the traditional side shot approach staring from the GNSS vertexes and are used for the evaluation of the final accuracy of the process. Commonly the GCPs are employed to perform the adjustment and as a consequence to georeferencing the photogrammetric block, on the other hand the CPs whose coordinates are known as well in the common reference system are used to verify (check) the results of work. As a consequence is very important to known the accuracy of the CPs in order to have a reliable statistical indicator of the achieved results. That points in the area of the Mastio were represented both from codified paper target and from natural features of the building and were homogenously distribute on the façades surface and on the ground around the surveyed object. As is shown in the following Figure 4 for the UAV flights 12 artificial target were placed on the area. As is already reported before, due to the position of the Mastio, that is located in a central area of Turin with a high density of buildings and services, and the conformation of the surrounding area, that is today a small urban park with many trees, it was decided to perform the flights using a modified Spark with a lower weight than the

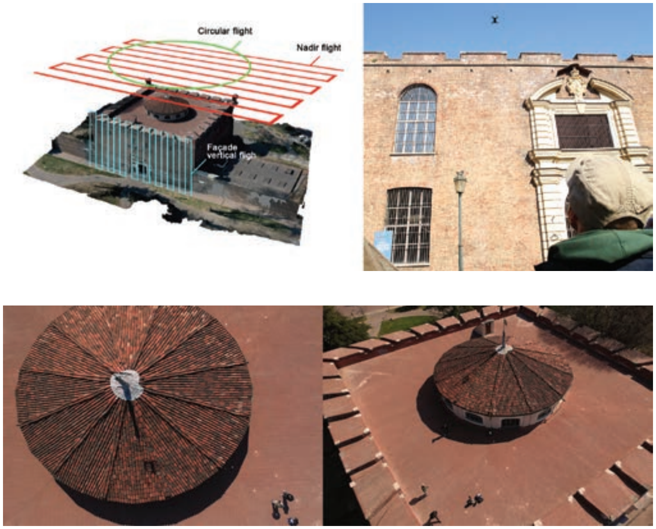
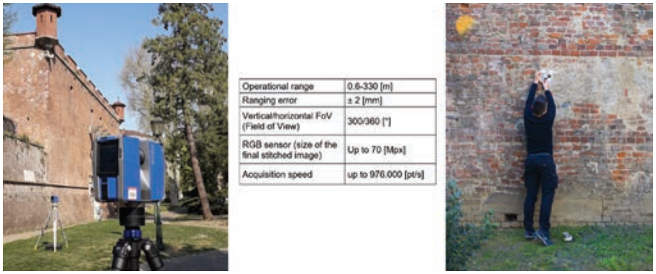


Figure 5. Employed acquisition schema: nadir in red, circular oblique in green and vertical in blue (above on the left), the drone during the manual fly (above right). Sample image of the nadir flight (below left) and oblique (below right).

original commercial one. For the same reasons it was better to carry out manual flights and not to adopt pre-programmed flight plans in order to maintain the total control on the aerial platform during the whole operation. In order to acquire images suitable for documenting and completing in a correct way the Mastio geometry, as is reported in Figure 5, three types of flight schemas were carried out: a nadir flight at an altitude of 40 m from the ground (GDS, Ground Sample distance = 1.3 cm) to cover the building and a portion of the surrounding, a circular flight with an oblique configuration of the camera at the same altitude, and finally different vertical flights (with the axis of the camera perpendicular to each façade at distance from the structure of about 5/7 meters (GSD between 1.6 and 2.3 mm). Without any doubt, today the use of UAV allows to describe the environment and the Built Heritage, in an easy way and with a high level of detail especially when high resolution images are acquired by the employed platforms.



Operational range	0.6-330 [m]
Ranging error	± 2 [mm]
Vertical/horizontal FoV (Field of View)	300/360 [°]
RGB sensor (size of the final stitched image)	Up to 70 [Mpx]
Acquisition speed	up to 976.000 [pt/s]

Figure 6. The employed Laser Scanner (left), technical specification of the X 330 TLS (center), marker employed for the scan registration (right).

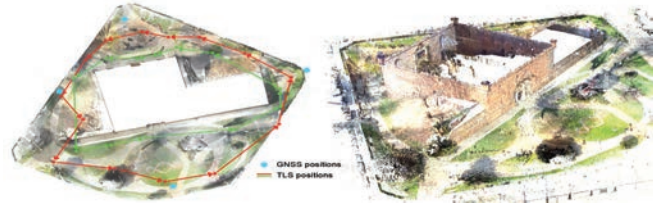


Figure 7. Main paths followed by the TLS acquisitions (left), a 3D view of the complete laser point cloud (right).

In the case of the Mastio due to the well-known limitation related to the actual UAV regulation a very light platform has been used and as a consequence for improving the quality of the terrestrial data, a complete laser scanner survey has been performed as well.
Mainly, the approach was followed for giving to the students a more complete panorama of the different geomatics techniques that could be applied for a multi-sensor and multi-scale documentation.
Finally, since the two afore mentioned techniques were applied outdoor, for the indoor survey a Mobile Mapping System based on the SLAM techniques was employed to complete the survey. For the laser acquisitions the phase shift laser FARO Focus X330 by CAM2 was employed (Figure 6).
To cover the area of the Mastio n°30 scan positions (at a density of 6 mm at 10 meters) were acquired. The positions of the laser were selected according to two main path: the first one (green in Figure 7 left) very close to the building structure (less than 10 meters)

in order to obtain an accurate documentation of its consistency and the second one (red in Figure 7 left) on an highest distance (20-40 meters) useful for a more general knowledge of the object shape.
The laser scanner is equipped with an integrated digital camera that allows to acquire the images necessary to associate the RGB information to each acquired point.
In order to connect the scans to the reference system different GCPs placed on the Mastio (Figure 6 right) facades were measured by a total station, the GCPs were then employed for georeferencing the resulting point cloud that is obtained by merging together the entire set of single scans. The final point cloud is composed by about 750 million of points (Figure 7 right) For the indoor survey a Mobile Mapping System technology based on SLAM algorithm was used.
The employed instrument, that is able to speed up the acquisition phase in comparison with laser or photogrammetric techniques, was the last update of the first pioneering solution developed by GeoSLAM. The Zeb Revo RT (Figure 8) is equipped by a laser mounted on a rotating head that progressively extracts range-based profiles and couples them to the position estimated at the same time by an Inertial Measuring Unit (IMU) in real time thanks to the implemented SLAM algorithm (Sammartano & Spanò 2018).
In order to complete the indoor acquisition 2 scans were performed, the adopted strategy was achieved with the consolidated approach that consist in the execution of closed loop in order to minimize the drift errors that usually affect the trajectory of this kind of system (Barba et al. 2019; Murtiyoso et al. 2018). In the next Figure 9 some views of the acquired data are reported. As is possible to notice from the figures the point clouds are without any RGB information since

Wavelength	905 [nm]
Eye-safe laser	Class 1
Laser speed (repetition rate)	100 [Hz]
Laser lines	100 [lines/s]
Scan speed	x 2,5
Maximum range	15 - 30 [m]
Points density	~ 43,200 [pps]
3D measurement declared accuracy	± 0,1 [%]]
FoV	270° HFOV/ 100° VFOV
Weight/portability (head + data logger)	~ 2 [kg]

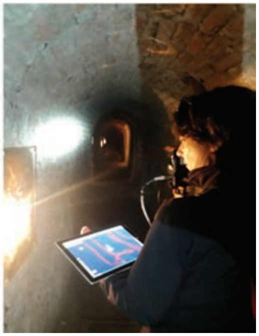
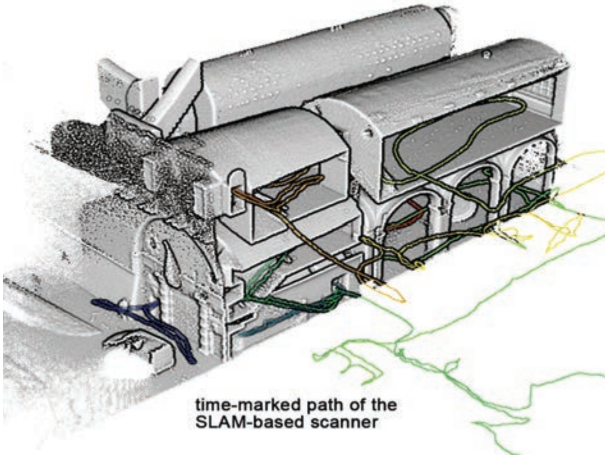


Figure 8. Zeb RT with the connected Tablet (left), technical specification (centre), acquisition phase (right).



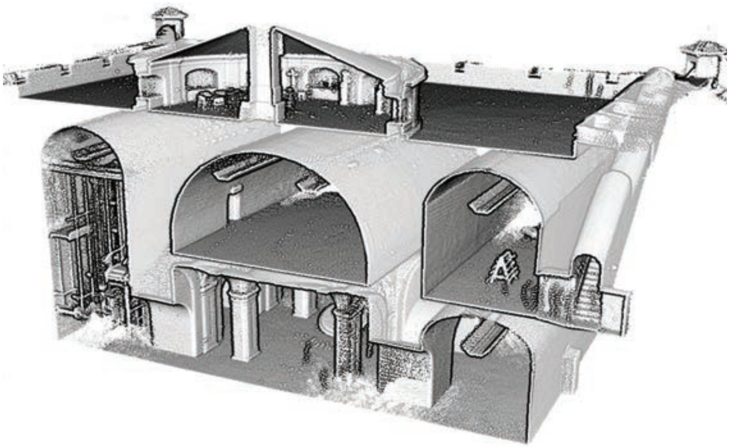


Figure 9. Visualization of the ZEB point clouds with (left, longitudinal section) and without (right, transverse section) trajectory.

actually the direct point cloud coloring tool, despite the new development of the software, is still a crucial issue that needs further progress or different approaches not connected to the instrument.

5. Data processiong and integration for complete multiscale and multisenson model. Some achieved products

All the different acquired data were processed following consolidated approaches during the lab activity section of the course and their metric accuracy was always considered and verified especially in connection with the desired representation scale (1:100 – 1:200).
For UAV images a traditional SfM approach combining the typical aerial UAV images with the ones acquired for documenting the facades was followed; the achieved accuracy (mean GCPs [n°7] RMS= 0.015 m, mean CPs [n°4] RMS= 0.020 m) of the obtained results is similar with other tests performed in urban scenarios using the DJI Spark like the one reported in Calantropio et al. 2018; Adami et al. 2019; Stek et al. 2016; and Russo et al. 2019.
The traditional pipeline for LiDAR data processing has been pursued: first of all, a cloud-to-cloud registration, which uses the well-known ICP (Iterative Closest Point) algorithms to co-register each scan. Thereafter, a second data registration based on the previously surveyed set of topographic GCPs was performed in order to assign a known reference system to the final point cloud. After the registration process, it is possible to obtain a residual error of 1 cm.
During the processing, the radiometric content (images) acquired with the integrated digital coaxial camera of

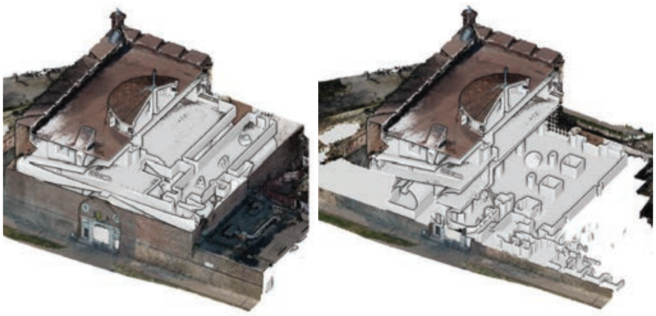


Figure 10. Co-registration between outdoor point cloud and SLAM point cloud.

Figure 11. An example of the metric orthoimage derived from the UAVs flights (Group 2: A. Alaimo, A. Bertero, C. Bovet).

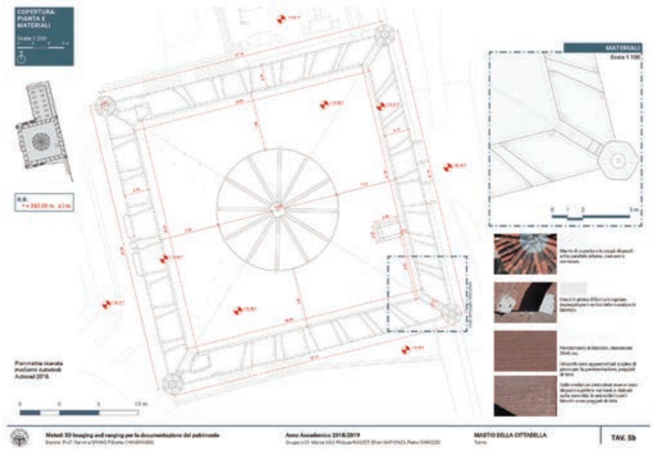


Figure 12. Plan of the Mastio with a study on the materials of the structure using UAV images (Group 1: M. Agù, P.Rosset, E. Sapienza, P. Tarozzo).

the system has been associated to the metric component (point cloud).

Concerning the SLAM data, in the post processing phase is possible to correct some typical problem encountered in the raw data during the first acquisition like the drift error in the trajectory and the connection with non-closed loop acquisition.

This process is performed by the GeoSLAM Hub software. Finally, since this portable SLAM-based system is not equipped with devices able to determine the absolute spatial location of the scans the problem of positioning was solved by a cloud-to-cloud registration using similar geometric features in the static LiDAR point model (Figure 10).

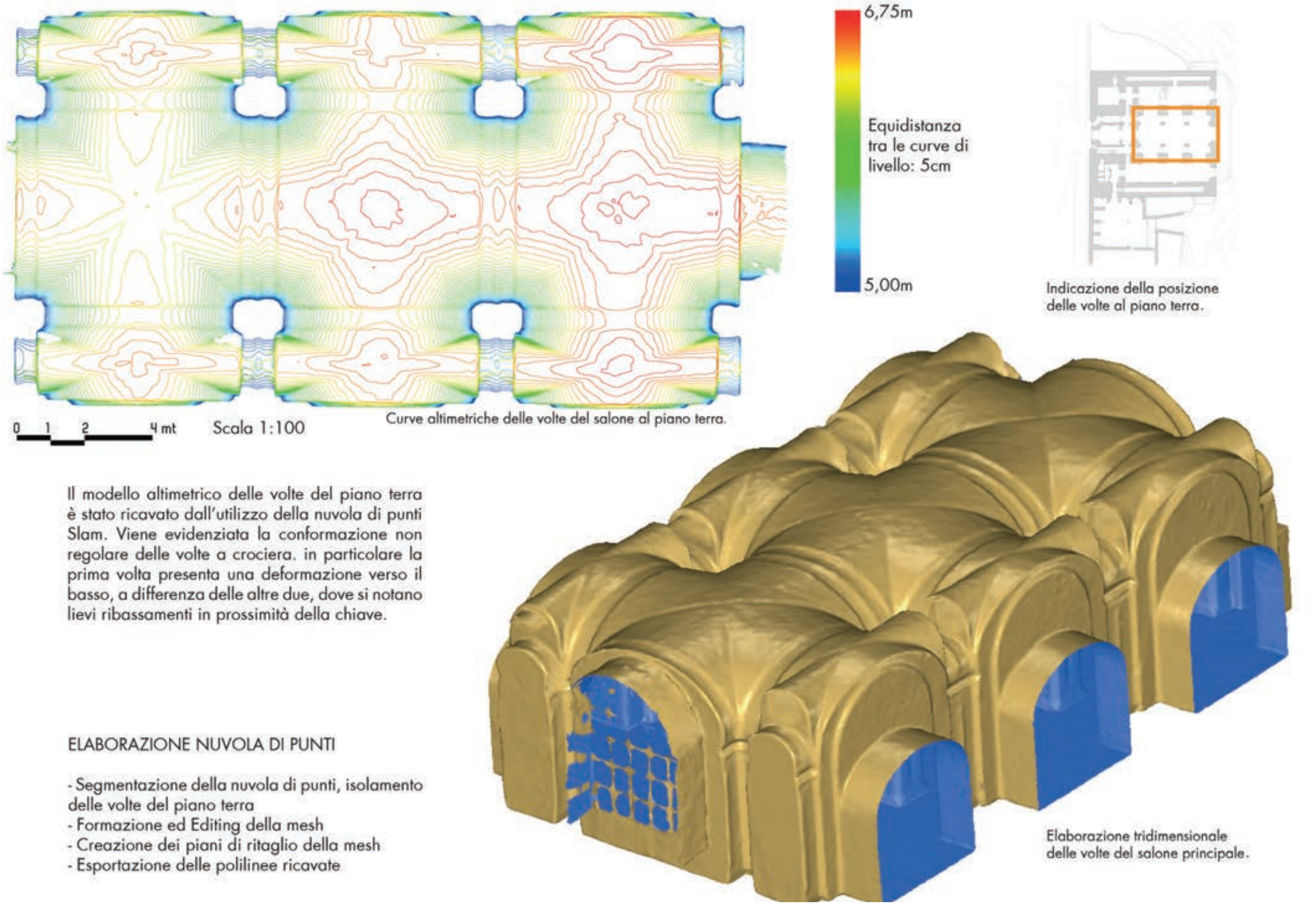


Figure 13. Main façade 2D drawing and achieved orthophoto from LiDAR data (above), photogrammetric orthophoto (centre), study on the deformation of the first floor vault (Group 2: A. Alaimo, A. Bertero, C. Bovet).

At the end of the different processing steps, according and thanks to the common reference system it was possible to connect and integrate all the specific products of the techniques employed in the field.
In fact, one of the teaching objectives of the course was connected with the possibility to integrate the different datasets together in order to obtain the traditional 2D drawings and digital 3D models (outdoor and indoor) of the architectural object and to perform more accurate analyses.
In the following figures some of the achieved results are reported.

6. Conclusion

Analysing the outcomes, the achieved activities both on the field and in the lab, as well as the feedback of the students, it is possible to abstract several conclusions. According to the direct results (drawings, 3D models and specific analysis) the Mastio was well documented and the acquired data allow to describe with a high level of detail the consistency of the structure.
From a didactic point of view, the integration of theory lessons, instruments operative tutorial, on the field activities and lab data processing is for sure a winning approach and the course model will continue.
Probably the drawbacks that can be highlighted are related to the time planning balancing of the survey works, as usual. The data acquisition phase (depending on the type of student involvement experience, 1 full immersion day, 2-3 days internship, etc...) otherwise allows to interact and participate with different learning levels in fieldwork to which, however, the students will approach after dedicated training lessons on the use of digital technologies.Nevertheless, the rather short time of data acquisition allowed them, on the other side, to understand how complex and lengthy the processing and optimization pipelines could be, that has been developed throughout the course. The feedback from the students was very positive, they especially appreciate the possibility of understanding how is possible to "certificate" the final products according to the achieved accuracy and to learn all the processing steps, algorithms and approaches followed by the employed software. In conclusion from the undertaken experience is possible to state that introducing the actual research trends and topics in the master's courses is very important and for sure is an advantage for the next professional career of the future Architects and Engineers.

Note

1 https://www.enac.gov.it/la-normativa/normativa-enac/regolamenti/regolamenti-ad-hoc/regolamento-mezzi-aerei-pilotaggio-remoto.

2 https://www.easa.europa.eu/easa-and-you/civil-drones-rpas.

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We would like to report that the graphical results based on innovative 3D survey technologies presented in this paper are made by the students of the course, under supervision: M. Agu', A. Alaimo, A. Bertero, C. Bovet, A.P. Compte, A. Craveri, C. Dallere, F. Davino, A. Ferrarino, F. Giacco, M. Giancarli, G. Giaquinto, B. Giardino, E.F. Moncullo, S. Mudarra Cisnero, Anginelly, L. Perez De Ciriza Galarza, P. Rosset, E. Sapienza, P. Tarozzo. Special thanks to the colleagues of the Geomatics for Cultural Heritage Lab involved in the data acquisition: E. Abbate, A. Calantropio, E. Colucci, F. Giulio Tonolo and G. Patrucco.

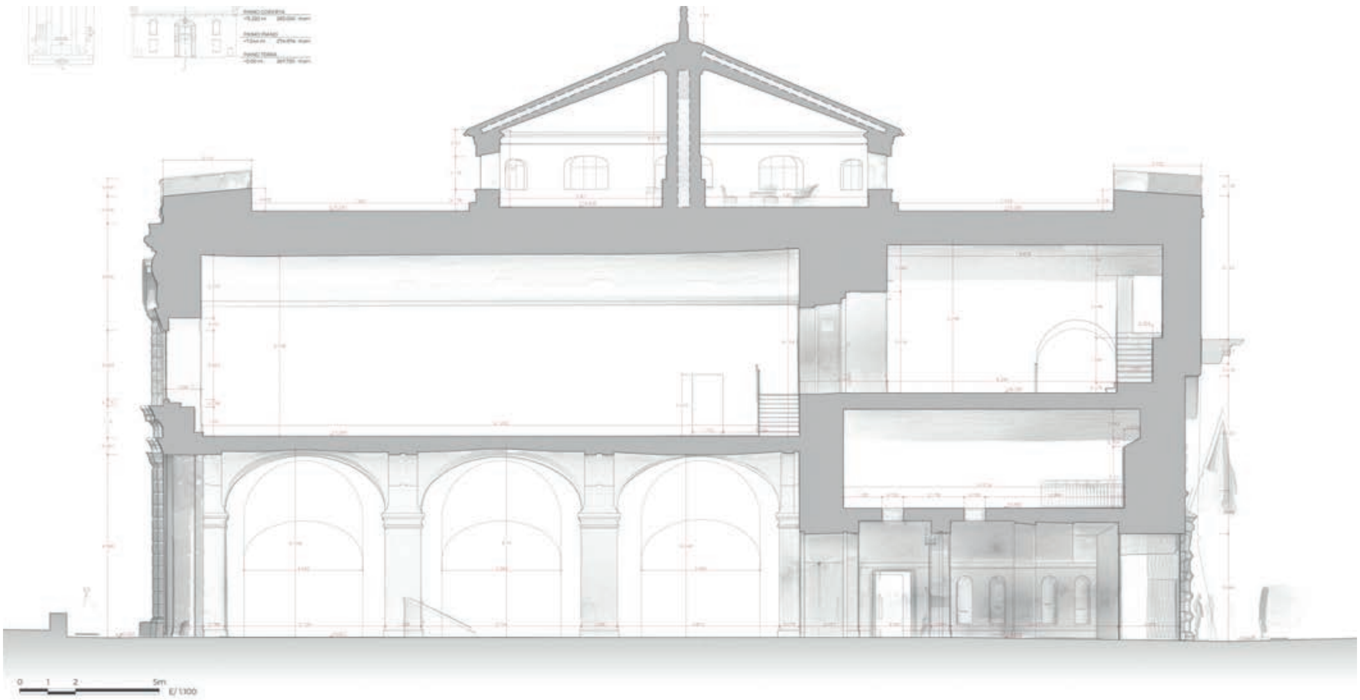

Figure 14. Longitudinal section (Group 5: P. Compte, M. Giancarli, L. Pérez De Ciriza A. Mudarra).

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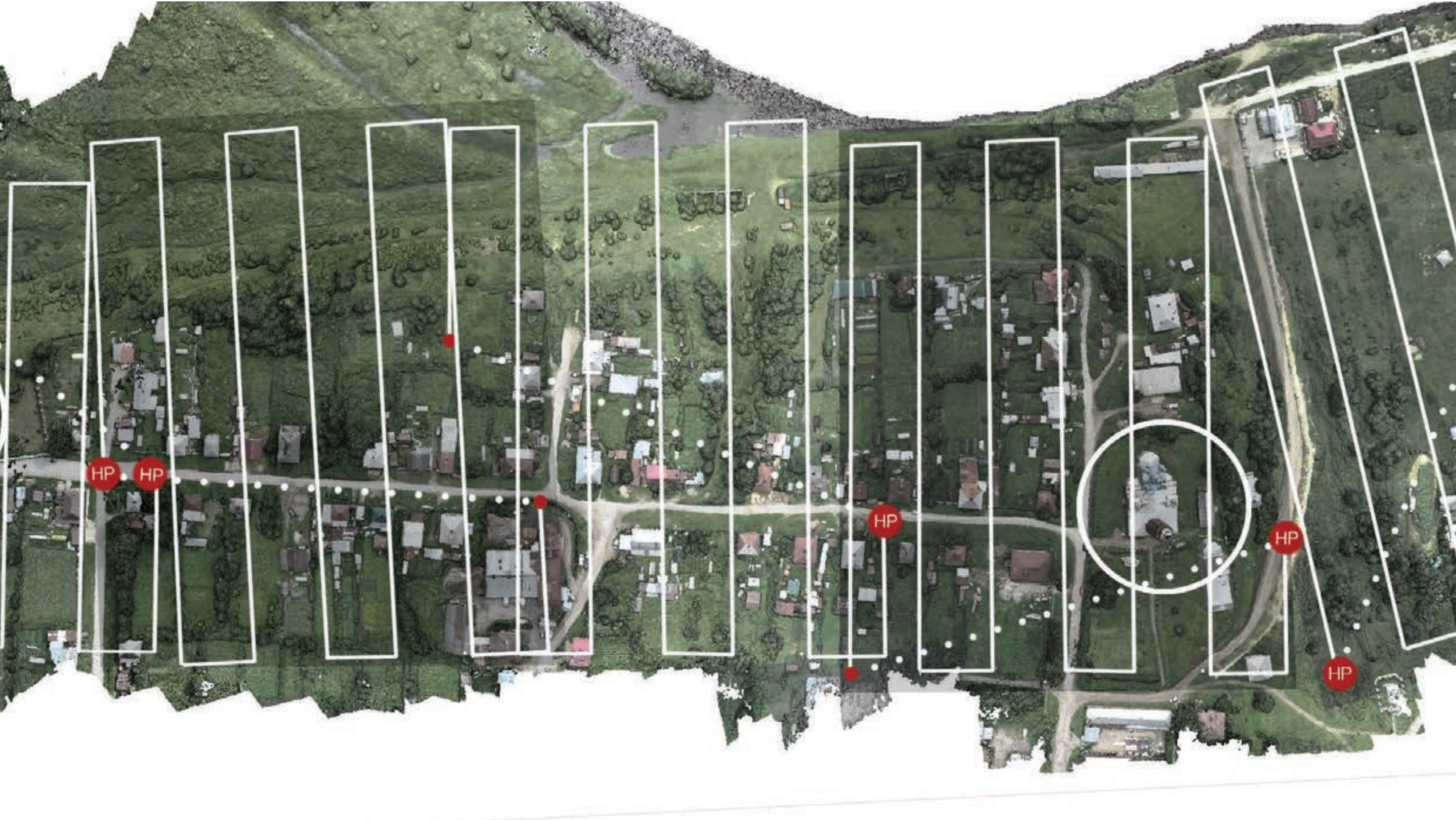

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UAVs, documentation, Structure from motion, acquisition protocols, architectural and townscape heritage.

ABSTRACT

The importance assumed by the photographic instrument for the documentation of the architectural and townscape heritage has seen the increase in the use of manageable and performing UAVs, aimed at the production of reliable photogrammetric databases from which to extrapolate from the detailed up to the cartographic drawings. The paper discusses the application of some commercial DJI drones tested on different contexts, in order to evaluate the updating of the product used in reference to the case study and the developed a methodological protocol that produces an output to integrate, support or, in some cases, replacement of other digital terrestrial instrumentation outputs.

Acquisition protocols for UAV photogrammetric data. Comparison in methodological SfM procedures from architectural till urban scale

1. Introduction

To represent the complexity of the cultural heritage, both at the architectural and urban scale, today the digital survey uses tools capable of overcoming the gap between the use of "traditional" aerial photogrammetry and terrestrial survey tools as topographic, photogrammetric or laser scanner (Lo Brutto et al. 2014). In particular, the spread of small unmanned aerial platforms (micro and mini UAVs) gives the possibility to obtain images of many inaccessible contexts with advantages of fast and very high resolution of the images obtainable. So, the use of tactical UAVs for photogrammetric scope[1] is basically due the production of 3D point clouds o architectural and landscape ground from which to obtain high quality ortho image to complete

the metric information obtained by topographic or laser scanner instrumentation. Just as it does for terrestrial photogrammetry workflow[2], to carry out SfM (structure from motion) photogrammetry campaigns from UAVs is necessary to analyze the structure of the context.

The complexity of cultural heritage is characterize by a levels of investigation that include both the formal structure of the place and the set of specific descriptive features of each subset. These levels are defined through the structuring of a hierarchical drawing capable of describing the assets and the relationship between elements that generate each system to be acquired. The semantic analysis and decomposition of the heritage in hierarchical systems and levels of analysis will allow greater control both in the acquisition phase and in the postproduction phase of the data.

The acquisition by macro structures and elements will allow to obtain 3D models more easily manageable and reliable, as well as higher quality and resolution outputs that can be used as systems for a multiscale reading and analysis on heritage.

For this reason, even in the case studies presented here[3], the acquisitions with UAVs were preceded by a process of semantic decomposition of built and landscape systems into sub-systems to better manage the data complexity of architectural and urban heritage.

2. UAVs platforms and acquisition methodologies

The applications of different mini UAVs in the photogrammetric survey activities here illustrated aim both to consolidate the UAVs platforms potential in Cultural Heritage documentation and to establish a methodological protocols for the acquisition phase. The different contexts and the level of detail to meet the objective to which each of the research projects is aimed at, show different uses of drones according to two fundamental aspects.

The possibility or not of overflight areas or buildings according to specific legislative restrictions:

the introduction of several restrictive laws for safety purposes (in Italy, for example), which have bounded the use of UAVs in specific context and operative condition[4]. That situation pushed the operator to prefer the use of nooffensive micro-RPAS[5] in critical contexts, opening new scenarios for close-range photogrammetry applications and improving the architectural survey quality thanks to the possibility of

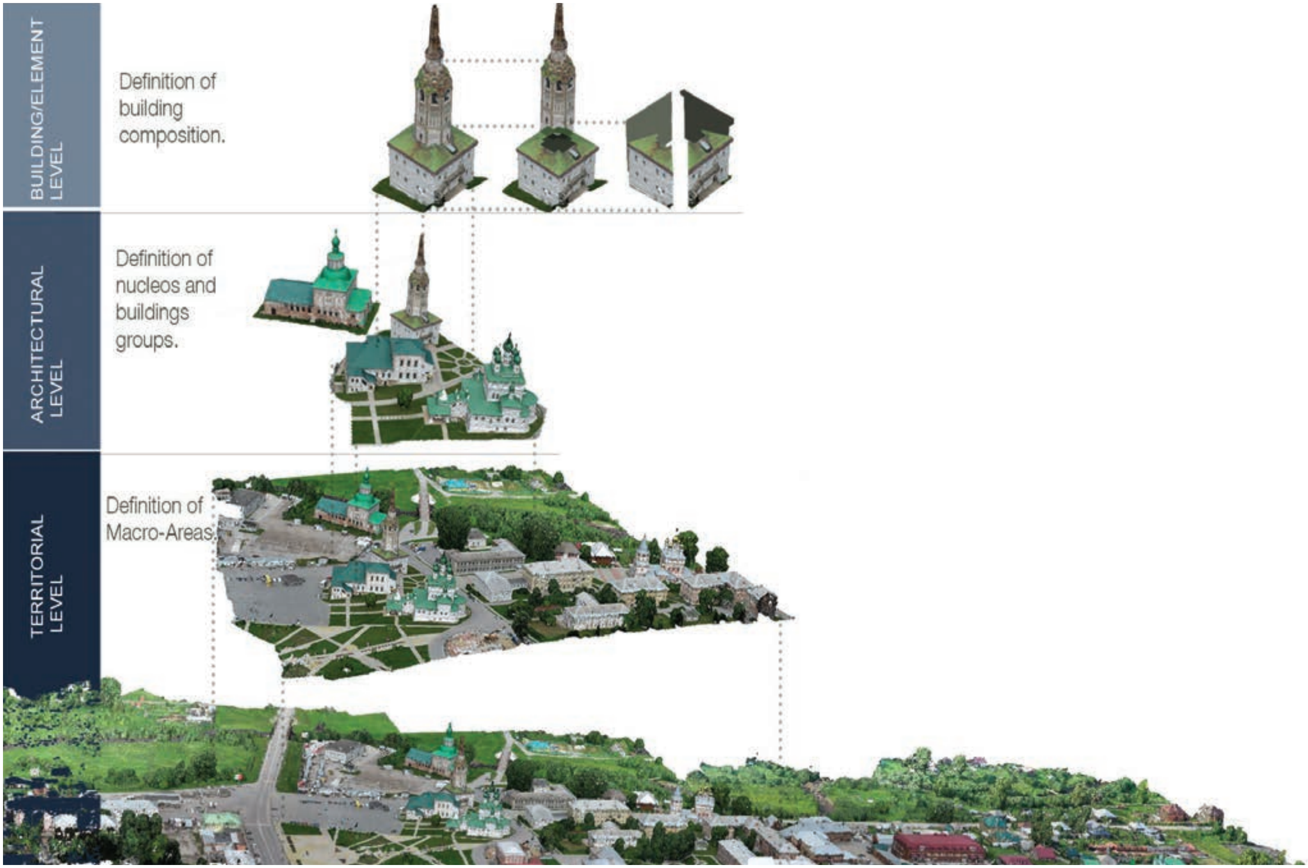

Figure 1. Definition o levels o investigations for SfM data acquisition based on semantic decomposition o territory features.

getting closer to the surface to be detected (Carnevali et al. 2018). Certainly the disadvantages are related to piloting in wind conditions, to the ease of signal loss between radio control and platform (which forces the operator to keep the distance within a narrow range) and a general loss of image resolution compared to light UAVs.

Moreover, the acquisition of the portions and subsystems into which the object is divided can only take place manually by the operator, given the impossibility of making preset flight plans.

Despite this, the extreme portability and the unconditional possibility of use make them today among the most used in the field of monitoring and acquisition of details for historic architectural documentation.

The performance of the instrument regarding the extension covered by the platform flight: in the documentation of large areas, (buildings monumental facades or portions of urban contexts), it is necessary to evaluate the choice of the drone to be used also according to the performance of the flight, i.e. the height and the maximum distance it can reach (or minimum distance from a surface), the possibility of control of each shooting position and image resolution, the battery issues[6]. These aspects contribute significantly to the planning of the operations, especially as a function of the complete and exhaustive SfM photogrammetric coverage of each subsystem (also if it is represented by a neighborhood) into which the object has been semantically divided. For this reason, and in order not only to strengthen the image network geometry but also to better cover hidden parts (Murtiyoso et al. 2018), each subsystem is acquired following a specific flight plan with converging axes, capable of acquiring each element of the system from 5 inclinations of the gimbal camera (Aicardi et al. 2016)[7]. Each mission must be evaluated in the number and duration of the batteries, to ensure total coverage of the area within a period of time that allows uniform exposure of the surfaces (essential for image texture homogeneity during the alignment phase by the software).

This acquisition method was used for the survey of facades and large vertical surfaces (in totally manual mode but with GPS, RTK, GNSS / INS devices, which improve the recognition of the drone position at the time of shooting, optimizing the SfM camera orientation phase). It was also used to acquire large areas of the historic center, suitably divided into areas, using both preset flight plans at constant altitudes, and manual acquisition systems at variable altitudes to ensure greater coverage of all surfaces of the object but also considerably increasing the time for acquisition.

Figure 2. UAVs for architectural acquisition: DJI Phantom RTK and DJI Mavic mini for acquisition of vertical fronts o Monumental facades. On the left, The facade of Certosa of Pavia; on the right, the facade of San Michele Maggiore in Pavia.

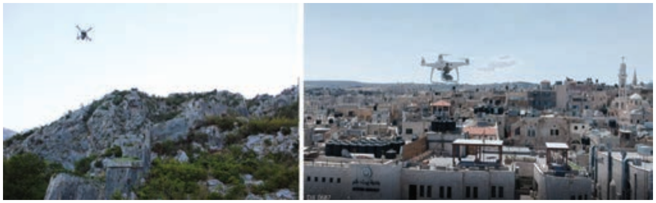

Figure 3. UAVs for territorial acquisition: DJI Phantom 4 Pro and for acquisition of extended portions of areas. On the left, the fortified system of Kotor; on the right, the urban city center of Bethlehem.

3. Case Studies: contexts analysis and issues

Below are illustrated some architectural and territorial contexts of different conformation and features present, which provided for the use of some small UAVs to define a specific survey pipeline, valid for each case study but replicable as an operating protocol on other contexts.

At territorial scale, the documentation activities on cultural heritage has been conducted for landscape context (Upper Kama region, Russia, 2019); for urban context (Bethlehem city center, Palestine, 2018); for architectural fortified system (Kotor city center, Montenegro, 2019)[8]. Each of these contexts has different formal elements, characterized by the presence or dominance of the naturalistic landscape aspect, by the morphological complexity of the historical fabric, by the conformation of unreachable defensive structures articulated on mountain ridges and by the planimetric extension of the sites to be acquired. All these aspects had led to prefer the use of UAVs that provided for semiautomatic flights, as DJI Phantom 4Pro or DJI Mavic 2 Pro. These small drones are able to guarantee a good image resolution even from a certain distance from the surface to be acquired and a good signal control even from considerable distances of the platform than the operator. The area is divided in several flight plans at constant altitude, while the monument are also acquired with point o interest to improve the quality of data. Each of the sites has been decomposed according to the logic of semantic structuring and analysis of the space.

Figure 4. Different DJI UAVs performed by DAdaLab of DICAr during acquisition campaign of Cultural Heritage. From the left: Phantom RTK, Phantom 4 Pro, Mavic 2 Pro, Spark, Mavic mini.

The linear elements (such as rivers, roads or continuous perimeter walls) constitute elements of division of the areas, as well as the difference in the conformation of the fabric, the building density, the presence of characterizing elements, etc. The division has determined subsectors of each system, which can be acquired with flight plans or points of interest able to guarantee the correct overlap between contiguous areas. In the case of the historic center of Bethlehem, 26 areas have been identified, for each of which 5 flights of the DJI Phantom 4 Pro with gimbal converging axes and constant altitude have been provided. Being an urban context with very high density and full of systems and technological elements to be documented near the roofs, the height of the aircraft with respect to the surface of the roofs has been set at constant 35 m, also in relation to the safety conditions to be maintained given by the proximity to the Israeli check point[9].

To document the identity landscape of some historic centers of Upper Kama, the acquisition with points of interest around the main monuments in the area were integrated with the flight plans (planned at constant altitude) executed for each area, in order to obtain two database levels: a more general one at a territorial scale, and a more specific one at an architectural scale. The double acquisition (flight plans and points of interest) was also used in the case of the documentation of the city walls of Kotor: the historic center, which develops at the

Figure 5. General scheme acquisition with UAV at territorial scale in Upper Kama region: the area is divided in several flight plans at constant altitude, while the monument are also acquired with point o interest to improve the quality of data.

Figure 6. Scheme acquisition with UAV at territorial scale: on the left, the mixed acquisition with point o interest for different altitude morphology conformation in Kotor; on the right, the acquisition scheme or the city center of Bethlehem. The area has been divided in several flight plans, overlapped thanks to common point selected on roofs surfaces.

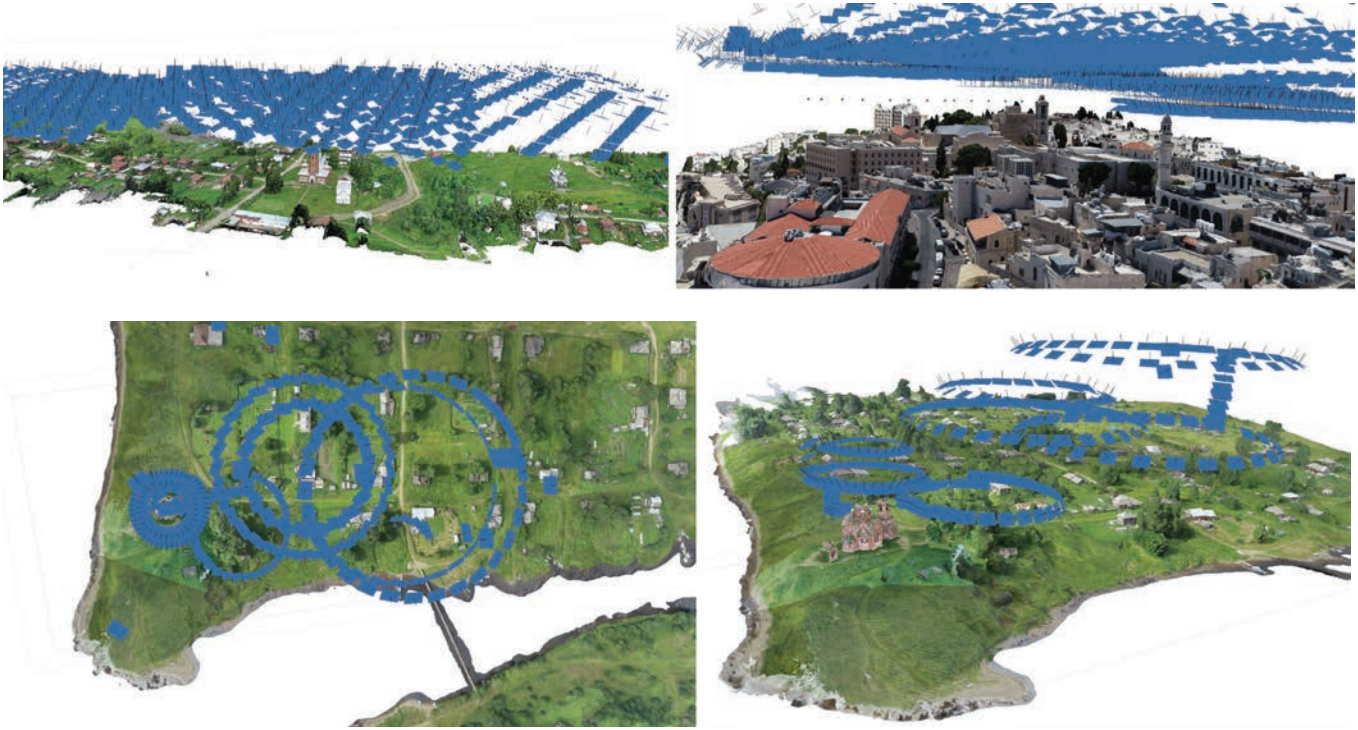

Figure 7. Views of some point clouds generated at territorial levels: above, the flight plans; below, the points o inter-est. Phantom 4 Pro, Mavic 2 Pro, Spark, Mavic mini.

foot of the mountain system, was acquired with a flight plan of DJI Mavic 2 Pro (planned at constant altitude), while the extensive fortified perimeter which is divided into different altitude systems and overhanging walls, was acquired through several points of interest planned for homogeneous portions of the wall positioned at different levels. Certainly the greatest difficulty of these acquisitions lies in the choice of the starting and takeoff point, as well as the piloting of the drone, so that it remains always visible to the operator (VLOS). Therefore, for each case study, preliminary inspections were carried out to understand if the roofs of the buildings were accessible, if the presence of trees or electrical systems could have compromised the feasibility or safety of the flight conditions. In all these contexts, the various individually generated subsystems have been aligned with each other on the basis of homologous points identified in the architectural corners of the buildings or artificial structures of the landscape[10].

At architectural scale, both monumental and detailed, three different drones were tested: the DJI Phantom RTK for the acquisition of the rich decorative apparatus present on the facade of Certosa di Pavia (Italy), the DJI Spark for the acquisition of a *awash* (annex of buildings)[11] in the historic center of Bethlehem, the DJI Mavic Mini for the acquisition of a south front of the church of San Michele in Pavia (Italy). Compared to the documentation of large areas on a territorial scale, whose photogrammetric UAVs survey pursues the main objective of documenting the relationships

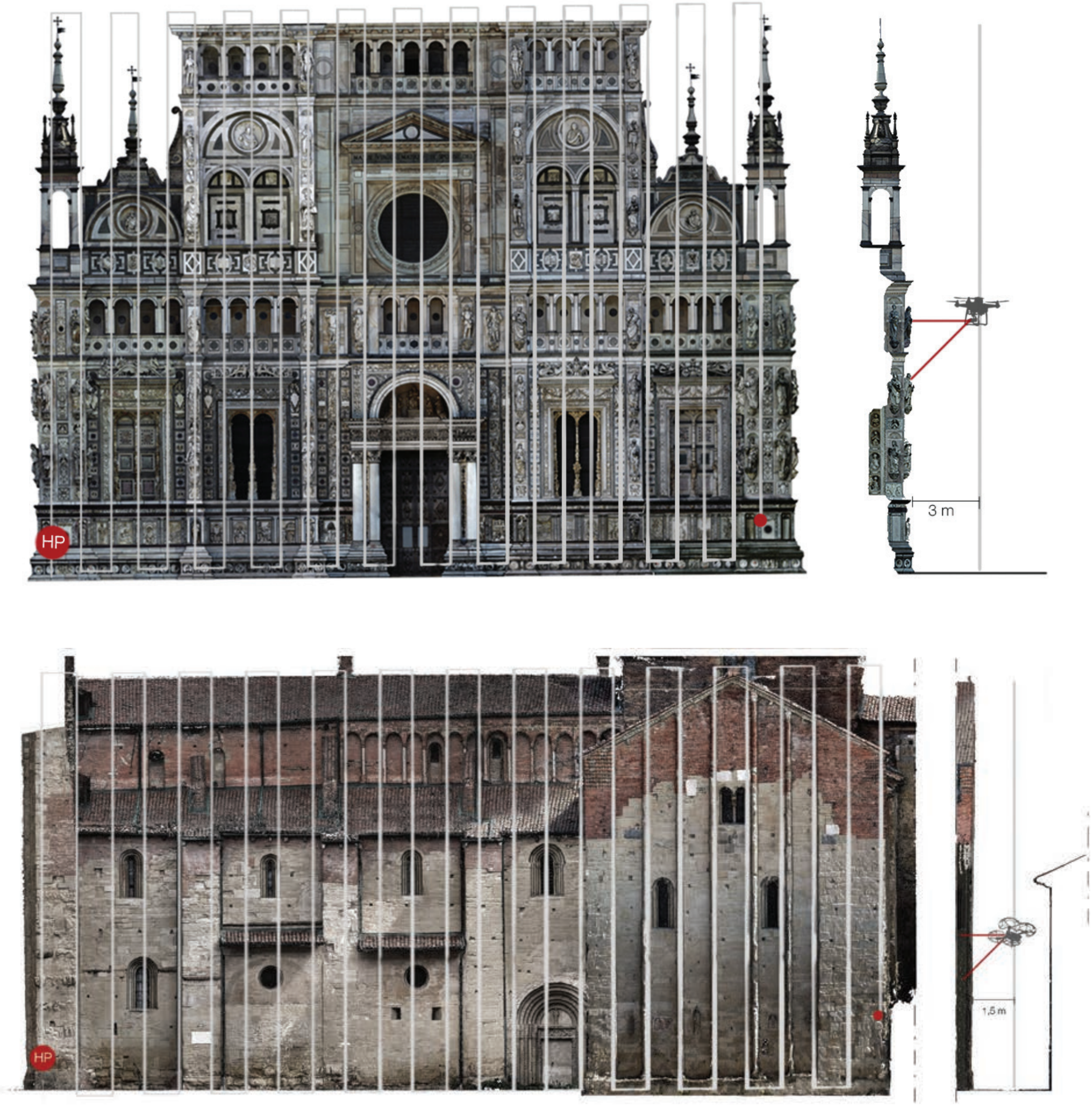

Figure 8. Scheme acquisition with UAV at architectural scale: above, the acquisition with Phantom RTK for the facade of Certosa of Pavia; below, the acquisition o South front of Basilica di San Michele in Pavia with Mavic mini.

Figure 9. Views of some point clouds generated at architectural levels: above, the point cloud generated with Phan-tom RTK; below, the points cloud generated with Mavic mini.

between the elements of the space and creating a tool to promote their management in the area, architectural documentation with UAVs has the main purpose of producing a very detailed database, a tool through which integrating the missing information of the other tools and monitor the state of conservation of the building surfaces. For this reason, each system to be acquired (which in the case of territorial acquisition constituted the minimum unit of acquisition) is further broken down into subelements, up to defining the decorative detail as the smallest element to be acquired. The distance between the surface to be acquired and the platform used is considerably reduced, while the images taken for each context to be acquired are increase.

The predominantly vertical conformation of the surfaces to be acquired forced the acquisitions in totally manual mode. For the facade of the Certosa di Pavia, a vertical flight plan has been prepared, configured as an "S" path, at a distance of 3 m (tried to keep constant) from the facade surface. For each position of the drone with respect to the facade (almost 170 drone positions) 4 shots were taken, one perpendicular to the plane, the other to the left, right and downwards, with camera axes rotated by about 45° in all directions.

The convergence of the axes and the overlapping of 80% between sequential photo pairs allowed to obtain an extremely detailed photogrammetric 3D model which, compared on the basis of corresponding points with the laser scanner point cloud, confirmed the contribution of the RTK in the improvement of accuracy of UAV position with respect to the GPS Phantom signal. The latest experimentation carried out in the field of architectural documentation is that relating to the acquisition with mini drones, such as the Spark or the Mavic mini.

The spark has already been tested for the acquisition of architectural facades (Carnevali et al. 2018) and for the acquisition of objects or aggregations of threedimensional elements distributed in space (Parrinello & Picchio, 2019).

The DJI mavic mini has been tested for the first time on a wall surface in order to document its conservation status and evaluate the effectiveness of the SfM photogrammetry output in relation to the cloud of laser scanner points. the choice of the instrument, conditioned by the impossibility of using another drone within the historical context in which it operated, confirmed the effectiveness of the method used for the facade of the Certosa di Pavia, obtaining a highly reliable photogrammetric model. Certainly the use of this instrument, much less stable in windy conditions or poor GPS signal, makes it more subject to inaccuracies in the acquisition phase, with the risk of keeping less control over the overlap between the images and the actual height of the drone in the various positions assumed.

4. Conclusions

The survey campaigns carried out on some case studies, even of vast extensions contexts, show how these commercial UAV are able to offer excellent support for the digital acquisition campaign from lasers, being configured in all respects as tools to integrate both metric and given data quality.

The choice of each UAV must be weighed on the basis of the morphological characteristics of the context to be acquired and of the real possibilities of use (both of the aircraft's performance and of specific regulation). Moreover, the methodological acquisition protocols must also follow an update of the data processing software to verify the quality of what has been acquired. Beyond this, the contribution intends to highlight as well as with mini UAVs, by applying acquisition o converging axes methods for semantically subdivided areas, it is possible to obtain very highdensity point clouds, responding in all aspects to the documentary needs of the cultural heritage, projecting these lowcost tools towards the scope of fast survey and reliable output.

Note

1 The UVSInternational classifies the UAVs into three major classes: tactical, strategic and for special purposes (Remondino et al. 2011). The UAVs used for photogrammetric scope usually belong to the tactical UAVs; in particular, they belong to the mini and micro UAVs sub categories. (See Lo Brutto et al. 2014).

2 For an indepth treatise on the methods of semantic decomposition of the architectural space aimed at terrestrial SfM acquisition, cfr. Picchio F., 2015; and also Gaiani M., (edited by), 2015.

3 The paper presents some research projects developed by DICAr's DAdaLAB laboratory of University of Pavia, from 2018 to 2020, which saw the integrated use of image-based and range-based instruments for the documentation of the architectural and landscape heritage in different national and international contexts.

4 For the most o operative flight missions in historical city center and in specific areas, it is necessary requiring only specialized flight operator.

5 Remotely Piloted Aircraft System. Some of them are prefer to the big or medium size drones because lighter than 300 gr. (maximum for Italian regulations). See ENAC Regulation "*Mezzi Aerei a Pilotaggio Remoto* - Ed.3 dell'11 novembre 2019".

6 The resolution of image and used camera focal length are generally fixed in order to derive the mission flying height and distance from the surface. The flight is normally done in manual, assisted, or preset mode, according to the mission specifications, platform's type, and environmental conditions. The overlap between the images to ensure the automatic recognition of homologous points in photogrammetry is maintained between 70-80%.

The presence onboard of GNSS/INS navigation devices is usually exploited for the preset flight and to guide the image acquisition. (Nex & Remondino; 2013).

7 Generally a flight plan set with UAV for each subarea provide for 5 missions: one with a 90° gimbal angle (nadir), the other 4 with 45° angle directions from north, south, east and west sides. For a better understanding of this methodological acquisition approach to urban scale, see Parrinello, Picchio, 2019.

8 For an indepth discussion on the methods of digital documentation integrated in the various contexts, cfr. Parrinello S. Picchio F., (edited by) 2019; Parrinello S. et al. 2019; Parrinello S. Picchio F, 2019; Parrinello et al. 2017.

9 The methods of acquisition and the characteristics of the historic center of Bethlehem are fully described in the contribution Parrinello S., Picchio F., 2019.

10 The shrewdness in the acquisition phase was, in this case, maintain a certain overlap in the acquisition of the various portions in which the fort was broken down, in order to allow their subsequent alignment on the basis of points common to the various SfM models generated.

11 The city of Bethelehem was formed from small rural settlements, which constituted the first building agglomerations formed by small volumes distribuited around central courtyards (*awash*).

Credits

Those research were enforced in a collaboration between DJI Enterprise and the University of Pavia for the development of research activities, and the promotion of the different ways of using drones for cultural heritage. This collaboration is based on the "Agreement for the development of research activities about the digital documentation of cultural heritage and landscape using drones" between the Department of Civil Engineering and Architecture of the University of Pavia and iFlight Technology Company Limited, signed in February 2020, lasting three years.

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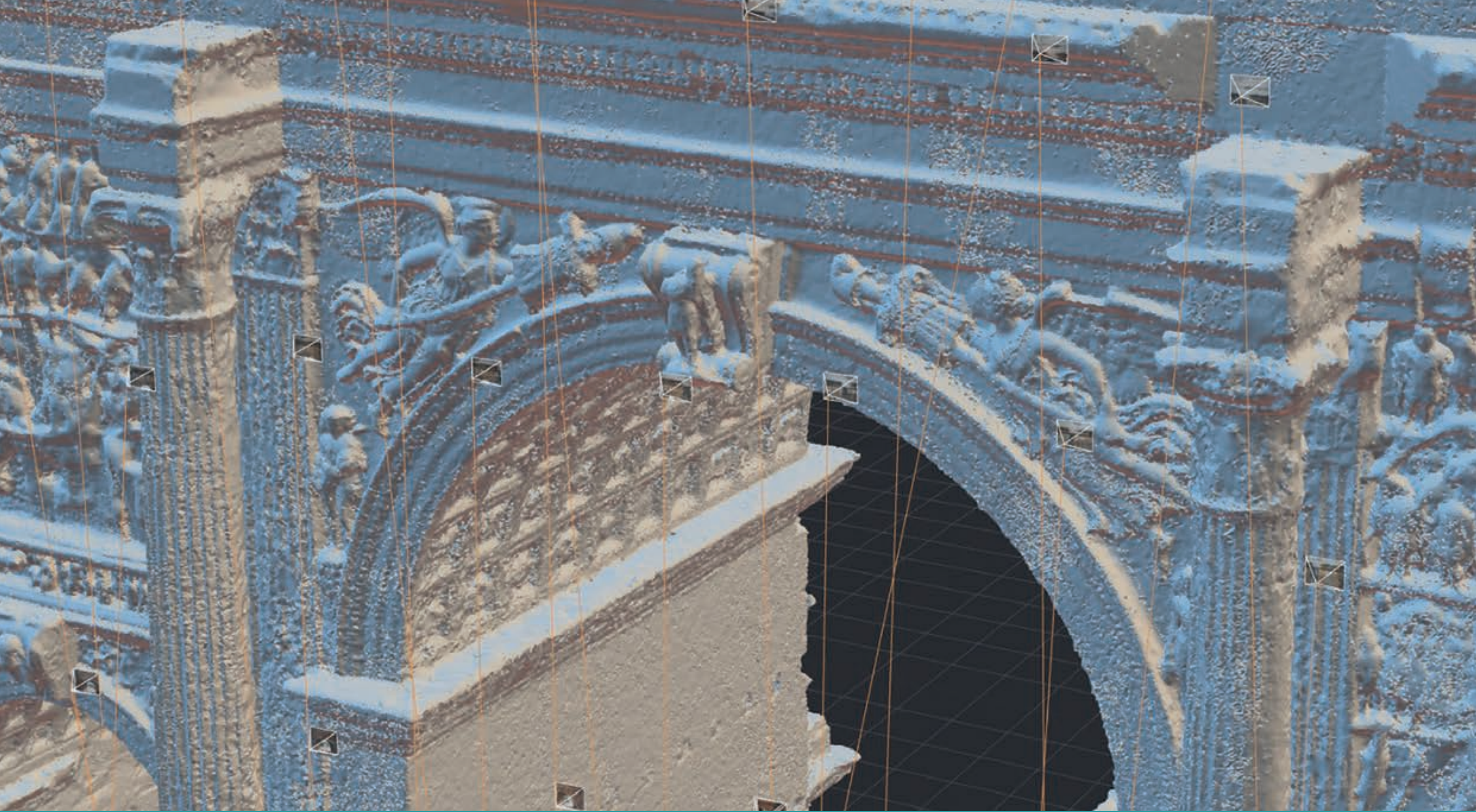

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UAV, Structure from Motion, drone photogrammetry.

ABSTRACT

The use of drone photogrammetry can today be considered among the faster procedures for detecting spaces and architectural objects. Possibility offered by aerial shots and consequent image processing, within three-dimensional model return programs, through automatic photogrammetry SfM (Structure from Motion), speeds up operations that until a few years ago required a much more complex acquisition process. Also, in this process, as in all techniques for detecting and/or organizing data on an object, multiple procedural steps must be taken into consideration, aimed at perfecting the "level of accuracy" and the "level of reliability" of the derived model. These activities must be very clear in the drafting of the project, upstream of the image recording phase, thus realizing a careful planning of the operations to be carried out in the survey campaign. Equally clear should be selective activities of data collected by the drone and integrated with data from other technologies, which generally always complement such data (total station, laser scan, etc.).

The use of UAV for expedited procedure in architectural survey

1. Introduction

Manuals have always made a distinction between survey with “direct” and “indirect” method. The availability, effectiveness and level of confidence with the tools designed for this purpose has led to a greater use of the “indirect” or “instrumental” method. Among tools that allow “indirect” survey operations to be carried out, can be included those that allow the use of aerial photogrammetry through the use of drones. Aerial photographs, in this case, follow a personalized route programmed by the surveyor. Different types of drones, whose main component is the type of optics and the resolution of the photographic camera, can be used to make single shots or video sequences, depending on the objectives. The choice of the type of drone generally falls on technical aspects related to the payload of the equipment, therefore to the photographic quality and the permanence in the air of the drone. However, the choice of the dimensional relationship of the drone and the object to be surveyed is of considerable importance, since - if properly calibrated - it can play a fundamental role in obtaining definition, accuracy and reliability in the model detected. Lastly, it should not be overlooked that flight activity, more specifically dedicated to survey, can be synergistically integrated with a more generic narrative\disseminated activity of the object to be surveyed. Technical, meteorological and authorization complexities, which prelude to the use of UAV, once overcome, motivate to fully use the flight opportunity; for this reason, the two objectives should always coexist.

In this paper two surveys are examined in parallel, carried out by means of UAV, and dedicated one to a detail scale of the architectural partition, and the other to the more general scale of artefacts and their context. For both, affinity and criticality are analyzed reported.
Use of drone follows “air rules” and regulatory provisions issued by ENAV, both in terms of piloting and the areas where flight is allowed.
Aerial photogrammetry is integrated with ground photogrammetry, especially for those parts that have horizontal surfaces parallel to the ground and are not detectable from above (e.g. intrados of vaults, balconies, shelters, etc.). Further integration and completion of the registration phase is allowed by terrestrial laser scanners. Data return procedure involves processing them with sequential transformations among photography> point cloud > mesh> texturing. Data from laser scan have direct output in “point cloud” and are integrated in the “point cloud” management phase, as indicated above.

2. Topic of research

The triumphal arch of Septimius Severus, erected between 202 and 203 AD it is in the center of Rome, north-west of the Roman Forum near *Palazzo Senatorio* (Figure 1). It consists of three arches, one central major and two lateral minor ones, which create, with the attic, a front of 25 x 23 (WxH) meters and a depth of 7 meters. The “ancient quarry” of granite columns is in Grottarelle area (Figure 2) of the municipality of Campo dell’Elba, not far from the beach of Cavoli, Elba island.

Figure 1. Arch of *Septimius* Severus facing Campidoglio hill in Rome.

Figure 2. Ancient quarry of granite colums in Grottarelle area, facing the sea, Elba island.

It has an extension of about 2000 square meters, it is located at 250 m a.s.l. Extraction of the Elban granite began around the 1st century AD by the ancient Romans and ceased in the second century AD for the opening of the quarries in Egypt. It resumes from 1005 when the Pisan Republic acquires jurisdiction on the Island of Elba.

In the "ancient quarry", the best preserved of the Elban quarries, are clearly visible the various phases of extraction and processing of granite, testified by the columns still present.

The "freezing" state the area is probably due to the black plague, which, unexpectedly and suddenly, decimated the Elban population in 1348, making the area abandoned and unused to the present day.

3. Drone flight planning

Flight planning, in any scale situation, must naturally take into account the most substantial climatic conditions, which we can summarize in the absence of wind and rain (Remondino 2011). Presence of wind would make UAV trajectories unstable, slowing down maneuver and creating potential dangers to people and things and to the UAV itself. Presence of rain, in addition to compromising flight stability of the drone, would significantly affect quality of the shooting. Time window in which to carry out the flight - and for which to request any authorizations - must therefore be sufficiently large to guarantee operation in the climatic conditions indicated above, as well as a repeatability margin of the shooting, if, operating in the field, we need to refine and repeat the flight plan.

For the filming of the Arch of *Septimius Severus*, it was planned to operate four days, thinking of dedicating one day for each main facade, one day for the two lateral fronts and one day of eventual recovery. Of course, these are not full days, since the usable time slot is limited - for safety and light reasons - to one and a half hours of light per day, from 7:00 to 8:30 in the morning (Figure 3). The intervention of four consecutive days is scheduled within a wider time period of 14 days for which authorization is required to fly in a prohibited area.

Accessibility for flight so reduced are very frequent when working with cultural assets of considerable

Figure 3. Early morning light hour in *Septimius Severus* Arch shooting.

Figure 4. Overview of the “ancient quarry” with zenithal light.

importance, for which it is difficult to limit - even if only temporarily - the presence of visitors, in presence of which one would not fly safely. But time slot restricted to a few hours of dawn also derives from the particular and favorable lighting conditions. Photographic documentation of the surfaces of the object to be surveyed is in fact preferable to be acquired in absence of sharp shadows. An alternative solution, to shooting with the light of dawn (or sunset), is to shoot within the day by gradually acquiring the side not directly exposed to the sun. This technique, however, requires careful handling and quality of the shooting equipment, both necessary to maintain the high quality of the image of the photographic shots, which could have strong lighting contrasts or even be partially backlit. In order to be able to register in the area, authorization has been requested from the Prefecture of Rome and the bodies responsible for protecting the air, since the entire historic center of Rome falls within the LI P244 area with an absolute flight ban, which is supported by the limitations of Ciampino Airport and of Urbe Airport which allow to reach the maximum altitude of AGL (Above Ground Level) 45 m from the ground.

For the registration of the area of the “ancient quarry” the flight recovery has a simplified programming. The particular position and nature of the area, which faces east and has a thick vegetation, suggested to operate with a zenithal light, in a time slot between 12:00 and 13:00, with a proper shadow perpendicular to objects in the surrounding landscape. The area can be reached through a path marked by CAI (*Club Alpino Italiano*), which involves overcoming a difference in height of about 150 m from the parking area, greatly reducing visit of the site by hikers and scholars, allowing to operate safely in any time of day. Only limitation is AGL overflight altitude at 120 m above the ground (Figure 4). Flight plan stems from considerations concerning general and detailed spatial articulation of the object to be detected, metric and photographic definition to be obtained, precautionary redundancy of data acquisition. Each of these considerations is conditioned by specific characteristics of the UAV used.
In the specific case of the arch of *Septimius Severus*, where there is a reduced general spatial articulation, we can, on the other hand, detect a substantial articulation of detail.

Figure 5. View from 3D model of *Septimius Severus* arch.

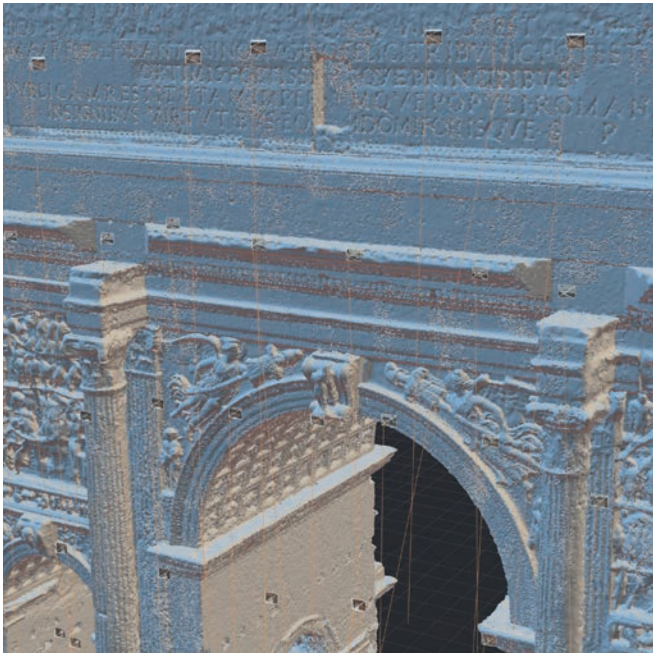

Figure 6. Structure from Motion, *Septimius Severus* arch.

This, in addition to covering the vast sculptural apparatus and the epigraph, finds its maximum complexity in the architectural order present on both main fronts, characterized by 4 composite columns, which protrude from the fronts (Figure 5).

With a view to a flight plan dedicated to “scanning” the arch with a network of shots equidistant and orthogonal to the fronts, this particular spatial condition requires the acquisition of shots even at 45 degrees from the front to prevent parts of it that remains hidden by the presence of the columns.

Quantity of images to be taken is an easily computable value, considering optics and sensor resolution, minimum maintainable distance between UAV and surface to be detected, overlapping and redundancy of the images (Azzola 2019).

Distance is a fundamental element for the quality of architectural detail and to reduce the shadow areas caused by undercuts and present, for example, in sculptural systems.

For this reason, small UAVs, which can be brought closer to the object to be detected with greater safety, are best suited for this purpose, especially if equipped with good sensors.Both in the case of the Arch of *Septimius Severus* and the “ancient quarry”, a DJ Mavic Pro Platinum was employed, with which it was possible to fly about 1.50 meters away from the fronts.

The small UAV was also able to pass inside the central archway, while the minor arches were not crossed, since in such confined spaces there is a reflection of air turbulence. UAV camera can capture both video and images but, in favor of the subsequent SFM return, it was preferred to capture images, because they have a higher definition and chromatic quality (Kunii 2018). Having the UAV a gimball with control only of the zenithal angle between 0 and - 90 degrees, for the

main fronts we have planned a shooting mesh of 10x10 shots performed first orthogonally and then at -45 degrees zenith compared to the front of the elevation. The parts behind the columns were further shot with vertical sequence and drone rotated azimuth by + and - 45 degrees respectively from the right and left side of the column. Series of vertical shots with drone rotated 45 degrees with respect to the main fronts were also taken at the intersections between the fronts, so as to have functional images for the perfect stitching of the parts. Complete the series of shooting from UAV 15 zenith images (10x3).
Captured at a slightly higher distance (5 meters), as normally happens, numerous obstacles, especially at low altitude, prevented full compliance with the theoretical flight plan of the UAV (Figure 6). Limited orientation of the gimball also prevented taking photos from the bottom up, useful for example to capture the vaults of the arches. These limitations have been solved by integrating with photos taken from the ground with a full frame digital camera equipped according to the conditions, with a special lens.

For the "ancient quarry" of Grottarelle, the type of shooting has seen above all zenith and 45 degree recordings in the areas where there are multiple elements of interest: area of the semi-finished columns; area of the boulder where the different cutting and detachment phases of the columns are present. Zenith recordings have seen a flight mode with "streak trajectory"; on the granite boulder, where the processes to detach the blocks are present, recording took place on a double helix trajectory with camera inclined at 45 degrees from the ground for a trajectory of 5m and the other of 10m from the ground. Images are all overlapped by at least 50%. It was not necessary to integrate photos from the ground (Figure 7).

4. Data processing and normalization

In the case of *Septimius Severus* Arch, a total of about 1000 images were acquired, of which only 600, selected according to quality criteria, were subjected to processing for the reconstruction of the model. Images oriented with a rear projection error contained

Figure 7. Zenithal image, from 3D model, of the "ancient cave".

Figure 8. Orthogonal representations of *Septimius Severus* arch.

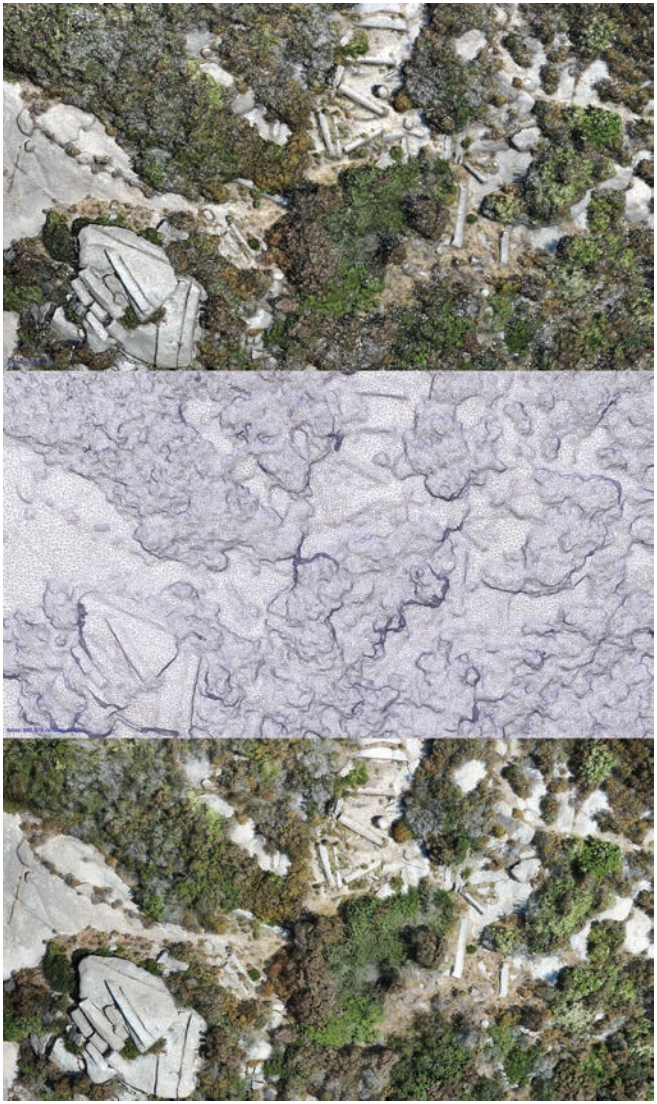

Figure 9. Ancient quarry 3D reconstruction model: points cloud, mesh. and texture zenithal views.

within one pixel, made it possible to easily calculate a cloud of points with samples every two cm. Slight noise that characterized mesh in some areas of the

Figure 10. Ancient quarry 3D reconstruction model: block of granite with processing steps.

arch was attenuated by a selective algorithm capable of operating on the surfaces, leaving the edges that delimit them unchanged. At the end, from the three-dimensional model obtained, the usual orthophotos were derived in correspondence of the main representations (Lo Brutto 2014) (Figure 8).

Derivative works can be considered reliable, for a scale of representation, of 1:50. In these representation scales, a graphical and reading error of only 1/2 millimeter can absorb errors of 2.5 cm. which are greater than those of the model. About 500 images were acquired for the “ancient quarry” of Grottarelle, 350 of these were selected. The main difficulty in creating the mesh model is due to the Mediterranean scrub vegetation, which slowed down the calculation of the overlap of the individual pixels, with a scale of representation of 1:50 (Figure 9, Figure 10).

5. Conclusions

The two experiences, from an operational point of view, highlight how the use of small drones (Gerke 2018), to be flown at close range to the object to be detected, is generally preferable, compared to use of larger drones and to high payload. In fact, when operating on a large scale, small drones may encounter operating limits only due to particularly adverse weather conditions.

Vice versa, operating at the small scale of the architectural work, for large drones, it is basically always forbidden - for safety reasons - to fly near the object to be detected and, consequently, to avoid presence of shadow areas of shot photographic, especially in presence of particularly articulated structural or decorative elements.
However, it should be noted that, in a little justified way, small drones available today are mostly designed for non-professional activities of popular documentation. Technology, and consequently quality of the shot, are in fact considerably inferior, not only - obviously - to that of digital SLR cameras, but also to that of dimensionally similar cameras, which are equipped with modern smartphones.
It is therefore desirable that the UAV production industry focuses interest on these needs and creates products where there is greater convergence between small size and quality of photographic apparatus (Valenti 2014). A more complete sensors could also allow UAV to follow a flight plan, moving within a simplified three-dimensional model of context, thus greatly facilitating maneuverability and allowing to operate safely even in dark spaces with GPS.

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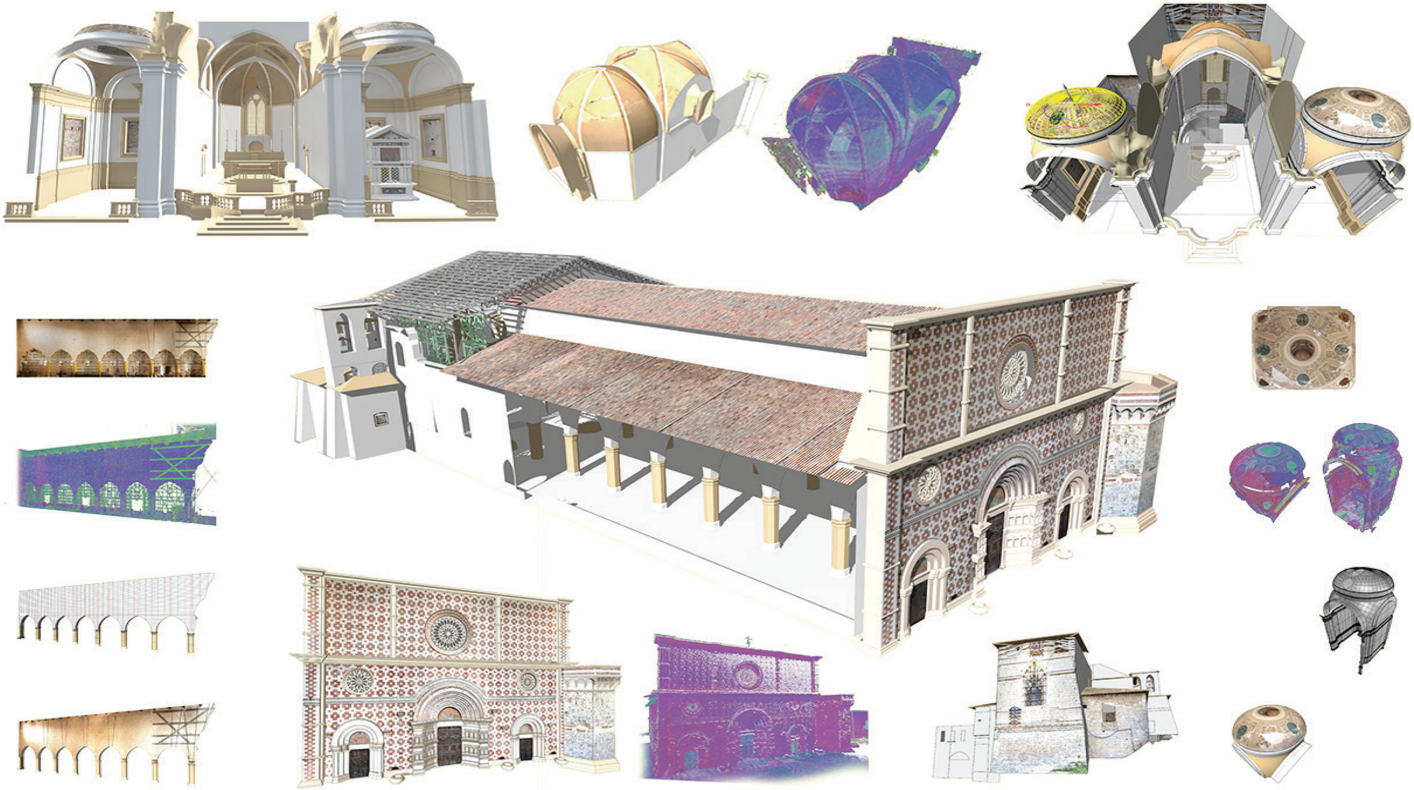

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ABSTRACT

This paper outlines a multi-stage method to improve historic building information modelling (HBIM) projects using unmanned aerial vehicle (UAV) based photogrammetry data. The digital reconstruction of semantic models is based on the application of novel grades of generation (GOG) and the integration of data coming from the use of different type of drones, with which it is possible to improve the level of detail (LOD) and information (LOI) of different types of architectural elements, supporting the conservation process of two complex heritage buildings of international interest.

Keywords:
Drone, photogrammetry, 3D drawing, Grade of Generation (GOG), Historic Building Information Modelling (HBIM).

Drone meets Historic Building Information Modelling (HBIM): Unmanned Aerial Vehicle (UAV) photogrammetry for multi-resolution semantic models

1. Introduction

Nowadays, market applications of 3D data capture technology such as total station (TS), terrestrial laser scanning (TLS), and high-resolution cameras for photogrammetric methods result to be quick and accurate methods for the 3D survey of complex heritage buildings. These digital tools exponentially simplify the measurements procedures as well as improving the accuracy of the data produced such as drawings and 3D models. They require a post-processing phase characterised by the main editing operations such as the registration, cleaning, decimation and segmentation. Thanks to point set registration algorithms, it is possible to merge a huge number of data sets into a globally consistent project, and mapping a new measurement to a known data set to estimate its pose and identify building features. The results obtainable with the post-processing phase vary from method to method, user to user and depend on various factors. The final product is a point cloud or mesh ready for CAD and BIM authoring tools, which cannot be automatically converted in historic building information modelling (HBIM) projects useful for subsequent analysis such as design, restoration and structural simulation. This issue is representing an obstacle for companies and professional firms who want to introduce this technology in their own workflow. Another factor that prevents the adoption of these tools and methods on a global scale is the cost of the instruments and the long data processing times for the virtual reconstruction of the surveyed building. For this reason, many studies have proposed innovative methods with the aim of increasing the level of automation of the generative phase of complex models, defining guidelines for the transformation of point clouds into'informative' models (Grilli & Remondino 2015; Previtali & Banfi 2018; Wang et al. 2015). In this specific application field, some studies have shown instead that the digital photogrammetry can be applied to the digital reconstruction of heritage buildings through very accurate rigours method, significantly lowering costs compared to the TLS survey (Guarnieri et al. 2006). In fact, the photogrammetry (especially that aerial one), allows professionals to complete the points clouds obtained from the TLS survey in a more sustainable way, operating on images of objects captured from different altitudes and angles using drones and digital cameras. The state of the art of the last decades is full of interesting studies that place the development of increasingly complex models from UAV based photogrammetry data at the centre of their research (Barba et al. 2019; Oreni et al. 2014; Nex & Remondino 2014). In this specific field, the paradigm of complexity of heritage buildings represented a theme to be addressed in every aspect such as digital reconstruction from 3D survey data (scan-to-BIM process), accuracy and information sharing (Banfi 2016; Bruamana et al. 2019; Fai & Rafeiro 2014).

2. Research objectives

Analysing and sharing the uniqueness of historical shapes of built heritage handed down through the centuries with a high level of detail (LOD) and accuracy are the primary goals of the 3D data capture. The uniqueness of the surveyed artefacts and the information gathered during the surveying campaigns represented a cultural richness to be transmitted during the life cycle of building (LCB).

Figure 1. The research case studies: the Basilica of Collemaggio in L'Aquila (left) and the Basilica of S. Ambrose in Milan (right), Italy.

Data collection and the connection of information within digital models make it possible to centralize the historical, current and future value of the built heritage. The transmissibility of data and the development of new technologies played a crucial role during the generative process of complex historic models. On the other hand, there are a huge number of factors that prevent the full adoption of BIM for built heritage such as limited knowledge of the most useful modelling techniques, difficulty in changing people's habits, limited budgets, interoperability issues and slack in following operating standards. HBIM, in the last few years, has also given the possibility to professionals to work separately on the same project and to share all the information gathered in real-time. This aspect has not been underestimated by the disciplines of restoration and conservation, which have tried to adapt it as much as possible to this epochal change (Volk et al. 2014).

For all these reasons, the following paragraphs summarise the scientific research aimed to optimise the benefits derived from the use of the main three-dimensional survey techniques, making an in-depth focus on the benefits arising the integration between aerial photogrammetric data and novel scan-to-BIM modelling requirements in complex contexts such as the Basilica of Collemaggio in L'Aquila and the Basilica of Saint Ambrose in Milan, Italy (Figure 1).

3. Data collection

The level of detail (LOD) of the HBIM models and the grade of accuracy (GOA) between point clouds and BIM depended on the quality of the 3D survey data (point clouds and geodetic network).

The main instruments used for the 3D survey of the research case studies were Faro Laser Scanner Focus, Canon EOS-1D X, Astec Falcon 8 equipped with RGB camera Sony NEX - 5N, DJI Mavic mini and Leica TS30 (Figure 2). Faro Laser Scanner Focus 3D allowed a combination of accuracy and speed for non-invasive automated 3D scanning inspection.

Laser determined the locations of a vast number of 3D points and related spatial information. It operated up to a range of 200 metres and at speeds of up to 1,000,000 points per second. The average scan resolution of the research case studies was about 100 million points per scan. The main benefit of this technique is the acquisition of an enormous amount of points by scans. It is capable of measuring the position of hundreds of thousands of points that define the complex surfaces of the surrounding objects, decreasing field times and improving the accuracy of the survey (Riveiro & Lindenbergh 2019). The laser scanning survey of the Basilica of Collemaggio is made up of 182 scans (8 billion points), and the average precision of Basilica of Saint Ambrose's 56 scans was ±3.0 mm. The good distribution around the compound objects and the semi-automatic extraction of geometric primitives and slice provides a preliminary base for the generation of the HBIM models (Figure 3). The second method of 3D data collection was digital photogrammetry. It allowed the determination of three - dimensional coordinates and mesh surface models. This technique reduced to the maximum the lacks of 3D laser scanning survey (Baltsavias 1999). Security structures, scaffolding and inaccessible areas (a grey area) found during the survey did not allow the proper position of the laser scanner in particular areas. This integrated approach provided an alternative solution that drastically decreased the number of grey areas typically obtained from the 3D laser scanner. The flexibility and manipulability of Bentley Pointools, Agisoft PhotoScan / Metashape, RhinoPhoto, and PhotoModeler also make photogrammetry a useful tool for the integration of missing part of the 3D point models. Different strategies for photo capture have been taken depending on the morphological characteristics of both case studies. The primary goal was to improve the automation of digital reconstruction of complex objects and very dateiled as-found drawings (Figure 5), supporting the generative process and the dissemination of true orthophotos and textured models for restoration and conservation project at the same time.

The third method was the UAV based data integration (Eisenbeiss 2004; Remondino et al. 2011, Rinaudo et al. 2012). Astec Falcon 8 drone has equipped with RGB camera Sony NEX - 5N was useful for capturing pictures at high altitudes over the Basilica of Collemaggio' s roof. The acquisition of images from the DJI Mavic Mini has been instrumental in the photogrammetric reconstruction of the Basilica of Saint Ambrose's roofs. Furthermore, the generation of true - orthophotos from a set of UAV images and point clouds have integrated with those previously obtained by laser scanning. It has determined the actual thickness and current condition of the wooden roof layers, encouraging the development of a powerful tool for the completion of terrestrial reconstruction.

The average flying height over the Basilica was 60 m, obtaining a pixel size (on the roof) of about 13.5 mm, i.e. more than sufficient to obtain a true-orthophoto with scale factor 1:100. The whole photogrammetric block is made up of 52 images acquired with the software AscTec AutoPilot Control. The software allows the operator to import a georeferenced image where waypoints can be added (manually or in an automated way by defining the overlap) (Figure 4). The flight plan is then transferred to the drone that flies autonomously (the user has to take off and land). A previous study showed a photogrammetric methodology for true-orthophoto generation with images acquired from UAV platforms (Barazzetti et al. 2014).

The method is an automated multistep workflow made up of three main parts:

(i) image orientation through feature-based matching and collinearity equations/bundle block adjustment, (ii) dense matching with correlation techniques able to manage multiple images, and (iii) true-orthophoto mapping for 3D model texturing.

It allows automated data processing of sparse blocks of convergent images in order to obtain a final true-orthophoto where problems such as self-occlusions, ghost effects, and multiple texture assignments are taken into consideration.

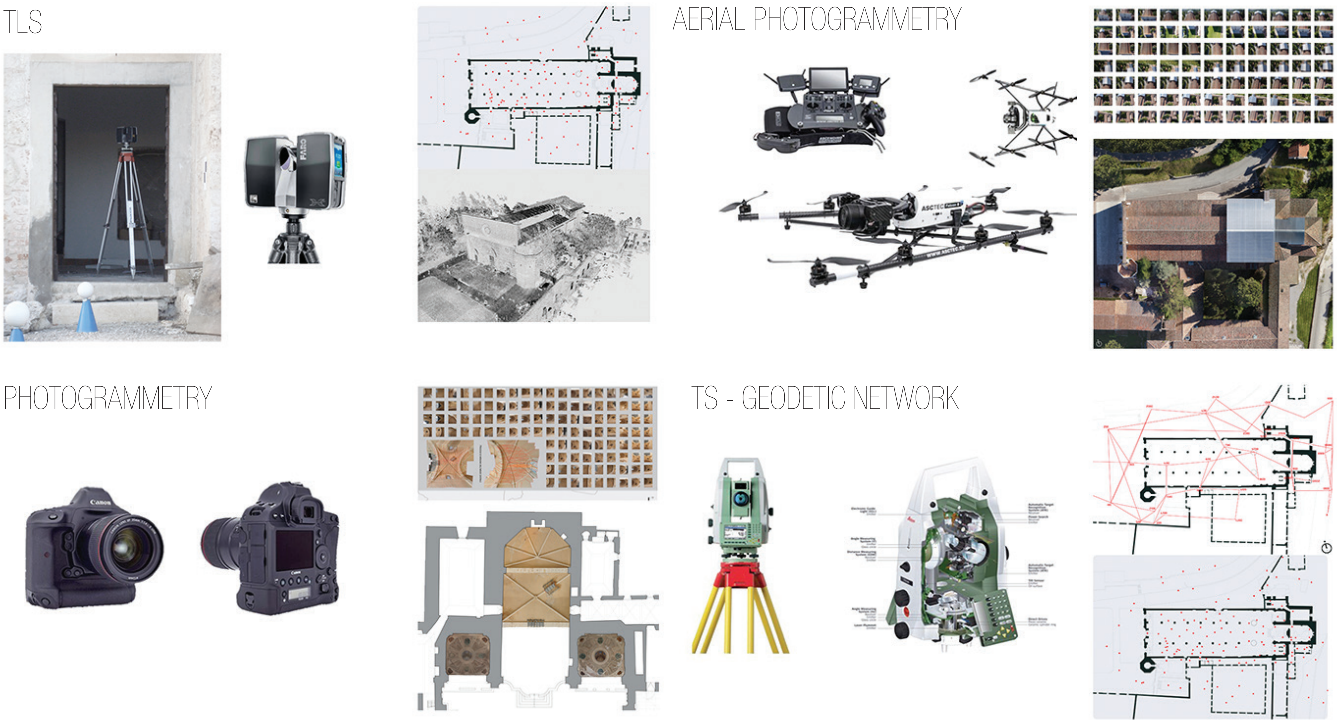


Figure 2. Data capture tools used for the 3D survey of both heritage buildings.

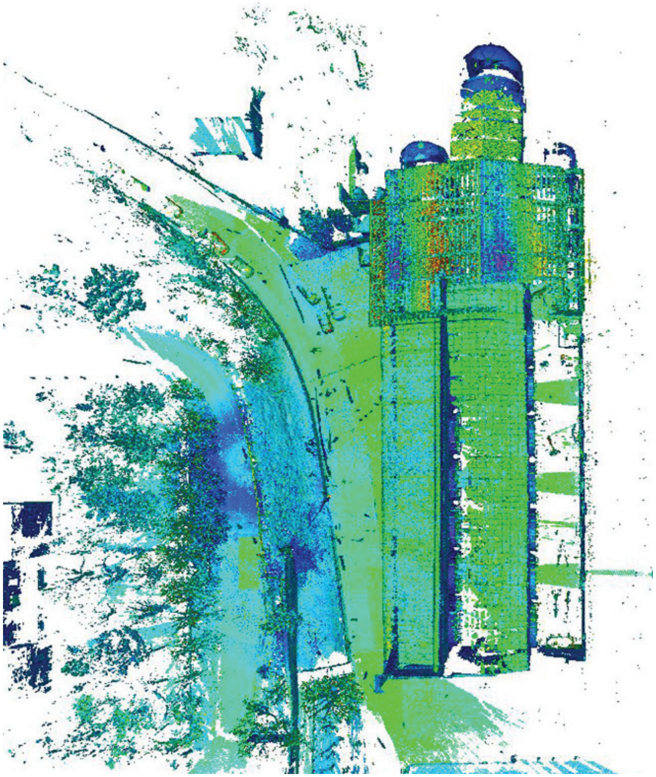
Finally, thanks to the integrated use of the total station, it has been possible to obtain a rigorous data registry by the generation of a geodetic network, verifying, checking and updating the laser scanning data with TS's control points. The creation of geodetic networks composed of surveyed points and new interest points allowed the proper geo-referencing of all the scans obtained with a laser scanner and photogrammetry, giving a single system with shared coordinates in all modelling applications.

4. From points to HBIM models

Bentley Pointools, Autodesk Recap and Faro Scene permitted measurements, verifications export into various CAD formats such as.sat and .dwg.

They also permitted the first operations of cleaning and editing but also combining the point clouds obtained from TLS and drones. The exchange formats of Autodesk Recap and Bentley Pointools are PTS, RCS, e57, PCG, ASCII XYZ and POD. They are text-based formats that contain point clouds commonly generated by a 3D scanner such as Faro Focus 3D. The PTS and RCS formats allow the proper import in Mc Neel Rhinoceros and Autodesk Revit.

The definition of the best input/output formats and the setting of the NURBS software permitted the activation of each point of the scans in the digital space, giving the best base for the generation of geometric primitives. The OSnap (Object Snap) function in MC Neel Rhinoceros



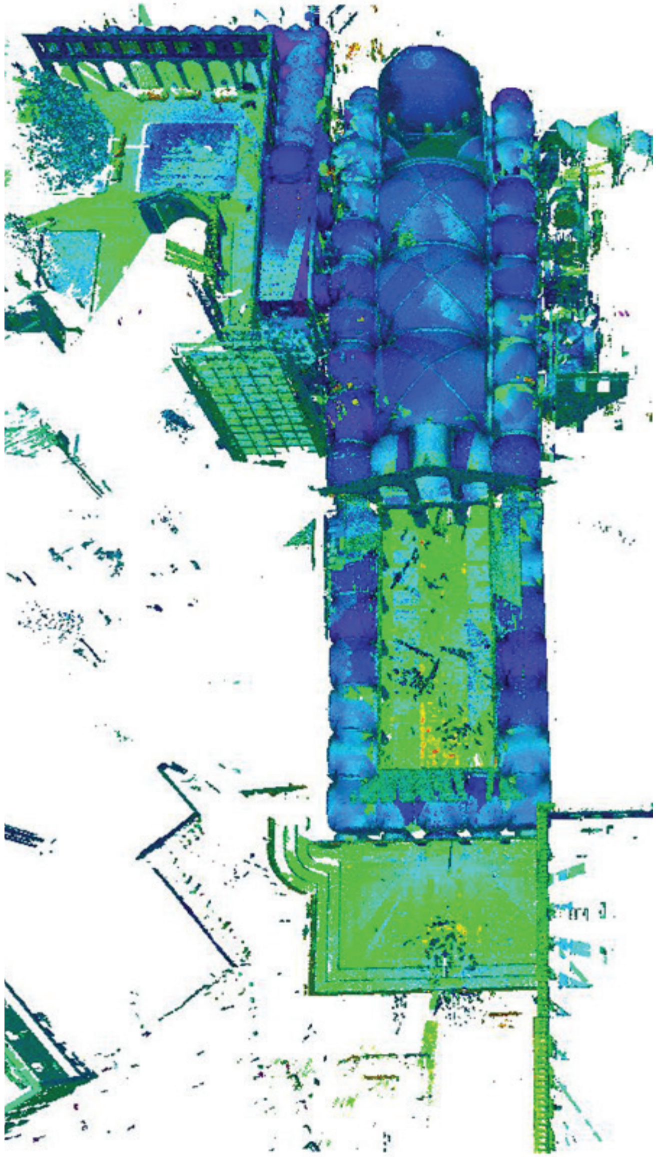


Figure 3. The point clouds projects: the Basilica of Collemaggio in L'Aquila (left) and the Basilica of S. Ambrose in Milan (right), Italy.

was the best support to anchor polylines and slices at the scan's point with shared coordinates (exact location x,y,z). PTS and RCS formats allowed one to import point clouds in Mc Neel Rhinoceros and Autodesk ReCap. Selecting the best input/output formats and setting a proper NURBS-based modelling solution permitted to have point clouds that are not only visual supports during the modelling phase but also active objects to be exploited for the generation of geometric primitives. The final goal was therefore to obtain appropriate management of point clouds in both modelling software (Mc Neel Rhinoceros and Autodesk Revit) and consequently align the models thus avoiding manual operation between one software and another.

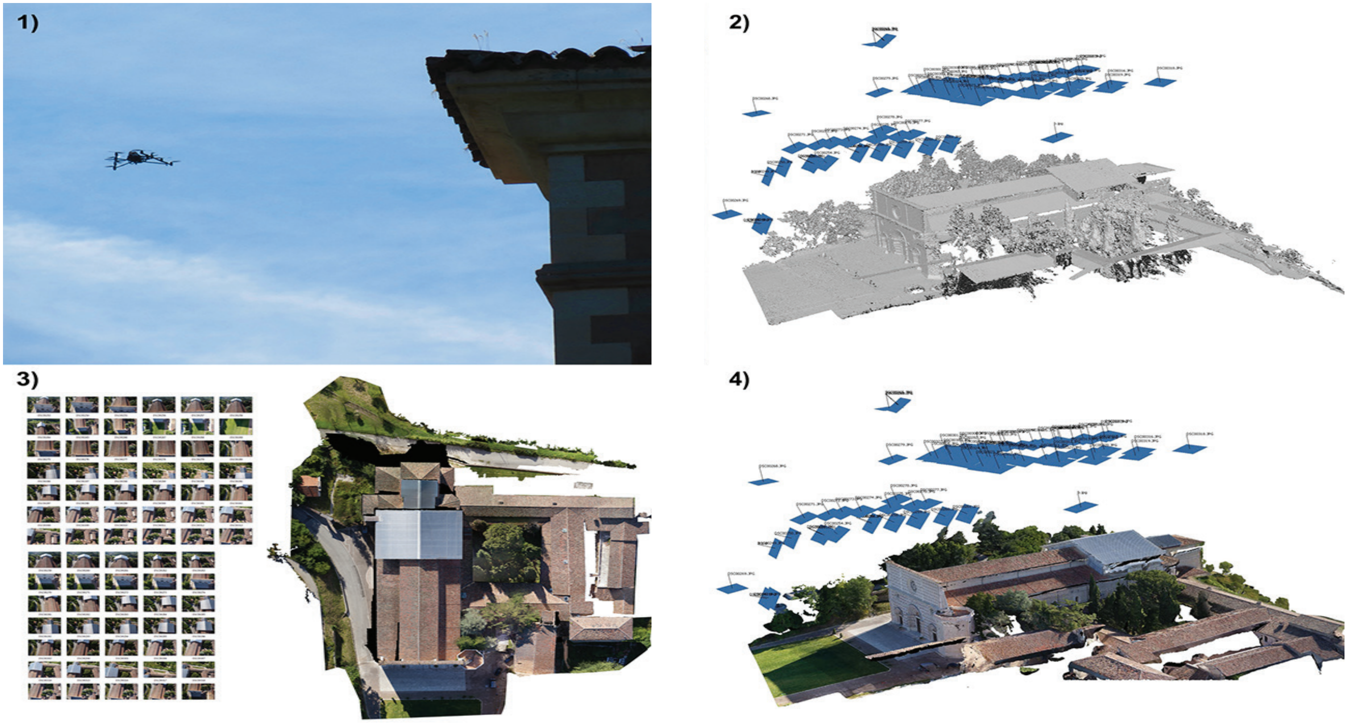


Figure 4. (1) The UAV fligh over the Basilica di Collemaggio, (2) Camera position / attitude and 3D points after the image orientation step, (3) final true-orthophoto from the UAV project (4) The textured mesh model.

The building's components have been identified directly on the field thanks to the support of historical documents, structural reports and 2D drawings (secondary data sources) which, can complete the interpretive analysis of the building. As mentioned in the previous paragraphs, at the beginning of the'transformation' process (from scan to model), point cloud processing applications lead an automatic generation of mesh models. Software as Meshlab, Bentley ContextCapture and Agisoft Photoscan enable the automatic creation of mesh from dense point cloud thanks to specific algorithms that recognise the scan's point like the data source to generate the mesh's polygons. Mesh interprets the complexity of the shapes through the union of points through polygons based on different algorithms. Import tests between free-form modelling software and BIM application found that the mesh model's physical features represent the main problem for the proper functioning of both software.

For this reason, the application of novel scan-to-BIM modelling requirements provided useful for the generation of HBIM objects from wireframe model and points. In particular, the application of novel grades of generation has been applied for different types of architectural elements (Banfi 2017) (Figure 6). The growing need to represent the detected reality of historical buildings has allowed the application of the GOG 10, simplifying the modelling process, but also, maintaining high levels of detail (LOD) and complexity

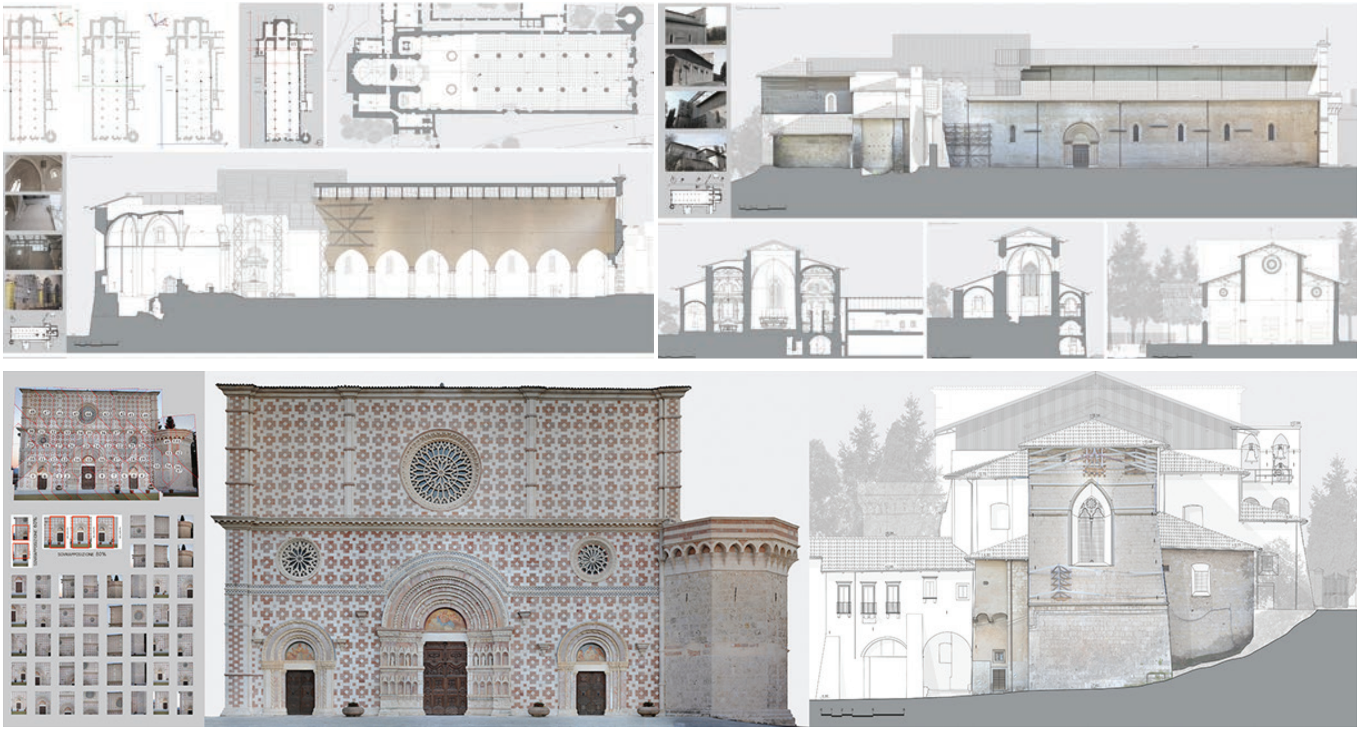


Figure 5. The As-found drawings from 3D survey and the Scan-to-HBIM process of the Basilica of Collemaggio in L'Aquila after the earthquake: Plans, sections and elevations.

for each digitally reconstructed HBIM object at the same time (Figure 7).

The geometric representation, through the 3D drawing and the understanding of the building's constructive logic with its architectural and structural relationships, turns out to be a fundamental concept to correctly interpret the paradigm of complexity in an appropriate manner by integrating different data sources from different types of 3D survey. It has also been found that the generation of a three-dimensional model must require high levels of interoperability and different types of software and applications, the latter oriented to manage different types of analysis and models derived from a Scan-to-HBIM process.

For this reason, this research is based on a method capable of defining the reliability and the LOD of each element realized through the use of BIM parameters and the grade of accuracy (GOA), the latter based on the calculation of the standard deviation between cloud of points and model itself (Banfi 2017).

The problem of managing this huge amount of points in the modelling environment has been solved by the use of automatic cloud decimation algorithms of Bentley Pointools and Autodesk Recap. These procedures have been able to change the characteristics of every single point cloud (amount of points and sizes) and get the right balance in modelling software. Thanks to the import of point clouds of the roof system's and the main

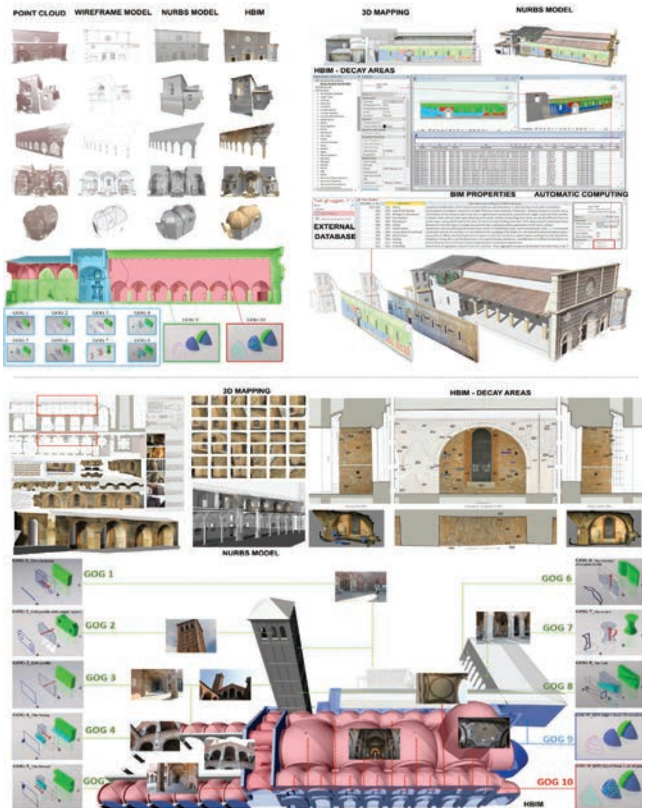


Figure 6. The HBIM models: the Basilica of Collemaggio in L'Aquila and the Basilica of S. Ambrose in Milan, Italy.

Figure 7. The high levels of detail (LOD) and complexity for each digitally reconstructed HBIM object of the Basilica of Collemaggio in L'Aquila: from as-found to as-designed HBIM model.

facades of both basilica has been possible to complete the HBIM models. Figure 5 shows the result with the HBIM generated from a combined photogrammetric (with close-range images) and laser scanning survey.

5. Conclusion

This study showed how the use unmanned aerial vehicle (UAV) based photogrammetry data can bring significant advantages in the field of HBIM both from an operative and informative point of view, collecting and synthesising data derived from heterogeneous scientific studies in which photogrammetry has represented an added holistic value for different disciplines. HBIM increasingly required a system capable of holistically represent and share heritage buildings with multiple grades of generation (GOG), facilitating the exchange of high levels of information at the same time. The planning of the project goals at the inception of the generative process of the HBIM models has enabled the development of an interoperable working method which aim to enhance information exchange at different levels of knowledge and automation, supporting the intrinsic and intangible values of two examples of heritage Italian architecture.

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ABSTRACT

Photogrammetric survey using UAV shows nowadays some aspects, especially related to the optimization of the operative workflows and best practices, that still need to be investigated. This work concerns the use of a small UAV for the documentation of an historical architectural complex, in which space constraints arises. The adoption of a rapid mapping workflow using frames extracted from videos is discussed, together with the exploitation of an automatic procedure for the acquisition of 360° shots, used for ensuring the minimum required overlap for a reliable and accurate image orientation.

Keywords:
UAV photogrammetry, 360° acquisition, Cultural Heritage, Image Orientation.

UAV multi-image matching approach for architectural survey in complex environments

1. Introduction

The use of UAVs (Unmanned Aerial Vehicles) is nowadays a widely adopted survey methodology, due to the wide diffusion of new and performant platforms and because of the easiness of handling the gathered raw data (images). Unfortunately, the enormous spread of image-based survey methods and techniques has not been supported by an equivalent diffusion of the validation strategies of the generated product, especially related to the quality control of the metric precision and accuracy of the georeferenced spatial data. The risk nowadays is to produce and disseminate 3D and 2D metric products with a not verified (and therefore probably not correct) geometric and radiometric information.

A special attention must be focused on the proper use of non-metric cameras, as these devices needs to be tested and compared, in terms of reliability and quality of the generated products, with more consolidated instruments and survey techniques.The tests carried out in this research have been performed in order to evaluate a consistent workflow for image-based rapid-survey of architectural objects, with complex shapes and in narrow space conditions. This work concerns the use of a lightweight UAV for the documentation of an historical architectural complex, in which space and time constraints arises. A rapid mapping workflow, consisting in using frames extracted from videos has been tested in the framework of this research. In view of speeding up the survey phases, without sacrificing the quality of the final 3D products, it has been experimented an automatic procedure for the acquisition of 360° shots, used for ensuring the minimum required overlap for a reliable image orientation. Photogrammetric 3D reconstructions using terrestrial 360° acquisition have been already conducted (Perfetti, Polari, Fassi 2018; Barazzetti, Previtali, Roncoroni 2018), and there are also very few examples of the use of spherical camera on light or very light UAV (Calantropio, Chiabrando, Einaudi, Teppati Losè 2019). In this research only normal frame images acquired with a 360° approach have been considered (without stitching the captured images in a single spherical panorama).

2. Case study

The *Borgo Medievale* is a reconstruction of a medieval hamlet, which was conceived for the 1884 Italian Exhibition. The Borgo Medievale were designed by Alfredo D'Andrade to symbolize the medieval Italian styles (Pagella 2011). Surrounded by walls and protected by a tower with a drawbridge, the Borgo is composed of a Church (the object of the presented tests), some houses, ecc. All these structures are related to real medieval architectures of two Italian regions, Piedmont and Valle d'Aosta. The buildings of the Borgo are located directly on a 7 meters wide royal road; its morphology fits very well the aims of this research. At first, an area of the Borgo that can be considered difficult to survey using a traditional photogrammetric workflow has been selected, in order to gain feedbacks concerning the potentialities of the proposed approach.

The selected area is the little square in front of the Church, a narrow space faced by 4 buildings. The Church is, moreover, higher than 17 meters and is in front of an 11 meters tall building, at a relative distance of only 7 meters. It is easy to understand that this morphology introduces different issues in planning and executing a terrestrial survey, since it requires an elevated number of control points, apart from other significative issues related with obtaining metric data related to the higher portions of the taller buildings.
Nevertheless, performing UAV flights in this area is particularly difficult, due to the low reliability of the on-board GPS in a narrow space surrounded by buildings, and issues in connecting different parts of the photogrammetric block related to facades of different objects. The main problem is related to the reconstruction of the relation between the different buildings, given the difficulty in guaranteeing the necessary image overlaps. The possibility of using drones embedded with a 360° camera sensor is to be avoided in this condition, because of lack of a reliable GNSS signal and the necessity to disable the sense-and-avoid system to attach the external camera. Moreover, the use of an UAV capable of carrying an additional device, would have required (due to the weight of the drone and the related operation typology) the closure of the site, as provided for in the Italian Civil Aviation Authority amendment "Remotely Piloted Aerial Vehicles Regulation" (ENAC 2019).

Figure 1. Ortophoto of the Borgo Medievale in Torino; highlighted in red the little square, object of the survey carried out in this research.

3. Material and methods

Due to issues related to space constraints of the case study, the platform DJI Spark has been selected for carrying out this survey. DJI SPARK is a lightweight UAV with a take-off mass below 300g, considered "unoffensive" by ENAC (Ente Nazionale Aviazione Civile) thanks to the use of a 3D printed lightening kit. The use of this UAV has already been tested for the generation of 3D model with a photogrammetric approach (Adami, Fregonese, Gallo, Helder, Pepe, Treccani 2019), using frames extracted from video (Calantropio, Chiabrando, Rinaudo, Teppati Losè 2018; Carnevali, Ippoliti, Lanfranchi, Menconero, Russo, Russo 2018) and in this research using the automatic 360° shots function for ensuring that the necessary minimum overlap is respected. The employed UAV, especially for its unoffensive capability, allows a fast, low-profile and easy to authorize operation, ensuring a safe and stable flight without altering the VPS (Visual Positioning System). Before discussing in depth the followed workflow and the subsequent results, it is necessary to define that the main aim of the test presented in this article is to reduce the time required for carrying out the data acquisition and processing, as this procedure could be easily transferred to emergency scenarios (Giordan et al. 2017; Murphy et al. 2008). Because of this, all the acquisition have been performed in a semi-automatic way, using frames extracted from videos acquired following parallel photogrammetric stripes, with the optical axis of the camera perpendicular in respect to the façade of the buildings (Einaudi 2019). This granted the reduction of the acquisition time, as well as allowed the pilot to focus only on the flight operation, as an intelligent extraction of the frames at an ideal frequency will satisfy the optimal overlap.

The accuracy of the reconstruction has been evaluated using a set of 10 GCPs (Ground Control Points) and of 4 CPs (Check Points) measured using a traditional topographic approach with total station (LEICA Viva TS16 – angular accuracy Hz and V 0.1 mgon – distance range 1.5 m to 3500 m). Moreover, a C2C (Cloud to Cloud) comparison has been performed between the dense cloud obtained following the photogrammetric process, and a single TLS (Terrestrial Laser Scanning) cloud, used as a ground truth.

As reported in the introduction, the automatic 360° acquisition of frame images needs some preliminary considerations; because this semi-automatic procedure is functional to the generation of spherical panoramas, it is necessary to acquire multiple shots in order to ensure the optimal overlap between the images, that has to be acquired using (almost) the same camera position. This procedure can be executed by an UAV using an integrated function that autonomously acquire the necessary number of images for ensuring a good result of the final product.

There are different mobile applications (apps) that allows to plan the automatic 360° acquisition of frame images; for the purpose of this research two apps have been testes: LITCHI and DJI GO 4; according to the camera of the DJI SPARK the optimal number of frame images to be acquired is 46.

With the aim of defining a fast-photogrammetric acquisition workflow, the followed approach has been used to acquire videos and subsequently extract the necessary number of frames. Considering that during the fights the speed of the UAV was (more or less) constant, and that the video has been recorded at 1080p with a framerate of 30 fps, frames have been extracted each 2 second (1 frame each 60 frames). It is important to note that the frame extraction procedure lead to a loss of the EXIF information (aperture, focal length, etc.). This is very important to consider especially when important information (typology of the employed sensor and its pixel size) are used during the camera calibration and image orientation steps.

For the generation of the sparse point clouds, the software Agisoft Metashape has been used, setting the quality at medium (downscaling the original images by factor of 4 – i.e. 2 times by each side).

4. Results

The objective of this test is to demonstrate the potentialities of the automatic 360° acquisition for enhancing the orientation of frames extracted from videos.

Figure 2. Different view of the position of the three automatic 360° acquisitions. Highlighted is the one used in the dataset B.

In order to evaluate the potentialities offered by this approach, three different datasets have been used; one dataset contained only the frames extracted from the video, without the use of the automatically acquired 360° frames (Dataset A – 305 images). The second dataset (Dataset B – 351 images) contained all the frames extracted from the video plus one of the acquired 360° frames (+46 images). A third dataset (Dataset C – 443 images) contained again all the frames extracted, together with all the 3 acquired 360° frames (+138 images). Concerning the dataset A, about half of the images haven't been aligned during the orientation phase. As expected, this is because there is not enough overlap between the two sub-datasets employed (West building and East building), this led to the generation of only one façade, arbitrary chosen from the software. One strategy to avoid this problem is to process the two sub-datasets in a separate way, or to introduce some images to cover lack of overlap.
Following this last consideration, a 360° acquired set of frame images has been added (dataset B), and this allowed to align all the frame; therefore, the whole scene has been successfully reconstructed. In order to evaluate if only one 360° acquisition (46 images) is enough to enhance the alignment, a third dataset (C) containing a total of three 360° acquisitions (138 images) has been processed. As it is possible to observe in the following table 2, the residuals on GCPs and CPs are lower (almost the half) when more than one 360° acquisition is used. We can say that the results obtained in the third dataset C reports an accuracy compatible with the restitution of products at a scale of 1:100 (precision of 2 cm). For obtaining these results, no pre calibration of the sensor has been done, but only a self-calibration during the processing phase. In order to validate the results, a C2C comparison has been done between the photogrammetric dense point cloud (Dataset C) and a TLS acquisition of the same architectural space, used in this test as a ground truth. The TLS acquisition has been performed using a Faro Focus 330 (CAM2) with a ranging error of ± 2 mm.
The average density (number of points per m2) of the point clouds at 1 and 4 meters starting from the ground level is respectively 48k and 38k points for the TLS point cloud and 21k and 20k points for the

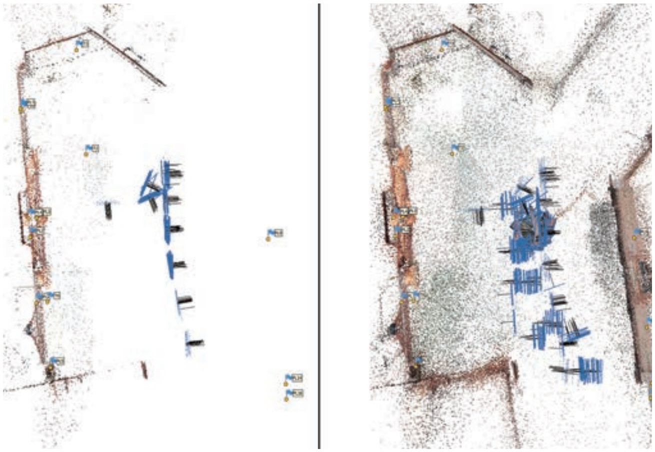

Figure 3. On the left, image aligned in the dataset A (only the Church is successfully reconstructed); on the right, all the images are successfully aligned (dataset B and C).

DATASET	A (Frame only)	B (Frame + 1 360°)	C (Frame + 3 360°)
IMAGES [aligned/total]	160/305	351/351	443/443
N. of tie points	38,091	372,094	505,401
Matching time	2 h 25 m	20 h 00 m	28 h 27 m
Alignment time	1 h 08 m	5 h 15 m	6 h 13 m

Table 1. Information regarding the three processed datasets. The processing has been carried out using the same settings in Agisoft

DATASET	Number of GCPs	X error [cm]	Y error [cm]	Z error [cm]	XY error [cm]	XYZ error [cm]
B	10	2.5	1.4	1.5	2.9	3.3
C	10	1.0	0.6	0.5	1.2	1.3
DATASET	Number of CPs	X error [cm]	Y error [cm]	Z error [cm]	XY error [cm]	XYZ error [cm]
B	4	3.2	2.7	1.2	4.2	4.4
C	4	1.2	1.8	0.4	2.1	2.2

Table 2. Table showing the residuals of GCPs (Ground Control Points) and CPs (Check Points) for the two datasets B and C.

photogrammetric point cloud. In the validation phase, the registration of the TLS and the photogrammetric cloud reported a mean error of 20 mm and a standard deviation of 32 mm. Analysing the results of the C2C comparison for the Church façade, the points with a residual error of ± 1 cm are the 35% of the results, and the ones with the residual error of ± 2 cm are the 85%. Analysing the results of the C2C comparison for the building façade, the points with a residual error of ± 1 cm are the 69% of the results, and the ones with the residual error of ± 2 cm are the 67%. We can thus say that the generated model is validated for a survey at a scale of 1:100.

5. Discussion and conclusions

Thanks to the integration of the adopted techniques, which are the extraction of frames from video on one hand, and the generation of linking images for ensuring the minimum overlap using an automatic function on the other hand, it is possible to generate products useful for the architectural survey, like high-quality orthophotos of the façade and elevations, that allows the correct description of the surveyed architectural heritage. Talking in deep about the façade of the Church, as it is possible to observe from the already discussed results, the level of reached accuracy allows to produce drawings at the scale of 1:100, with the possibility of generating accurate 3D models. Concerning the second façade (the facing building), the same considerations can be done. In order to generate good quality orthomosaic, the followed workflow began with a cleaning operation of point cloud, i.e. to segment it correctly in order to delete wrong reconstructed or not necessary geometries. After the point cloud cleaning and segmentation, the next step is the generation of a 3D mesh, on which the images (after the un-distortion process) are projected for the creation of a texture. For a better result, it has been created a mesh with a high number of triangles, and to furtherly improve the obtained results, the geometries have been refined using an external software of 3D modelling. Then the improved mesh has been imported again in the software Agisoft Metashape, in order to allow a better generation of the applied texture. Following this, an ortoprojection plane has been defined; this has been done using several (at least 3) points surveyed on the façade that

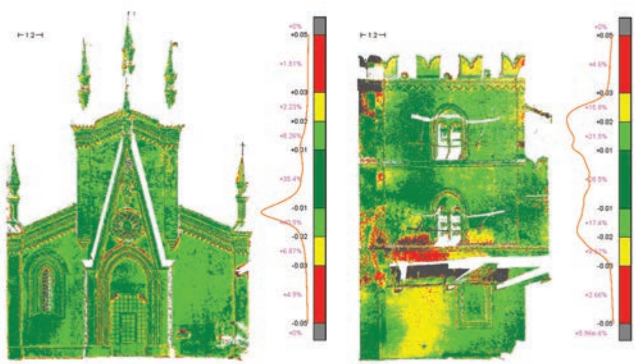

Figure 4. Different C2C analysis concerning the Church (on the left) and the facing building (on the right). The colour shows, for each point of the clouds, the relative distance between the photogrammetric and the TLS point clouds.

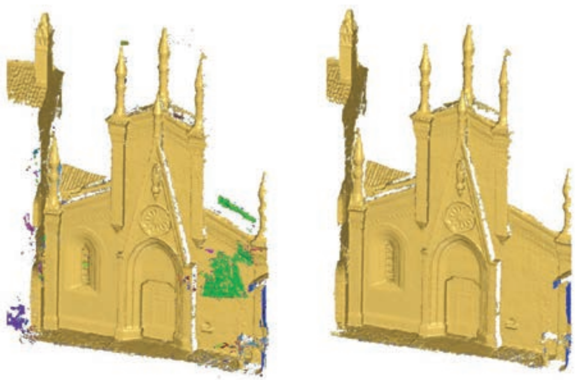

Figure 5. Triangulated mesh before the segmentation and cleaning process (left); final version of the 3D model (right).

allowed the definition of a mean plane with a least square approximation method. After the generation of a correct ortoprojection plane (parallel to the mean plane of the façade) an orthophoto has been generated. The ortophoto, that is the last step of the followed procedure, could be used to produce traditional 2D drawings, useful for a complete documentation of the surveyed object.

According to the achieved tests and obtained results, is possible to state that nowadays the flexibility of the UAV platforms, able to acquire high resolution data in different ways (video and or images) in conjunction with the SfM (Structure from Motion) software that can process different kind of data in a common environment, allow to explore non-conventional surveying strategies that are difficult to imagine some years ago.

One the one hand it is clearly proven that the availability of a large number of images allows to improve the rigidity of the photogrammetric block, on the other hand it is important to underline that, especially in complex scenario, the use of GCPs and CPs allows to define in the correct way the accuracy of the final results.

This is a crucial outcome for an architectural representation, where the scale of the drawing is strictly related to the precision of the photogrammetric process.

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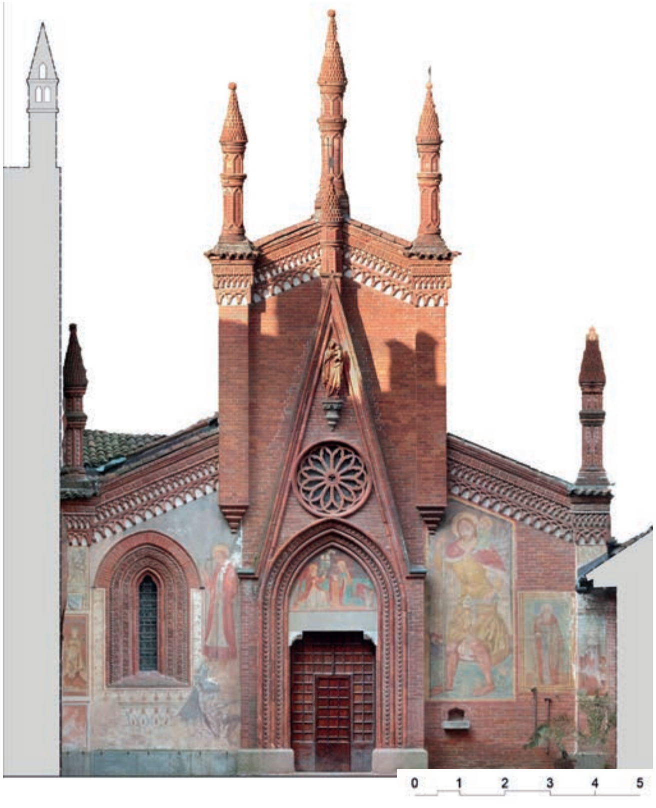

Figure 6. On the left, Orthophoto of the Church, generated following the photogrammetric approach.

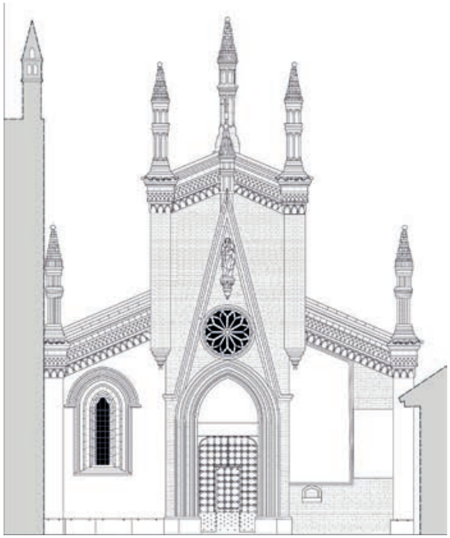

Figure 7. On the right, Traditional 2D drawing (elevation of the Church), produced starting from the previously generated orthophoto.

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ABSTRACT

The ruins of the ancient citadel of Agira testify a long past. Investigations based on the theoretical apparatus of the restoration discipline and ran out through the most innovative 3D survey methodologies have recently highly improved the knowledge of a lieu of great historical and architectural complexity. In particular, data captured by UAVs, together with the information obtained by terrestrial measurements, were essential to evaluate the criticality of such valuable heritage. This study, part of a larger research, intends to illustrate a methodological program aimed at the documentation, conservation and valorisation of a significant witness of Sicilian culture, today at risk.

Keywords:
3D survey, conservation, Cultural Heritage, Sicily, drone.

Integrated 3D methodologies for the knowledge and the valorisation of fortified heritage in Central Sicily: the castle of Agira

1. Introduction

The field of RPAS (Remotely Piloted Aircraft Systems) is the new frontier in the development of aerial sensing. They allow obtaining a series of information - in addition to the consolidated data acquisition methodologies - capable of producing virtual models of the built heritage, more and more accurate and realistic (Monti & Selvini 2015). In recent years, the explosion of the small drone market highlights the fervour of a constantly improving technology. Semiprofessional models at low costs, equipped with increasingly compact and sensitive mirrorless cameras, are now more and more widespread. At the same time, there is a noticeable improvement in both flight management and image capture software, which are today increasingly performing and easy to use. This essay aims to illustrate the new opportunities offered by these tools to integrate other relevant surveying technologies. In particular, concerning large monumental complexes of arduous accessibility, their systematic use, based on strict and carefully planned methodological processes, can prove to be very helpful in the knowledge phase. This, not only in terms of greater accuracy and speed related to metric characteristics of artefacts - often in a state of ruin - and therefore of their complete stereometry, but also in support of the material, stratigraphic analysis and the study of degradations and cracking and deformation phenomena. After a series of experiences carried out on other manors of central Sicily - as part of a wider research project on the defensive systems of the island - the restoration and enhancement project of the castle of Agira was the testbed of experimentation founded on new survey methods, for the knowledge of the built heritage and the assessment of its state of conservation and risk mapping.

Figure 1. The castle of Agira: tower C and a part of the walkway.

Figure 2. The castle of Agira: tower C and a part of the walkway.

Figure 3. The castle of Agira in history.

2. The city of Agira and its castle

The ancient city of Agira rises in Central Sicily, on the top of Mount Teja between Dittaino and Salso rivers, in a strategic place for the control over trade routes, already indicated in the Itinerarium Provinciarium Antonini Augusti, which from Catania led to the interior areas of the island (Patanè 2012). The urban settlement, as we understand it today, was built between the Late Antiquity and the Early Middle Ages after a point of decline and partial abandonment in Roman times.

The presence, in the Byzantine era, of an important Basilian monastery, named after the monk Filippo di Agira, "to whom people from all over the island flocked" (Provitina 2009) and entrusted to the Benedictine order after being refunded between the 10th and 11th centuries, is mentioned in ancient sources. The oldest document on the castrum of San Filippo di Agira is the 'Statute on the repair of castles' established by Charles I of Anjou, King of Sicily that in 1267 attests the existence of a fortress that overlooked from the top of the mountain the underlying district'of Lombardia', so-called because inhabited by Gallo-Italic immigrants (Maurici 1992).

The village, cited in the *Historia Sicula* by Michele da Piazza, in the 14th century is described as *castrum erat in cacumine dicte terre constructum, et terre predicte undique dominabatur*. However, the presence of a fortified site already during the Islamic period is most probable, even if the present remains are typical of the architecture of the Swabian fortresses (Agnello 1961). Modern age's chronicles describe the city but often remain silent about the castle. Vito Maria Amico in the famous Lexicon Topographicum Siculum testifies its state of ruin. The castle between the 16th and 17th centuries had lost its military importance, as it results from the lack of typological adaptation for the use of artillery.

Moreover, recent technical-construction studies and stratigraphic analyses exclude subsequent interventions. In reality, the transformations that came after the 1693 quake and the urban redevelopment processes between the close of the 19th and the start of the 20th century - to adapt the town to the need for modern living and to equip it with new administrative and social buildings - caused a progressive shift towards the valley of its pounding heart (Figure 1).

Today, a kind of fracture, consisting of a non-urbanized area, separates the ruins of the castle from the new town "facing *Libeccio* and *Mezzogiorno* where the ascent is gentle and the plain occupied by the famous temple of San Filippo is not narrow" (Amico 1757-60).

3. The castle's ruins

The castle, of which today only a few vestiges remain, despite the wars, landslides, earthquakes and the action of time, tells the story of Agira and its development. The ruins of the fortification, while not allowing easy interpretations, neither on the origin nor on its spatial organization, highlight marked similarities with other medieval military architecture, such as the Federician Castello di Lombardia and Torre di Federico, both located in Enna, and the oldest castles of Assoro and Pietrarossa. This allows confirming the existence of (at least) two distinct building phases: one, during which a first city wall was raised and a second when the replacement/erection of the tower system occurred (Linguanti 2018; Alberti 1995). The typological comparison based on the surviving masonries highlights, both the use of rough-hewn stone blocks arranged in horizontal rows and tied by a limestone-sandy mixture with small filling stones for the external wall and the use of blocks of white limestone - regular and square - installed in concretum for the towers (Contino 2001). The systematic study of medieval military architecture and, in particular, Sicilian castle studies, began between the 19th and 20th centuries; the cultural interest that grows in those years towards these monuments will become a driving force for their restoration. The German scholar Eduard Sthamer, together with his collaborators Bodo Ebhardt and Caesar Rave, carried out in the first half of the 20th century, the first investigations and surveys on castles in Sicily, including that of Agira, so creating an "inventory without antecedents and extraordinarily up-to-date in the island" (Piazza 2015, p. 120). The architect Piero Gazzola, Superintendent of the Monuments for Eastern Sicily from 1939 to 1941, strongly attached to the castle culture, in 1941 put in place a series of interventions aimed at conserving - through wall consolidation operations - the castle of Agira. Restoration work undertaken is very interesting because, unlike the unhappy demolitions conducted in those years, the architect focused his attention on saving the important ruderal testimonies (Aveta, 2007).

The first Sicilian to start important studies on fortresses in Sicily in the second post-war period was Giuseppe Agnello, who, with bitterness, affirmed how the Sicilians had neglected their historical and artistic heritage for many years (Figure 2). He was responsible for the name of the towers (indicated as A, B and C): a nomenclature that is still given to the surviving structures.

The A tower has a trapezoidal plan, is made of squared blocks and today shows two floors with a wooden attic inside and an ogival vaulted roof. A section of the wall, made by different irregular masonry, continues in a northerly direction and then stops at the ridge. The B tower, octagonal in plan, is the least preserved; of it remains the perimeter walls of the lower floor covered by a hemispherical vault and the fragments of the upper floor with the vestiges of a splayed window. Close to the northward, was probably located the fortress gateway. A long stretch of walls leads towards the C pillar, square in shape close to a natural scarp. Only one compartment remains covered by a barrel vault, illuminated by both the doorway and two splayed slits. To the C tower follows another wall gap, which at the north-west corner of the city wall probably ended with a fourth tower, which no longer survives.

The defence of the castle was entrusted to the steepness of the site, accessible only along the western side via a sloping path. The construction of the walls then followed the orography of the area, becoming more powerful and enriched with towers along the most vulnerable side. It is very complex to reconstruct the geometry of the city walls and above all to distinguish them within the various historical periods. Nevertheless, the archaeological excavations made during the 20th century's restoration, have made it possible to distinguish three different defensive enclosures. The first enclosure, the innermost and the highest, belonging to the first phase (or perhaps more ancient, but nothing can be said for sure)

Figure 4. The ruins of the Castle of Agira, today.

contains the remains of the church of San Filippo and other small buildings, as well as a hypogeum room with barrel-vaulted ceilings (perhaps a cistern). The second enclosure, the most preserved and imposing with three surviving towers, develops in a north-south direction and closes the top of the mountain from the village downstream. The third enclosure, outermost and placed at a much lower altitude, of which only a few wall traces persist together with the tower of San Nicolò, an isolated structure, perhaps a sighting. The enhancement of the fortified area through the creation of an urban park to be used, in the summer, as a theatre, was entrusted to the architects Pasquale Culotta and Nicola Leone in 1982. The project also included the consolidation of the structures at the top, the restoration of the towers and the church of San Filippo, essays and archaeological investigations on the entire perimeter. The C tower, in particular, required reinstatement of a part of the wall, due to the excavation of a posthumous cave to accommodate an animal shelter, the remaking of a window, and the reconstruction of ancient openings that were torn because of the loss of part of the vestment.

The design philosophy was "*to donate a complete spatial configuration to the tower*" (Culotta & Leone 1989, p. 92) also through the creation of a vertical connection of the internal levels (Figure 3). The fortress has a high historical, landscape and symbolic value and therefore, preservation and conservation activities are essential to ensure its maintenance and transmission to future generations, removing it from the indifference and neglect that has long accompanied. Aware that an abandoned building is inevitably destined for ruin, this work was intended to define an intervention methodology aimed at documenting and enhancing the ancient fortified area, paying special attention to its ruins and the archaeological fragments now both hidden and assaulted by vegetation.

4. The 3D survey: a knowledge tool for heritage conservation

The geometric and morphological knowledge, as well as the information related to the characteristics of the materials and construction techniques employed, is the foundation of the architectural survey, i.e. the initial and essential episode of every process of protection and enhancement of cultural heritage. The investigation phases carried out through increasingly accurate and high precision measuring devices, alongside the investigation undertaken by direct analysis and instrumental diagnostics, are part of the intervention project, which can thus be implemented based on a real awareness of both nature and state of the monument. The castle of Agira, a complex architecture, both in terms of size and shape, required the use of multiple data acquisition techniques - subsequently processed in a single virtual environment - to obtain a digital model of high metric and chromatic quality. The integration of 3D laser scanning data with the colourimetric information of the photogrammetric models (Rodríguez Navarro 2012; Bolognesi et al. 2014; Federman et al. 2017), has made it possible to re-create the real condition of the place and to enrich it with maps showing decay processes.In particular, terrestrial acquisitions made both with active and passive sensors were enriched with aerial images from UAV systems, captured by various zenithal flights carried out at different altitudes. The opportunity to easily use frames from an aerial video in an intelligent way - and not automatically by choosing the number of images per unit of time, but by extracting all the frames to eliminate part of them based on similarity and quality - made it more convenient the use of videos instead of simple photos (Cardaci et al. 2019). If it is true that the dpi resolution of a single photograph is greater than that of a frame of a video, it will still be affected by problems of micro-blur, low depth of field and underexposure due to both the drone vibrations and the necessary short shutter speeds with very wide apertures. The greater fluidity of a short film, the high percentage of overlapping of the parts and the multiple possibilities of correcting the videos offered by the shooting software allow, in general, higher-quality input data than individual manual capture (Torresani & Remondino 2019). The survey, therefore, benefited from an approach more suited to a - while conscious and sensitive - videomaker than to a mere operator, in which much attention was paid to the lighting of the scene, the framing and the setting of the camera to obtain the best result in terms of sharpness and purity of colours. The flight plans have been designed according to solar lighting (to avoid backlighting and/or areas of strong contrast) by carrying out several flights even at different times of the day, and by appropriately correcting the different chromatic temperatures, to benefit from the best light conditions. An innovative and unusual practice that has produced films of high visual quality and great fluidity that is well suited to the survey requirement of the Sicilian castles, characterized by impervious and extensive areas, with

Figure 5. The integrated survey technologies.

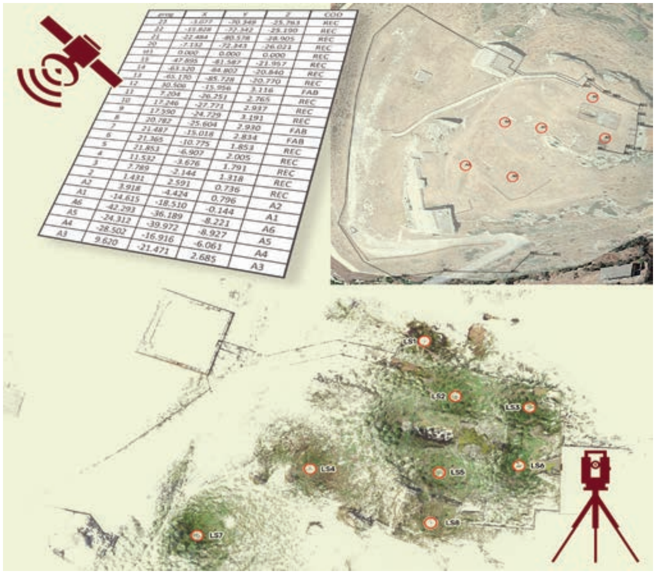

Figure 6. The survey with active sensors.

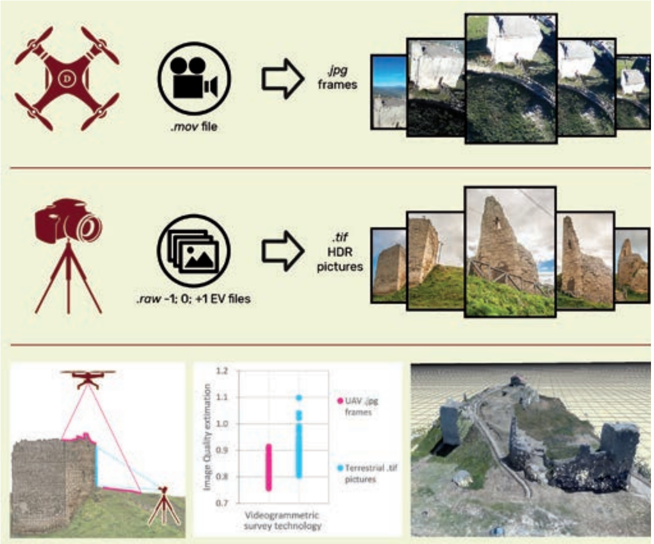

Figure 7. Terrestrial and UAV photogrammetry.

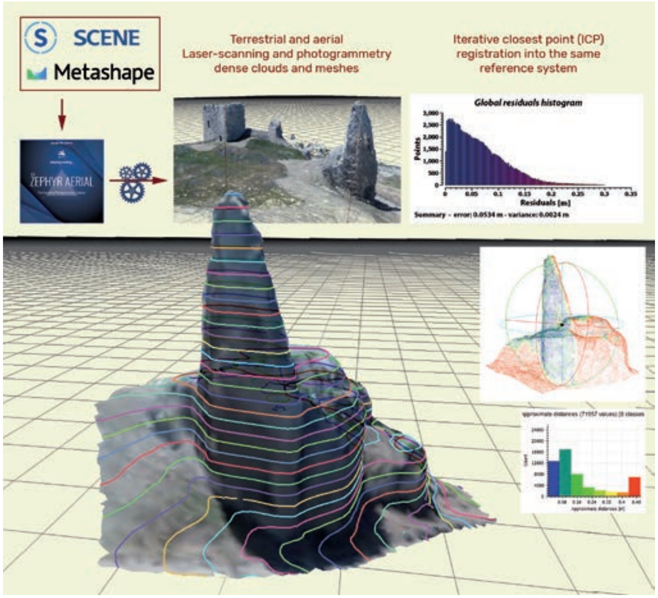

Figure 8. Data processing. Point clouds comparison and analysis.

a heritage in ruins; organic architectures in which the built integrates, almost merging, with the landscape (Versaci & Cardaci 2011). The metric survey (Figure 4) therefore began with the preparation of a topographic network whose vertices, indicated on the ground through specific targets, were statically acquired by GPS technology. The geographical coordinates - geo-referenced in the Gauss-Boaga and ETRF2000 systems - constituted the Ground Control Points (GCP) necessary to scale and rotate-translate the models into a single global reference system; other targets were placed in situ to build a second Ground Control Constraint (GCC) network for error checking.

The operations followed with the 3D laser scanning acquisitions, operated by a Faro Focus 3D, a phase-based instrument (Figure 5), the terrestrial photogrammetry and the UAV aerial videogrammetry (Figure 6). In detail, the photographic campaigns, operated with professional equipment, followed a rigorous procedure to obtain the maximum depth of field, the control of the electronic background noise and the correct evaluation of the ambient light using a colour checker; three shots were taken for each capture to obtain HDR images. The aerial acquisitions carried out by a DJI Phantom 4 quadcopter were very fast and conducted semi-automatically, making a video recording at the highest possible resolution (1920 x 1080 pixels) and a capture rate of 30 fps. The reconstruction of the photogrammetric models was carried out using multiple Image-based 3D Reconstruction software (Agisoft Metashape and 3DFlow Zephyr) following the traditional workflow divided into the following four phases: external alignment based on Structure-from-Motion (SfM) algorithms; creation of a discontinuous point model based on Multiview Stereo Reconstruction (MVS) algorithms; creation of the continuous polygonal model; creation of a photorealistic model with the projection of photographic images on the surface of the polygons. The final model was assembled in a 3DFlow Zephyrenvironment thanks to the great capacity of the software to import and manage point clouds also produced by third parties; in particular, the global cloud of the 3D laser scanning survey processed by Faro Scene was imported, as well as the point cloud and the images of the terrestrial photogrammetric model processed by Agisoft Metashape and the videogrammetric model, the only one processed by 3DFlow Zephyr (Figure 7). The three models were superimposed in a single reference system, minimizing the relative distances of the individual parts through Iterative Closest Point (ICP) algorithms and then combined (in a single final model) optimized to ask for the gaps, homogenise the density of points, balance the overall colour organically. The final result (Figure 8 and 9), the closest approximation of the reality that it was possible to create virtually, allowed to return the plan of the top of the hill and the orthographic projections of the risers of the wall structures, which were therefore enriched with material characterization and degradation (Figure 10). This was the starting point of a hypothesis of conservation and valorisation of the whole area, based on the minimal intervention and in no way marred by attempts at mimesis or completion (Figure 11 and 12).

5. Conclusions

The integrated survey carried out both with different technologies for the acquisition of metric data, materials and degradation pathologies and with different procedures for data processing, offers the opportunity to be aware of the state of conservation of the built heritage following a procedure compatible with the protection and enhancement needs. The inventory and study of these architectural artefacts are, in fact, still today based on direct investigations, photographic investigations and, if existing, on old architectural surveys – often incomplete and not very accurate - that misrepresent the actual state of the goods. The aerial shots, for some years possible thanks to the use of small drones, if integrated with more accurate measurements performed with active sensors (3D laser scanning) and passive sensors (digital photogrammetry), can return

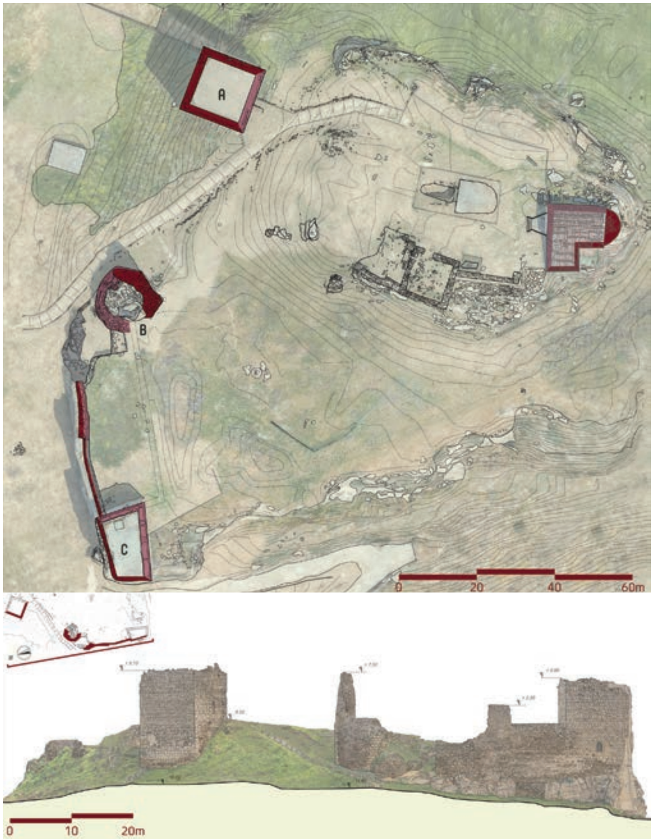

Figure 9. Survey's rendering: the planimetry and orthographic projections.

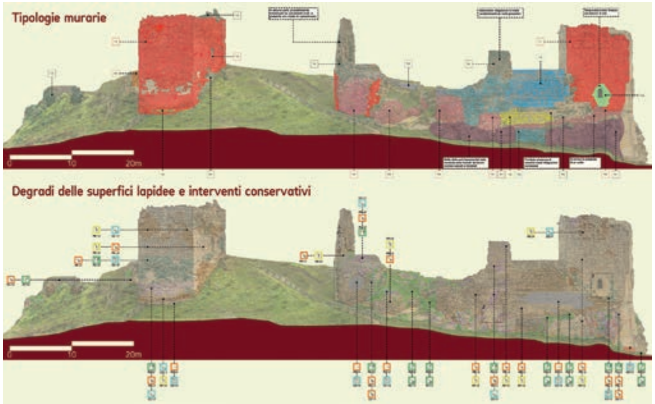

Figure 10. The decay mapping and the conservation project.

three-dimensional models of high geometric reliability and elevated chromatic quality. The data captured by UAVs, together with the information obtained by the terrestrial measurement campaigns, if treated with the appropriate processes and the necessary skills, are an effective survey methodology for the evaluation of the criticality of isolated architectural sites - frequently located in non-urban areas - like the strong medieval buildings which are still visible in Central Sicily. Abandoned and in the state of ruin architectures, which, in general, stand away from road infrastructure networks, located in areas affected by depopulation, so risking to be forgotten and to disappear due to the inexorable passage of time. The case study on the castle of Agira wants to illustrate a project aimed at the knowledge and documentation of these important testimonies of the culture of the island. Fortresses that are identifying elements of the territory as well as highly recognized and recognizable architectures that only if suitably safeguarded and controlled would become the nodes of a widespread and sustainable tourist system accessible to a wider public.

Figure 11. The enhancement project: planimetry.

Figure 12. The enhancement project: orthographic projections of the risers.

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ABSTRACT

The essay presents the outcomes of a research about the rule of new technologies for the critical understanding of stratified architecture, having as reference the numerous experiences that are aimed at the contamination of knowledge in the promotion of cultural heritage (Bertocci et al. 2014, Barba et al. 2019). The research proposes a reconstruction of major historical phases of the castle of Agropoli, sits just south of Paestum. Using the potentials of UAV (Unmanned Aerial Vehicle) photogrammetric survey, metric information and graphics were transformed into instruments of knowledge for a better understanding of the history of the building.

Interpreting and restoring. Digital technologies to reconstruct the transformations of Cultural Heritage

1. Introduction

Any restoration project on exiting architecture begins with a systematic and thorough knowledge plan which involves transversal skills and requires a multidisciplinary approach (Campi et al. 2018).

It is divided into a series of general operational steps, which can be refined in the tools and objectives in relation to the problems encountered, which are generally different for stratified cultural heritage buildings.

The starting point is always direct observation in situ, to then proceed with the critical study of indirect sources (bibliographic, iconographic, documentary, etc.). But the path of knowledge cannot be separated from an accurate survey of geometries.

The survey for restoration is aimed at the graphic representation of the physical component of the reality analyzed, as well as to allow the analysis of the transformations undergone by the building over time, preparatory to the restoration project. New possibilities offered by digital survey techniques allows today an exhaustive documentation that brings to light aspects of buildings that were hitherto invisible to the naked eye, providing significant new information about historic monuments, enabling us to fuse databases and combine information from secondary sources and to show historic hypotheses through 3D models and animations (De Feo et al. 2018). Historical research can be assisted, enriched and sometimes transformed by the advent of accessible and increasingly user-friendly technologies (Bruzelius 2017).

This paper presents a digital project in which the architectural transformations of an ancient building and its context over time have been converted in a narrative message using a more intelligible language.

2. Case study: the castle of Agropoli and his history

The castle of Agropoli, located in the homonymous city in the south of Paestum, dates to the VI century AD, when Byzantines constructed a kàstron, a fortified sea-front lookout, during the Gothic war (Cantalupo 1987). The building, just as it appears today, is the result of modifications and enlargements occurred in different historical periods (Figure 1).

After its foundation, the kàstron quickly became one of the safest and most protected places in the region.

Figure 1. Aerial photo of the castle of Agropoli.

Figure 2. Photographs from the late 19th and early 20th centuries which attest the state of total abandonment of the Castle (La Greca et al. 2008).

The structure of the site was based on a wall with a triangular plan with sharp edges instead of corner towers. The fortification was later conquered by the Saracens, who occupied it for thirty years between the ninth and tenth centuries. The castle was then amplified by the Normans, who probably built the corner towers. During Swabian domination (1189-1266), Federico II declared that the castle was his property for its strategic position and to protect it against further deterioration. The birth of the Borgo Nuovo or Casale Nuovo, a small inhabited nucleus, dates back to this phase; the neighborhood, devoid of fortified structures and isolated on the promontory, was then abandoned after the Vespro war (1282-1302). During this war the castle was the centerpiece of the Angevin resistance against the Aragonese armies. During this time the castle underwent continuous restoration and transformations. In 1412 the building returned to the bishop of Capaccio until it was ceded to feudal lords, first of all the Sanseverino family. During this period the most substantial changes were made: the reconstruction of the entrance with the construction of the quadrangular tower and a drawbridge, the escarpment of the cylindrical towers, the creation of deeper ditches, the enlargement of perimeter walls and the construction of a Baronial Palace, the residence of feudal lord (La Greca et al. 2008).

Following the unification of the Kingdom of Naples under the Spanish (1503) and at the end of the dynastic struggles, the Castle of Agropoli lost its strategic role. With the decline of the Sanseverino family, in 1552, and the division of their fiefs, the city passed from feudal lord to feudal lord, the last were the Sanfelice Dukes of Laureana, in 1660, which have kept the ownership until the abolition of the feudal system in 1806 (Del Mercato 1981, Cantalupo 1984). Despite the city walls were subject to constant care and the houses strengthened with the addition of towers, in 1630 the Citadel was sacked by the Turks. The population who escaped the danger took refuge within the walls of the Castle. For these reasons throughout the seventeenth century urban expansion concerned the interior of the fortified walls. In the nineteenth century, the city core expanded beyond the ancient walled village following the development of the old road routes up to outline the current image of the city. With the French domination of the Kingdom, from 1805 to 1815, the Castle, once again used for military functions, fell definitively into ruins and this led to the progressive isolation of the historic center of Agropoli. In 1820 a decree of Ferdinand I ordered the purchase of the castle for the military genius, but the decree of the sovereign was not executed, so the Sanfelice family passed the ownership of the castle to the Corasio family of Agropoli (Cantalupo 1987). Photographs from the late 19th and early 20th centuries attest the state of total abandonment of the Castle, used for several years, improperly for agricultural purposes (Figure 2). It remained abandoned for a long time, only in 2008 became municipality property and was subject of several interventions, which still continue today.

3. Ancient structures and new technology

The castle of Agropoli, despite its historical significance, is not sufficiently documented by an updated survey. The choice to operate with UAV aerial photogrammetric survey was suggested by some questions.

The first question is linked to the complex structure of the castle, characterized by great dimension in plan and elevation and many areas difficult to reach and detectable with traditional survey or other digital terrestrial survey techniques.

The second question is linked to the necessity to use a survey methodology to obtain a tridimensional survey, at the same time, metrically and chromatically correct. The color data, in fact, is particularly important for the analysis of restoration because it allows to recognize the stratigraphic information, eloquent signs of an architectural transformation. For all these reasons it was necessary to prepare a preliminary and careful project of survey (Barba et al. 2019). The UAV used was a DJI Phantom 4 quadcopter drone equipped with a camera (Figure 3). The flight plans were designed taking into account the expected GSD (at least 6 mm/pix for 1:50 scale representations), the technical characteristics of the photographic sensor (12 MPx with 1/2.3” CMOS sensor) and the desired overlap between consecutive shots (at least 70%). All operations were planned remotely on a web platform automatically connected to the in situ flight management software application. The take-off point was positioned on the terrace of the Sala dei Francesi, as it is the only point from which it is possible to have a clear and continuous view of the drone during overflight. Six flight plans were programmed: two at an altitude of 30 meters on the entire castle and its surroundings with nadiral camera (inclined at 85° with respect to the horizon) and with orthogonal

Figure 3. The UAV system during the survey.

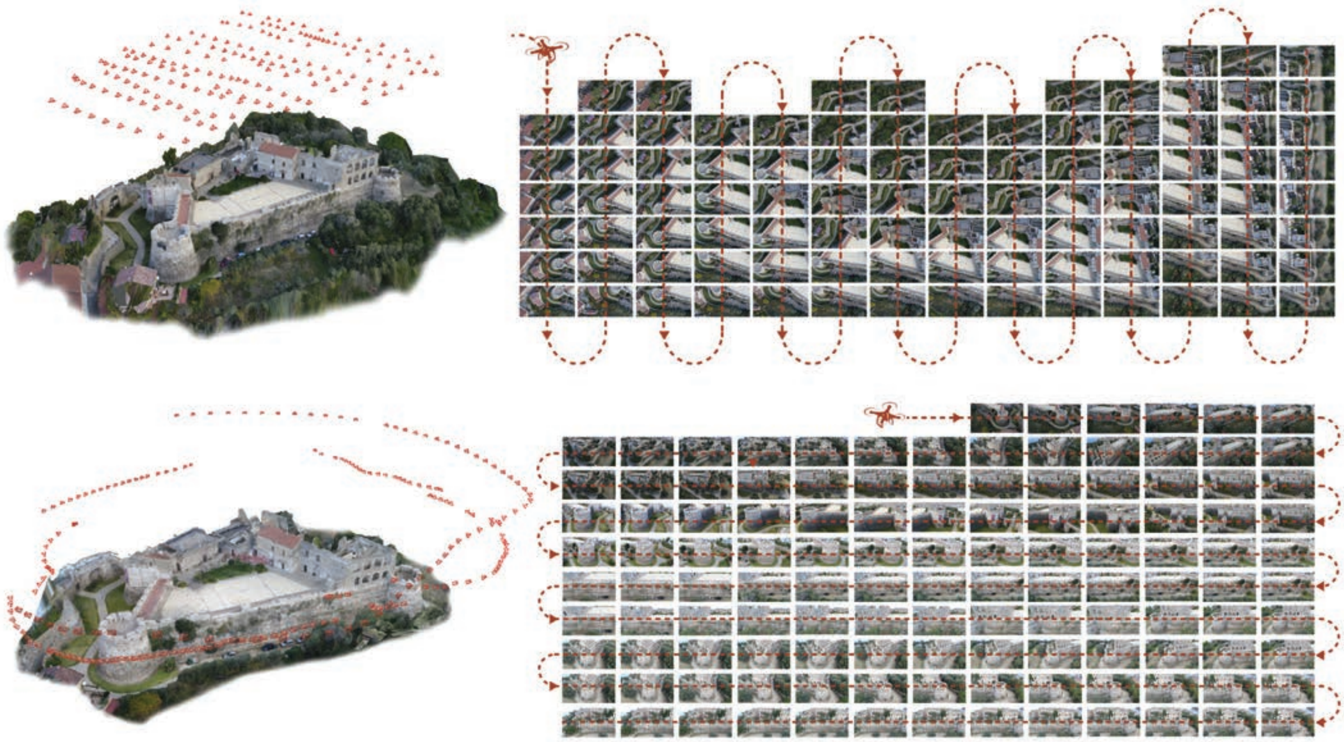


Figure 4. The top image shows the flight plan with nadiral camera, the image below the survey of vertical walls with camera inclined at 45°.

north-south and east-west directions, two at an altitude of 30 meters on the entire castle and its surroundings with camera inclined at 45° and with orthogonal north-south and east-west directions; and final two all around the castle to survey vertical walls with camera inclined at 45° (Figure 4). The aerial photogrammetry was than integrated with a terrestrial survey in areas that are difficult to reach by drone, such as the walls under the drawbridge. The aerial photogrammetry was supported by a topographic survey with the Leica GNSS GS08 system after defining the position of sixteen ground control points (GCPs) evenly distributed over the entire area, especially along the moat and in the courtyard of the castle. This step allowed to scale the model, geo-reference it and check the alignment algorithms. The data acquired (about 1200 photos and GNSS measurements) were then processed to obtain a point cloud model in 3DFlow Zephyr Aerial software. The model obtained constituted the database from which to elaborate updated two-dimensional graphs of the castle (Figures 5, 6 and 7) and the metric base for following elaborations.

4. Critical interpretations and virtual reconstruction

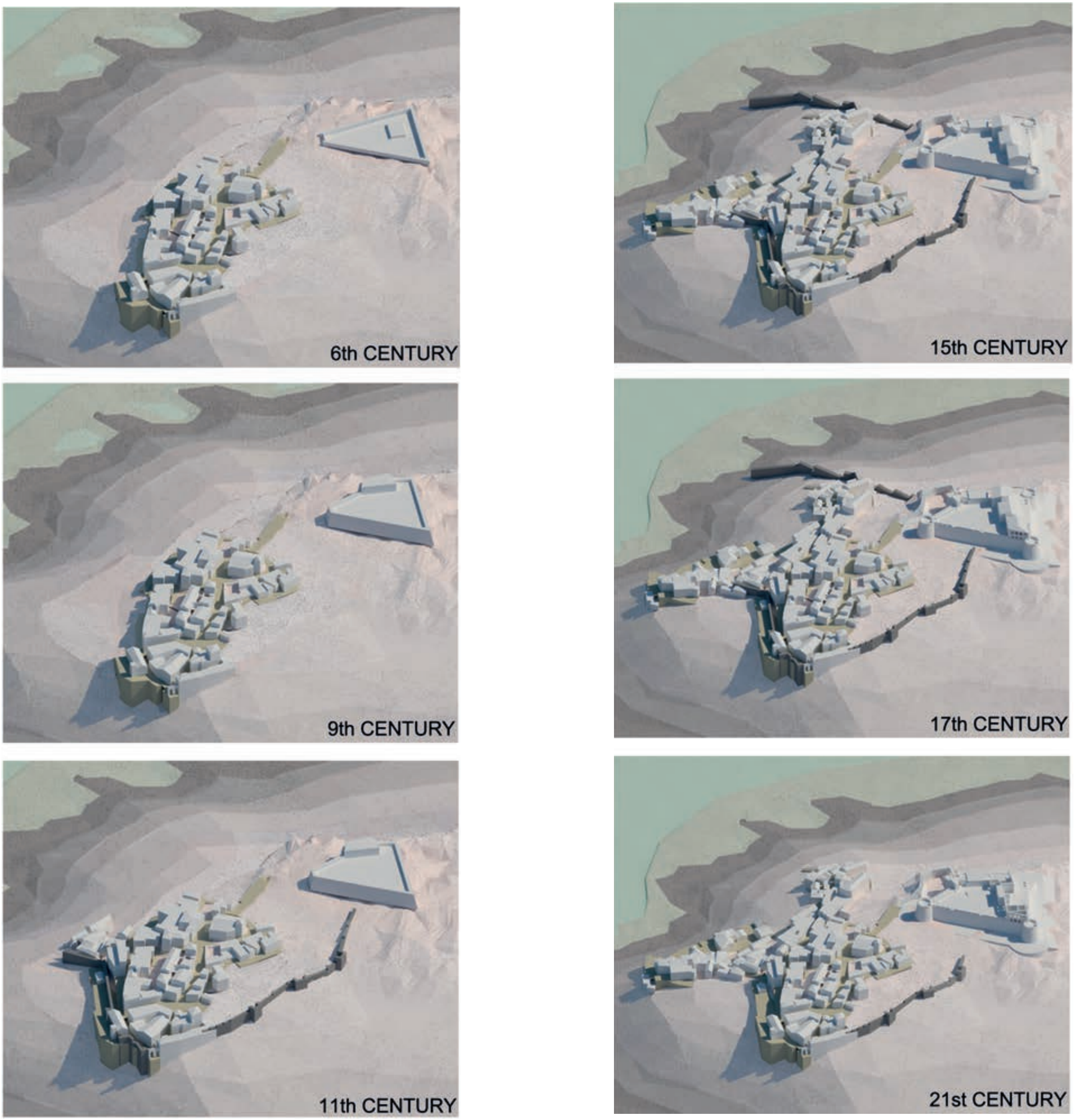
The next step was the virtual reconstruction, result of merging the digital survey with historical and iconographic documents, through a process that starts from the actual state and goes back in time.

Figure 5 Orthophoto of the top view of castle.

Figures 6, 7. Two-dimensional graphs of some facades of the castle.

To be specific, significant sections were exported from the point clouds and the survey, way before modelling the actual contest; these sections were placed at particular levels in order to upgrade the cartography of the municipality of Agropoli, which then served as a basis for the area containing the study case.
As far as concerns the modelling of the past phases, bi-dimensional blueprints of the earlier stages were used.
Eventually, the modelling of the castle was achieved thanks to the orthophotos of the elevations, the orthogonal views and the exported characteristic profiles.
The 3D models were realized using SketchUp software, then the selected scenes were rendered with the use of the Autodesk 3D Studio Max software. The presentation mode didn’t require realistic textures; instead the results were presented in grey scale, highlighting the walls with a different colour to make them stand out of the context and improve the visibility of their placement and transformations within the city. In this way the users cannot speculate about anything beyond what can be demonstrated on the basis of the clear data emerged from the academic research.
In total 3D models of six main historical phases were created related to the principal architectural transformations documented (Figure 8):

- 6th century settlement and 6th century Byzantine kàstron. The shape of the *kàstron* is the result of a hypothesis, probably in the same area previously the ancient temples of Greek origin stood. The first settlement was built on the southern slope of the promontory;
- 9th century Norman period. The *kástron* was expanded. It had a polygonal shape with high fortified walls. While the inhabited center did not undergo substantial changes;
- 11th century. The settlement turns into a small fortified citadel, with the construction of the first city wall south of the kàstron; the perimeter of the inhabited area expands;



Figures 8. Rendered views of the historical phases of the castle and the historic center of Agropoli.

- 15th century. Norman *kàstron* undergoes the most substantial changes, taking on the appearance it has today. The defensive system was expanded, with the addition of the walls to the north. The ancient inhabited nucleus becomes a village;
- 17th century. The construction of the Baronial Palace is completed, with the construction, on the South-West side, of a volume characterized by a double level of arches;
- 21st century. The castle appears deeply transformed. The Baronial Palace was almost entirely destroyed. The second level is no longer present. Of the defensive system of the ancient inhabited center only a tract of walls remains on the southern slope.

5. Conclusion

There is no doubt that today's technological revolution opens new horizons for displaying historical content, giving us multimedia tools that make it possible for a wider, more diversified audience to see (and to interpret) research findings (Svalduz 2013). One of the objectives of this work, in fact, was to develop a methodology to make the transformations of a cultural heritage site visible and usable through the potential offered by new technologies applied to the sectors of history of architecture and restoration.

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ABSTRACT

This study applies Building Information Modeling - BIM and photogrammetry to documentation and asset management. The object of analysis was the Cultural Center of the Federal University of São João del Rei, called Baroness Solar, in the historical center of São João Del Rei, Brazil. It is based on three methodological steps: literature review, including Eastman (2011), Oliveira (2008), Grotelaars (2015), and Tolentino (2016); documentary research in local public institutions; facade photogrammetry and BIM modeling. The results reflect on the benefits and challenges of heritage preservation.

Keywords:
BIM, heritage buildings, Reality capture, photogrammetry from UAV, Baroness Solar.

BIM and reality capture applied to heritage buildings, a study based on Baroness Solar, Brazil

1. BIM methodology applied to heritage buildings

Eastman et al. (2011, p.93-94) state that a reliable and updated BIM Model is one of the best ways to manage as-built constructions. This database is a useful facility management tool because of its accuracy and integration with other areas. Also, it can be used on all buildings, including heritage ones, which in most cases have a long-life cycle involving renovations, demolitions and modifications over time. According to Khaddaj and Srour (2016), the as-built BIM model can work as a database for professionals and users for maintenance and restoration, contributing to building conservation and sustainability.

According to Oliveira (2008), "one of the best practices for preserving heritage memory is the registration and documentation, which has been done throughout the history of mankind, from prehistoric paintings to sophisticated laser scanning." At this point, it is necessary to reflect on the role of documentation and the fact that it will never replace the artifact itself. This consideration is particularly relevant when it comes to heritage, in which the environment, the light, the sensations are unique; one can simulate it but never replace it. All the tools have to work to preserve and maintain the original state. The research of BIM application to heritage buildings brings a new branch named Historic Building Information Modeling (HBIM). Among these new studies and possibilities, one can notice the significant development of techniques in reality capture like photogrammetry, laser scanning, and their use for creating models based on point clouds that work as a source for 3D modeling, visualization, measuring, material information, quantification, and many other BIM uses.There are relevant researches in Brazil about reality capture and BIM, among which it is possible to cite: the Glass House by the architect Lina Bo Bardi; Ruins of the Jesuit Missions, a historic site in the state of Rio Grande do Sul; and the photogrammetry from Unmanned Aerial Vehicles (UAV) of facades in the historical center of Salvador city in the state of Bahia. In order to contribute, this study focuses on a medium-sized city in the state of Minas Gerais, which concentrates the majority of designated heritage buildings by the National Institute of Historical and Artistic Heritage - IPHAN in Brazil.

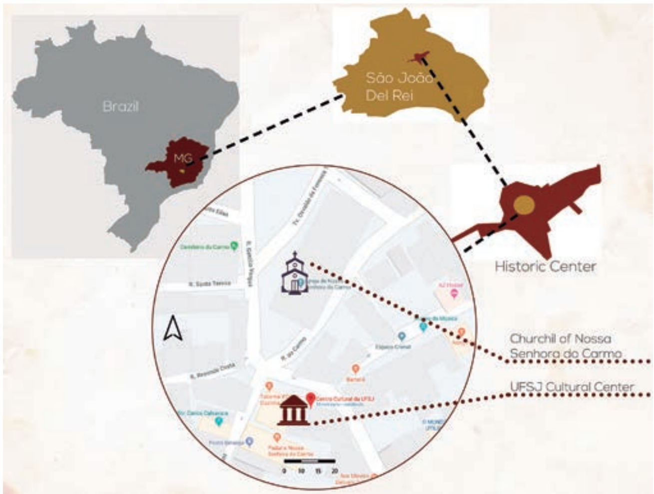

Figure 1. Localization of Baroness Solar. Source: Silva (2017).

2. The building: Baroness Solar Minas Gerais, Brazil

Baroness Solar is a typical house from the colonial period in Brazil built in the historical center of São João Del Rei, an inner-city in the state of Minas Gerais, Brazil, and integrates the historical site listed by the IPHAN. There are some representative characteristics in constructions of that time, like stone portals, solid wood doors and windows, many adornments inside and outside. In addition, the walls combine two construction types: stone walls and adobe bricks, the roof is composed of clay tiles, and wood structure. According to documents of the Federal University of São João Del Rei (UFSJ), the three-story house was built in the beginning of the 19th century by orders of Francisco de Paula de Almeida Magalhães, a relevant person in the city by that time. Throughout its existence, the house has been a residence, shoe factory, military quarter, Italian immigrant hostel and a school (UFSJ, 2017). Nowadays, it belongs to the UFSJ and it functions as a cultural center, hosting art exhibitions from national and international artists and also as an administrative office.

3. Data capturing

In order to create a virtual building, this research used many sources such as photographs, CAD Files, blueprints, and as a primary source, the point cloud made by photogrammetry from UAV. The study starts with the analysis of two CAD files: one provided by the UFSJ Infrastructure Department and another one by UFSJ students under the guidance of professor Luzia dos Santos Abreu. Both files offered highly detailed documentation about the building components. However, on-site verification was necessary due to the fact the research exists in two different files without any standard among them, which could lead to errors and rework.

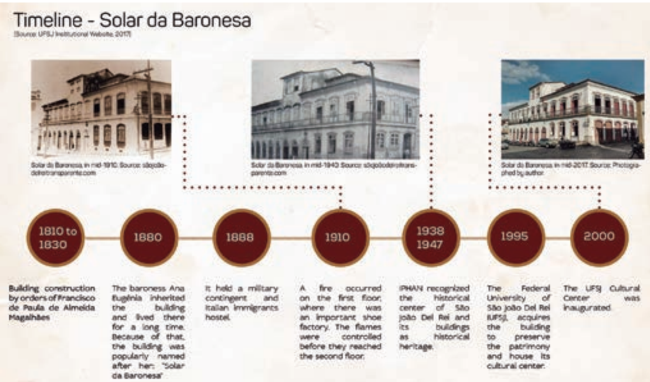

Figure 2. Timeline of Baronesa's Solar. Source: Elaborated by the author.

During on-site visits, it was noticed the walls are self-supporting. They were stone masonry in exterior and adobe masonry in some internals. In some cases, the materials could be verified through observation windows, which made it possible to see the wall core. Furthermore, the photographs, annotations, and interviews during the research were crucial sources of information to model the facades and building details virtually. The next stage was the documentation by photogrammetry of the facades. Grotelaars states about the technique:

"*Aerophotogrammetry, when the camera is carried by aircraft, helicopters, balloons, or unmanned aerial vehicles (UAV), with applications in areas such as agriculture, rural and urban cadastral survey, mining control activities, environmental monitoring, disaster prevention plans, and others.*" Grotelaars (2015, p.69)[1]

The photogrammetry was made in collaboration with the agronomist Marcos Resende and the architecture students of UFSJ. The equipment used by the team were a Total Station Topcon GTS 239W for coordinates survey, a drone Phantom 4 Advanced for the flight, and the digital camera GoPro Hero 4 for capture photos.

The first stage was an on-site observation of the building and its surroundings.

Secondly, control points were marked on the Solar's facade to be referenced in photos; this process is not essential but highly recommended. After that, the coordinates were measured with Total Station equipment, defining an origin point distant from the edification and measuring distances and angles between them. The next and final stage was the photo capture by a camera aboard an UAV.

In this regard, an automatic flight plan was made, covering all the building facades. The pictures were captured every five seconds; thus there was at least thirty percent overlapping in every pair of photos, a requisite of major manufacturers. After the first flight, it was decided that a higher one had to be done in order to increase the number of roof details captured.

4. Data processing

The survey of facades ends with the processing of the collected data in Autodesk's software Recap Photo 2018 and Recap Pro, which are available in the educational version. The entire process of creating a point cloud took about four hours, including the upload and some configurations, such as specifying coordinates between control points and choosing a geographic coordinate system.

Results were given in two format files: one three-dimensional mesh with textures in Recap Photo which was exported in.OBJ file format, good for visualization and measures such as walls and roofs. Another one was a point cloud in Recap Pro in.RCS file format, that can be used as a source for BIM modeling and other analyses, such as constructed and projected comparisons.

One can notice the applications are not restricted to one building; they can expand to the urban scale, capturing data from a vast area. Moreover, the point cloud was optimized and refined in Recap Pro software. According to the publication English Heritage (2011, p.12), the step of refining and checking is particularly relevant to use it as a reference for modeling. Three necessary steps are: defining an origin system for the project, sectioning the model to cover only the relevant region and cleaning unnecessary points; this way we can improve the navigation and modelling

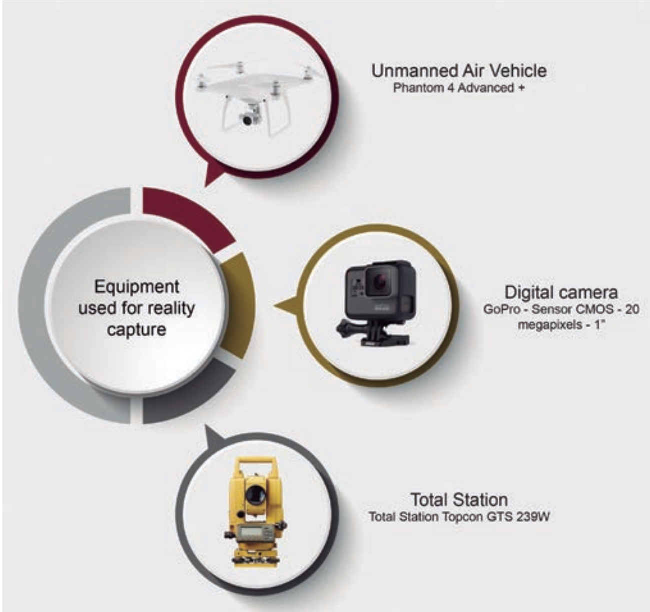

Figure 3. Localization of Baroness Solar. Source: Silva (2017).

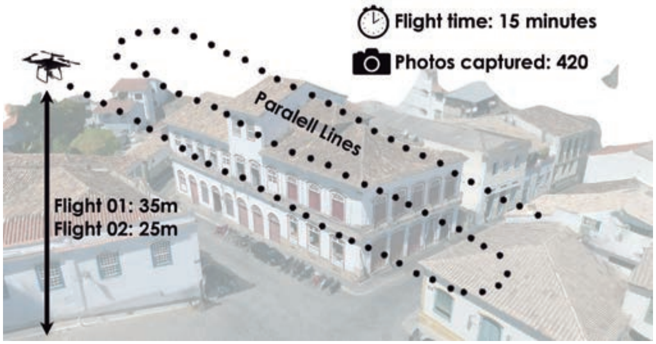

Figure 4. The UAV flight plane over Baroness Solar. Source: Silva (2017).

performance. The point cloud density achieved was in average 81 pts/m^2 and the measures were compared between virtual model and site building.

One can notice that BIM processes with reality capturing data can increase precision and reduce work time. According to Groetelaars (2014), it is a fast process in comparison with traditional surveys, requiring a lower number of people working on-site and consequently decreasing workplace accidents. On the other hand, considerable investment in pieces of equipment and computer software is required, which is an obstacle to popularizing the technique.

5. BIM Modelling

The Baroness Solar BIM model was created in Revit educational version with LOD 300 and LOD 350 classification for components. It was made to study how this kind of modeling can contribute to maintaining updated building documentation and possible applications such as maintenance, design authoring and asset management of UFSJ.

At that stage it is necessary to analyze what are the BIM uses and the respective processes defined by the BIM manager. Therefore, in Baroness Solar's virtual construction, parameters such as location, date, management agent, window conservation state, or wall humidity were input into the model. Thus, the information can be exported, shown in schedules, or connected to an asset database management. In the modeling process, the first step was setting the origin point, and linking the point cloud with CAD files at the same coordinates, in order to assure a reliable positioning and subsequent stages. After this, the levels were created to reference the different component heights, one for each story. The walls were the first components modeled since they are needed to host components such as windows and limit others like floors and roofs. The regular walls were created with their respective layers containing data about thickness and material, which allows an accurate quantification. However, issues with the irregular wall thickness were reported and to solve that problem, it was necessary to use a specific software technique called Model In Place, which is not useful for quantification since it does not allow layers. The doors and windows were created based on CAD files and orthoimages extracted from the point cloud. In this as-built model, there is not much variance in frame measures, so it was decided to create only material and text parameters and keep the same geometry for similar components. All of them have a parameter named "conservation state" to be filled, updated, and scheduled. After all the processes involved in the modeling, the virtual building can provide much information such as sections, floor plans, schedules, renderings, clash detections, and other uses that serve many professionals. However, it is important to mention that it is not a simple process, nor is it a fully automatized one. For a proper BIM model, it is essential to know how the data is managed accordingly to the software and how to model and to manage data.

Figure 5. Measuring extraction from the mesh model of Baroness Solar. Source: Silva (2017).

Figure 6. Urban scale 3D mesh and photo captures location above the Baroness Solar building. Source: Silva (2017).

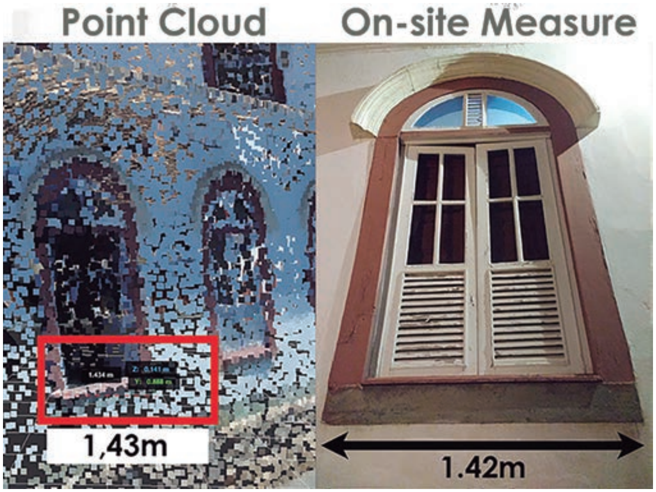

Figure 7. Comparison between the point cloud and real measures show an average accuracy between 1cm to 3cm. Source: Silva (2017).

6. Results and applications

The study of the whole process from data capturing to modeling and organizing it in intelligible information generated three main products: a BIM Model with updated facade documentation, a point cloud of the exterior building, and a Bachelor's dissertation. From the process of BIM modeling in order to update the documentation of Baroness Solar, one can notice that it is a relevant issue to preserve the edification and facilitate future activities of renovation and maintenance of the UFSJ cultural center. As for importance of documentation, Oliveira states that:

"*Besides the documentary, symbolic, and social value of cultural building representation, it is a crucial instrument for those who have the mission to preserve a monument. Furthermore, it is the basis to develop intervention projects; the surveys made with precision permit detailed analysis of the architectural design and its transformations.*" Oliveira (2008)[2]

The BIM model of a pre-existing edification could be created over a real and accurate point cloud given by

Figure 8. Baronesa's Solar model in Revit Software. Source: Silva (2017).

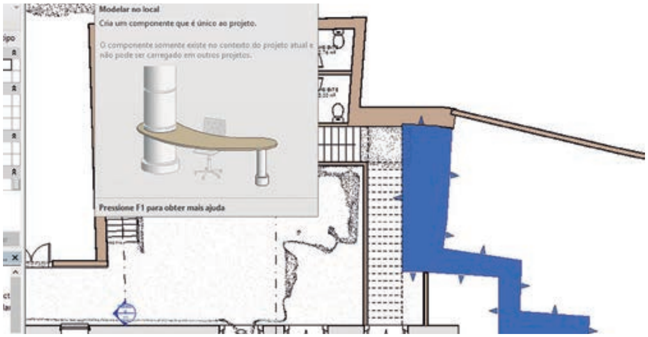

Figure 9. Irregular thickness of walls is a modeling difficulty in Revit Source: Silva (2017).

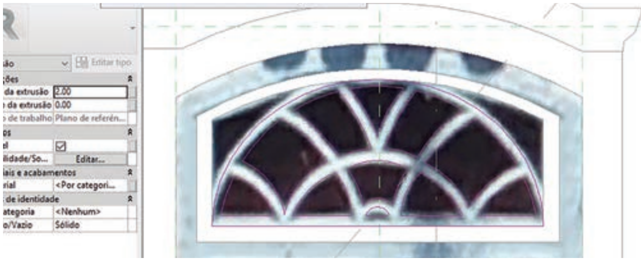

Figure 10. Orthoimages used for creating building components. Source: Silva (2017).

Figure 11. Point cloud + BIM model. Source: Silva (2017).

photogrammetry. After the modeling process, it serves for documentation, energy analysis, maintenance planning, among other needs. These simulations are particularly useful for heritage buildings because of their specific construction systems and cultural value.

Furthermore, this work seeks to contribute to the inventory process of the cultural center. Since the model is a centralized database, all the information is integrated and any addition or modification shall update all sources of data simultaneously. That fact helps professionals to work over reliable documentation, doing simple tasks such as making a painting budget, or more complex ones such as retrofit projects. In the end, the Bachelors' dissertation documented the process, with the advantages and challenges of applying new technologies in heritage buildings. The survey of Baroness Solar shared results with other professionals who are also looking forward to a better application of BIM in historic edifications.

Note

1 Translation provided by the author: Aerofotogrametria, quando a câmera é transportada por aeronaves, balões, helicópteros ou veículos aéreos não tripulados (VANT), podendo ser aplicadas em áreas como: agricultura, levantamento cadastral urbano e rural, controle de mineração, monitoramento ambiental de cidades, prevenção de desastres naturais, etc.

2 Translation provided by the author: Mas, além do valor documental, simbólico e afetivo da representação cadastral de um edifício de interesse cultural, ela é instrumento inseparável dos que têm a difícil missão de intervir em um monumento. Além de ser a base óbvia sobre a qual vamos elaborar o nosso projeto de intervenção, os cadastros feitos com apuro e exatidão nos permitem leitura mais detalhada da evolução do organismo arquitetônico e suas transformações.

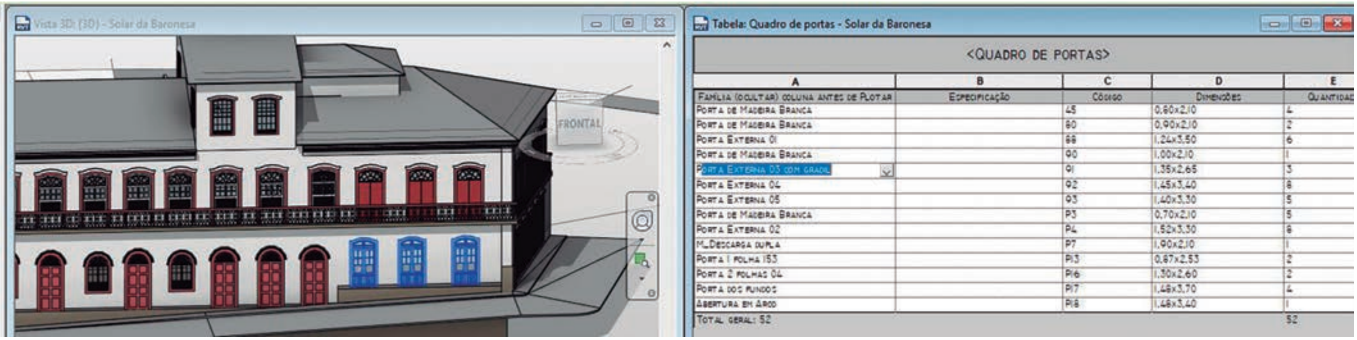

Figure 12. Model and schedules are linked when modeled in BIM software. Source: Silva (2017) .

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Keywords:

SLAM, UAVs sistems, drones, DJI Terra, fast survey, Mompox.

ABSTRACT

In the world of representation, the last decade has seen the development of tools for the acquisition of metric data designed to halve the working time during the surveying activities, towards an increasingly fast data acquisition direction. The use of UAVs aerial systems and SLAM technology amplifies the potential for documentation and monitoring in the context of the extensive survey of large and small urban centers, thanks to the competitive characteristics of expeditious recovery of morphometric data. The rapidity of acquisitions makes these technologies competitive on the market for the purpose of investigations at an urban level in terms of quality relationships and acquisition time. The paper presents a SLAM and UAVS integrated methodological survey experimentation applied to the case study of the historic center of Santa Cruz de Mompox, Bolíva Department (Colombia).

The application of fast survey technologies for urban surveying: the documentation of the historic center of Santa Cruz de Mompox

1. Introduction: Fast acquisition methodologies for Cultural Heritage

The digital transposition of the architectural heritage implies a comparison of experiences and an in-depth evaluation of the digital acquisition methodologies to undertake the appropriate methodological choices based on the spatial qualities and the objectives to be pursued with digital replication. The identity between original material and digital virtual, the digital expression implies giving a second life to the dimension of places, a life whose laws are dictated by computer science (Proserpio 2011). This determines a process of simplification of the complexity of real space, through the construction of the image, the act of digital transposition replicates in all respects the act of drawing and the elaborate products become tools from which to derive simplified and critically interpreted information. The complete digitalization of the data acquisition and processing chain has led to a massive boom in cultural heritage applications.

The recording, processing, modeling, analysis, archiving and representation of elements of cultural heritage cover the entire spectrum from the registration of small archaeological finds and statues, monitoring of archaeological sites, modeling of individual buildings, complexes and sections of cities, down to the royal flush 3D city models.

The inclusion of UNESCO sites and landscapes in the list of cultural heritage has access to the attention to the digitization of urban centers for the insertion and dissemination within the different digital databases that allow their remote friction such as Europeana, preserving their memory of today's image (Portalés et al. 2018). The morphometric information generated by photogrammetry and laser scanner acquisition is subsequently processed and modified into information models thanks to actions on the optimization of the model's texture and the association of information. The digital revolution has upset entire sectors, every day we live in parallel with our digital self, which allows us to reach people and places all over the world in a few moments, browsing through the informative bombardment of the web, we live daily the effect of digitization on our life starting from the trivial use of a smartphone. The economy of 2020 is based on the sharing system with dematerialization through on cloud solutions that allow the creation of new collaboration and innovation ecosystems. The paradigms of the market change so radically in short times, the initiatives of private and public companies must translate into the rapid adoption of digital value chains, as a strategic element of recovery, growth, and acceleration (Poggiani, Tedeschi 2014). The digital transformation cannot represent only an option or an accessory channel. Still, a central element gave the exponential development, which keeps pace with the rapidity of action sought by the technological upgrade. The research presented offers a reflection between the relationship that exists between digital surveying and the development of 3D databases through the testing of fast survey[1] acquisition methodologies. Fast survey solutions for urban-historical documentation of the cultural and historical heritage allow us to relate to

Figure 1. Church of St. Barbara.

Figure 3. Church of St. Francisco.

Figure 2. View of the ancient landing place in the city the market square with the church of the Immaculate Conception.

different urban contexts, overcoming the difficulties related to reduced accessibility or to a scale that cannot be covered in an adequate time by 3D investigation procedures consolidated over time through the use of terrestrial laser scanners (TLS). In order to overcome the time factor problem, several portable solutions for fast and close mapping systems (SLAM[2]) are now available on the market which is based on data overlapping, i.e. on simultaneous localization and mapping (SLAM) and simultaneously allow to estimate the position of the instrument and generate a digital model of the detected scene (Dissanayake et al. 2001). To these must be added the recent commercial growth of unmanned aerial vehicles (UAV), low cost (weight <25 gr.) has opened up the possibility of acquiring low-cost aerial images for the documentation of cultural heritage sites through altitude survey and methodological application of aerial photogrammetry (Murtiyoso et al. 2019). The advantage of being light instruments and designed for the survey in motion through the movement of an operator or a remotely piloted vehicle makes these instruments suitable for transport and action in a work field where the time for operational actions is extremely limited. The data acquired by the mobile laser and drone if not integrated by precise surveys aimed at the acquisition of detail, if compared to the given output of the point clouds processed by terrestrial lasers, are less detailed. However, in detail, it is possible to guarantee a certain level of precision of the final 3D point cloud, operating through the programmed design of the recovery paths of the MLS platform.

2. The case study: The urban center of Santa Cruz de Mompox

For some years the DAda-LAB Laboratory of the Department of Civil Engineering and Architecture of the University of Pavia has been carrying out methodological experiments regarding the use of fast technologies and different case studies, in order to analyze the different critical issues faced in the acquisition campaign of the given to refine the methodological shooting techniques[3]. On the occasion of the III International Seminar of Levantamiento del Patrimonio Arquitectónico[4], it was possible to test two different data acquisition systems aimed at surveying the historic center of Santa Cruz de Mompox (Bolíva Department Colombia): the aerial photogrammetry recovery using UAVS systems using a DJI Phantom 4 RTK[5] drone and a laser scanner survey through the KAARTA[6] mobile laser Stencil. Santa Cruz de Mompox, was founded in the first half of the 1500s on the banks of the Magdalena River, constituted the main waterway of the country of commercial connection between the port of Cartagena and the hinterland of the country. The effect of Spanish colonization is still reflected today in the architectural style of its monumental and domestic buildings; the forms, materials, construction techniques are authentic of the period (Parrinello & Picchio 2019). The original street model of the historic center is still visible, perfectly preserved in its scheme of grid roads, which develops linearly following the course of the river embankment, on which the barricaded walls (albarradas) were built to protect the city during flood periods. Along the line, there are three nodes that coincide with the three large urban voids in correspondence with the three main dominated squares of the three great centers of worship: church of Santa Barbara (Figure 1), the church of the Immaculate Conception, in the best-known Market square (Figure 2), and the church of San Francisco (Figure 3). Precisely for its characteristic urban development and for the authenticity of its buildings, it has been included within the UNESCO declaratory as a World Heritage Site since 1995. Heritage at risk due to frequent floods, La Albarrada, which protects the historic center, is slowly deteriorating, causing damage to structures due to floods. The action of digital documentation, in this case, assumes a dual function of the possibility of risk monitoring and archiving of the image of the historic center (Figure 4), avoiding the loss of the historical memory of such an outstanding example of colonial architecture.

Figure 4. Aerial photography allows to appreciate the longitudinal development of the colonial neighborhoods of the historic center of Mompox.

3. Mobile Laser Scanner Acquisition Methodology

At the basis of the acquisition operations with mobile laser, it was necessary to define a project for the data acquisition phases, going to analyze the urban macro-system, breaking it down into subsystems that were subsequently detected as individual units. SLAM mobile technology is based on a shooting process in motion, the operator directly maneuvers the head of the aquisition tool while holding the tool in his hand through a support arm (manfrotto stick), travels the area to be acquired by structuring suitable paths to cover the entire area covered by the documentation analyzes (Becherini 2019). The technology is able to simultaneously record the acquisition points by keeping track of the position and relative trajectory.

The instrumental limitation of the shooting angle (360 ° horizontally FOV 30 ° - + 15 ° to -15 °- vertical) requires the structuring of a path design structured at different altitudes by tilting the instrument in order to frame the different surface portions, for this purpose the basic instrumentation has been integrated with a monitor which, connected to the laser management computer, allows to view the acquisition area (Figure 5) simultaneously (Dell'Amico & La Placa 2019). Through the design of the paths, it is thus possible to contain the drift error generated starting from the summation of the linear tracks, it is possible to provide this error through the structuring of paths based on the design of a closed polygonal (Chiabrando et al. 2018). Based on these considerations, the first phase involved the analysis of the urban macro-system, breaking it down into subsystems, which were later detected as individual units.

Three macro paths have been defined on the basis of which the secondary circuits aimed at integrating the data acquisition have been inserted: one path corresponding to the outer perimeter of the city center (Carrera 1A, Calle 15, Calle 20, Carre 3) one longitudinal

along Carrera 2, and an external one through the use of a boat along the stretch of river that flows from the plaza of San Francisco to Santa Barbara to retake the banks of the river (Figure 6). These were supplemented by circular paths around the three main squares and individual blocks. The database has 103 laser shots for a total of 10 hours of work. The various shots, once converted into a compatible format (.e57) with the Cyclone software, were processed through the union through the identification of homologous points. The

Figure 5. Survey activities using the mobile laser scanner KAARTA.

Figure 6. Survey activities using the mobile laser scanner KAARTA. Experimentation of acquisition of the river banks using a local boat.

final database is descriptive of all the streets of the city center excluding the data relating to the roofs of the buildings, in some cases, the data has been integrated through the inclination of the instrument increasing the distance from the building of interest in some cases such as in perpendicular streets the main ones were not possible due to the proximity of the buildings (Figure 7 8, 9, 10).

4. UAVs Acquisition Methodology

To integrate the data of the mobile survey, an aerial photogrammetric survey was planned to acquire the three areas of the squares and part of the blocks adjacent to them.

A DJI Phantom RTK drone was used, among the various DJI products to accuracy of the detailed data. In the specific case, it was impossible to use the RTK module due to the lack of the GPS support station. The acquisition phase took place through the planning of three flight plans structured based on an essential grid (75x85m) divided by a scheme of diagonals used to guarantee the overlap between contiguous shots (side overlap Rate 45%; Forward Overlap Rate 50 %) estimated acquisition time 17 min.

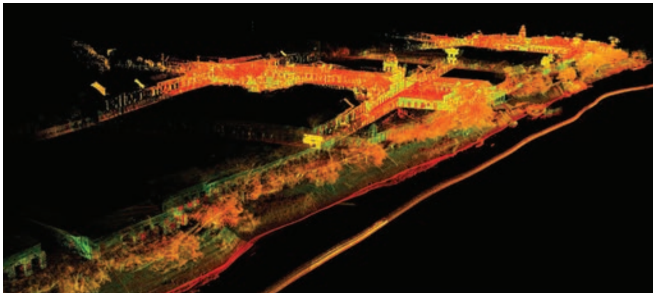

Figure 7. Point cloud view of the river bank acquisition.

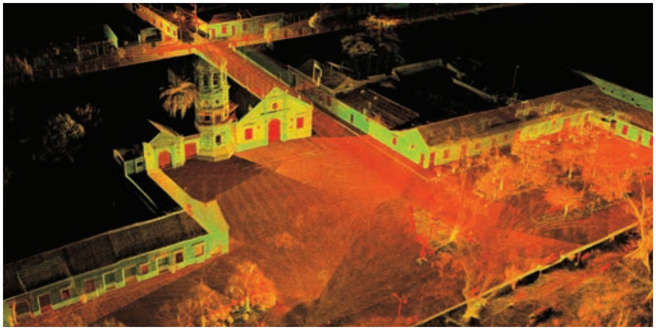

Figure 8. Point cloud view of Santa Barbara church.

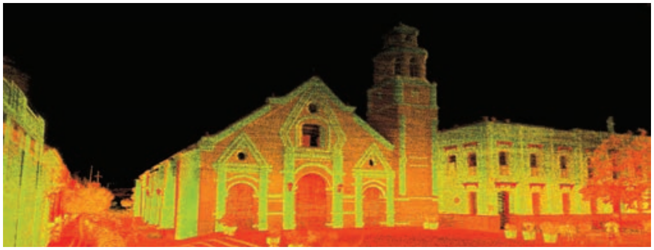

Figure 9. Point cloud view of San Francisco Church.

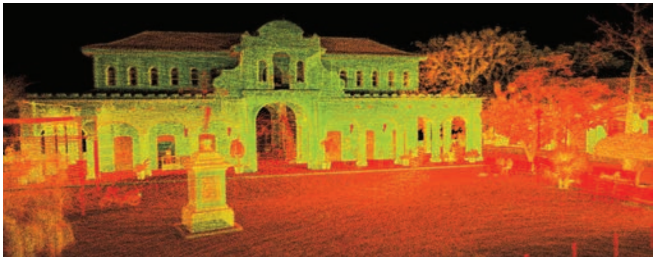

Figure 10. Point cloud view Historic Market.

In particular, the grid made it possible to facilitate the acquisition campaign, facilitating the photographic recovery of the urban fabric. Given the particular weather conditions, the camera's white balance factor has been set to "Sunny," and the Gimbal has been tilted at an angle of 45 °.
Also, due to the weather conditions due to the high temperatures (+ 40C °), it was necessary to carry out the flights both for the various video and photographic shots during the early morning and the last afternoon in order not to send the instrument in "over temperature".
The photographic archive acquired through flight plans includes Santa Barbara 265 photos, Piazza del Mercado 320 photos, San Francesco 209 photos.
The photos were subsequently processed through the experimentation of the DJI TERRA software, data processing software for the creation of three-dimensional models compatible with only certain types of DJI drones. Thanks to the system compatibility, the calculation algorithm is more efficient. They obtained a highly descriptive textured model from the images. You can see the definition of the different models obtained (Figure 11, 12, 13).

5. Conclusions

In recent years, virtual representation techniques based on point clouds and real based modeling have opened up many new areas of application. With the recent expansion of photogrammetry data acquisition tools (sensors) and processing techniques, many other new applications emerge. The generation of reality-based data for virtual environments, animations, video games, and the like is a massive potential for future work. The urgent need to geographically model our 3D environment (3D city and terrain modeling) from high-resolution satellite and laser images and laser scanners has already had and will continue to have a huge impact on protocols for the enhancement of cultural heritage in the near future. The survey campaign conducted shows how in a few hours, it is possible to obtain descriptive models through commercial UAV systems and mobile lasers.

Figure 11. Elaboration of the aerial photogrammetric survey, which took place through the setting of a flight plan. The models were generated through the use of the Terra software, in the figure you can see the different positions of the shooting cameras and the degree of detail of the textured model.

Figure 12. Elaboration of the aerial photogrammetric survey, of San Francisco's square.

Figure 13. Elaboration of the aerial photogrammetric survey, of San Barbara's square. From the image it is possible to appreciate the high level of detail of the model of the church bell tower.

The use of these technologies must, however, be supported by well-planned survey planning so that these methods are effective in their final rendering taking into account the different morphometric variables of the place and the instrumental performance. Knowing the tool and knowing how to use it by applying an acquisition method remains a fundamental method for obtaining data. These fast operations aim to significantly reduce the timing of data acquisition during the operating campaign, also halving from an economic point of view the costs necessary for the realization of the relevant acquisition campaigns. This new kind of spatial information, visualization, and software systems are experiencing continuous and dynamic development. However, it should not be overlooked that a computer model is only one, sometimes inaccurate, always incomplete, an expression of reality.

Note

1 The term fast survey refers to survey operations using mobile technologies such as UAVs systems and SLAM systems that do not require a long acquisition time, mainly used for surveying in emergency conditions or critical areas.

2 The SLAM acronym in robotics refers to “Simultaneous Localization And Map building”, that is the process of robotic mapping through the use of a robot or a vehicle that without pilot manages to navigate an environment using a map that is generated by the same simultaneously.

3 The mobile surveying operations and UAVs were coordinated by Ph.D student Anna Dell'Amico. The mobile survey activities were made by Ph.D student Anna Dell'Amico and Ph.D student Silvia La Placa. The aerophotogrammetry operations were carried out by Ph.D student Anna Dell'Amico. Video and photographic shooting from drone Ph.D student Anna Dell'Amico and Francesco Severino.

4 The SiLepArq 2020 seminar (16-21 February 2020) was organized by the Bolivarian Pontifical University of Monteria with the contribution of the Ministry of Foreign Affairs and International Cooperation Italian Institute of Culture in Bogotà, Architecture & Engineering survey of enviroment and infrastrutture ICOMOS Colombia, Universitat Politécnica de Catalunya, Universitat Politècnica de Valencia, Escuela Taller de Mompox, UID Unione Italiana Disegno. During which professors, students and doctoral students of the University of

Salerno, University of Naples Federico II, Polytechnic of Bari, University of Florence, University of Florence worked on the phases of the survey favoring cultural and disciplinary exchange. of Pavia, University of Basilicata.
Organizing Committee: Massimo Leserri, Alvaro Castro Abuabara.
Scientific Committee: Stefano Bertocci, Antonio Conte, Riccardo Florio, Salvatore Barba, Sandro Parrinello, Gabriele Rossi, Francesca Picchio, Alfonso Morone, Valentina Castagnolo, Raffaele Catuogno, Ana Torres Barchino, Andrés Gaviaria Valenzuela, Victor Velasque Hernandez, Patricia Schnitter Castellanos, Merwan Chaverra Suarez, Mariana Patino Osorio, Giovani Rojas.

5 Those research were enforced in a collaboration between DJI Enterprise and the University of Pavia for the development of research activities, and the promotion of the different ways of using drones for cultural heritage. This collaboration is based on the "Agreement for the development of research activities about the digital documentation of cultural heritage and landscape using drones" between the Department of Civil Engineering and Architecture of the University of Pavia and iFlight Technology Company Limited, signed in February 2020, lasting three years.

6 Stencil is an autonomous, mobile, light and low-cost system. This type of mobile stencil laser scanner is based on a reworking of LIDAR and IMU data for localization. The system uses Velodyne (VLP-16) connected to a low cost MEMS IMU and a processing computer for real-time mapping and localization.

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ABSTRACT

This paper presents an effective acquisition and data processing method for landscape surveying aimed at producing cartographic data dedicated to archaeological cartography. The case study presented, part of the Banditaccia necropolis and of the "*Via degli Inferi*", allows to analyze in detail the acquisition phases and the vegetation filtering procedures to obtain a single DTM by separately processing photogrammetric surveys from UAV and data obtained with TLS (Terrestrial Laser Scanner). The aim for this paper is to underline the importance of producing cartographic bases dedicated to archaeological cartography, rather than using cartography created for other purposes.

Keywords:
UAV, photogrammetry, TLS, archaeological cartography.

Landscape survey and vegetation filtering for archaeological cartography. A UNESCO World Heritage site in Cerveteri: "Banditaccia" necropolis and the "Via degli Inferi"

1. Intruduction

The wide diffusion of relevant and convenient technologies in the field of cultural heritage documentation, favoured by the constant decrease in costs to access necessary equipment, makes urgent the formalization of protocols useful to define operational and qualitative standards. This requirement is made more complex by the cultural heritage's nature, characterized by episodic typologies, often making it extremely complex to reach univocal formalizations for documentation and data restitution. This situation, given the importance of the opportunity offered by the constant evolution of acquisition sensors, therefore makes the need to share procedures and instrumentation used in the greatest number of cases as extremely topical. This work also encourages discussion points about the importance of landscape mapping as activity connected to those needed while planning an archaeological survey (Musson et al. 2005).
The case study presented illustrates some solutions, operational and for data processing, useful to discuss the integration of aerial photogrammetric surveys with laser scanner data. In particular, through the discussion of the survey at "Banditaccia" necropolis, an approach is proposed aimed at integrating active and passive sensors according to the morphology and cartographic products to be delivered. More specifically, to document the entire area a UAV was used for aerial photogrammetric purposes, while for "*Via degli Inferi*", considering its morphology with narrow spaces, a Terrestrial Laser Scanner (TLS) was preferred. Subsequently, the paper illustrates a procedure for filtering the data acquired from the vegetation in order to produce a DTM and contour lines.

2. Case study: the "Banditaccia" necropolis and the "Via degli Inferi"

2.1 Historical framework

The territory belonging to Cerveteri appears, since the Villanovan period, densely populated with small settlements centered on the coastal plain. During the VII BC the material culture coming from the city reveals, probably for the mining exploitation of the Tolfa massif, a flashy leap in quality, with the emergence of an aristocratic elite, documented by princely tombs. From this same era (second quarter of the VII BC) the Banditaccia necropolis, on the plateau adjacent to the north-west side of the city, has been systematically used, showing an extraordinary quantity of tombs, exemplifying, from VII to III BC, the entire typological range of Ceretan funeral architecture.
The "*Banditaccia*" necropolis (Zapicchi 2006) covers an area of about 400 hectares on a tuffaceous hill north of the city of Cerveteri, the ancient Caere, one of the most flourishing centers of southern Etruria (Moretti Sgubini 2001), as evidenced by the extension and monumentality of the sepulchral area.
The first systematic excavation was conducted between 1909 and 1936 by R. Mengarelli (Cosentino 2016; Cosentino 2017) who also brought to light the main sepulchral way, calling it "*Via degli Inferi*" (Enei 1985).

The oldest nucleus, near the "*Cava della Pozzolana*" area, dates back to the Villanovan period, but the necropolis was used until the full Hellenistic age, thus counting multiple sepulchral typologies. The "*Via degli Inferi*", immersed in spontaneous vegetation, is deeply embedded in the tuff, with an amplitude that varies from 60 cm to 2.5 m. in the widest spaces. The road starting from one of the gates on the northern side of the city and passing the "Fosso del Manganello", constituted, in its western bifurcation, the original path inside the necropolis of the Banditaccia. The road continues sinuously up to a crossroads directed: on the left to "Ponte Vivo", while on the right to the ancient city. In this section, characterized by the presence of numerous squares, there is a series of tombs at different heights dating from the Orientalizing age up to the late Hellenism.

2.2 Aims

Surveying activity was aimed at producing a 1:200 scale cartographic base, with excerpts on a more detailed one (1:50), for subsequent creation of an archaeological map (Barba et al. 2019). The project concerned, as first step, an area of about 18 hectares between the "*Via degli Inferi*" in the North - West and the "*Via dei Vignali*" in the South - East. The intervention area, which in addition to the "Via degli Inferi" interested various other burial areas, including the "*Necropoli del Laghetto*" (Rizzo 2018, Linington 1989), it also involves a portion of the "*Fosso del Manganello*". The problems posed by this area of intervention, characterized by sharp jumps in altitude, concerned primarily the vegetation which, on the one hand imposed filtering activities, and on the other made it impossible an exclusively photogrammetric acquisition, requiring an integration with TLS for the "*Via degli Inferi*" (Figure 1).

3. Data acquisition

3.1 GCP and topographic measurements

In order to be able to reference TLS and photogrammetric acquisitions in the same geographic system (WGS 84, UTM 33N) and optimize the photogrammetric survey, the first operation consisted of a nRTK measurement of 20 GCP materialized on the ground with photogrammetric target (dimensions 60x60 cm), to be used in the photogrammetric restitution, and vertices of a topographic polygonal from which measuring,

Figure 1. "*Via degli inferi*" in Cerveteri from UAV.

with total station, further 30 natural points distributed along the path of the "*Via degli Inferi*". The instrumentation used to measure each target consisted of a Geomax Zenith 20 antenna with a built-in receiver, while the total station used to measure the natural points along "*Via degli Inferi*" was a STONEX STS2. The accuracy achieved in the topographic survey of planimetry was below 1 cm and 2.5 cm for altimetry.

3.2 Photogrammetric survey

After the topographic survey, two flights with two different UAVs were carried out, one in planned mode, using a DJI Mavic pro, to detect the entire area (case study A), and one in detail for the "*Via degli Inferi*" (Case study B), in manual flight, with DJI Phantom 4 pro. To map the entire area with the Mavic pro, a UAV characterized by a 1/2.3 "CMOS photographic sensor and 12 MP resolution (sensor size 4000 x 3000, pixel size 1.57 µm, focal length 4 mm). A number of 1132 nadiral images were acquired at an average flight altitude of 60 meters, setting an average overlap of 70% and a side lap of 60%. For the detailed photogrammetric survey of the "*Via degli Inferi*", 393 images were acquired in manual flight with an UAV camera characterized by a 1" sensor with 20 MP resolution (sensor size 5472 x 3648, pixel size 2,41 µm, focal length 8,8 mm). The images were acquired in manual mode at an average height of 10.5 m, without a flight plan, with a camera tilted at 45 °, capturing the two side walls in two different swipes, and adding a flight focused on the pedestrian road, connecting the previous two.

3.3 TLS surveying

The aim of TLS surveying technology in this case was the creation of a dense and accurate point cloud of the area under the thick vegetation (Figure2), for subsequent integration with the aero-photogrammetric point cloud. Moreover, TLS is irreplaceable for surveying narrows spaces as the one characterizing the "*Via degli Inferi*" (case study B). In this scenario a medium range laser scanner was chosen: a Leica BLK 360 (range 0.6 m - 60 m, Max measurement speed 360.000 points / second, HDR integrated camera, Field of view 300° on vertical - 360 on horizontal, Ranging Error 6mm @ 10m), mounted on a photographic tripod with a height of 6 m. The BLK 360 is controlled by a tablet, connected to it through Wi-Fi, running the Autodesk app Recap Pro. The operational phase on the field for the data acquisition is simplified,

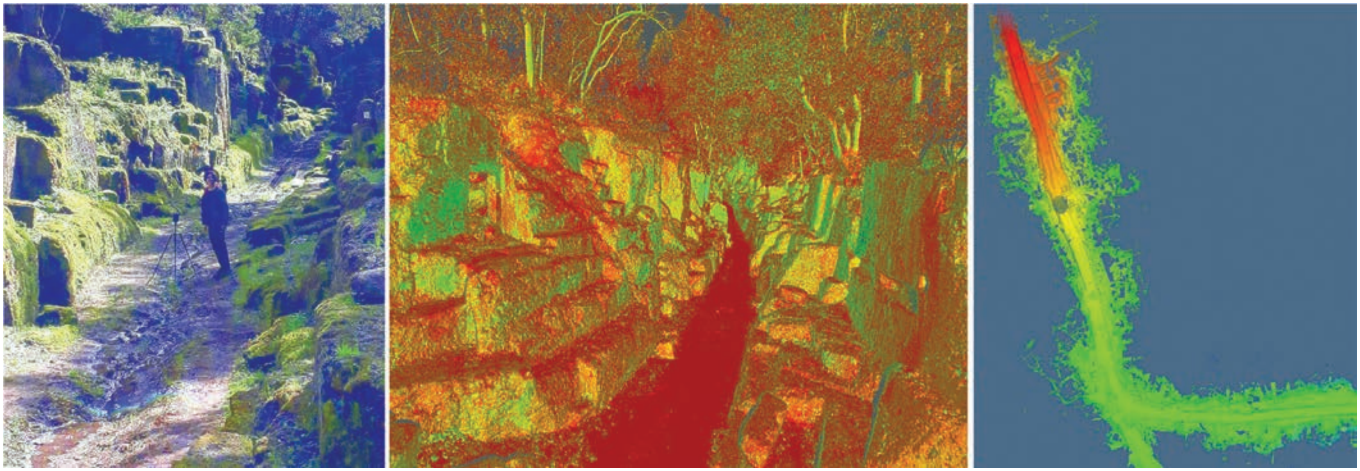


Figure 2. From left to right: data collection, TLS cloud detail, DSM from TLS survey of the "*Via degli Inferi*".

accessible also for non-expert users, and part of the data processing can be completed directly on the field using the tablet. Size and maneuverability of the BLK360 are key factors for the application of this sensor in survey activities for Cultural Heritage, especially in narrow spaces like our case study. The Leica BLK 360 was used only for surveying the "*Via degli Inferi*": the acquisition phase included 40 scan positions obtained in 2 working days (approximately 14 hours in the field). Scan resolution was set to high mode (5 mm @ 10 m). During the acquisition weather conditions were cloudy, guaranteeing diffuse lighting, an ideal condition to capture RGB data. In this acquisition, in order to facilitate alignment, spherical targets of 7.5 cm radius were used. Targets were needed due to the scene's geometry, with rounded corners, homologous texture and thick vegetation, a situation that would have made impossible to achieve a sufficient overlap for cloud to cloud registration.

4. Data processing

4.1 Photogrammetric Data

The 1132 images (case study A) have been processed in Agisoft Metashape using a PC equipped with an Intel I9 9900k CPU, RTX2080ti GPU, 64GB RAM, the project, with its temporary files, was located on SSD M.2. In Agisoft Metashape data processing is articulated into four consecutive steps, reconstruction parameters were chosen to obtain resulting outputs as accurate as possible: Align Photos (Accuracy Highest, key points 70.000 tie points 70.000); Build Dense Cloud (Quality: High, Depth Filtering: Aggressive); Build Mesh (Surface type: Height field, Face count: High); Build Texture.The time taken to complete the batch process was approximately 4 hours and 11 minutes. It can be outlined that the average error on GCPs is about 4 cm, more than adequate for planned scale restitution. For the "*Via degli Inferi*" (case study B), using the same workstation, Reality Capture software was preferred to process data for its ability to integrate photogrammetry with TLS data.

In this software data processing is divided into three steps 1) Align Images (Max feature per image70.000), 2) Reconstruction (normal detail), 3) Texture. At the end of the process, for each project an orthophoto (case study A 1.7 cm/px; case study b 1cm/px), a dense cloud (case study A 61 million points, case study b 29 million points) and a DSM (only for case study A) were exported from the SFM software (Figure 3).

4.2 Vegetation filtering and DTM generation

Considering the dense vegetation cover and the absence of aerial LIDAR data, in order to obtain a terrain model as close as possible to reality, we proceeded with a vegetation filtering activity using the CSF plugin in CloudCompare (Zang et al. 2016). This tool allows to filter the vegetation by offering two menus, in the first one, in which it's possible to choose the scene type, we chose, as general parameter "*Relief*", in the second menu, where it's possible to set advanced parameters, we choose a grid size of 0.2 m (Cloth Resolution), the iterations have been set to 200 and the classification threshold to 0.5 (default). The filtering process took 10 minutes. After obtaining two clouds for each surveyed area (ground points, off ground points) the ground points were converted into a raster grid using the CloudCompare Rasterize plugin.

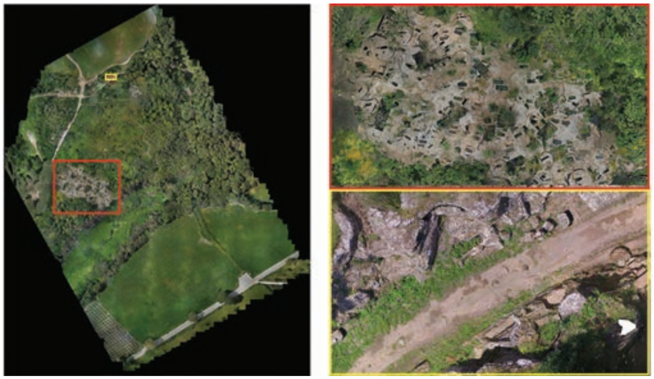


Figure 3. Ortophoto and its details: "*Necropoli del Laghetto*" (in red) and "*Via degli Inferi*" (in yellow).

This plugin allows to obtain a raster grid with attribute Z from point cloud. For both projects, a cell size of 2cm was chosen. The two generated DTMs (Digital Elevation Model) were then imported into the Global Mapper software for merging operations between the two DTMs (Figure 4).

In this software, once the two DTMs were imported, the "Combine / Compare Terrain Layers" tool was used, first subtracting from the general DTM (case study A) the DTM of the "*Via degli Inferi*" (Case Study B), obtaining a subtraction of overlapping data with different Z in general DTM.

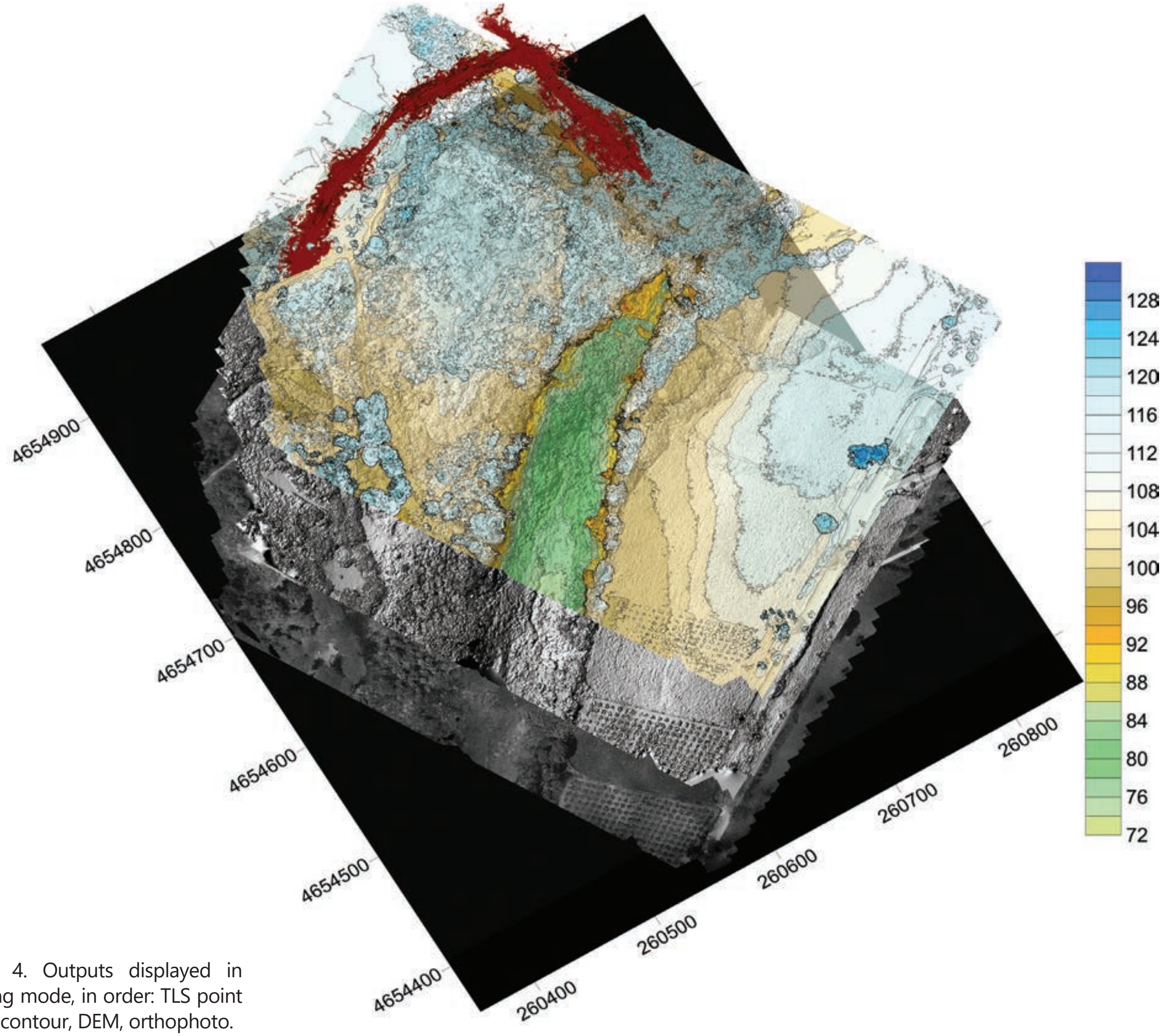
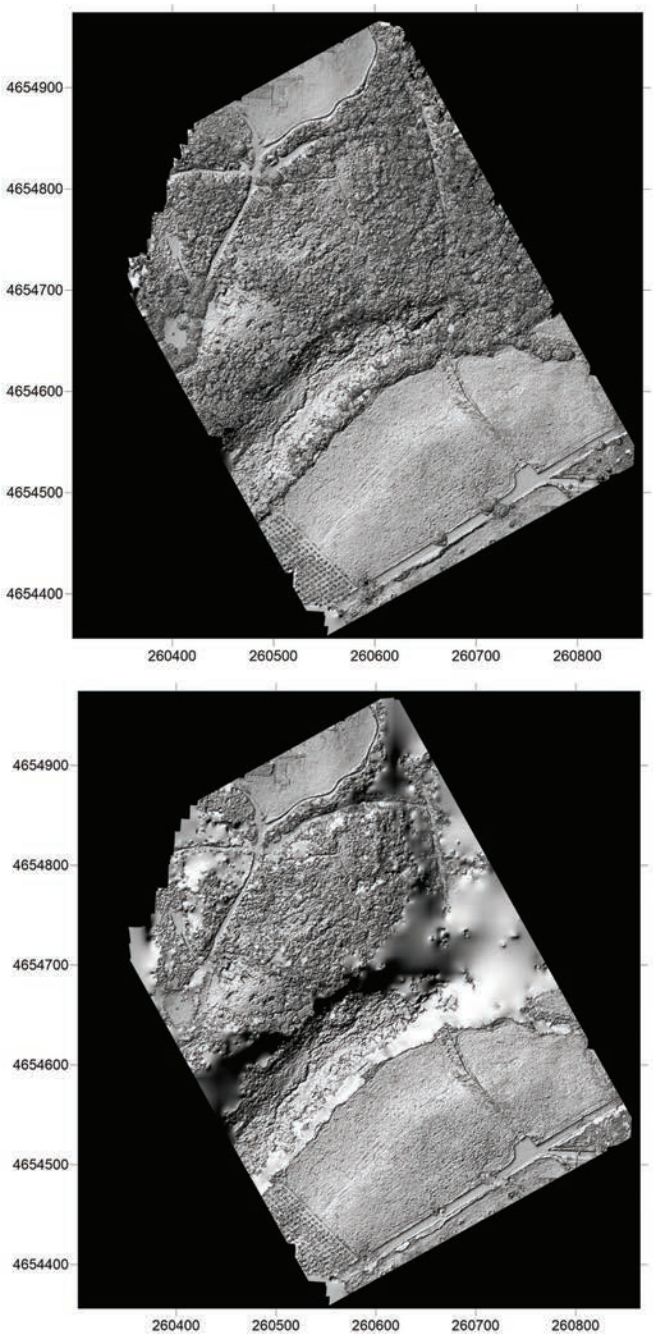
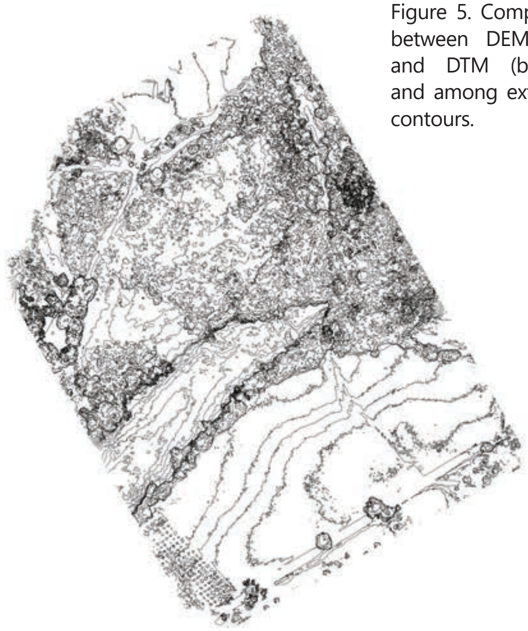


Figure 4. Outputs displayed in stacking mode, in order: TLS point cloud, contour, DEM, orthophoto.

Figure 5. Comparison between DEM (top) and DTM (bottom) and among extracted contours.





Once this operation was completed, an addition (average value) was made between the general DTM and the "*Via degli Inferi*" with the same command, obtaining the integration of the data in the area covered by vegetation (Figure 5).

5. Conclusions

For the surveyed area the most detailed cartographies available were the CTR of Regione Lazio in scale 1:5000 and the LIDAR data from the National Geoportal with a resolution of 1m. This cartographic repertoire was considered not sufficiently accurate for the subsequent positioning of archaeological findings. It was therefore necessary to plan a data acquisition aimed at producing an adequate cartographic set for the subsequent creation of an archaeological map. Despite having considered the option of a direct terrain survey carried out exclusively with GPS instrumentation (Capra et al. 2002), nevertheless the conditions of tree cover and the extension of the area, being the accuracy of the DTMs coming from photogrammetric data for these scale factors comparable with that of topographic surveys (Haala et al. 2012, Leberlet al. 2010), an approach based on a photogrammetric acquisition, with possible integration of TLS data, was preferred. The critical issues to be faced for the two areas were mainly related to vegetation cover and the presence of narrow spaces. Circumstance that imposed a topographical registration of the point clouds and the treatment in open source software for filtering the vegetation, passing from a DSM to a DTM. The result demonstrates how the use of data acquired from the ground, in this case from TLS, and aerial photogrammetric data, can be the solution to derive DTM from DSMs, in order to produce cartography sufficiently accurate for archaeological mapping purposes. This approach also proved to be promising to map archaeological traces under vegetation with extreme precision.

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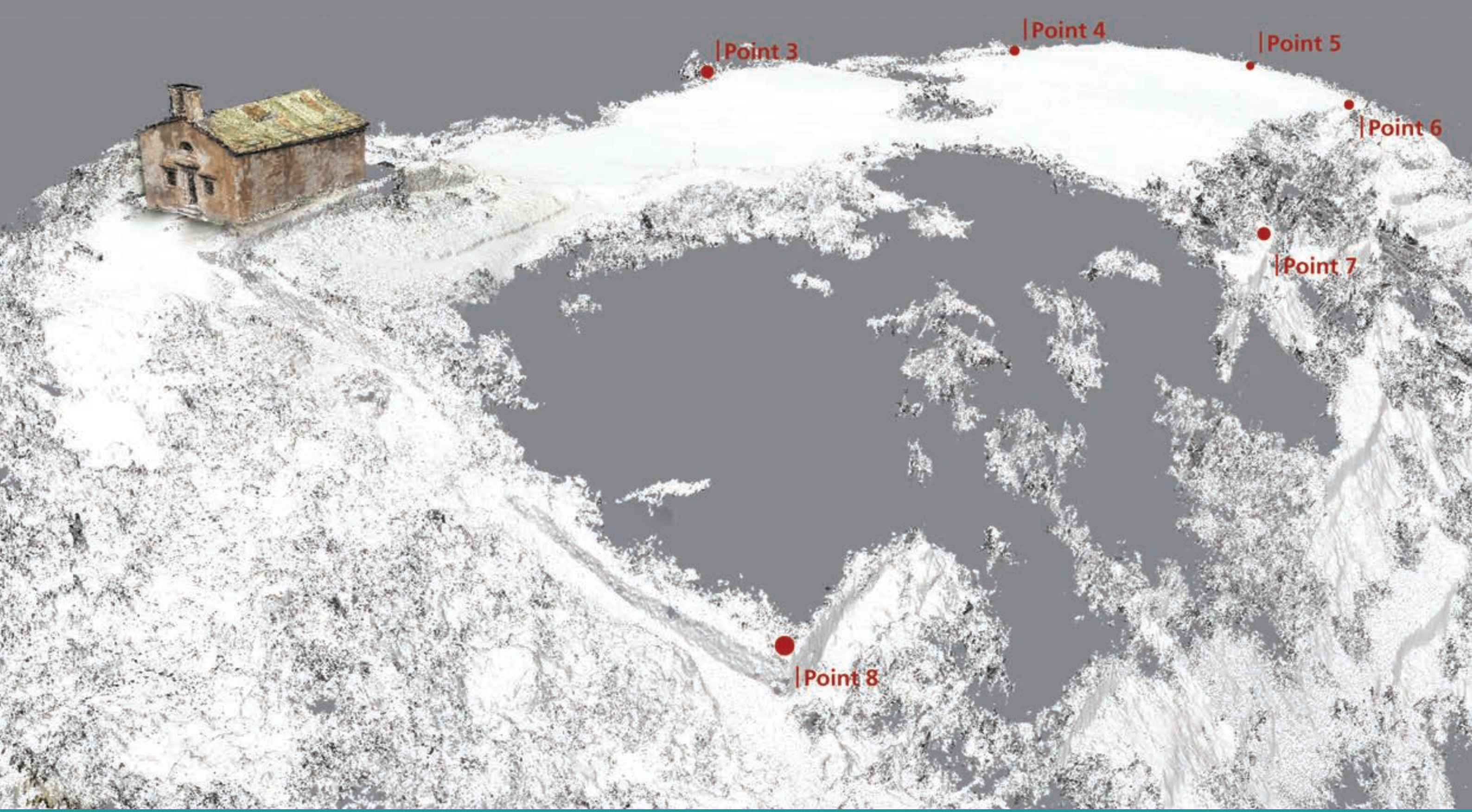

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ABSTRACT

This paper reports the results of a research project aimed at the survey, historical knowledge and archaeological understanding of the St. Agatha church in Povo (Trento), which was supposed to be built in XV-XVI century over the ruins of a castle that some sources refer from 1208 to 1375.

An extensive use of digital photogrammetry with UAVs and DSLRs, alongside the topographic instruments like total station and GNSS receiver, provided a complete survey of the church and surroundings, and eventually brought to the discovery of borders and walls of the ancient castle.

Keywords:
Architectural heritage, photogrammetry, Reverse Modelling, Trentino, UAV survey.

Survey with UAV and DSLR: an integrated approach. The case study of St. Agatha church and castrum Padi

1. Introduction

The St. Agatha church is set in Povo, near Trento, on the tallest point of the St. Agatha hill, that overlooks a plateau where the small towns of Povo and Villazzano are located. The hill was anthropized since the Iron age with settlements at the base and the top; since that moment continuous activities took place, led by the strategic and dominant position of the hill. The ideal exposure to the sun led to the development of a subsistence agriculture that shapes the slopes with dry stone walls defining a system of terrace cultivation. Then, a quite strategic and autonomous fortification system could be developed, and so a castle (castrum Padi) raised between XII and XIV centuries, which was later destroyed by numerous riots and rebellions due to poverty and political instability.

Currently, St. Agatha church is the only building survived on the hill; there are no evidences about the period in which it was raised, if it was either a part of the castle system, or an evolution of the castle chapel, or a later building erected on the foundation of destroyed structures. What we know for sure is that no other defensive structures were built after the destruction of the castle. The church became the destination of two processions per year (on recurrences of St. Agatha and St. Lucy) and the hill was used only for agricultural purpose. Then, after the small town of Povo was absorbed by the urban development of Trento ('80s ca.), the entire system of church, terrace agriculture, dry walls etc. was abandoned.
Then, the will to preserve this cultural heritage and to react to the general decay led the community to form

Figure 1. St. Agatha hill (in colour) from SE. The little church is hidden by the vegetation. (Photograph by F. Giampiccolo, 2018).

Figure 2. St. Agatha church from SW. (Photograph by F. Giampiccolo, 2018).

a committee named "*A town, its hill, its church*" and started to raise resources and volunteers in order to revive interest and to promote a restoration.
The University of Trento provided, through a master's thesis, the scientific and methodological support that become a test bench for a multidisciplinary approach where different knowledges from architecture, engineering and archaeology could encounter.

2. Topics and goals

The main goal for the committee was to replace the old wooden roof as soon as possible: it was more than five years that the rain could penetrate up to the inner part of the church, causing damages to the plasters and the risk to compromise the whole statics of the building. On the other hand, treating such an historical and delicate architecture meant to survey both the church and the surroundings, understanding the possible construction phases of the church, planning how to couple the new roof with masonry. Eventually, every step had to be checked by the Superintendence for Cultural Heritage of the Autonomous Province of Trento. Furthermore, there were no sufficiently detailed studies about this complex: more than the few sources that allow to date the castle between XII and XIV centuries, no archival document and / or material trace allows to suppose the date of construction of the church. On the architrave of the entrance, a damaged inscription reported *de tva protectione vt in aeternum protegas an.* [1566], that suggests that an intervention was completed in 1566, but probably this is not the date of the whole construction of this little church.The Acta Visitalia (inspection proceedings with the census of every existing church) were conducted in this area by bishops since 1537, but the first complete census was in 1579, where the church was named; considering that only since the Council of Trent (1545-1563) these proceedings have become mandatory, no useful information can be obtained from written sources. Then, it was clear that only a systematic and farsighted research on the entire complex and the surrounding

Figure 3. The damaged inscription: dense point cloud from SfM in grayscale.

site could provide knowledge and assumptions in order to replace the roof as a first step in a larger restoration project, as well as indispensable intervention for the protection of the ancient wall structures.

3. Methodology and materials

The objectives of the planned acquisition process of oblique and nadir shots by drones are different.
First, they lie in the need for a more accurate description of the place, which also allows the interpretation of the temporal evolution and the comparison between the present and the past.
The aerial images, both single and generated by the mosaic of several shots (ortho-mosaic), can be an effective material for comparison with historical photographs, paintings, engravings and views. From the never seen points of view allowed by drones, you can see relationships that are not visible to the naked eye which, until the advent of the first air flights, could only be simulated by the draftsman or the surveyor through operations of abstraction. Just think of the first cartographers and the attempts to represent cities in a bird's eye since the 17th century, as shown in the Figure 4.
Obviously, these descriptive purposes represent the most well-known and widespread potential of the use of drones, which can instead support the processes of knowledge of cultural heritage in much more complex ways. This happens when aerial shots are the starting point for 3D geometric modelling and graphic representation.
Indeed, the relationship between Cultural Heritage and Information Technologies have been deeply investigated, with some efforts to set a reliable, innovative and grounded operating framework for

Figure 4. Grafschaft Tirol, Warmund Ygl, 1604/05.

documentation, survey and interpretation of ancient architecture. The vast potential of Structure from Motion (SfM) allows nowadays to overcome expensive systems like laser scanners in a lot of situations and permit to easily integrate aerial and terrestrial photography. A correct and reusable metric reference system can be set with the common topographic instruments like total station (TS) and so it is possible to arrange a reliable and scalable methodology.
The software Agisoft Photoscan (v. 4.1.1) was used to process the geometric model.
The aim was to generate a high-resolution 3D model which would contain colour and metric data for further multipurpose analysis. It was important as well to provide and define some control points that must be fixed and recognizable, in order to scale the digital model and permit later to extend it with certain references. The equipment used to acquire images was the DSLR camera Nikon D3200 with lens Nikkor AF-S DX 18-105 mm f/3.5-5.6 ED VR. Control points were defined by 15 12-bit markers that the software Photoscan generates and recognizes automatically; some markers (6) were post up on a fixed height determined by a laser level, so it would be easy for any operator in site to check gradients. Other markers (9) were post up on different heights in order to acquire a better accuracy. The measures were acquired with the total station theodolite Leica TCRP1203+ and processed by the software Leonardo XE365 (to import the survey and save it in.dxf format) and Autodesk AutoCAD; then the coordinates of the surveyed points were referred to the markers in Agisoft Photoscan. The church was surveyed with two separate photo set of inner and outer part; the aim was to achieve a ground sampling distance (GSD) less than 1 cm to an overlap of about 50% between the images, while the distance was limited to 4-5 meters. Then, the inner set was of 102 images, each with an average weight of 20 Mb (for a 24,2 megapixel image in .raw format, 6016 x 4000 pixels, acquired on a tripod with these settings:

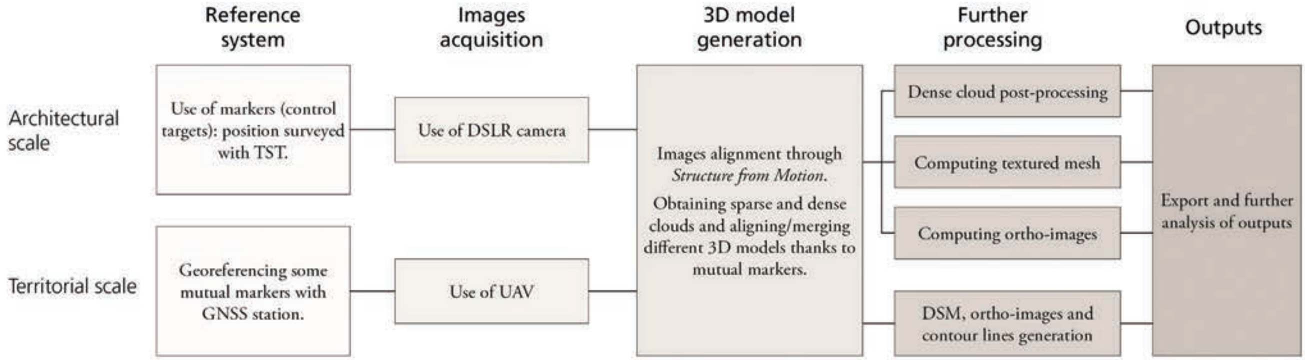

Figure 5. The workflow.

focal length of 18 mm, ISO 100, f/4.2, 1/50 sec); the SfM computation by the software showed an average absolute error of 3,66 mm on the GCPs compared to the metric data acquired by TS. The sparse cloud obtained was of 104.446 points (Key point limit: 50.000, tie point limit: 5.000, accuracy: high), then the dense cloud counts more than 75 million of points (quality: high); finally, the textured mesh was composed by 443.523 polygons and the texture resolution was of 1,38 mm/pixel (face count: medium, interpolation: enabled, texture size/count: 4096 x 2).

ùThe resolution of about one centimetre and the partial elimination of the crowns allow a careful evaluation of the geometric consistency of the terraces surrounding the church, as well as of their mutual positions, and they produce an information support from which to obtain different types of representation depending on the type of requirement. Three major methods could be followed to export data and carry on the analysis: the first one was to export ortho-images of plan and fronts (inner and outer) and then tracing 2D drawings in CAD; the second one was to export the dense point cloud and then use it in a 3D CAD environment (e.g. through Autodesk ReCap and then AutoCAD); the third method was to export the entire mesh to further operations of refinement and analysis. As we need mostly 2D drawings (fronts, sections, plans, etc.) it was chosen the first one, which ensure the most precision at a quite fast computing. The textured mesh was used only to generate orthophotos of plans and fronts. Similarly, the outer part set was of 87 images; the SfM computation by the software showed an average absolute error of 8,34 mm compared to the metric data acquired by TS. The sparse cloud obtained was of 115.893 points, then the dense cloud counts more than 45 million of points; finally, the textured mesh was composed by 799.998 polygons and the texture resolution was of 0,96 mm/pixel. Then, other images sets were acquired when necessary (e.g. at the demolition of the old roof, in order to survey the outer part of the vault) and step by step processed and linked to the main 3D point cloud model. At the territorial scale, there were almost no possibilities to survey with the TS the whole top of the hill (ca. mt. 200 x 60), due to the presence of vegetation, gradients, dry walls and terraces. It was considered more reliable to use drones in order to create in Agisoft Photoscan a 3D environmental model that could be linked with the one of the church, that could be geo-referenced and that could generate orthophotos, DSM and height maps which would be useful to any kind of analysis. The equipment used to acquire images was a UAV DJI Phantom 3 Standard, then a GNSS station Leica System 1200 GPS was used to geo-reference 7 ground control points (coordinate system UTM-WGS 84 (EPSG:4326).

The drone survey was planned with the app DJI Gs Pro with these settings: height: 31 mt., overlap: 75%, 256 waypoints for a covered area of about 260 x 120 mt. The set counts 256 photographs, and the SfM process generated an absolute error of 52,73 mm (due to the resolution of the photographs), a sparse cloud of 225.837 points, a dense cloud of over 30 million of points. Then, it was computed a DSM, which resolution was 40,4 mm/pixel (as the GSD), an orthophoto, which resolution was 20,2 mm/pixel, and contour lines (every 50 cm, but it could be possible to achieve a better, though useless, resolution). As we can see in figures 6 and 11, the SfM could not reconstruct a quite large area full of spontaneous vegetation.

Figure 6. Front S, inner: resulting ortho image from the textured 3D model.

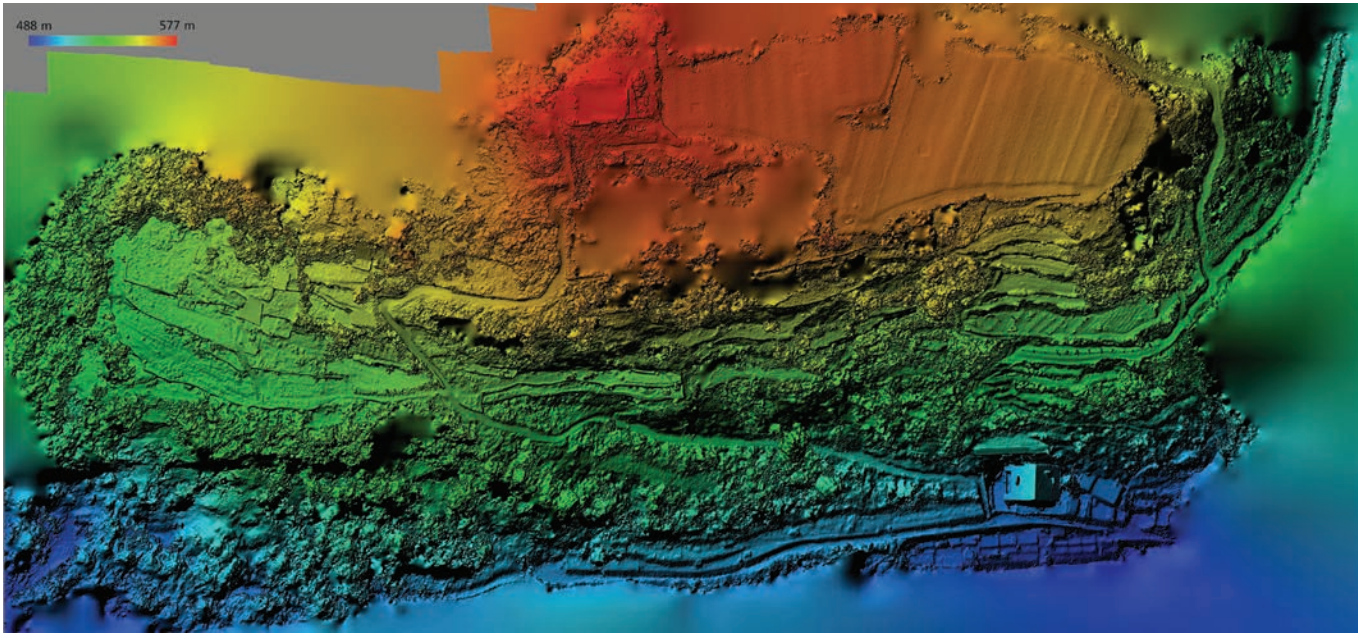

Figure 7. The Digital Surface Model (DSM): interval between 576 m (red) and 488 m (blue). In grayscale the missing data due to vegetation; St. Agatha church was not represented because of the presence of building scaffolding for the replacement of the roof.

The dense foliage of the trees did not allow the drone to recognize key points on the ground in order to rebuild the model of the terrain.
The 3D model was successfully matched with the church's one; the resolution of the two models, although slightly different, was consistent and makes the 3D model easy to be used and investigated.

4. Interpretation of results

The analysis of the church by means of drawings and ortho-images of plan and fronts made recognizable at least three different construction phases, as the different shape of the vault suggested. An additional survey of the extrados of vaults was made during the removal of the old roof; what was unexpected was that the longer but thinner vault surmount the thicker one, that seems older, but it is statically independent and it doesn't load the thicker vault.

Figure 8. The orthophoto generated from the 3D model.

Then, the survey allowed to design properly the new roof and to realize it in just three working days. Furthermore, matching the inner and the outer fronts, it was supposed that the cupboard in the south wall hides an old entrance, a small vaulted door; further investigations and sampling by the archaeologist Enrica Vinante confirmed the hypothesis.

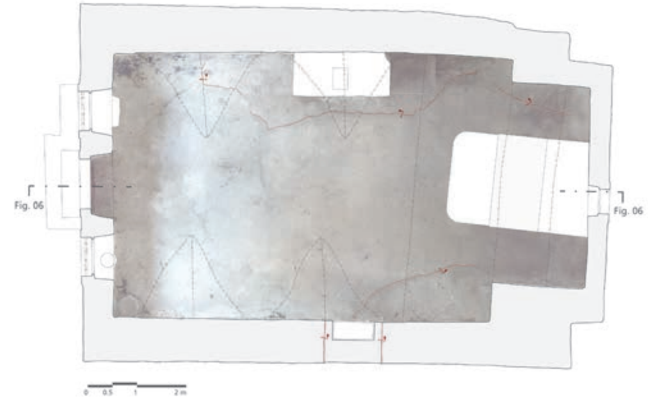

Figure 9. Architectural plan of St. Agatha church with the resulting ortho image from the textured 3D model.

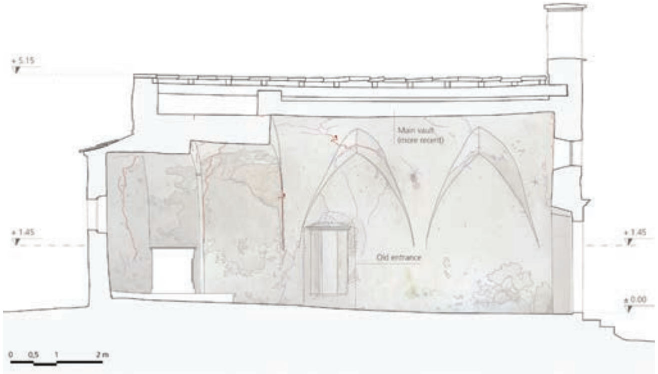

Figure 10. Front S, inner: resulting ortho image from the textured 3D model.

The territorial survey gave the most unexpected answers. Although the areas covered by thick vegetation were noisy and not reliable, large part of the boundaries of dry stone walls terraces were successfully reconstructed. The analysis of the metric data provided by DSM and contour lines, paired by the observation of the orthophoto, showed a quite levelled perimeter between heights of 560 and 566 m a.s.l. in correspondence of some dry stone walls. The perimeter is more recognizable at East, where a wall defines the boundary of the big top lawn at 560 m altitude, then go on to South, where sometimes is hidden by vegetation and rise up to 566 m, then drop down gently to West and finally rise up again toward the north end, where is less regular in height but defines a remarkable boundary between the lawn plateau and the wooded slope. So, the perimeter is nearly continuous, at times interrupted by small collapses, landfills and breaks provoked by the passage of paths. Further inspections along the above-mentioned walls revealed that these are taller, better preserved and the stones are slightly bigger and more regular than others.

So, it was supposed that the perimeter coultd be the one of the ancient castle, which destruction in the XIV century started a methodical dispossession of building materials for the town at the base of the hill.

Moreover, the manual agricultural activity lasted for centuries (Tovazzi 1785) and it has been working out again terrain and materials without modifying the overall shape of the perimeter. These results made the Superintendence for Cultural Heritage to promote a two-weeks campaign of archaeological test excavations in the fall of 2019, that confirmed the presence of remarkable structures and buildings in the surroundings of St. Agatha church. Further excavation would be held during 2020 by the University of Trento and the Superintendence, in order to better understand what the survey suggests being a rich and articulated castle system.

5. Conclusions

One of the most innovative aspects of the St. Agatha project is the interdisciplinary approach that encouraged surveying and studying at different levels of scale (the project involved researchers, architects, engineers, archaeologists, both the universities of Trento and Pavia, as well as Povo’s citizens and politicians). Indeed, only the mutual use of image-based methods (both with DSLR and UAV instruments) and common topographic instruments made possible the above-mentioned results. The use of drone permitted to manage an uncommon point of view that, correctly referenced, allowed to

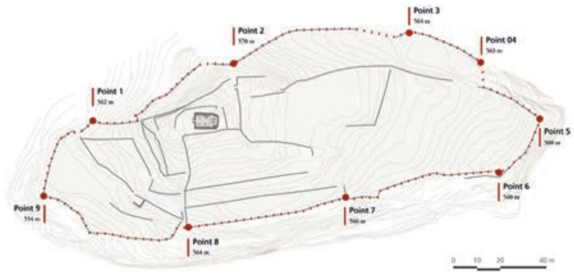

Figure 11. Dry stone walls, contour lines and boundaries of the perimeter with the main vertices.

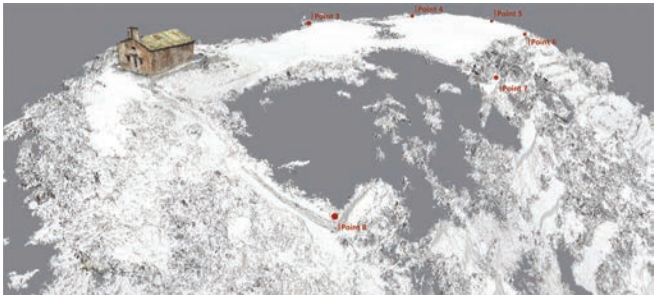

Figure 12. A grayscale view of the final dense point cloud obtained from the large-scale model and the small-scale one; empty spaces are due to the dense foliage of trees. St. Agatha church is rendered in colours.

obtain a three-dimensional metric output (point clouds, 3D models, DSM, contour lines) from a bidimensional input (photographs). Again, a correct and steady reference system is mandatory to use also the fourth dimension: time. Without that system it would not be possible to extend, overlap and replace parts of the model, making possible comparison and further investigations.

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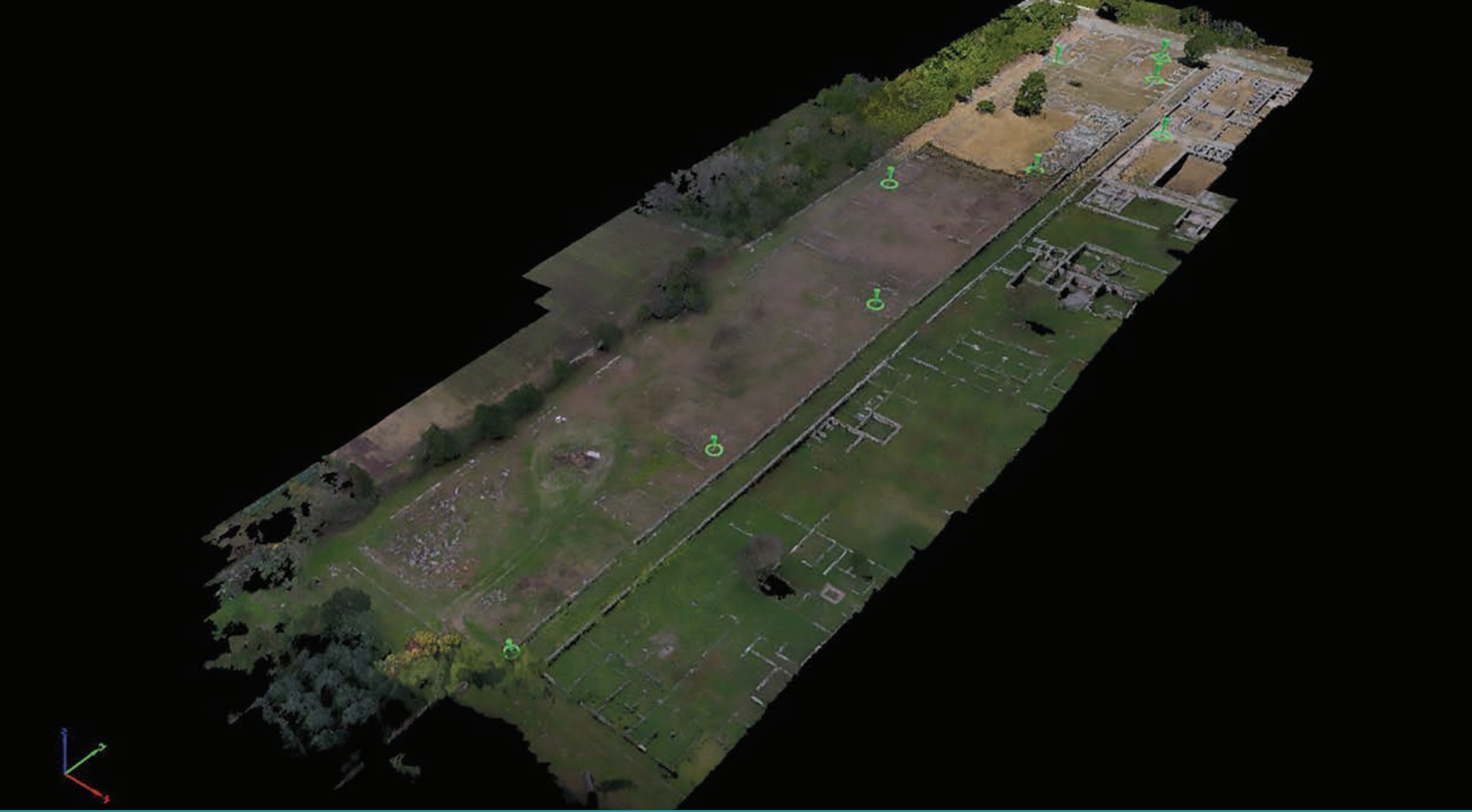

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ABSTRACT

The paper deals with the drone-based photogrammetry survey of the insula 4-6 of *Paestum* (Italy). From the final geo-referenced model, a high-resolution orthophoto has been extracted to update the map of the visible structures, while the point cloud has been used to create an ABIM (Archaeological Building Information Modelling). The 3D model supported the reconstruction of this insula, scarcely studied. It has been possible to re-built in a parametric way the masonry, the architectural features and the decorative elements. Furthermore, the global vision of the insula allowed to precise the inner divisions.

A drone-based survey to support an archaeological BIM: a project for reconstructing the Insula 4-6 of Paestum

1. Introduction

In the last decade archaeological research has begun to take advantage of new remote-sensing methodologies and tools as Terrestrial Laser Scanner and UAV (Unmanned Aerial Vehicle) for site mapping. In particular, the applications of surveys from drones are evolving thanks to the quick development of the instruments (Eisenbeiβ and Saurbier 2011), making UAV photogrammetry a very useful technique in archaeological and cultural heritage documentation (Masiero et al. 2019; Barba et al. 2019). Indeed, drone-based survey permits to map landscapes or monuments providing geo-referenced orthophotos (undistorted and spatially accurate) and Digital Elevation Models in a very high-resolution quality (Remondino 2014; Barazetti et al. 2014).

Moreover, UAVs, increasingly easy to handle and pilot, low in cost and size, allow to document in a short time and at high-resolution very large areas (Azzola et al. 2019), with the possibility of vertical or oblique views and by transporting various types of sensors (RGB, multispectral, IR, Lidar) (Remondino and Campana 2014). The paper shows the "drone to BIM" solution for the insula 4-6 of Paestum (Italy) and the related methodology. The combination of the digital survey with the parametric reconstruction of existing structures, which characterizes the so-called ABIM, provides a complete information system useful for different purposes ranging from documentation to interpretation and management (Lopez et al. 2018). The ABIM represents a big opportunity to make available, in a virtual environment, all the data related to a single monument. Furthermore, the ABIM can be an effective method in managing various archaeological buildings, materials and different architectural elements (Bosco et al. 2019). Like many applications, BIM is not born for archaeology. The challenge is to adapt this approach to the needs of historical analysis through an optimisation of data allowing to operate a complex modelling in the easiest way possible.

2. The case study: the insula 4-6 of Paestum

During the 2018 an aerial photogrammetry survey has been carried out in the insula 4-6 of Paestum (Figg.1 - 2). The project aimed at providing an updated map of all the structures still visible in the area also for the implementation of an ABIM. As the Archaeological Park of Paestum had for the area only an old map, digitized in 2008, a drone-based photogrammetry survey was planned; different UAVs and methods were used to set up the best data-acquisition approach considering the state of conservation of the monuments and the available time to complete the on-field work.

Insula 4-6 dates back to the late-republican period with several remakes at the end of republican age and the beginning of imperial age.

The insula has a length of 272-273m and a width that varies from about 35m in the northern limit to 38-40m in the central part. At North there is a large domus with double atrium. Southernmost, some rooms of a termae, built at the edge of a large open space, probably a palestra, are recognized.

Figure 1. Location of the Archaeological Park of Paestum (elaborated from Google Earth).

Figure 2. Placement of the insula 4-6 in the Archaeological Park of Paestum (overlapping of the orthophoto elaborated from drone-based photogrammetry survey on Google Earth).

Another *domus* with *atrium* and *peristilium* follows at South. The insula is almost completely unpublished, with the exception of a few brief general notes (Bosco et al. 2018). Given the absence of graphic documentation, excavation reports and ceramic materials, the study of the insula, in the past, has been included in a wider examination of the housing blocks.

The 2018 work proposed to draw the detailed plan of the existing structures, enriched by a deepened description of the masonry, the only archaeological evidence allowing to provide a chronological and interpretative analysis of the insula. To facilitate the 3D reconstruction of the area and to test an innovative management of the 2D and 3D archaeological documentation, a "Drone To BIM" approach was designed (Figure 3).

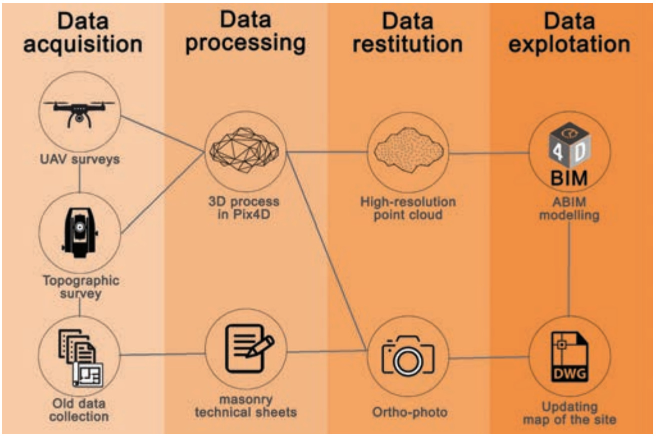

Figure 3. Flowchart of the methodology.

3. UAV SURVEYS

The insula 4-6 is approximately extended 12.000smq and it is located in an area of the park relatively marginal to the visit route and, for this reason, often completely covered by vegetation.

With the aim of integrating the 2008[1] map and create a more detailed documentation, an UAV survey was carried out in 2018. The area to be surveyed has been progressively cleaned up of vegetation; for this reason,

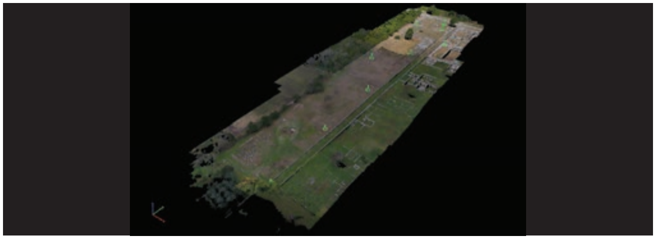

Figure 4. Positioning of the GCPs in the point cloud into Pix4Dmapper.

the acquisition has been conditioned by the timing of remediation and the flights were performed in different periods. To optimally calibrate the flight, the shooting and, therefore, to obtain a better quality of the 3D replica (correlation between number of pictures/altitude/resolution), an appropriate acquisition strategy has been set up by planning several flights with different UAVs and sensors (James et al. 2017). These surveys had the goal to identify the best GSD (Ground Sampling Distance) and the representation scale needed for the rendering of the structures (1:100). Moreover, all the datasets had to be compared to evaluate the re-projection and georeferencing errors based on the flight settings, as a low accuracy of the georeferencing work could compromise the graphic scale and the resolution of a model (Barba et al. 2019a).

After removing the vegetation, different data-acquisitions have been conducted from July to October starting from the northern part of the insula.

The first survey was taken with a DJI Matrice 100 equipped with a DJI Zenmuse X5 camera (Sensor CMOS 4/3"; 16 MP of resolution); the acquisition, from 30m, allowed to generate an orthophoto with a GSD of 0.69 cm/pixel.

Successively, other flights were performed at different altitudes with a DJI Phantom 4 equipped with a camera FC330 (Sensor CMOS 1/2.3", resolution of 12.4 MP). These surveys showed a ground-resolution values geometrically very reliable: the processing of the highest flight (from 40m) has produced an orthophoto with GSD of 1.57 cm/pixel, while those at lower altitudes have given GSDs between 0.53 and 1.18 cm/pixel. Unfortunately, after the clearing of the vegetation in the southern part, the access to the area was prevented by the presence of other activities in the nearby insula (the insula 2-4). For this reason, the area of our block which included the thermal sector and reached the southern limit of the insula, was surveyed with a single flight. The acquisition has been carried out with a nadiral flight with the DJI Phantom 4.

For the flight planning Pix4Dcapture has been used, while the alignment of the images and the point cloud elaborations, with mesh and orthophotos, have been processed with the PixD4mapper software.

In order to obtain a 3D model and an orthophoto of the entire insula, the survey dataset of the southern part needed to be aligned with one of those carried out in the northern sector.

Therefore, for the alignment with the southern part, a specific dataset of images relating to the northern part was selected precisely because it was acquired with the same sensor and because it had a similar GSD value.

In fact the merging of two datasets from different flights is possible when the highest GSD is smaller than twice the lowest one GSD value (the GSD in the overlapping areas should not differ by more than a factor of two[2]); another prerequisite is that the altitude of the highest mission must not exceed the double of the lowest flight height.

Precisely:

- For the northern part of the insula the most reliable acquisition was the one performed from 30m;
- The flight was planned with a forward and side overlap of 95% for the nadiral images and set with a grid plan mission. It included 312 images and the GSD was 1.18 cm/pixel;
- For the southern part the flight was at 35m and the dataset included 377 images; the final GSD was 1.56 cm/pixel.

The two selected photogrammetric datasets were processed in a single project. To align and roto-translate the model, 9 GCPs, previously measured with a Total Station (Trimble M3 - DR 5") were used. These GCPs, represented by features distributed throughout the entire insula and clearly identifiable in the images, were manually inserted in the pictures (Figure 4).

After the optimization, the final merged model comprised 689 RGB images covering a surface of approx. 2ha (Figure 5)[3]. The GSD obtained was 1.50 cm/pixel. To check the accuracy of the final 3D project some tests were carried out, also according to two

Figure 5. Orthophoto of the insula obtained from the UAV survey.

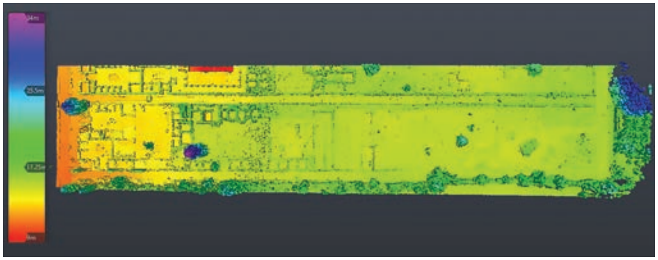

Figure 6. DTM of the insula, from Autodesk Recap.

points with known geographical coordinates provided by the Park (*Pasetum1* and *Paestum2*)[4].

First, the precision of the project was evaluated by considering the RMSE (Root Mean Square Error) of GCPs, that was 0.07 m. Secondly, the difference between the distances "*Paestum1 - Paestum2*" extracted from the point cloud and the measures supplied by the Park were compared; the calculated deviation was about 2cm, both in planimetry and in height.

Moreover, the reliability of the geometry was confirmed in an autoptic way by comparing the elevation changes in the thermal sector highlighted in the Digital Terrain Model (Figure 6).

The analysis of the high-resolution final orthophoto obtained by the point cloud allowed to accurately gather the limits between the domus area and the termae and to measure every single construction elements of the insula (walls, floors, basins, etc.); finally, the comparison between the new orthophoto and the 2008 plan permitted to update the map with new information (Figure 7) and to identify new different functional spaces (Figure 8). In particular it has been possible to identify new different functional spaces, highlighting the limits of the domus and the thermal area and to recognize, on both fronts of the insula, a space of about 5m that separates it from the road paving; in the North, the bases of two columns placed in axis with the fauces of the first domus are clearly visible. The projections of individuate intercolumns, thanks to the traces on the ground, would presuppose the definition of 8 elements related to a porticum.

Figure 7. The updated map after the digitalization of the new structure identified on the orthophoto (in orange).

These considerations allow to reconsider the hypotheses on the extension of the insula and its subdivision into Roman actus, as well as to endorse the hypothesis of the existence of shops in the area overlooking the North *porticum*.

4. From drone to BIM for structural analysis

In scan-to-BIM application, the 3D model is provided by the 3D laser scanner, which generates clouds with very high-resolution but, often, with laborious and long data-acquisition and alignment processes. The result is a very accurate survey but frequently difficult to manage within the modelling software because of its "weight".

As the area showed structures, mostly composed of low but well-preserved walls, devoid of any decorative with the exception of large decorative flooring, a drone-based survey has been preferred; the insula was free from visual obstacles and without limitations that hinder even low flight.

The metric reliability of low-cost 3D survey methodology, compared to laser scanner equipment, had already been tested in other case studies which have validated the horizontal and vertical reliability, especially if connected to an accurate topographic grid (Bosco et al. 2015).
The point cloud of the insula, exported in E57 format, is perfectly compatible with other applications like among them BIM software. The 3D model, imported into Revit (Figure 9), was used to create a model of the reference terrain functional to the "views" of Revit (Figure 10). Through an optimisation of the cloud in Cloud Compare, it was possible to build and load into Revit a topographic surface.
Then, to identify the different constructive techniques, it was necessary to analyse the bibliography available and compare similar contexts in the site. In the archaeological field, as no technical information are available about this step, is fundamental for the definition of the units to be classified in the ABIM. On the basis of the point cloud, the single architectural elements (walls, doorsteps, pavements, columns, pipelines, etc.) were modelled and assigned to specific "families" of Revit (Figure 11); these objects were parameterized by defining their dimensions and their variation according to established measurements.

5. Conclusion

Due to the limited access for the reclamation of the vegetation and to the contingent operations of other working groups in the same area, the UAV survey was carried out in more than one time and in less than optimal conditions, typical characteristics of a tourist archaeological context. The data-acquisition phase has faced particular situations.
Despite these problems, it was possible to align two different acquisitions by developing a geometrically reliable final project of the entire insula, demonstrating that the use of UAV images can be a valid solution for the 3D mapping of archaeological sites (Saurbier & Eisenbeiß 2010; Nikolakopoulos et al. 2017).

Figure 8. Digitisation of the structures superimposed on the orthophoto (in green and orange the new evidences).

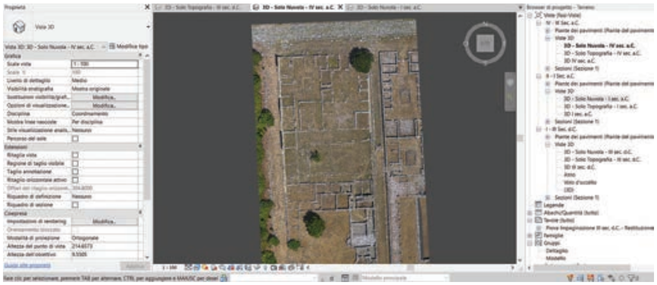

Figure 9. The model imported into Revit.

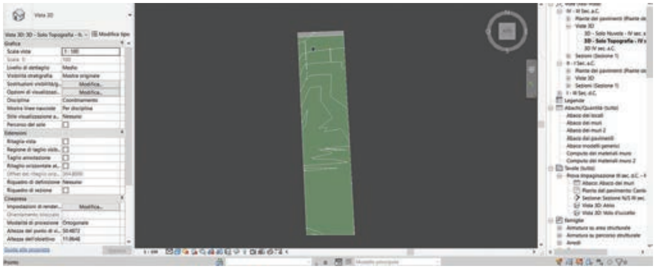

Figure 10. A 3D view of the BIM model showing the terrain model (in green).

The final 3D model supported the integration and characterization of the existing maps, as well as the identification of new elements that constitute important starting points to provide detailed drawings

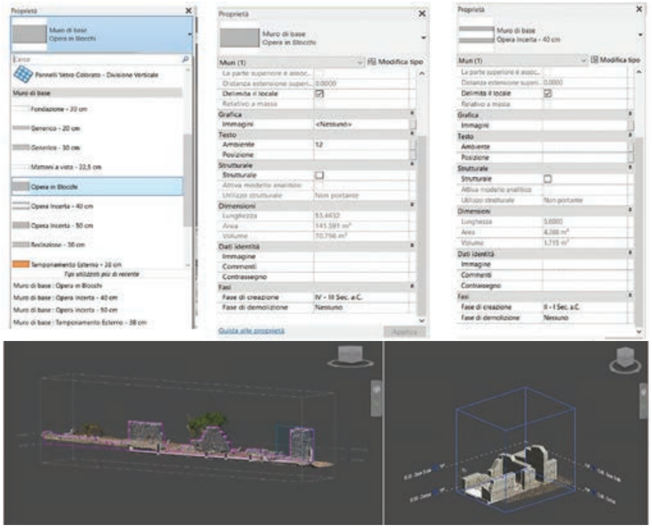

Figure 11. Part of the western limit of the insula modelled on the point cloud into Revit.

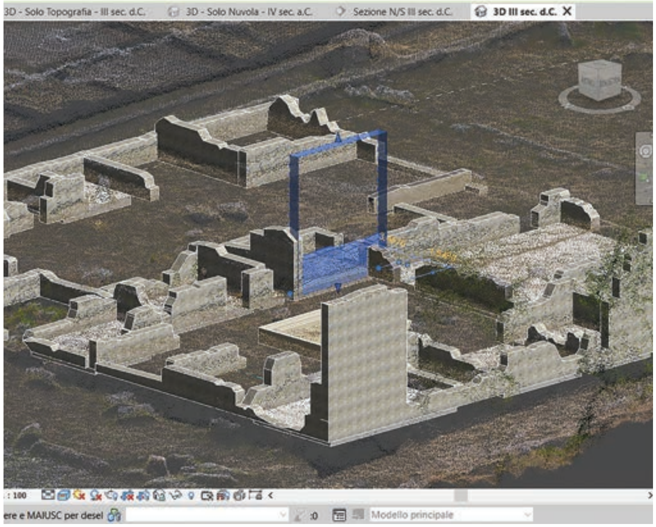

Figure 12. The data related to the masonry.

of the areas for a re-reading of the insula and for any further investigations (Ebolese et al. 2019).
Furthermore, some high-resolution orthophotos were extracted to investigate in depth the spatial organization of this part of the site. Unfortunately, archaeological excavations that took place in this area left scarce and inaccurate documentation. This caused the loss of the stratigraphic information as well as of the removed late-roman structures[5]. This particular condition required a detailed analysis of the walls to identify the relationships among the buildings, useful to provide a reconstruction of the insula life and its changes over time.
Contrarily from the traditional HBIM case-studies (Dore & Murphy 2012), in the archaeological contexts, like the insula 4-6 of Paestum, the creation of standard libraries has to be based on the existing architectural elements and masonries. This approach makes the modelling phases particularly complex since the geometrical features are linked to a verifiable and reliable measurements and parameters. The construction of the BIM on insula 4-6 allowed to obtain an updated and searchable 3D archive (Figure 12).

All the existing documentation could be in the future associated to the single objects to re-create a vertical stratigraphy supporting hypothesis on the reconstruction of the site.

Note

1 In order to identify humidity traces, any water paths and underground structures, especially in the thermal area, two flights with multispectral and IR sensors have been carried out during May and June (see Bosco et al. 2018).

2 https://support.pix4d.com/hc/en-us/articles/202558979-Can-Pi 4Dmapper-process-Images-taken-at-different-Flight-Heights.

3 The non-uniform chromaticity of the complete ortho-mosaic is due to different weather conditions during acquisitions, occurred over different days of work.

4 The coordinates provided from the Archaeological Park are: PAESTUM_1 (Lat. 40° 25'16,61464'' N; Lon. 15º00'12,97945'' E; ellipsoid height 60,2942 m) e PAESTUM_2 (Lat. 40º25'07,23686'' N; Long. 15º00'13,60645'' E; ellipsoid height 63,2882 m).

5 Still visible in rare vintage photos.

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Drone, photogrammetry, survey, Cultural Heritage, 3D models.

ABSTRACT

Nowadays, the introduction of digital cameras has significantly increased the use of images in many different sectors. In the field of cultural heritage, the use of digital photogrammetry, based on digital images is more and more apply for surveying, monitoring and analysis of cultural heritage from the urban to architectural scale through the architectural aggregate. The Unmanned Aerial Vehicles (UAV) technologies, onboard and remotely controlled, better known as drones are an important support to this aim. The paper shows some applications on the Italian cultural heritage thanks to the use of drones. The case studies are the historical town of San Pietro Infine, the structural aggregates of San Rocco village and Rocca Janula fortress.

UAV & Aerial Photogrammetry Technology for Cultural Heritage Survey. From Urban to Architectural Scale

1. Introduction

The "realism" in the representation, codified during the Renaissance thanks to the scientific definition of the perspective projections, became in common use with the introduction in 1839 of the daguerreotype (procedure for the development of images), to record the "perspective images" real as photographic. The importance of the camera immediately perceived became an inseparable tool for travellers and journalists mostly for the documentation of art and cities. During the second half of the twentieth century, due to the introduction of digital camera, the production of images has increased significantly opening important new developments in all sectors from the primary to the quaternary. Computers and digital environments are able to process and manipulate easily digital images thanks to their "numeric" features. In the recent time, digital images make up aerial digital photogrammetry used both as an analysis and control tool for cultural heritage. To support this new need, Unmanned Aerial Vehicles (UAV) technologies, onboard and remotely controlled, better known as drones are experiencing a strong increase. Drones has, in fact, sensors mounted on board such as cameras, thermo-cameras, etc. to acquire very heterogeneous data of the detected object. The technological potential with drones is immense and its uses will grow even more over time (Joshi, 2019). Whether drones are remotely controlled or accessible via a smartphone app, they can reach the most inaccessible areas with little or no-manpower needed, requiring minimal effort, time and energy, as shown in the numerous papers in literature.

This is one of the main reasons for using drones all over the world, especially in the military, commercial, agricultural and technological sectors. In the field of cultural heritage, drones are widely applied in archaeology: the scale of applications varied from the site to the landscape (up to about 10 sq km). Equipped with active and passive platforms and sensors specially designed for UAVs, drones are particularly used for three-dimensional (3D) documentation of archaeological excavations as the 3D survey of monuments and historic buildings, the survey of archaeological sites and landscapes, the aerial exploration and the survey of forests in archaeological areas. The role of these platforms in the archaeological survey of excavations and landscapes, and in diagnostics more generally, is of great interest and grows inexorably (Campana, 2017). In the field of urban and architectural heritage, drones have been widely used for the survey of different purposes. Drones more and more detect the damage status of historic centres following seismic events and they model for historic buildings or structural aggregates, known as H-BIM (Pelliccio, 2016). The purpose as demonstrated by the National Research Project developed by the University of L'Aquila, highlighting the critical issues and monitoring the status of buildings to prevent emergencies (Dominici, 2016). The aim of this paper is the description of some important drone activities, by means of digital photogrammetric surveys, carried out by the authors in different fields of cultural heritage study, from the urban area to the building through the structural aggregate with a different purpose.

2. "Urban area" analysis: the historic village of San Pietro infine

San Pietro Infine is a small medieval village on the border between Lazio, Campania and Molise regions in Italy. The village is located between two canyons along the slope of Mount Sabùcaro and it has a turreted wall on three sides, north, east and partially west. The main urban development is within a rectangle defined by five roads: three of which unfold along the line of maximum slope of the orography, in a North-South direction and consist of large steps of local limestone. The other two roads following the contour line are orthogonal to the previous ones, flat without steps. From these streets spread a series of secondary branches, mostly blind, called "alleys". San Pietro represents an important access to the Liri valley, theatre of bloody fights during the Second World War to the point that the village payed a very high price during the war. In the first 15 days of December 1943 the village was destroyed by the bombings between the German and allied troops; the devastation was such as to force the population to rebuild the town further downstream, leaving the ruins of the old village just as memories. For some decades, the urban layout and the rubble of the houses remained static, closed in the memory of the signs and fixed as in a picture: the only form of life is the greenery slowly regained possession of what the man had stolen over the time (Figure 1). Nowadays the village represents a place of memory.

Figure 1. San Pietro Infine village. Urban layout and two main views of the towns.

Nowadays, visiting to the old village of San Pietro, defined by many as "*the ghost town*" it is possible to hear still the sounds and voices that once gave colour to the life of the town. Looking inside the few houses, left partially intact by destruction, visitors can image the everyday life experienced once in the place (Pelliccio 2019). The process of valorising the place starts from its historical and material knowledge supported by a technical survey that allows the creation of a 3D digital model used as a support for different purposes: the virtual reconstruction of the village's remains and of the idea of what life was like in the town recovering the memories of the place. The use of drones for this purpose is fundamental to manage the size and complexity of the place through digital photogrammetry thanks to which a geometrically correct 3D model is returned as a cloud of points. The activity required the performance of two different flights: the first, by a DJI Phantom 4 Advanced drone flyover with 12 Mpixels camera (4000x3000 px) mounted on a 3-axis gimbal, flew over and reproduced the whole village. The weight of the drone is 1380 grams (without battery is 462 grams) and the maximum flight time is around 28 minutes. The characteristics of the flight are the following: Flight mission, according to the designed grid (Figure 2) had to take-up particular attention in the overlap between two consecutive frames (at least 70-75% longitudinally and 50-60% transversally between two contiguous creases (oversize)). Height of the flight established at 60mt to overcome the bell tower of the church of San Michele. Flight control piloted with a radio control that allows guide the drone in real-time by a pilot. During the post-processing, the pictures, around 1 thousand, are performed in appropriate photogrammetric modelling software. The parameters and the procedure used for the post processing are: Align photo-Medium Accuracy; Build preliminary mesh; Build dense cloud-Medium Accuracy. However, the large amount of vegetation did not allow analyse completely the ruins of the village. For this reason, a further survey by the DJI Spark drone guided at human height is carried out:

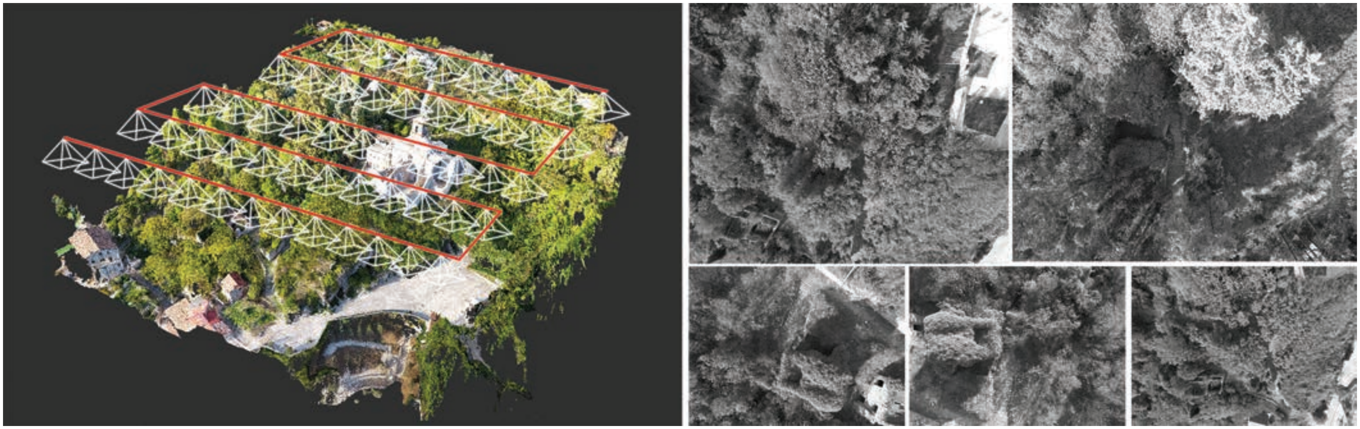

Figure 2. San Pietro Infine historic village. Flight mission and aerial views.

it is the smallest flying video camera equipped with a stabilized video camera. Spark weighs 300gr and has extremely small dimensions: 143x143x55 mm. Spark can take 12 megapixel photos that appear sharper and cleaner, all stabilized by the gimbal of the compact edge. The maximum flight speed is 50 km/h with a maximum flight time of 16 minutes. Common opinion considers Spark the commercial drone with the best performance in the category less than 400gr (Figure 3). The processing of the images, about five hundred with the same procedure used for the previous drone, had a bad result due to the shade for very narrow streets. At the end of the two investigations, the 3D returned models served both as a support for historical/ urban analysis and for designing augmented reality installations (sounds, images, holograms) on existing ruins (Figure 4).

Figure 3. San Pietro Infine. Surveying activity by DJI Spark drone.

3. "Architectural aggregates" analysis: borgo San Rocco in Sora

The large-scale remote sensing of cultural heritage allows having a complete overview of the "state of the art" of the place, fundamental for the enhancement process. However, it is also increasingly used for the monitoring and analysis of the main risk factors of the vulnerabilities of Italian historic towns, characterized by complex structural aggregates generated over the centuries and the localization usually on the Apennines. Recent earthquakes and environmental phenomena, such as landslides, floods, wind exposure, etc., are the most vulnerable factors and the analysis is the first step of a protection process. In general, the traditional survey would take a long time as opposite to the new digital one that quickly return models to perform a different type of analysis e.g. the structural and energy. In fact, the use of drones in the case of Borgo San Rocco study is obviously of great help. Borgo San Rocco village presents structural, geometric, material and territorial specificities very interesting for carrying out structural and environmental analyses. The origins of the village date back to the VI bC. but it took its current shape in the first half of the seventeenth century.

Figure 4. San Pietro Infine. Design of augmented reality installation.

The village has an interesting location between the Liri River and Mount San Casto. Two long structural aggregates (about 120/150 meters per each) connected each other by a masonry arch, make up the village. The aggregate has a homogeneous external composition opposite to the inside, which is rather irregular with types of horizontal elements transformed in the wooden, brick and concrete floors, mixed etc. The complex structural system together with the high seismic level of the town (as highlighted in the national seismic risk map) require the performance of structural analysis able to show the most likely kinematics of buildings under the action of an earthquake. Moreover, the urban layout of the village, oriented N.N.W., is similar to a street canyon. The longitudinal extension is 146 meters and the cross section instead varies from a minimum of 4 meters up to 11 meters. The asymmetry of heights of buildings does not allows classify this urban core univocally as one family of "street canyons". Indeed, the H / W ratio (H = building height; W = road width) defines the village as a deep and normal canyon. The typical conformation of street canyon together with the localization generate a strong phenomenon of wind exposure with consequent deterioration effects on the building's facades (Pelliccio, 2016). The effects of structural and wind exposure analysis are performed on a 3D digital model of the village carried out by the aerial digital photogrammetric processing of frames captured by drones. DJI Phantom 3 Advanced Drone with 12 Mpixels (4000 x 3000) mounted 3-axis gimbal returned the point cloud with a good resolution (less than 5 cm/pixel) and an appropriate nominal representation scale is driven for surveying. The flying height was set at 70mt from the ground.

By keeping the speed of the drone constant, photo cracks have been made in the longitudinal and transverse directions, based on a double regular grid. The frames were taken automatically with prescribed time lapses and the waypoints were specified during the planning of the flight and set in the management software (Flylitchi) (Figure 5). The photogrammetric survey was carried out with good weather and solar lighting conditions, around 6 a.m.

After checking the correct quality and exposure of the aerial images in order to reduce the large number of frames so as to optimize the computational time, a geometric 3D model was created as a point cloud with a rather good geometric accuracy. The workflow of the process is based on the alignment of photos, build of preliminary mesh and build of dense cloud with an high quality of the whole process. The points cloud returns the geometry of the buildings used to achieve the H-BIM model implemented with all the dataset necessary to perform the most suitable structural analyses. The H_BIM model with LOD "as built" allows integration with the structural calculation software FEM obtaining the visualization of the main structural vulnerabilities (Saccucci 2019). Furthermore, the phenomenon of the action of the wind on the buildings of the village was analysed thanks to the digital model still obtained from the point cloud. The analysis carry out from Computational Fluid Dynamic (CFD) technique that, if properly validated, represents a very useful support to measurements, reducing the number of experiments and so the costs. The experiments are conducted on a 3D printed and digital model in scale 1: 200 at the Laboratory of Industrial Measurements (LaMI) of the University of Cassino, using the wind tunnel and the Particle Image Velocimetry (PIV) technique (Figure 6). The results obtained were compared with the on-place observed actual deterioration with a good approximation (Arpino, 2017).

Figure 5. Borgo San Rocco. Flight mission by DJI Phantom 3 Advanced Drone.

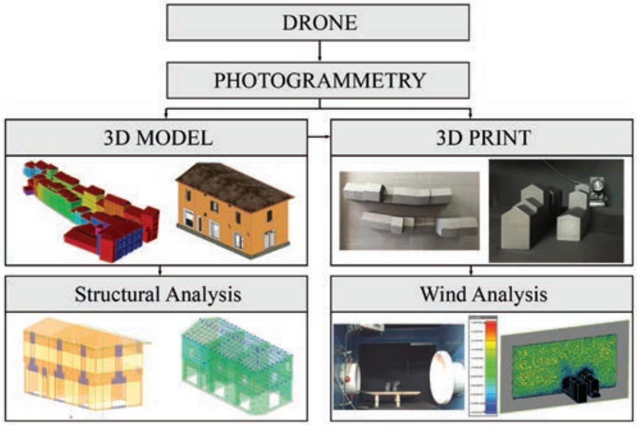

Figure 6. Borgo San Rocco. Examples of analyses that can be performed on a photogrammetric drone model. Structural analysis and wind exposure.

4. "Architectural building" analysis: Rocca Janula fortress

In relation to architectural building, the Italian Ministry for Cultural Heritage and Activities and Tourism (MIBAC) has created, in collaboration with the Higher Institute for Conservation (formerly ICR), an Information System (SIT) with alphanumeric and cartographic databases, capable of exploring, overlapping and processing information for the analysis of Individual Vulnerability (V) and Territorial Risk (P) of cultural heritage. The Ministry suggests satellite surveys and drones for implementing the SIT. According to this, the research activity has developed an H-BIM model, based on the photogrammetric survey with the drone, capable of containing the data set relating to (V) and (P). The procedure was tested on the historic building of Rocca Janula in Cassino. The fortress, built by abbot Aligerno (949-986) as a defensive system for the Benedictine abbey, is composed of one tower and walls. Over the centuries, the Rocca has undergone various expansionist controversies, destruction due to violent earthquakes and reconstructions. The most recent restoration of the 2000s took several years and the Rocca was only reopened to the public in 2015. It currently forms an important part of the prestigious

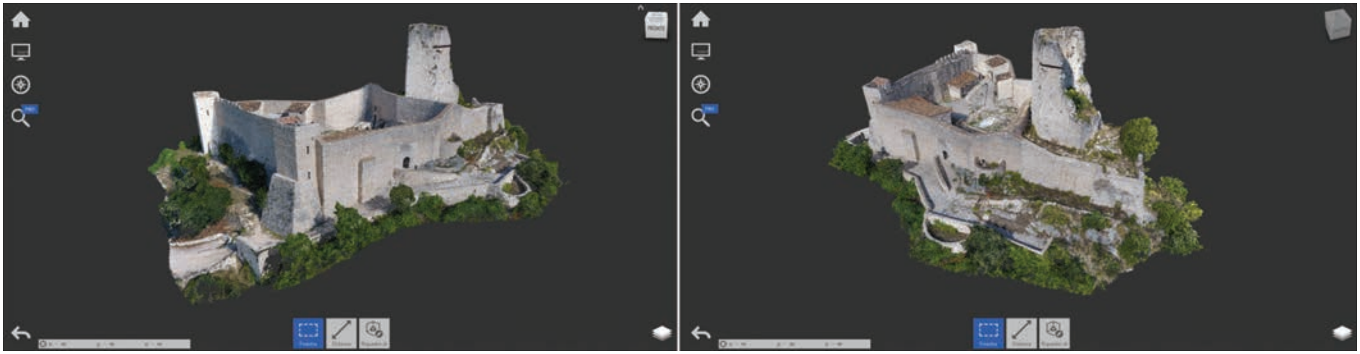

Figure 7. Rocca Janula in Cassino. Two different views from the digital photogrammetric model.

historical and artistic heritage of the city of Cassino (Figure 7). In this case, the H-BIM model was made from aerial photogrammetry with the same drone and according to the same procedures performed for the survey of San Pietro Infine (Figure 8). The flight was carried out at a height of 153 meters above sea level to overcome the tower (20 meters high), following the grid shown in the figure. Particular attention was paid to taking photographs around the tower, providing more information on the state of conservation. The H-BIM digital model contains a clear distinction between the original elements and those inserted at the time of restoration, to preserve the historical memory of the two different architectural components. The model is also 3D printed with the use of two different colours of plastic filaments showing the restored elements and the oldest one. The H-BIM reproducing the territorial context allows evaluate the Territorial Risk but above all the Individual Vulnerability thanks to the environmental analyses such as sun and wind exposure (Figure 9).

Figure 8. Rocca Janula Cassino. Flight mission by DJI Phantom 4 Advanced Drone.

5. Conclusions

Drones represent an indispensable tool for the management and analysis of cultural heritage. Thanks to the integration with digital photogrammetry, the drones quickly return 3D digital models on which to perform different analysis. In the cases of study,

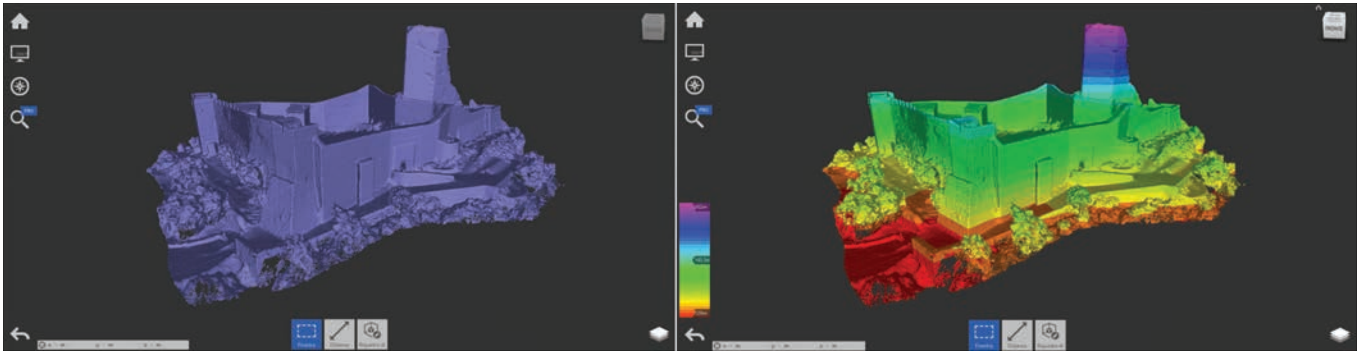

Figure 9. Rocca Janula. Mesh and altimetric analysis.

digital drone surveys were used for historical/critical understanding of the village of San Pietro Infine and for the designing of VR installations. In the case of architectural aggregates, the results obtained allowed structural and environmental analyses, such as exposure to the wind with accurate results. On Rocca Janula the survey contributed to the construction and conservation of the historical memory thanks to a 3D printing model obtained from the relief with the drone. Future developments will concern the possibility of using these tools with the integration of other relevant tools such as a thermal imaging camera or laser scanner.

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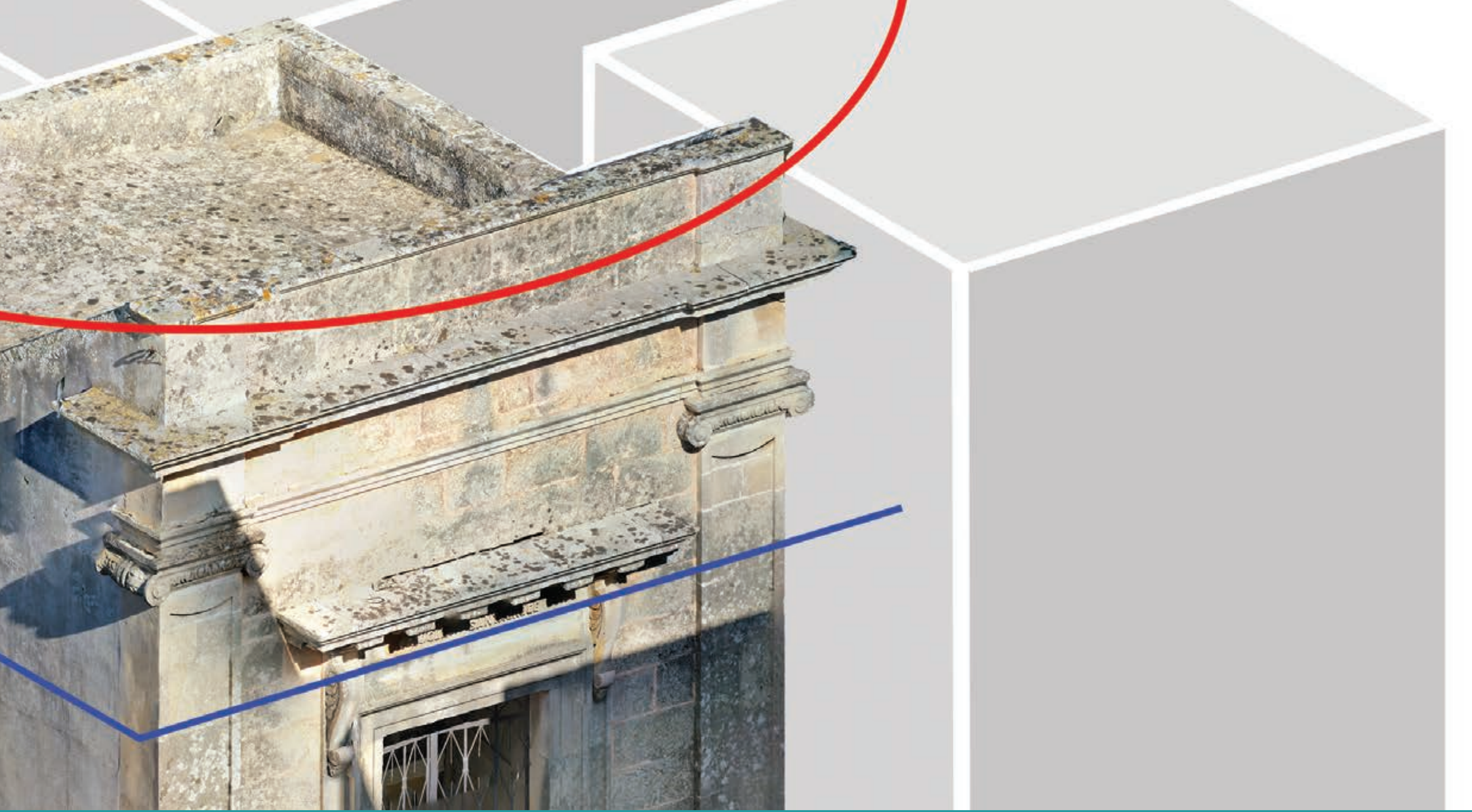

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ABSTRACT

The contribution aims to illustrate the potential offered by aerial photogrammetry associated with LiDAR instruments in operations of survey for the protection and enhancement of the architectural heritage. What is shown represents the final results of the direct and instrumental survey campaign carried out during the days of workshops organized by Superintendence of Archeology, Fine Arts and Landscape of the provinces of Brindisi Lecce and Taranto during the conference -workshop entitled "In the shade of cypress trees. Past and future of the historic graveyard of the Capuchins of Tricase".

Keywords:
Heritage, survey, graveyard, UAV, photogrammetry.

The knowledge and survey for the protection of the city of the dead of Tricase

1. Knowing to protect: ideas and objectives

"*Conoscere per tutelare - Knowing to protect*", is an initiative organized by the Superintendence of Archeology, Fine Arts and Landscape of the provinces of Brindisi Lecce and Taranto, with the aim of investigating and studying paradigmatic episodes within its territory of jurisdiction. The initiative stems from the need to share the interest in cultural heritage with the municipal administrations and citizens. Among the main objectives identified is the idea of increasing in the consciences of individuals the awareness and responsibility of being active players and participants in the difficult processes of protection and enhancement. We are convinced that knowledge is the basis on which to implement any project dedicated to the protection, and through which we can achieve sustainable enhancement of cultural heritage, preferring the historical identity of a community before economic returns.

2. In the shade of the cypress trees. Past and future of the Historical Cemetery of the Capuchin Friars of Tricase

The first edition of this particular conference-workshop was held in Tricase in October 2019 and saw the cooperation of important institutions: over to the Superintendence, the Municipal Administration of the City of Tricase, also the Department of Science of Civil Engineering and Architecture of the Politecnico di Bari, the Order of Architects, Planners, Landscape Architects and Conservators of the province of Lecce, and the sponsorship of the *Diocese of Ugento-Santa Maria di Leuca and the ASCE - Association of Significant Cemeteries* in Europe. The title "In the shade of cypress trees. Past and future of the historical graveyard of the Capuchin friars of Tricase" - taking up the well-known verse by Ugo Foscolo - aims and tries to summarize the problems of a particular area of the city, an urban landscape characterized by the presence of numerous cypress trees, high walls and crosses that can be glimpsed between the foliage. A critical interpretation with an open look at the memory of the past and proposals for the future, all aimed at the protection of a cultural asset and at the same time at sharing actions to safeguard and enhance it.

Figure 1. Tricase, identify the graveyard area. Cadastre sheets 29-30-31. Drone.

Figure 2. Tricase. Aerial photo IGM 1943.

The historical cemetery of the Capuchin friars of Tricase represents a paradigmatic and unique case in Otranto's land, where burials are no longer carried out, in fact for almost forty years the cemetery has not received the bodies of the citizens. But its uniqueness is not this, but in its location in relation to the urban construction and its history. Built in the second half of the nineteenth century after a long and troubled decision - making process, which started after the edict of Saint-Cloud was issued (June 12, 1804), it has been active only since 1876, the year in which the first burial was attested, until 1987 when the new graveyard built on the outskirts of the city was consecrated. From the issuing of the Edict until the start of construction in 1874, a lively debate animated the political and social life of the city of Tricase during the Duosicilian and post-unification period. At the centre of this debate is the identification of the most suitable and convenient site for the lean municipal saving banks where to build the cemetery and thus put an end to the burials inside or near the churches. The final choice falls on the former garden of the Capuchin convent located on the edge of the urban fabric built until then. The convent, with its annexed guestes, became part of the municipal heritage after the suppression of religious orders and the consequent forfeiture of property. From the analysis of the Land Registry carried out at the beginning of the twentieth century, it can

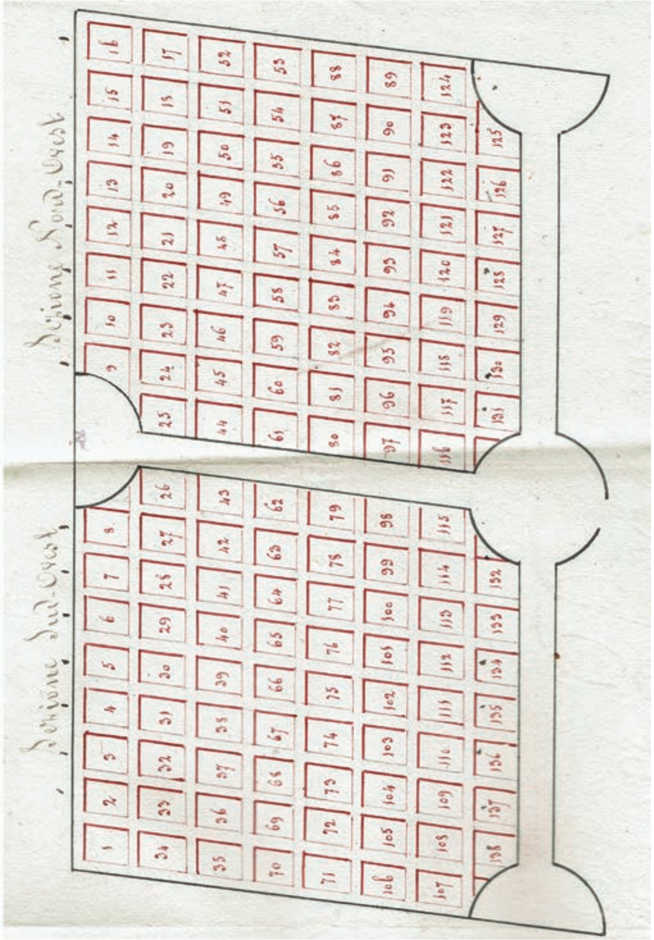

Figure 3. Project of the graveyard drafted by Eng. Rocco Pasanisi on April 9, 187, kept in the Historical Archive of the city of Tricase.

be seen that the cemetery is located in a marginal position comparated to the city of Tricase, however, was beginning to expand in a north-west direction, as if to saturate the areas that separated the old nucleus from the railway station, located just behind the cemetery (Figure 1), in a barycentric manner with respect to the two main hamlets: Tutino and Sant'Eufemia (Figure 2). In 1873, the municipal administration commissioned engineer Rocco Pasanisi of Torrepaduli to draw up

Figure 4. Tricase. Orthophoto 2020.

Figure 5. Floor plan and sections elaborated by LiDAR station and drawing of the plan with identification and numbering buildings.

the project for the cemetery, which was approved on 30 October 1873 (Figure 3). In December of the same year, the project was also approved by the Provincial Technical Office and obtained the authorization to proceed from the Lecce's prefect. The construction works were carried out for about two years, from 1874 to 1876, the year in which, as already mentioned, is documented the first burial. The initial project has undergone variations over time, even substantial ones, but some original ideas are still recognizable. Unlike the chapels built in other cemeteries of Otranto's land in the same period, in Tricase the noble chapels in a few rare cases have refined and monumental architectural features. Interesting episodes stand out among the about 100 chapels built, but they are not comparable with the majesty and richness of those found in Lecce, Maglie or Nardò.

Today the cemetery is now disused, it represents a green area in the urban agglomeration, a place of silence and memory, around which the contemporary city was built with its frenzy and its rituals (Figure 4). In recent years indifference and lack of knowledge have compromised the very existence of this cemetery, ideas have been proposed to transform this area into a parking lot at the service of the community. Fortunately, ideas that have remained so, however, inflaming the reaction of citizens and awakening attention to a place so full of values. The coexistence of historical-artistic values and values of identity are a source of interest in today's debate. But above all it is the many questions that keep the attention high, such as how and what future to guarantee the city of the dead that characterizes so strongly the urban landscape, occupying the center of the city of the living. For these reasons, with the conference-workshop, the whole community was asked to take part in the discussion. Thirty speakers and scholars were invited, who alternated in the six afternoon theoretical sessions open also to technicians, professionals and, to all interested citizens. These meetings represented fruitful occasions during which the problems related to the conservation of a heritage as vast as a graveyard can

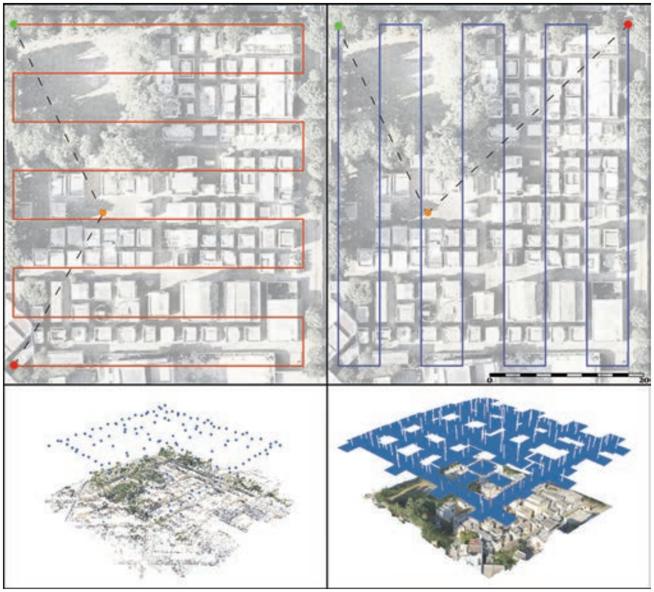

Figure 6. At the top are represented the flight planes that generate the orthogonal grid, the yellow dot represents the take-off base, the green dot represents the beginning of the flight track and the red dot represents the end. At the bottom are represented in axonometry the shooting points and gps coordinates.

Figure 7. Axonometries and nadiral view of the dense cloud points.

Figure 8. Axonometries and nadiral view of the textured mesh.

be, were examined and at the same time experiences of valorization were analyzed, which made it possible to transform a "problem" into an opportunity for growth and development.
Thirty-five, instead, were the membership by young graduates and undergraduates of the Politecnico di Bari, to the activities of the workshop in the antimeridian hours, entirely dedicated to the survey of cultural heritage and to monothematic laboratory meetings in situ. The topics detailed with the survey techniques, from the most traditional to the most innovative ones, showing how they are all complementary and integrable with each other. The forms of deterioration and their recognition were also analyzed; the techniques for cleaning and identification of the kinematics that can be investigated directly on the monument[1].

3. Preliminary investigations - The inspection

The survey activities were divided into three different phases.
During the first, which was of organizational nature, an inspection was carried out within the area, assisted by an indicative cartographic support to determine the strategic points for the positioning of the laser scanner. At the same time, the physical elements that could hinder the scans, such as trees and plant deposits, were identified.

4. Operations on a large scale - Planimetry and orthophoto

The objective of this phase was to draw up the cartographic planimetry which was necessary for the

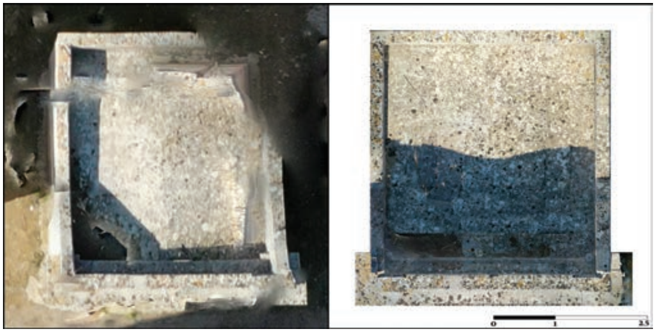

Figure 9. Breakline, comparison of the B30 model between the overall plan and the specific survey.

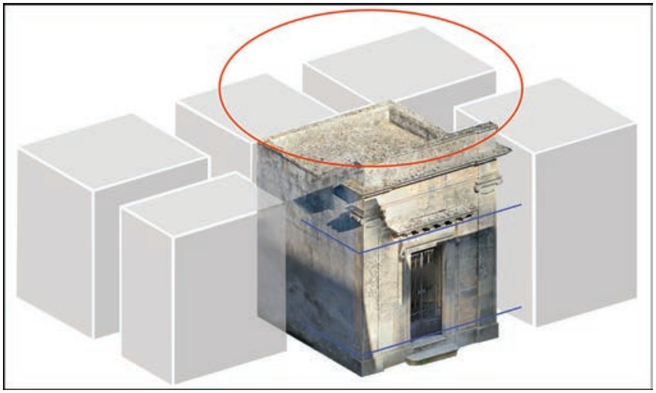

Figure 10. Flight paths used for the B30 building photo shoots.

planning of the operations that the different teams of surveyors carried out during the third phase. An orthophoto plan of the roofs and a redrawing of the area plan were made.
Having planned 89 stations, the scans were carried out with a laser scanner which collected not only the laser data but also the photographic data.
The collected data were analyzed and processed by means of the Faro software, the different scans were interpolated manually to obtain a unique overall data. From the 3D model obtained, several sections were extrapolated that has been useful for a preliminary study of the architecture. More over a planimetry was obtained by the same data, from which it was possible to redraw the planimetric section (Figure 5). The data from the laser scanner, after beeing processed, returned a highly degraded cloud of points both in the North-West sector and in the small spaces between the chapels. The noise in the collected datas was caused by the presence of grass on the burials north-west sector and by the proximity of the laser scanner to the walls of the chapels (approx. one meter in width). As far as the roofing levels are concerned, there was a complete lack of data, due to the impossibility of scanning stations to be elevated at higher altitudes. Photogrammetric techniques were used to fill these gaps that relay on the use of photographic images. These techniques allow an accurate reconstruction of the spatial positions of points using a pair of images. The reconstruction of the coordinates is obtained through automatic autocorrelation procedures that result in a cloud of points comparable to those obtained by LiDAR. Using the aid of an UAV aircraft, two flight plans were programmed at an altitude of 30 meters from the ground (Figure 6), whose aim was to form a single orthogonal mesh with camera orientation in zenithal position (CIPA, 1988)[2]. Although in aerial applications it is good practice to adopt multi-stereo view, both vertically and horizontally, in this specific case, since horizontal datas were derived from the laser stations, only the vertical part was covered with flights (Ferrières (de), 2004)[3]. The UAV used is a DJI Mavic 2 Pro equipped with a camera with 78.8° field of view of 26mm, CMOS sensor 1/2.3'' of 12.71 Megapixel and GPS - GLONASS system with vertical accuracy +/- 0.1m and horizontal accuracy +/-0.3m. In each mission the UAV flew over an area of just under a hectare, producing a total of 544 high-resolution, geo-referenced photographs, from which, using metashape software, a cloud composed of 62,946,417 points and with an accuracy of 1.08 cm/px was reconstructed (Figure 7). Subsequently, operating with the same software, we proceeded to the interpolation of the point clouds that allowed to generate a three-dimensional model (Figure 8).

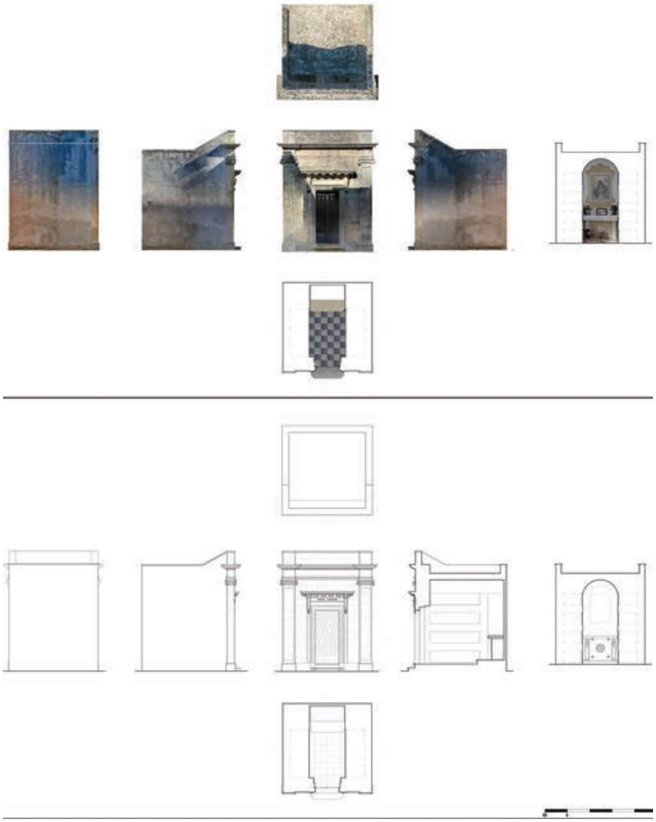

Figure 11. Photoplans and drawing of the elevations, plan and sections of the B30 building.

The data of the individual flights were merged using seven GCP (Ground Control Point) used for the laser scanner, the same points were then used to manually merge the point cloud generated by the TLS survey and the aerial model.

5. Detailed operations - From model to drawing

The third and final phase was mainly operational. The workshop attendees were divided into 13 teams, after drawing up preparatory sketches that are necessary to collect metric datas, each group proceeded with the traditional direct survey techniques, using metric rolls, plumb lines, flexometers and laser distance meters. An indispensable graphic support for the return of the metric data to be collected, both of the elevations and of the covered and underground compartments.
The participants, using the technique of photogrammetry, proceeded to a meticulous photographic survey, from ground level, of the buildings.
A series of further aerial flights dedicated to each single structure were necessary to refine the three-dimensional models, solving the problem of the altimetric breakline (Nex F. & Rinaudo F., 2011)[4] in the overall model. These are found near the edges of the buildings, where "rounding" effects are created and can be eliminated increasing the density of points (Figure 9).
With this aim, two circular flight plans were carried out with different altitudes, chosen with respect to the buildings heights. During the higher altitude flight, the UAV travelled along a circumference with the camera oriented at 60° downwards with respect to the horizon level, in order to have photogrammetric data of the roof. During the lower one, the aircraft covered the same trajectory, but photographing the subject with the camera positioned orthogonal to the walls in order to have as little aberration as possible (Figure 10). The collected data were elaborated and redrawn, graphically reproducing plans, elevations and sections, all the orthophotos of the buildings and a complete three-dimensional model in scale at 1:50 (Figure 11).

6. Conclusions

The experience presented wants to focus on the almost indissoluble combination of UAV instrumentation and LiDAR technologies that has been created in the survey.
Aerial photograph with UAV is a method appreciated for its low cost, handiness, and the amount of information it captures. It provides, through photogrammetry software such as Metashape, satisfactory results with high resolution, but remains dependent on a good calibration to obtain reasonable accuracy (Remondino 2011)[5].

The use of aerial photogrammetry has made it possible to carry out the surveys in a relatively short time and with a reduced number of specialized technicians. It has made it possible to detect the roofs of buildings, to know the state of conservation and kinematics in progress, information that is impossible to know with the use of the laser scanner and that would have required direct inspection by technicians through the use of stairs and decks, dangerous and expensive from the point of view of timing of use, but also economical.

Note

1 For further information, please refer to the Proceedings of the forthcoming conference: *Passato e futuro del Cimitero storico dei Cappuccini di Tricase, Monografie di Architettura e Design.* 3, voll. 1-2, QuAD 2020. Bari.

2 CIPA. Photogrammetric capture: the "3 * 3" rules. Sofia, 1988, 1 p.

3 Ferrieres (de), M., (2004). *Notions de photographie, prise de vue photogrammétrique*. In : Ferrieres (de), M. *Eléments de technologies pour comprendre la photographie : argentique et numérique*. Paris : VM éditions, 21 p.

4 Nex F., Rinaudo F., (2011). *Photogrammetric and LiDAR integration for the cultural heritage metric surveys. In: International Archives of the Photogrammetry,* Remote Sensing and Spatial Information Sciences, XXXVIII. Zurich.

5 Remondino F., Barazzetti L., Nex F., Scaioni M., Sarazzi D., (2011). *UAV photogrammetry for mapping and 3D modeling : current status and future perspectives*. Zurich, 7 p.

Chapters 1 and 2 written by Fernando Errico.
Chapters 3, 4, 5, 6 written by Remo Pavone. UAV operations and data processing performed by Remo Pavone.

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ABSTRACT

This contribution stems from the need for study and analysis for the conservation of architectural works such as the Igreja de São Francisco de Assis in the town of São João del-Rei within the Minas Gerais region north of São Paulo. Through the use of new APR technology instrumentation, experimentation with a flight campaign was carried out with satisfactory results, which made it possible to obtain a 3D model that can be interrogated for the common purpose of study, but also to enhance the object of analysis. effectively making the operation replicable on other sites and contexts in the Brazilian and international territory.

The photogrammetric survey with UAV instrumentation of the Igreja de São Francisco de Assis (São João del-Rei)

1. Introduction and site

The Igreja de São Francisco de Assis is a Catholic temple founded by the Third Order of Saint Francis of Assisi[1] in the Brazilian city of São João del-Rei which represents one of the most densely populated centers in the state of Minas Gerais[2]. The church, among the most impressive in the region[3], listed by the Institute of National Historic and Artistic Heritage (IPHAN) among the most prestigious works of the

Figure 1. The Igreja de São Francisco de Assis located in the center of São João del-Rei in comparison with the surrounding town.

national territory[4], has become over the centuries one of the main landmarks of Brazilian colonial art, for the beauty of its Baroque[5] architecture and the richness of its sculptures. The main author of the project, later modified by Francisco Cerqueira, was the master Aleijadinho[6] (Figure 2). The building is preceded by a large churchyard and surrounded by an elegant stone balustrade; internally the shape follows the conventional model of the colonial churches of the time, with a single nave (Figure 3), curved walls characteristic of the rococo style, in which the wooden altars are carved giving life to multiple decorations. Above the entrance stands a choir reachable from the two cylindrical bell towers on the sides of the facade, while at the back of the church, separated by a monumental arch, there is the presbytery (Figure 4) which culminates with an altarpiece of precious manufacture. This contribution constitutes one of the results of the mission conducted by the Florence Department of Architecture in the summer of 2019 aimed at the digital survey of the structure which requires accurate digital documentation aimed at the conservation interventions of the structures and of the conspicuous decorative heritage made mainly of wood. The colonial-era architectural works, such as the one in question on the Brazilian territory, currently require updated digital documentary equipment both aimed at the study, but in particular, also intended for the construction of adequate multimedia supports for the enhancement of heritage sites.

By having a digital database accessible not only by sector technicians but also by scholars and, with appropriate interfaces, also by a wider audience, it is possible to contribute to the dissemination of knowledge on the themes of Brazilian colonial architecture that has been preserved until today.

2. State of art

The documentation on new generation instruments (UAV[7]) and image modeling are very extensive as a mass of articles describing the general, methodological and photogrammetric aspects of this technology (Nex &

Figure 2. View of the nave with the choir placed at the top at the top.

Figure 3. View of the interior, the chapel, the presbytery with the altarpiece.

Remondino 2014; Colomina & Molina, 2014; Watts et al. 2012). The component that has diversified the "classic" aerial photogrammetry from the UAV photogrammetry is given by the models used[8] and therefore by the possibility of acquiring without the storage limits typical of analog media, in addition to the growing calculation capabilities available. Using the Structure from Motion automation method "SfM", the internal orientation parameters are estimated[9], as well as the position of the camera in a relative space - image coordinate system: these data are extracted autonomously, with high redundancy, using an iterative adjustment of the bundle[10] (Triggs et al. 2000) on a series of images. UAV image models are automatically dimensioned and georeferenced using the positions of the GPS / GNSS receiver and the onboard navigation system. Despite new technologies, to date, an optimal precision has not been achieved for a millimetric definition of the portions of land or buildings (Robustelli, Baiocchi, Pugliano, 2019). The correct georeferencing and sizing are still operations that are performed, possibly, on the basis of the manual collimation of the GCPs[11] detected on the ground generally with differential GNSS receivers in static mode (lidar).
Initially, the identification of control points in each image is taken into consideration through the use of markers positioned previously on the field, used to facilitate the software to match the various images with overlapping of 80% or, as in this case, through homologous points of the church structure. The possibilities of using this technology over the years have increased making accessible aerial shots that previously required more expensive tools and with less possibility of management during the flight phase. One of the major uses of this technology, which concerns our intervention, is the survey and study of architectural structures. As for the applications in the specific sector of the survey of ancient buildings, the drones were used to evaluate the volumes, degradations, instability after seismic activities and to monitor the areas more difficult to reach by ground instrumentation such as a laser scanner.

This study, therefore, intends to carry out, for the first time on this site, testing in an area, based on the estimated GPS receiver accuracy of about 0.5 m, in order to obtain photographic material useful for the previously set purposes.

3. Tools and method

The site studied is an area of over 18000 m² which includes, in addition to the church (about 3000 m²), a square in front of which follows the cemetery area. In particular, the external body of the church measures 80 m on the long side and 22 m on the front (N.E.-S.O. direction), while the back is 34 m considered the building of the sacristy attached in the S.O. of the church. The choice of a close-range aerial SfM methodology, therefore by UAV, was constrained by the position of the sun and the relative shadows (both of the palms and of the building) that was created on the case study. For a "cleaner" rendering of the 3D model and orthoimages, the best time of shooting was with the sun placed at the zenith (lack of shadows and noise on the walls), but this was not always possible due to weather conditions, wind, rain or, rarer, the continuous presence of flocks of birds.

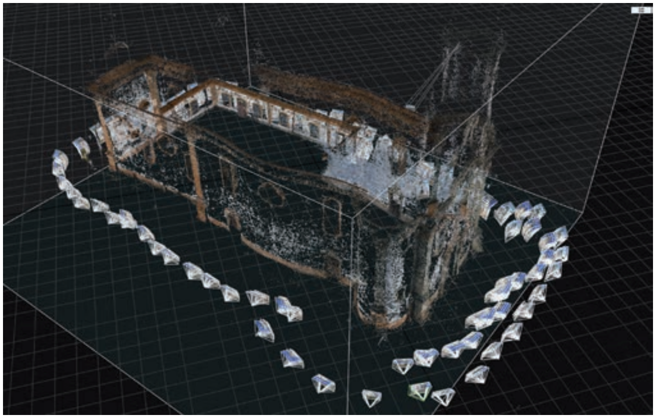

Figure 4. Partial result in post-production of the recovery, made in the field, of the lower part of the external perimeter of the church through the automation method Structure from Motion "SfM".

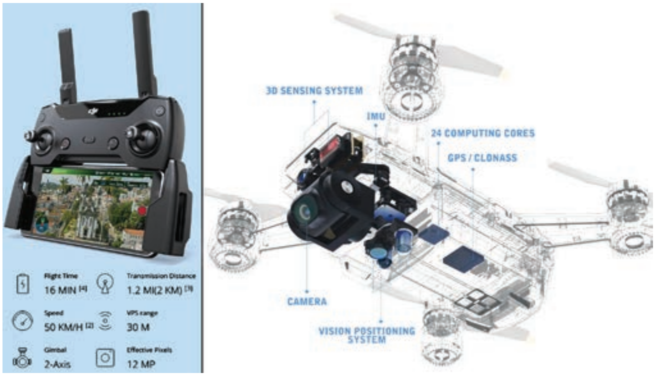

Figure 5. The remote control with a smartphone on the left. On the right of the image the DJI - Spark ultralight (< 300 gr).

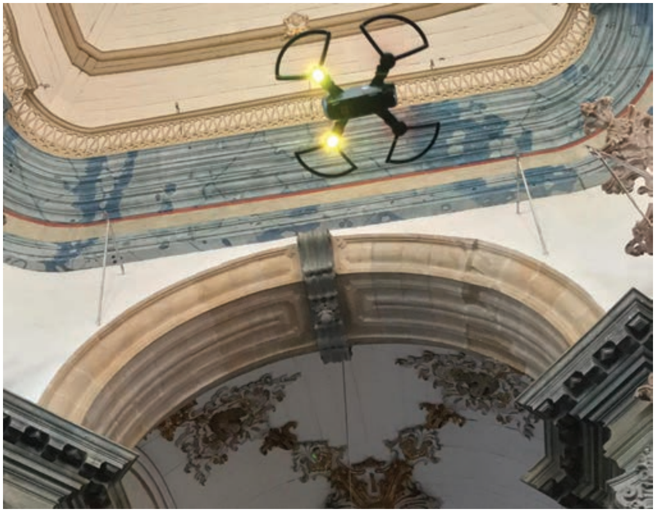

Figure 6. Resumption of the cornice placed in the top nave of the Church.

From time to time the operator has evaluated the "greater security window" to raise the drone in flight and, after obtaining the images, these were processed by a specific software called Reality Capture with which a questionable 3D model was obtained.
The acquisition flights were carried out with DJI's Spark[12] model, equipped with GPS / GLONASS satellite positioning systems.

The instrument consists of two components, a 2.4 and 5.8 GHz dual-band system remote control on which to mount the smartphone connected to the drone by application (DJGO 4 in our case), and the drone itself on which a gimbal is mounted with tilt control range from -85 ° to 0 °, mechanical stabilization of two axes (tilt and roll) and an obstacle detection distance of 0.2 to 5 m. On this, there is a 12 MP camera, a 25 mm lens that can capture images with different photographic modes[13], from single shooting, to burst (3 frames), HDR, automatic exposure bracketing[14] with different intervals obtaining images of 3968x2976 size as most of those used for this campaign. The structure of the drone has a weight of less than 300 g for 143x143x55 mm which allows it to run for about 15 minutes[15] with a maximum operating tangency above sea level of 4000 m. Unlike the more recent larger instruments, which use a technology with which, once the action plan has been set, it is possible to manage the instrument almost independently, for the entire flight, based on GPS systems, the problems, in this case, have been multiple as each phase, from take-off to landing, required continuous visual inspection of the instrument and the surrounding area. Despite this, the height of the aircraft with respect to the Home Point identified for each take-off point was one of the least critical checks considering the slight slope between the highest point (SO) and the lowest point (NO) placed at the limits of the park in front of the large stone churchyard of the Church. Take-Off points favorable to the continuous control of the instrument and two landing zones have been established[16]. To ensure the drone's stability to wind gusts, a flight distance relatively distant from the bell towers and palm trees was assessed; in addition, the presence of the site in the center of the town made it necessary to set restricted parameters for the overflight area of the territory to be analyzed[17], which was carried out in three days of recovery. With the first flight, the coverage of the church with its surrounding annexes was acquired to also provide a framework for the object of analysis, therefore perimeter flights

(Figure 7) were made to the church to determine the fronts with particular attention to the details. such as cornices, windows, decorations and doors. Finally, an experimental flight was carried out, as it does not have GPS inside the church in order to acquire the portion of the cornice located near the ceiling of the nave and to acquire the particular decorations of the altarpiece in the presbytery area. In this regard, with the aim of optimizing data acquisition, a radial flight scheme has been planned, consisting of chambers with optical axes converging at a central point to the shooting object, arranged at different heights to include multiple angles of inclination with respect to the different surfaces. Finally, to have easy cataloging of the object, at the end of each day, the files obtained were collected in folders divided by day and type of shooting made, collecting more than 1800 photographs in 5 folders divided by Coverage, Front Prospect, Side Prospect Sacristy, Side and Back Prospect.

4. Experimental

Extracting an accurate and repeatable digital model of the site at fixed time intervals, from which to evaluate the conservation and the state of the structure in question, is certainly a more complete way of documenting any deterioration states compared to conducting surveys on the con site with total stations. Complete information on the surface can also be provided by a terrestrial laser scanning survey (TLS) but for a complete analysis of such a complex, it is almost always necessary to access the site itself, which, at times, can be a disadvantage. In addition, TLS equipment is less easy to transport and usually more expensive than a UAV. The objective of this drone survey campaign was to obtain a cloud of points with the highest quality and density of data, from which to generate a 3D model of the Church and provide the basis for the clearest reading of the building as possible. The post-production phase with Reality Capture software generated a dense point cloud for each of the areas acquired.

Figure 7. On the left, the four trajectory cases carried out in the present case study. The 1 represents the nadiral shots of the coverage and the context; 2 the shot was taken for the front of the facade; 3 the recovery model has repeated also for the long sides of the structure. 4 finally for the more particular architectural elements (in this case the bell towers) the approach becomes more intense with recovery from above and below, where possible. In the right part of the image, some of the trajectories highlighted on the respective bodies of the church.

The point clouds[18] were subsequently aligned on the basis of homologous points identified between each pair of adjacent areas, in a single database. The external model was therefore composed of about 1500 photographic images, 318010 constraint points constituting the sparse cloud, 16 million points forming the dense point cloud and 3 million polygonal faces (mesh surfaces of the model). The same process was followed for the interior of the Church with the return of the nave and the altarpiece: in this case, the images processed were 400 ca. producing 217403 constraint points constituting the sparse point cloud, 3 million points forming the dense point cloud and 700 thousand polygonal faces. After analyzing the constraints that conditioned the SfM acquisition campaign by drone, it was necessary to analyze the morphometric, geometric and colorimetric aspects of the data obtained or the quality of the 3D models obtained from the extensive application of the Spark. The verification of the geometric model obtained made it possible

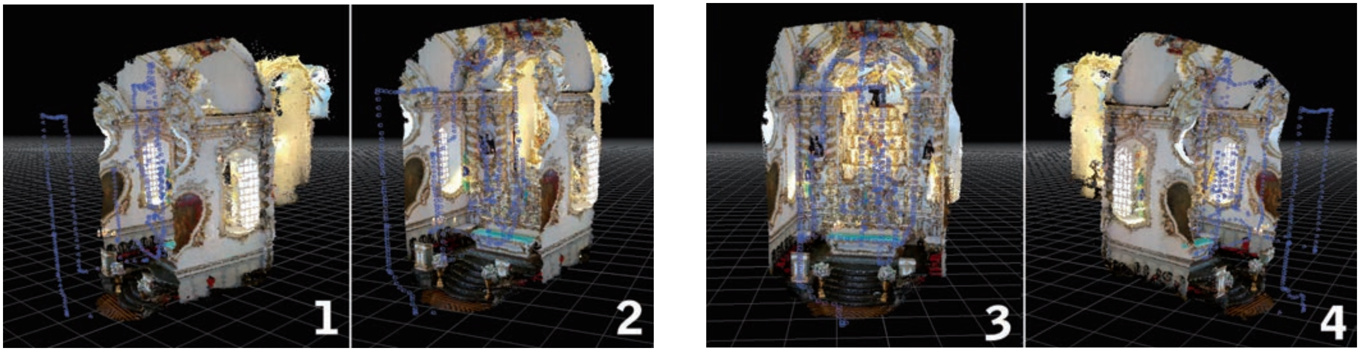

Figure 8. Views of the textured mesh obtained from the photos of the altarpiece.

to verify the reliability of the digital SfM database, to understand its limits and potentially applied to the case study and, if necessary, to improve the planning of the photographic acquisition. The metric tests between the various outputs, coming from different data acquisition tools, were made possible by the adoption of some homologous points. Consequently, the reliability of the Spark output was verified by comparing the 3D model obtained from the acquisition[19] of the church carried out with FARO laser scanner instrumentation and the 3D model obtained from the UAV described above within the Reality Capture software. The recording was carried out on the basis of remarkable architectural points (windows, corners of cornices, sharp corners of the roofs), common to the two-point clouds[20]. Although in the planimetric extension the two outputs, photogrammetric and laser, seem to coincide, the main problem encountered in the output obtained by the Spark was the lack of geometric correspondence of the volumes at the base of the Church: corners and edges lose their precision with respect to the cloud of laser scanner points, taking on a rounded shape, which makes post-production of the SfM model problematic for any secondary use. Similarly, the portions next to the eaves and the roof result in a greater noise caused by the difficulty of the laser scanner to obtain the data (Figure 11). As regards the portion of data on the ground, (Figure 4) this critical point is partially solved with the use of terrestrial photogrammetry, integrated with the models mentioned above, which minimizes the geometric deformations of the photogrammetric model, obtaining a greater number of details of even complex elements present in the area.

Similarly, it happened inside the church, where, however, the main problems were found in the cleaning of the cloud generated by the altarpiece. In fact, the mixed color between white and gold, reflected by natural light, did not allow a linear acquisition of the myriad of decorations present.

It is therefore considered appropriate to take a shot with a fixed machine, given the particular height of the object, and the use of a telescopic rod such as that of the 3D Eye used on previous occasions[21] is recommended.

5. Discussion, conclusions and future developments

In this work, the degree of reliability of the treatment of optical images has been studied in order to monitor the morphological variations, in particular, vertical ones, that can occur in this plant.

Quantitative data, extrapolated from optical images, have values comparable with traditional detection techniques; the accuracy obtained in the 3D reconstruction of the church survey showed values

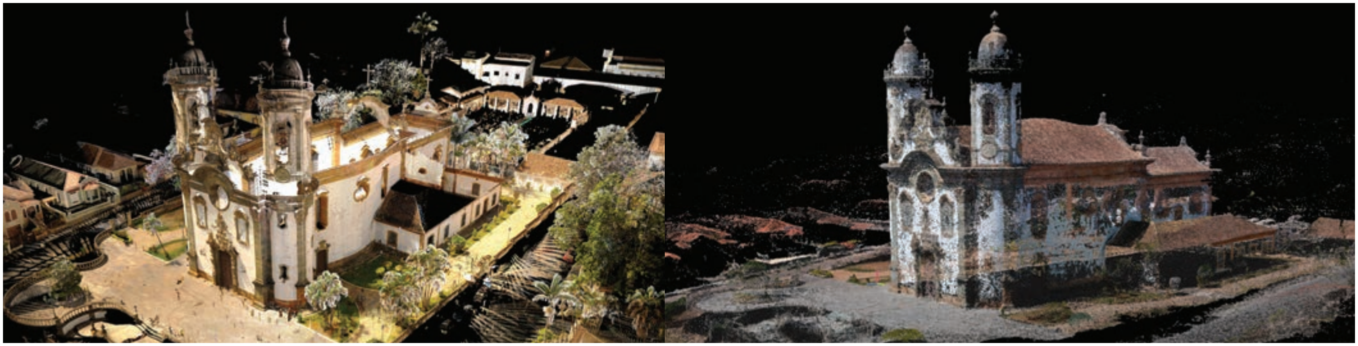

Figure 9. Comparison between the point cloud obtained by the FARO laser scanner and that, on the right, obtained from the UAV images.

less than 1.5 cm, more than enough for monitoring the complex. This specific application of UAVs can interest many actors; in this specific case the activity of the IPHAN, responsible for the control of the architectural and cultural heritage[22] on the territory.

In general, the results obtained can be considered positive both with respect to the specific topic studied and with respect to other types of conventional detection of buildings and historical monuments in the area, taking into account that the use of UAVs for photogrammetric purposes can be further elaborated and standardized to depending on the context and the objective set.

The preliminary analysis of the site configuration was an operation of primary importance for the use of the Spark and the consequent study of the time and place parameters where it can be used.

The differences of a few centimeters of the two models acquired from the UAV model and the laser scanner used and the elaborations with the software confirmed the validity of the experimental approach.

The use of UAV technology favors a type of study otherwise difficult to obtain, as the cases of the past document us. The expectations that can be thought of these instruments on the national and international territory are therefore optimistic in order to preserve what culture has brought to the present day.

Figure 10. Return of the plan of the church with highlighted the control points used to join the two-point clouds (FARO and UAV).

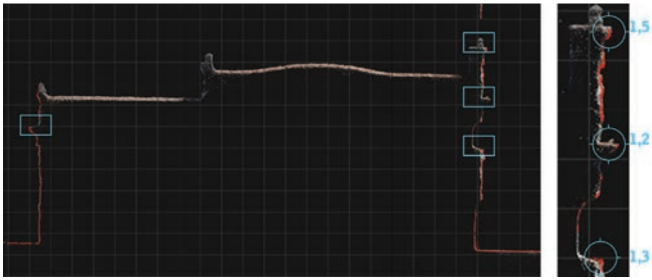

Figure 11. Slice overlap between the point cloud obtained by drone, (in color) through which it is possible to read the coverage with the relative cornices of the complex, and that obtained from the TLR. On the right side, the margin of error of the overlap is highlighted with a maximum value of 1.5 cm at the top of the front of the church.

Note

1 Secular Franciscan Order (OFS; in Latin Ordo Franciscanus Sæcularis) is the current denomination of the Venerable Third Order of Penance of St. Francis of Assisi (or Brothers and Sisters of Penance) an organization of the Catholic Church designed to bring together lay faithful and clergy diocesan (the Third Order - OTFS). OFS members try to observe the Gospels in the footsteps of St. Francis of Assisi in their homes, work and daily life. The SFO (Secular Franciscan Order) is one of the three fundamental components of the great Franciscan Family, consisting of the three orders founded by Francis of Assisi: the first order (the friars), the second order (contemplative religious called the Poor Clares because they were founded by a saint Chiara) and the Third Order has the noble mission of reviving in conscience the honesty of the customs and Christian sentiments of peace and charity, intended for men and women who without desertion of their own family and without renouncing their properties, could lead to all Christian sentiments. He called them Brothers of Penance, now known as the Secular Franciscan Order, and its members try to achieve Christian perfection.

2 As in the case of other colonial mining towns, originating from the gold mining activity, the urban formation of São João del Rei occurred with the agglutination of small nuclei that appeared near the mining sites, discovered since the year 1704. Therefore, the initial occupation took place in a rather sparse and rarefied way, being limited to distant groups of low houses around a small chapel. Since the creation of the Villa in 1713, São João del Rei has grown, both of importance within the Minas region. Born as one of the main cities of the Brazilian colony, even after the decline of the gold cycle, the city has continued to develop. Initially a chapel was erected for the cult of San Francesco, but over time it deteriorated. In 1772, the initiative to build a new church of the headquarters belonged to the Third Order of St. Francis of Assisi, replacing the former chapel. The first preparations for the construction began immediately after the decision of the Order and in August 1774 the services of Maestro Francisco de Lima Cerqueira were hired to carry out the works.

3 By 1804 the central nave and other church works had been completed. In 1809 Aniceto de Souza Lopes completed the towers and the choir and carried out, according to IPHAN, the reliefs of the pediment and the frontispiece of the portal.

4 At the beginning of the twentieth century the church underwent numerous restorations works, carried out by the National Service for Historical and Artistic Heritage (SPHAN, now IPHAN), including the recovery of the choir and throne of the high altar. In 1954 electric lighting was installed, in 1956 the access staircase was restored and later, in 1959 the altar. Subsequently, the white paint that covered the altars of the nave was removed, according to IPHAN directives, since it was considered a late addition, thus leaving the interior with the color of the wood. The series of sculptures in the presbytery, the six altars in the nave and the pulpits, among others, which have a clear influence from the school of Antonio Francisco Lisboa, deserve special mention. The master's interventions include the design of the altarpieces (from the influence of D. João V to those of the rococo taste), as well as an image of Saint John the Evangelist. located in the sacristy. The relief composition of the Holy Trinity is noteworthy as a solution to the closure of the presbytery altarpiece, bringing this altarpiece closer to that of San Francesco d'Assisi in Ouro Preto.

5 Formally, the Baroque ended in 1816, with the arrival of the French artistic mission and the neoclassical style, in vogue in Europe, in Rio. But for many, the baroque influence didn't end there. "Brazil was born under the baroque sign," historian Nicolau Sevcenko of the University of Sao Paulo told SUPER. "The Brazilian physiognomy and soul were made up of this mystical breath. It was not a style of passage, but the basic substance of the country's cultural synthesis." For Sevcenko, there are "latently baroque" signs on Brazilian identity, in particular popular Catholicism, such as "extremes of faith, illusion of grandeur, exaltation of the senses, celebratory ecstasy, propensity for the monumental, coexistence with disparity and compulsion to hope ". Italian Mannerists were the first to explore the use of elliptical plants in churches, and the architects of the Upper Baroque were also interested in these new possibilities. At the end of the seventeenth century, the ellipse was already a motif of the international baroque, used in Europe throughout the eighteenth century. What is interesting, however, in the church of Sao Francisco de Sao Joao del Rei, in contrast to the baroque church of Sao Pedro dos Clerigos, in Porto, is that, initially, the canvas of the nave is a very elongated oval, the entire emphasis of the design resting on the length of the ship. The convexity of the walls is an underlined or even secondary feature. This rococo softness, or, as one might say, this distrust in the side curves of Sao Joao del Rei, contrasts with the robust convexity, for example, of Sant'Andrea al Quirinale by Bernini in Rome, or to give a more careful example, Madonna del Rosario, in Ouro Preto.

6 The most admirable expressions of this mining style of the late eighteenth century, both in architecture and in sculpture, are traditionally attributed to Antonio Francisco Lisboa (1738-1814), known as Aleijandinho, born in Ouro Preto, whose nickname was adopted for the name of the style. The facade, of the artist's matrix, basically follows the usual Portuguese arrangement of the great mother churches, but despite this convention, all the principles of the mannerist treatment of the previous Jesuit style were abandoned. In the towers, this emancipation appears with particular clarity. They are cylindrical in shape, decorated with balustrades and topped with elegant semi-oval domes crowned with obelisks. It can be argued that the overhanging facade, the towers and the interior decoration of the church of San Francisco de Assis de Ouro Preto and the sanctuary of the Congonhas do Campo Sanctuary offer more perfect examples of some Aleijandinho style features, but the church of Sao Joao del Rei represents it more completely. The development of this style is well illustrated by a series of transitional works: the churches of the Third Order of Our Lady of Carmel, Sabara, Ouro Preto, Mariana and Sao Joao del Rei.

7 It is an acronym intended to identify an unmanned aircraft on board. The abbreviation UAV is English and means Unmanned Aerial Vehicle and can be used as a synonym for drone, APR, etc.

8 The classic photogrammetric approach is based on collinearity equations and describes the acquisition of images considering the geometric and camera characteristics (Baiocchi V., Napoleoni Q., Tesei M., Servodio G., Alicandro M., Costantino D., 2019). The reconstruction of the image acquisition geometry is obtained by studying the acquisition mode, the characteristics of the sensor, the position and attitude of the camera.

9 According to sources of the parent company of the UAV model used: Accuracy of parking in flight Vertical:+/- 0.1 m (with visual positioning) or +/- 0.5 m. Horizontal: +/- 0.3 m (with visual positioning) or +/- 1.5 m

10 The bundle adjustment estimates the camera position for each image and its internal orientation which allows the creation of 3D point clouds.

11 Acronym for Ground Control Points which are clearly visible points on the ground whose coordinates are known with high accuracy because they are measured with professional instruments such as a GSP RTK receiver or a Total Station.

12 The use of the Spark model allowed to approach the surfaces to be acquired of the object, allowing to take detailed photographs of the

surface of the Church, obtaining a higher level in the resolution of the image describing the various decorative elements and therefore a better quality of the model final photogrammetric.

13 The image output is a common Jpeg, unlike the more recent machines that also allow you to obtain tiff files. As for videos, the output is an Mp4 format. You can also make Full HD video at 1920x1080 with 30p and a maximum bit rate of the video at 24 Mbps.

14 Bracketing can be defined as the shooting of a subject (person or environment) that has at least one image correctly exposed and at least two others visually the same with an exposure higher and lower than the correct one.

15 According to the parent company, flight autonomy is 16 minutes at 20 km / h constant and without wind).

16 The decision to have two landing points is normal practice in order to avoid dangerous situations of control of the vehicle if the first station is prevented.

17 As previously written, it was the operator's concern, despite the weight of the drone is officially below the minimum risk threshold undertaken by ENAC, that of evaluating the best time of the day, therefore with less circulation of vehicles and people, for filming videos and photographs of the Church and the immediately adjacent body.

18 In consideration of the structure and the lack of GCP, at least 9 homologous points have been selected for each single model in order to obtain a reliable and precise 3D model for the relative destination output.

19 This work was developed within a research project, conducted by prof. Bertocci of the DIDA, undertaken between the Departments of Architecture of the University of Florence with the USP (University of Sao Paulo) and the UFSJ (Federal University of San Joao del Rei), where in addition to the use of Spark DJI, a FARO was used CAM2 and a Nikon D3000 SLR for ground-level photography.

20 16 homologous points were placed in the area under study, (four per side) in order to have greater reliability of the product obtained. Then the points of the context were identified by edges or geometric structures easily recognizable both from the photographic image and from the laser scanner.

21 3D eye instrumentation has been widely used in past years when the use of UAV instruments was still not so widespread. In recent studies carried out at the Certosa of Florence (Picchio, Cioli, Volzone, 2018), Villa Adriana (Rome), as in the Palazzo del Generalife in Granada (Spain) (Dell'Amico 2018) has solved, in part, problems related to documentation photographic and consequence made a photoplan of the relative fronts or architectural elements analyzed.

22 The survey carried out in view of a possible restoration intervention must lead to a comprehensive knowledge of the work in question, completely exhaustive in both dimensional and structural and construction aspects; must take stock of the state of health of the building, its degradation conditions and static conditions.

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Keywords:
Photogrammetry, 3D Modeling, analysis.

ABSTRACT

This proposal is an abstract from my degree thesis: "Between the Ionian and the Aegean Sea. The Phenomenon of the Cubas in the oriental Sicily". The Cubas are some isolated cultic buildings from the Byzantine period, located as picturesque "folies" in the Sicilian rural landscape. The attention is on one specific cuba: the Cuba of Santa Domenica in Castiglione di Sicilia. The workflow of this project starts from the photogrammetric survey, in which the use of the drone played an important role allowing obtaining a complete 3D model, ending to the analysis of the geometry the dome is based on. The Cuba of Santa Domenica in Castiglione di Sicilia, with the lava rock of which it is composed, stands out between the Alcantara River and the Etna Volcano, looking as a black jewel. The name, "cuba", according to research, probably comes from the Arabic word "cupah" that means cube[1] or "qubbah" meaning dome, so both words explain its typical configuration: a cubic form with a dome.

The "Cuba" of Santa Domenica

1. Test case

The workflow of this project is organised into three main phases: data gathering, 3D model creation, detail analysis.
The data collection phase includes photogrammetry from the ground with camera and aerial photogrammetry with drone.
The first allowed obtaining a complete 3D model of the inside, the second a complete 3D model of the outside. The two 3D models have been combined for subsequent processing and analysis.

2. Acquisition data

To carry out the aerial survey, the drone was positioned on three progressive heights, taking photos during rotation around the entire object, to have a high percentage of overlap between each photo.
Additional photos were then taken on specific areas to have as much material as possible to work on.
The UAV used is a Mavic air with these technical characteristics: sensor 1/2.3"; effectives megapixels 12.0; focal length (35mm equivalent) 24; FL focal length (mm) 4.26; pixel size/FL 3.64E-04.
To make the survey inside, the camera was positioned parallel to the walls and around the four pillars.
The camera used is a Canon model EOS 2000D with these features: 24.0 effective megapixels APS-C CMOS sensor; image sensor size 22.3×14.9 mm; focus areas 9AF points; ISO sensibility 100-6400. Camera mode dial used: aperture priority mode.

3. Elaboration data

By the photogrammetry software Agisoft PhotoScan Professional the work starts from the alignment of the photos, it proceeds to the construction of the point cloud and finally to the creation of the mesh and the texturization. Coordinate system is set using camera positions.

Figure 1. Aerial photo with the Etna Volcano.

PhotoScan parameters used are high accuracy in the photo alignment phase; medium quality in the build dense cloud phase; high face count in the build mesh phase; planar type, average-blending mode in the build orthomosaic phase.
The textured 3D model is the start point for building orthographic elevations and sections.
The purpose of these orthographic drawings is to allow an efficient identification of the typology, morphology and symbolic-ritual meaning of the building's component parts as well as hypotheses on what cannot be defined with certainty.
It is sufficient to have the real measurement of an element of the cuba to be able to know the measure of every part of the 3D product, since the point cloud is very faithful to reality. 1,239 photos with 1,113,737 points have been processed for this cuba.

4. "Cuba" overview

The Cuba of Santa Domenica, dating back to the 8th century, is quite small measuring 9.10 meters in length and 9 meters in width and a height of approximately 8.50 m. It has a square shape in the plan with a very articulated plant despite its size.
Divided into three naves, it has a main square space, it is not as central as the plant of the Byzantine martyriaunless we consider the narthex of which only the traces on the facade are present. For these elements, the cuba presents the fusion of the Byzantine central plant whose fulcrum is the dome, and of the Roman basilica with the division into naves whose fulcrum is the direction towards the apse. Around the perimeter, there are buttresses in order to strengthen the structure without making it too heavy. Those located in the centre of the sidewalls are not aligned with the inner walls. Proceeding eastwards, the two pillars are more robust as they serve as a support for the dome and they are surmounted by a round arch that acts as a diaphragm between the naos and the transept. The side naves are covered with three small cross vaults each resting on four protruding corner stones.
The presbyter area is divided into three parts, the central part is covered with a cross vault while the lateral ones with a barrel vault.
In the two lateral parts there are semi-circular niches, reminiscent of the most ancient lateral apses (Margani, 2005) called prostheses and diaconicons, that is the places where the sacred objects needed for the function were placed and where the priest wore the vestments.
The median apse is oriented east according to the Byzantine rite of Easter. During the consecration, the altar was struck by a ray of light from the first full moon of spring. In fact, a mullioned window opens in the centre of the apse (Valpreda 2015) and a half moon window above the apse.
In the main facade to the west, a three-mullioned window gives light to the naos, while two single lancet windows open on the sides in correspondence of the secondary naves.
The openings on the sidewalls are six: three on the south side and three on the north side arranged symmetrically to the previous ones. Two of the mullioned windows on the south side are in correspondence with the side naves while the third, located slightly higher, lights up the central part of the transept.
The cuba has two entrances, both on the western facade: a central one that leads directly into the naos and a lateral service in correspondence of the left nave. The two entrances, being asymmetrical, evidently had no aesthetic function since once covered by the narthex. The central door, larger and wider than the one on the left, has a round arch made up of blocks of lava stone. The secondary entrance is surmounted with a similar smaller arch.
On the south side of the building there is the reference to a third entrance door later walled to structurally consolidating the wall then statically compromised. Probably the door had been opened late following the abandonment of the religious use of the building in favour of civil use (Margani 2005) as a law of the king of the two Sicilies, Francis I, could testify in the first half

Figure 2. Front Elevation.

Figure 3. Cross-Section.

Figure 4. Back Elevation.

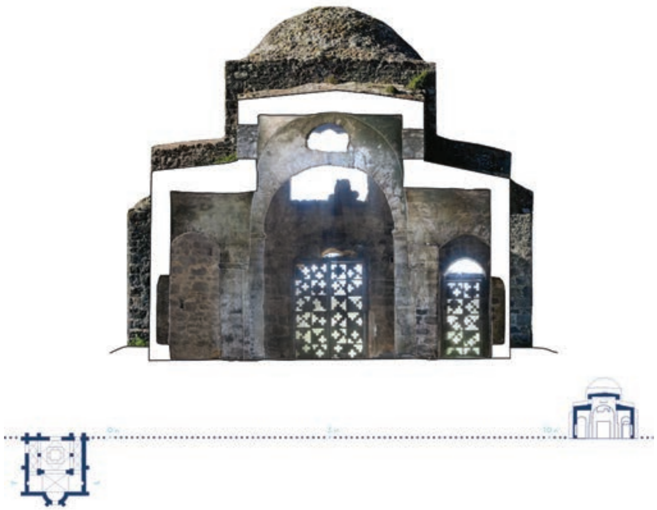

Figure 5. Cross-Section.

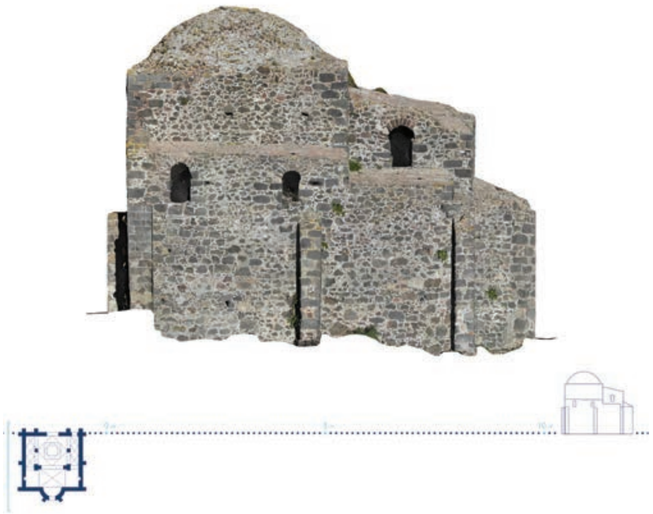

Figure 6. Left Elevation.

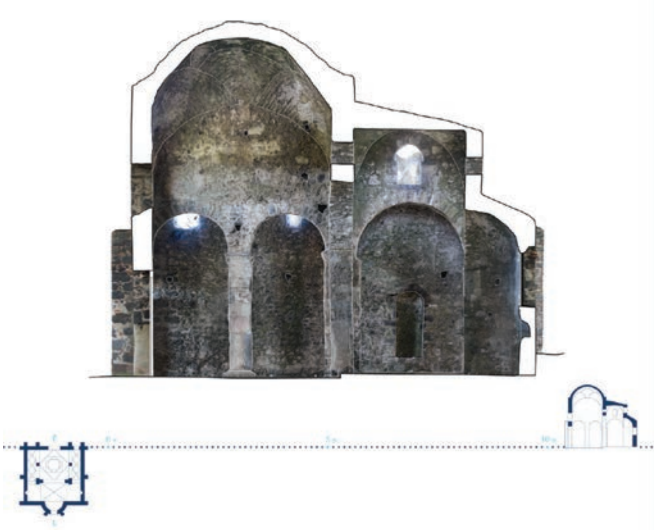

Figure 7. Longitudinal Section.

of the 19th century, according to which the adaptation of a religious monument for civil use entailed certain structural changes. Concerning the building technique, the materials and construction methods are local. The external and internal walls are built using primarily volcanic stone blocks; most of the blocks are irregular in shape while some are squared. Some sandstone ashlars appear in the lower level of the inner and outer walls and as corner stones. These latter had a symbolic value: this white stone represented the good in contrast with the black colour of the lava stone, moreover its location as a corner stone recalls the Gospel phrase saying that the stone rejected by the builders becomes a corner stone. The central part of the cuba retains a deep symbolism: the vault represents the sky and therefore Paradise and the divine while the basic square represents the earth and humanity. The structural union of these two elements represents the re-joining of man with God (Manitta 2017).

5. Geometry analysis

The element that captures attention the most is certainly the vault that covers the central space. Apparently, it is a ribbed vault but composed of several orders of fan-shaped elements (Manitta 2017).

Each fan can be assimilated to a portion of sphere generated by three secant planes of different inclinations as it can be seen from the curved trace left in the plan, these elements are progressively projecting in order to close the dome. Each of them also fits onto the two underlying fans by a rotation of 45 degrees until the vault is closed with a single element. Each fan is made of listels arranged in concentric rows. On some of them there are still traces of red, white and blue paint, each row has a different colour probably to emphasize the geometric lines.

6. Geometry analysis

The element that captures attention the most is certainly the vault that covers the central space.

Figure 8. Right Elevation.

Figure 9. Longitudinal Section.

Figure 4. Roof Plan.

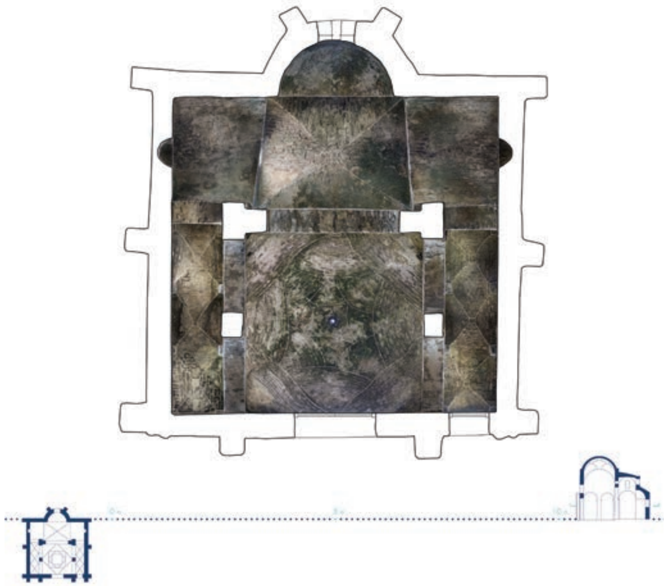

Figure 5. Interior Roof Plan.

Apparently, it is a ribbed vault but composed of several orders of fan-shaped elements (Manitta 2017).
Each fan can be assimilated to a portion of sphere generated by three secant planes of different inclinations as it can be seen from the curved trace left in the plan, these elements are progressively projecting in order to close the dome. Each of them also fits onto the two underlying fans by a rotation of 45 degrees until the vault is closed with a single element. Each fan is made of listels arranged in concentric rows. On some of them there are still traces of red, white and blue paint, each row has a different colour probably to emphasize the geometric lines. An alternative hypothesis could be made: considering the vault generated from a single origin solid, which is not a perfect sphere but an ellipsoid and therefore it is an irregular ripper vault due to its raised profile. This solid can be obtained by tracing the profile of the dome and creating from the latter a solid of rotation.

Figure 12. Vault components.

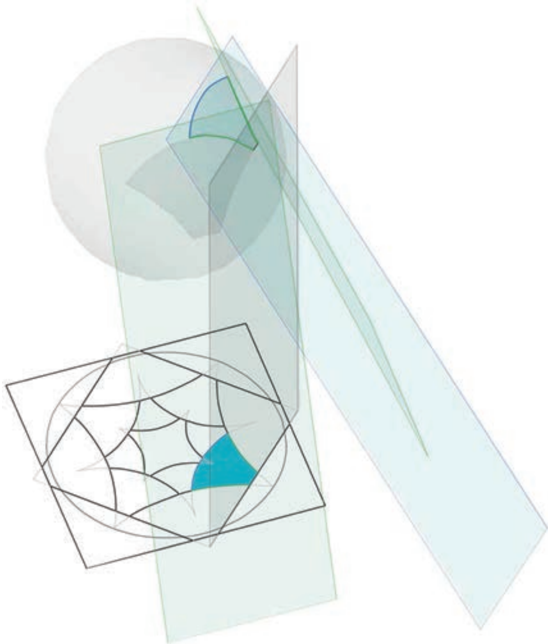

Figure 13. Geometric reconstruction vault components.

According to this interpretation, the fans are therefore only the construction means chosen to form this solid.

7. Conclusion

All the material generated by this work can be inserted in what we can call virtual archive named Heritage BIM (Building Information Modelling), and it can be used in some applications in order to enhance this precious heritage and the place that keeps it.

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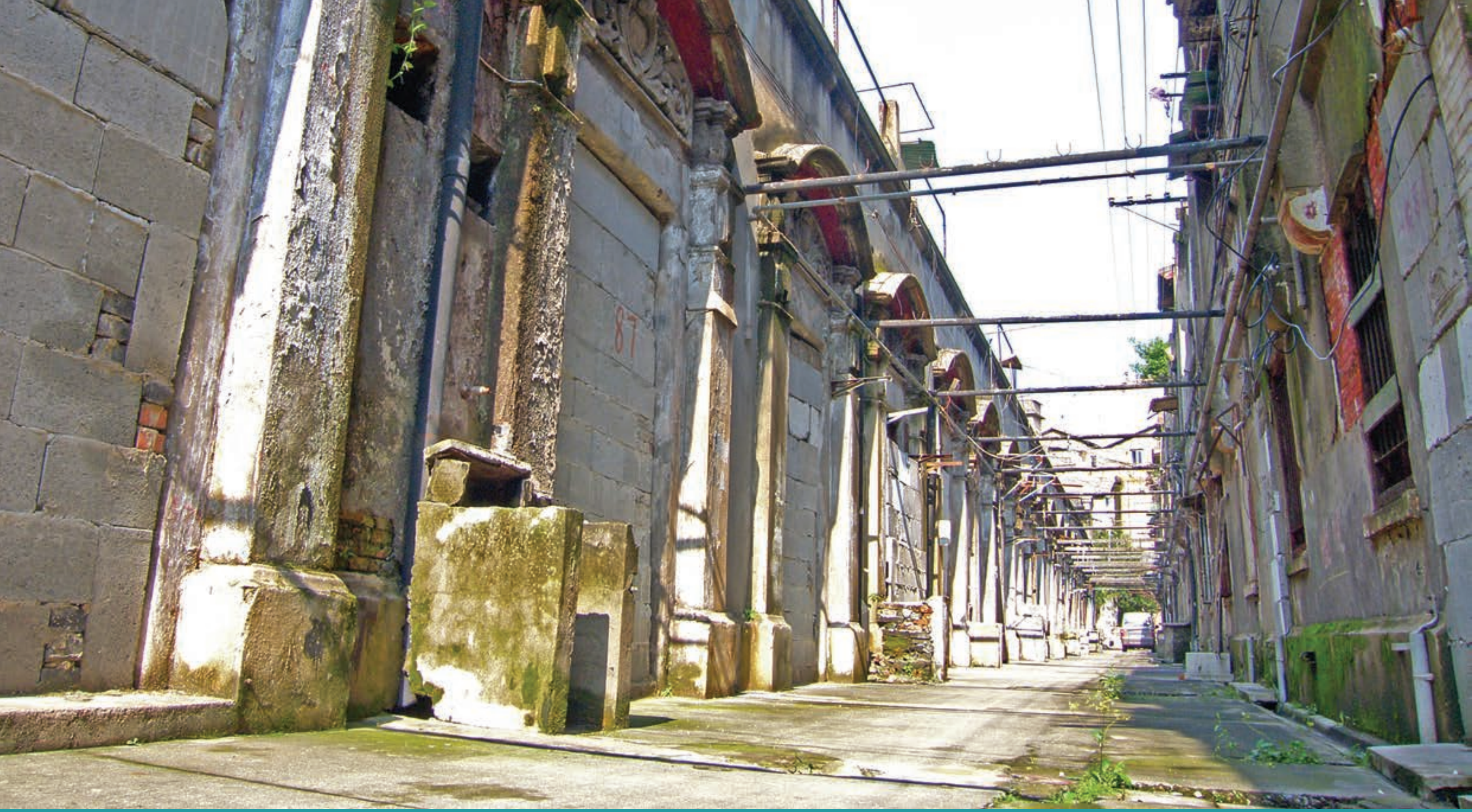

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ABSTRACT

The rapid evolution of images of unmanned aerial vehicles (UAVs) results in the multiplication of applications in various fields such as military and civilian surveillance, delivery services and wildlife monitoring. From the collaboration with the Jiao Tong University in Shanghai it was possible to experiment with aerial photogrammetry to understand the complexity of one of the most significant and meaningful historic districts of the metropolis.

Keywords:

UAVs, integreted survey, Shikumen, Shangai.

The Shikumen of Shangai. The use of UAVs technologies for the documentation, reuse and restoration of a Shikumen

1. Introduction

A city that has become a metropolis and is characterized by European contamination is the very essence of the city of Shanghai and the cosmopolitan culture it has been a part of since the mid-nineteenth century. Following the treaties that gave foreigners the opportunity to settle and operate in China, Chinese and Western culture began to merge into characteristic districts, a tangible sign of the slow process that has determined the current urban planning of today's metropolis. Today Shanghai is constantly and dizzyingly transformed and the traditional urban and architectural structure of its ancient core is being lost. The operations of construction speculation, necessary to satisfy the exponential population increase of the metropolis, have led to the replacement of many of the architectural 'inventions' that have made Shanghai famous - and which, in some ways, can be juxtaposed with the beijing hutongs - the so-called longtang or lilong. These residential districts, which have sprung up within the nineteenth-century concessions and therefore characterized by a mixture of Chinese and Western architectural style, constitute, seen in a much larger plan and on a much larger scale, an extension of the Chinese 'backyard house' enriched by influences derived from traditional architectural types still found today in villages in southern China.

2. State of the art and research need

The traditional dwellings, called Shikumen and developed along the Lilongs, the narrow alleys that give the neighborhoods their name by extension, are the subject of a perpetual replacement due to a drastic program of demolition and renovation of the ancient buildings with new housing formulas that can accommodate a greater number of inhabitants.
The interventions made that preserve the structure are instead aimed at a change of use, from residential to commercial-tourist.
To slow this constant loss of historical fabric, the Survey Laboratory of the Department of Architecture of the University of Florence in synergy with Jiao Tong University in Shanghai has activated research for documentation and analysis of the fabric of one of the oldest neighborhoods: Dong Siwenli.
The district boasts about a century of age and the primacy of surface extension in the city of Shanghai and is linked to multiple periods of past splendor. Today, unfortunately, it is in an advanced state of abandonment

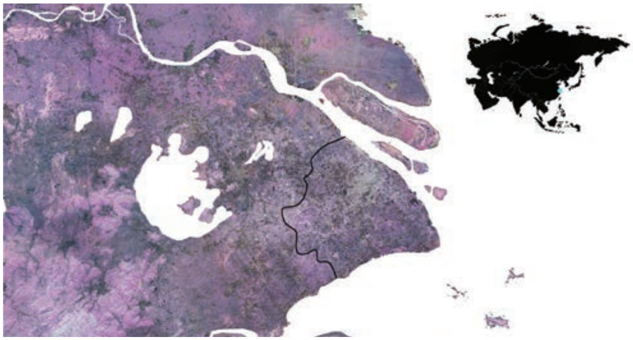

Figure 1. The intervention area.

Figure 2. Aerial shooting of the area of intervention.

and degradation, due in particular to the recent decision of the government to clear and demolish, a choice that fortunately has not been concluded, but which leaves the entire district in isolation.

From the ancient splendour only a few families resist inside these accommodations, waiting for precise indications on the future of the area inhabit in inhuman and uncomfortable conditions. Located in the heart of the city, Dong Siwenli is a rectangle of 28,000 square meters of land that fits into a dense urban settlement consisting mainly of skyscrapers, but which heroically resists and identifies itself as a historical unit.

3. Survey Methodology
3.1 Case Study Framing

The collaboration between the two universities developed a first phase of investigation following a precise methodology that described all aspects of the Dong Siwenli district. From the interpretation of large amounts of data acquired by sophisticated technological instruments, a precise and accurate morphometric model of urban survey has been obtained. The integrated acquisitions and the resulting three-dimensional model have proven to be effective tools for an objective and reliable interpretation of the place with the final result of an exhaustive product. Built on a former international concession and squeezed between the grip of major infrastructure arteries, the historic district containing Dong Siwenli and King Siwenli is in the floor plan as a rectangle with a total of 736 units built on about 48,000 square meters, approximating 20,000 square meters for King and 28,000 square meters for Dong, thus boasting the record for size in the entirety of the city. After following all the historical phases of stylistic transformation generated mainly by the sublet, the western part was destroyed following the phenomenon of "destruction-relocation", which began after the economic rebirth of the city and its housing reform in 1991. In 2012 the aforementioned phenomenon also occurred for Dong Siwenli, but in this case the demolition company did not work immediately, allowing to treat the abandonment of the residents through a payment, then buffering every empty dwelling and giving the area under management to staff, who took advantage of it to rent the houses. To date, therefore, only 6 families live there, opting to abandon themselves because of dissatisfaction with the solutions proposed to them. Siwenli, while making the previous forms readable, belongs to the tipology of new Shikumen Lilong built under the Republic of China, recognizable by the arched medalls of baroque influence found above the doors, which show how, since the opening of China, the local architecture had embraced international styles. This settlement is also characterized by the density and linearity of the plant along with the corner houses, symbol of the modern family that is home to only two generations.

Figure 3. Detail of ancient door.

The research was also an opportunity to assess the effectiveness of the methodological/procedural system adopted, aimed at describing all the aspects that characterized the Lilong: the historical evolution, the relationship between the street and the Skikumen, the characteristics of the architecture sign of the uniqueness of the neighborhood, the presence of discontinuity and/or superfetations etc. The integration of advanced techniques and methods of architectural importance were the result of distinct phases of investigation through the use of different tools. The methodology followed, in fact, is that of integrated survey, with detection phases that took place through the use of instruments such as: Laser Scanner Terrestrial system, Photogrammetric Survey. The survey of the area was carried out with the help of a Leica Laser Scanner Laser Scanner Leica ScanStation C10 3D. The data captured by the various scans is reported on the PC via an operation called 'buffering', then the various scans were superimposed via a recording made through the Cyclone software. From the point cloud obtained, the various snapshots were processed, which were used for the subsequent graphical return.

The amount of environments and spaces documented necessitated an orderly and always up-to-date cataloging of photos. The photographic relief on the ground was performed with Samsung PRO 815 camera, with which you captured every surface of the different architectural elements. The photos taken were then used for the creation of three-dimensional models and two-dimensional perspectives with the softwere Agisoft Photoscan. The greatest difficulty was found in creating quality photos as urban spaces offered cramped environments where the room was properly placed. Finally, to get a complete reading of the neighborhood and given the complexity and morphology of the site to be detected, a further step was needed for the information acquisition campaign to support the photographic survey. This phase was operated at the air level by drone instrumentation. The drone, Phantom 4, was used to photographically detect the entire site in order to create a complete three-dimensional model and a high-definition ortho-photogrammetry. The photogrammetric survey of an unmanned aerial vehicle (UAV) in the Dong Siwenli district proved to be particularly efficient at the expense of the complexity of

Figure 4. Diagram of the photographic acquisition path.

the area, which has covers of different heights and little movement.

It was necessary to carefully design the flight plan and geo-referencing, also evaluating the accuracy rate indicators, in order to achieve highly accurate and reliable results.

The photogrammetric survey of an unmanned aerial vehicle (UAV) in the Dong Siwenli district proved to be particularly efficient at the expense of the complexity of the area, which has covers of different heights and little movement. It was necessary to carefully design the flight plan and geo-referencing, also evaluating the accuracy rate indicators, in order to achieve highly accurate and reliable results. In particular, it was chosen to operate with a DJI Phanthon 4 Pro drone for the SfM photographic survey based on a number of instrument specifications, such as the camera and gimbal system. In terms of other hardware used, there was a backup battery, and an Ipad, which was used to control and monitor the UAV through the use of the DJI Go app. The survey area has been divided into 15 systems related to each individual alley of shikumen, to roughly define the

Figure 5. Three-dimensional model made from photographic images obtained from the flight plan of survey.

main architectural areas of each residence. The different flight plans were designed using the app. DJI GPS.

For each alley, about 100m long, 3 different types of flight were planned: a first photographic campaign that maintains the tilt axis of the chamber perpendicular to the ground and two more shots along the main front and on the tergal front with a tilt of the room that would allow a better acquisition of the roofs and upper fronts of the architectural complex by converging the axes to obtain a geometric reconstruction of the buildings according to the principles of photogrammetry.

Drone-acquired images become a key resource as they facilitate the reading of the context and implement the photographic investigation from the ground, made complex due to the narrow alleys that conform the neighborhood. The photographic campaign from the ground has found some critical issues due to the presence of clutter of the last inhabited houses: kitchens, chairs, work tables, vases, climbing plants, workers' depots, such as concrete sacks, shovels, signs, and mainly due to means of transport, such as cars, bicycles and mopeds parked at the site.

Based on the parallel arrangement of the 15 alleys that make up the neighborhood, image-based detection operations were planned, and it was thus possible to merge the two different photographic campaigns and obtain the entire three-dimensional model of the analyzed area.

4. Conclusions

The use of a multirotor drone to make aerial footage and photographs on the area set out to achieve a reliable point cloud to be integrated with the acquisition campaign carried out with laser scanners to obtain a 3D

Figure 6. The 3D model.

model of the Dong Siwenli district, capable of generating an exhaustive picture of the built. Given that the area of the Dong Siwenli lilong is among the most relevant in the metropolis and that having programmed in advance parameters such as GSD, flight paths and models and camera orientation, to minimize the waste of time on site and there were no problems or special constraints to consider for the proper detection of the whole area , UAV detection stretched out for a full week of work due to the inability to recharge the batteries on site, as the area was in a state of disrepair. The complexity of the context and the strategy of capturing oblique images for the top of the buildings, implemented to the data processed by the Earth survey, have yielded adequate results for the creation of groups of general floor plan and general elevations.

From using PhotoScan to the initial image to align and process dense clouds, we switched to ContextCapture for mes generation. The work process turned out to be a workflow of which produced adequate quality work of the orthophoto products.

The real cognitive process of the area is therefore the result of the two distinct phases of survey and representation. The natural working practice of acquiring dimensional geometric elements once developed triggered a process of interpretation that defined qualitatively the descriptive character of the real.

UAVs (Unmanned-Airborne-Vehicles) are now an important instrumentation for the acquisition of morphological information of architectures, context and environment that offer an interesting platform for the acquisition of photogrammetric elements.

The research highlighted the possibility of obtaining a 3D model of an important urban space from the interpretation of data obtained from the integration of the point cloud obtained by the terrestrial laser scanner survey and the point cloud obtained from high-resolution photographic information.

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UAV System, Drones, DJI Terra, Reverse Modeling, Certosa of Pavia.

ABSTRACT

The technological advancement, which affects the instrumentation and updating of software in the context of integrated architectural survey, invites to experiment with new and improved forms for the optimization of the acquired data. Through the case study of the facade of the monumental complex of the Certosa di Pavia, the present research focuses on the methodologies of data processing obtained through aerial photogrammetry with UAV systems, finally comparing the results achieved through the use of two different software for the reliable three-dimensional rendering of the sculptural apparatus on the facade.

Comparative data processing methods: analysis and considerations on photogrammetric outputs obtained from UAV. The case study of the facade of the Church of the Certosa di Pavia

1. Introduction

The use of techniques and tools for an integrated architectural survey, from the acquisition of point clouds, to digital processing for three-dimensional documentation, requires specialist knowledge and at the same time presupposes the adoption of standard systems, readable by all, of sharing and use of data.
Significant changes in the transition from traditional to digital design include the loss of the discretization and synthesis phase in the field. The use of laser scanner technologies and photogrammetric instruments, from the ground or air, allows the detector to no longer have to select the elements to be reproduced. At the same time, however, it highlights a different criticality, which occurs in the post-production phase of the data: it becomes necessary to ensure the accuracy of the acquisition to ensure accurate remote analysis[1].
The growing use of UAV (Unmanned Aerial Vehicle) for the study of Cultural Heritage is today motivated by the increased ability to produce, through these, forms and interpretative models of heritage aimed at creating protocols for its safeguard and protection (Aicardi et al. 2016). In particular, data processing processes based on photogrammetric documentation have the advantage of a virtual reconstruction of the historical and architectural artifact that is easy to read and understand for everyone and has a significant communication impact. The digital restitution of a survey carried out through aerial photogrammetry systems, oriented both to the correctness of the data and to the realistic reproduction of the morphology of the surfaces, allows us to arrive at an increasingly widespread and decisive scientific dissemination for knowledge and education to heritage (Balletti et al. 2015). This cognitive need, inherent in the construction, functional and dimensional characteristics of historical architectures, is answered not only in the definition of improved survey methodologies, but also in the comparison of software for the most reliable and correct return of three-dimensional digital models.
In this sense, the contribution intends to deal with the experiments of restitution of the photogrammetric data carried out on the case study of the facade of the *Certosa of Pavia*. In particular, the research compares the use of two different software, Agisoft Metashape, and DJI Terra, to evaluate the parametric models that can be developed, through qualitative and quantitative comparative investigations starting from the same set of photographs from an acquisition campaign carried out with Phantom 4 RTK drone.

2. The Certosa di Pavia, between history and architecture

The interest in the *Certosa di Pavia* factory is as historical-artistic as it is scientific: the need to know the construction, functional, dimensional, and artistic characteristics of the complex is answered in the definition of a methodological protocol for investigation and digital restitution. By applying integrated detection methodologies it is possible to obtain reliable measurements from which to represent in an organized way the metric complexities and the morphological and material information of the architectural object.

Figure 1. Details of the sculptural apparatus of the façade of the Church of *Santa Maria delle Grazie* in the complex of the *Certosa di Pavia*.

The design is configured as a data container and at the same time a tool for studying and understanding space and its evolutions.
The monumental complex of the *Certosa* (XIV century - XVI century) contains a mixture of styles, from Gothic to Renaissance to Baroque[2]. The basilica, which overlooks a large courtyard, has a 30-meter high facade, with a wall texture elaborated and richly decorated according to the typical procedure of Lombard Renaissance architecture (De Vecchi, Cerchiari, 1999). During the survey campaigns, the stone ornaments, arches, bas-reliefs and statues impose the use of photogrammetric techniques to integrate the data obtained from the laser, to ensure the correct detection of the architectural morphology and the reliable documentation of the sculptural elements.
The analysis of the site, aimed at creating a three-dimensional database that can be updated for the geometric and spatial knowledge of the factory, was started with the survey campaign of May 2016. The research conducted with integrated detection techniques, in addition to the use of laser scanner instrumentation, involves the use of different types of DJI drones, for the detailed documentation of the Charterhouse from the architectural scale of the church, to the detailed one of the stone sculptural apparatuses. The aerial photogrammetry operations carried out have enabled the acquisition of data speedily and effectively, allowing, on the one hand, to digitally reconstruct the territorial context of the Charterhouse, on the other to deepen the analysis of the sculptural apparatus present on the facade of the Church of Santa Maria delle Grazie. The need to detect the latter through Unmanned Aerial Vehicle (UAV) tools arises from the need to return the upper portion of the facade with the same level of detail guaranteed for the stone portions at the base.

3. Documentation and photogrammetric modeling of the decorative systems of the Charterhouse

3.1 Acquisition methods with UAV systems

The acquisition phase involved the use of the DJI Phantom 4 RTK drone, which is distinguished, among the various DJI products, by the accuracy of the photographic data. This feature is linked to the presence of the RTK[3] module, integrated with the drone and which allows you to collect data about the positioning of the aircraft in real-time, thus obtaining very accurate images.
The acquisition phase took place through the planning of several flights structured according to an “S” path and dividing the facade into three vertical bands, each of which was then divided according to a grid of 2 meters by 2 meters, with a strip of overlap between them.
In particular, the grid facilitated the acquisition campaign, facilitating the photographic recovery of the complex decorative apparatus, to finally obtain a complete database to be processed. For each position, the camera of the instrument made 4 types of shooting: the first keeping the camera inclination axis perpendicular to the facade, while for the others, the camera axis was inclined in three directions, first to the right and left and finally down. This allowed to improve the acquisition of all the details and to obtain a reconstruction of the sculptural elements, and more generally of the entire facade, according to the principles of SfM photogrammetry (Aicardi et al. 2016). This type of acquisition, based mainly on a manual flight, involved some problems related to the flight path and in particular to the estimate of the programmed grid measurements.

Figure 2. Acquisition campaign through the DJI Phantom 4 RTK drone. The presence of the RTK positioning system allows us to obtain a high degree of accuracy in the position of the instrument concerning the facade.

3.2 Photogrammetric data processing processes

The post-processing phase, aimed at obtaining a three-dimensional model of the facade, was managed through two different software: Agisoft Metashape and DJI Terra, the software produced by the drone manufacturer. Aimed at the production of three-dimensional models starting from photographic data, both software produces, during the first post-processing phase of the data, a dense point cloud on which the mesh model and its texture is then built. For the case study treated, a total of 783 photographs were processed by both software. As regards data processing through the Agisoft Metashape software, all the acquired images were processed and the process returned a model consisting of 4,712,957 points making up the sparse point cloud and 272,776,865 points making up the point cloud thick. The point cloud thus composed was aligned through the use of markers positioned on the morphological points of the architecture and homologous to those deriving from the acquisition campaign database using TLS instrumentation, to obtain a model of the facade properly scaled based on the point cloud laser scanner[4]. The points for the alignment were chosen to be evenly distributed over the entire facade and returned a total alignment error of 0.008 meters.

During the reconstruction phase of the mesh model, several problems were encountered related to the high number of points in the dense cloud, returning system errors related to the lack of virtual memory on the computer. For this reason, the cloud was first exported and the model was subsequently reconstructed using Geomagic Design X software, developed mainly for reverse modeling, to optimize the modeling process. The model resulting from this process is composed of 342,974,567 polygons, an amount that allows us to achieve a high degree of detail of the facade's decorative apparatus.

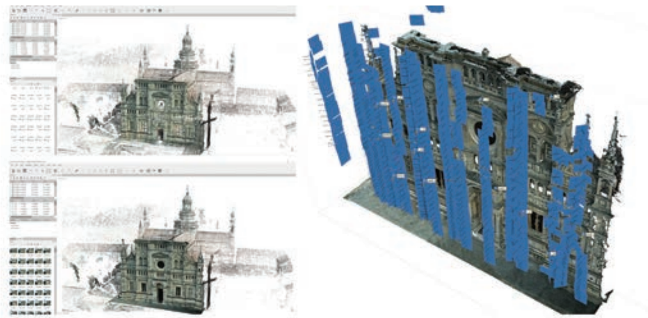

Figure 3. Point cloud processing through Agisoft Metashape software. On the left, we move from the processing of the sparse cloud to the creation of the dense cloud on which to build the model. On the right, the positioning of the photographic images that describe the high degree of accuracy during the acquisition phase using the tool on the entire facade.

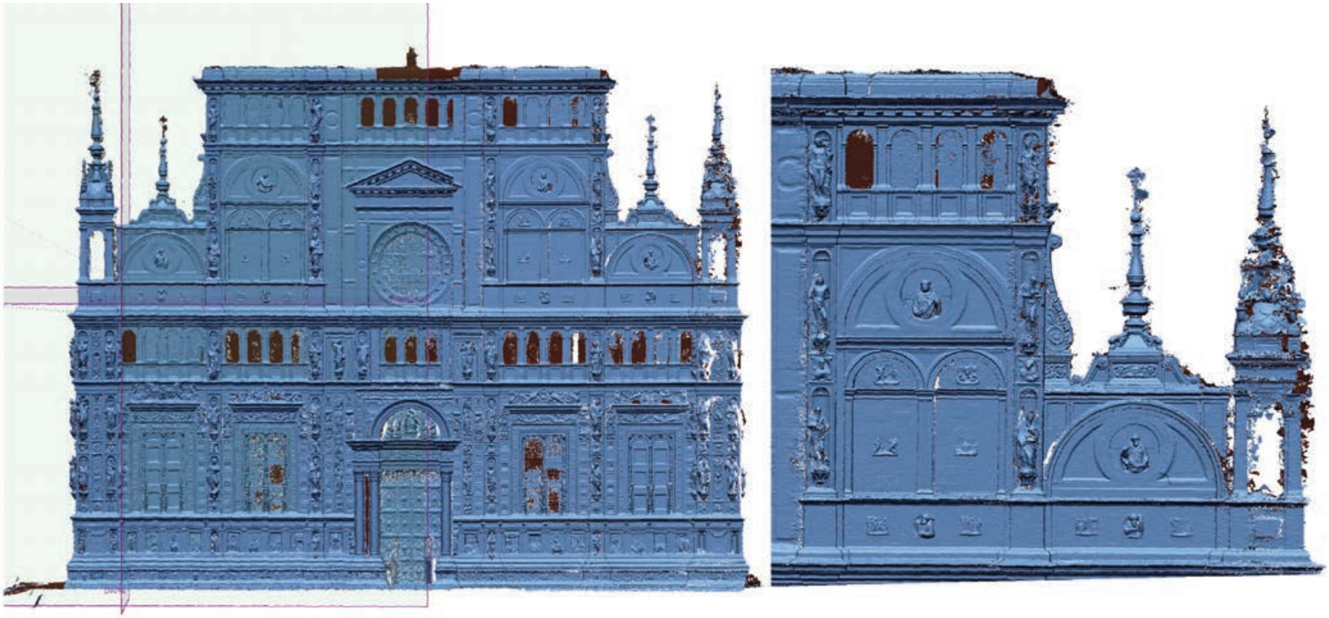

Figure 4. Result of the construction of the global facade mesh through the Geomagic Design X software. The process took about a week to process the point cloud, due to the high number of the latter. The result is a model made up of more than 300 million polygons with various problems (presence of holes, inverted normals, etc.) solved through model optimization actions.

In parallel, the process of elaboration of the mesh model deriving from the DJI Terra software was managed. Unlike Metashape, it was not possible to manage all the photos in a single processing phase.
For this reason, the three bands in which the facade was divided during the acquisition phase into as many rows were arranged and each of these was managed in the same way, i.e. generating first a cloud of points and then a three-dimensional textured model. In particular, 4,502,474 points and 9,002,616 polygons were processed for the right-wing, 1,240,711 points and 2,480,771 polygons were processed for the central wing and 3,222,670 points and 6,443,799 for the left-wing. polygons. Since the reference system was the same for all the models, they were brought together in a global model, subsequently reworked to obtain a unique three-dimensional system of the facade.

3.3 Comparison of detail models

Given the large number of details and the difficulty of managing global models, it was decided to focus attention on an architectural detail of the facade to start the last phase of comparison between models, finally assessing their criticality and advantages. Initially, the study area was extracted from both models and imported into Geomagic Design X.
This allowed the first management about the defects of the models, mainly for the model deriving from the point cloud obtained from the software processing Metashape.
In particular, processing phases have been started for the management of the polygons with correction of anomalies and holes found at the end of the global mesh creation process, as well as an optimization phase of the polygonal meshes through decimation and mesh

operations. For this reason, different actions have been launched aimed at the one hand at optimizing the model and on the other at the possibility of obtaining a comparable model.
A first visual comparison on the geometries of the model has allowed us to make some considerations about the level of detail of the architectural forms: most of the detail elements present on the facade are more legible and distinguishable from the DJI Terra model, compared to that developed with Metashape, highlighting the shape and geometric characteristics of each element.
On the contrary, in the Metashape model, the angles and edges of the architectural elements lose their precision, assuming a rounded shape without describing a series of details present on the different elements.
Despite this, the presence of a large number of small polygons has made it possible to obtain a more widely discretized and formally more detailed model. In general, the presence of a more dense point cloud in the case of the Metashape model has allowed us to reconstruct a model of greater formal precision, compared to the DJI Terra model in which, given the reduced number of points, a geometrical mesh was reconstructed more detailed. Once the optimization phase was completed, the models were aligned, to be able to start a comparative analysis of the meshes.
The alignment took place through the tools that Geomagic software offers, in particular through interactive alignment for homologous points. This tool was easy to use, also returning a report about the alignment errors of the first model with respect to the second.
In particular, some isolated cases of disjunction of the two models have been noted, in particular near the left sculptural apparatus (Figure 9), mainly due to an error during the phase of alignment of the images. Based on this alignment, the evaluation of the comparison of the two meshes was started using the Mesh Deviation tool, made by setting the model deriving from the Metashape processing as the Reference Model. In this way it was possible to analyze the deviation of the surfaces of the model coming from the DJI Terra, setting different tolerance ranges with values from 10 to 5 mm, thus obtaining visual information summarized in a colorimetric scale in which the green represents the areas of tolerated adhesion, red the overhang deformation, blue the displacement inward.
In general, the analysis showed a good congruence between the models, with some inaccuracies in the area on the right of the object of study, in which the maximum error varies between 7 mm and 12 mm.
This deviation is justified by the error obtained during the alignment of the Metashape point cloud based on the point cloud obtained by TLS instrumentation.
Finally, only a critical area is highlighted, previously identified with the qualitative comparison of the sculptural details, and confirmed with the quantitative comparison of the models.

	Agisoft Metashape + Geomagic Design X			
	#Img	#Tie Points	#Dense Cloud	#Polygons
	758	4.712.957	272.776.865	342.974.567
	DJI Terra			
	#Img	-	#Dense Cloud	#Polygons
Right Side	360	-	4.502.474	9.002.616
Center Side	515	-	1.240.711	2.480.771
Left Side	410	-	3.222.670	6.443.799

Table 1. Summary of points and polygons built during the processing by the two software.

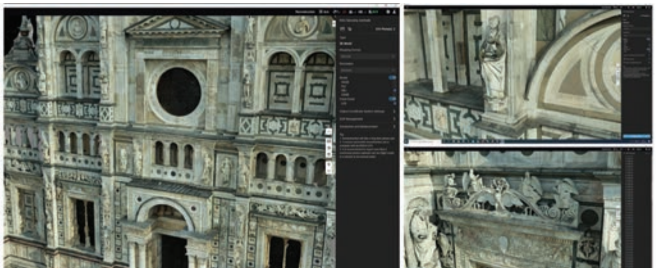

Figure 5. Processing of photographic images through DJI Terra software. On the left, a screen from the software of the construction of the point cloud referred to the central band of the facade of the Church. On the right, the details of the textured mesh model deriving from the processing of the point cloud within the DJI Terra software.

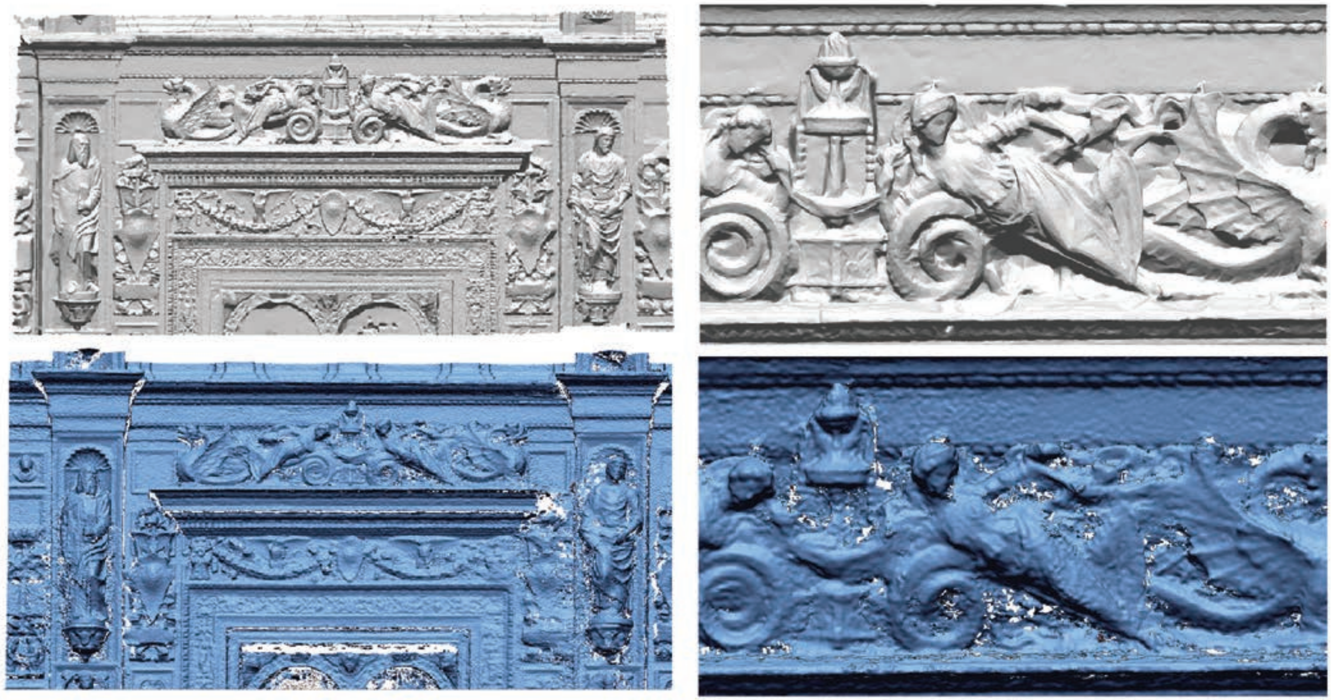

Figure 6. Qualitative comparison of photogrammetric models. In blue, the model obtained through the reverse modeling of the Metashape point cloud, in gray the model obtained through the DJI Terra software. The latter, consisting of a smaller quantity of polygons than the Metashape model, represents more legibly the signs that describe the geometries of the detailed elements. On the contrary, the Metashape model, given the number of polygons greater and considerably smaller, allows us to better describe all the curves of architectural objects, providing a high degree of detail.

4. Conclusion

The results shown in this article present two particular aspects related to the use of UAV systems for documentation in the context of Cultural Heritage.

On the one hand, the experimentation described confirmed that the use of drones can open new scenarios in the context of the documentation of Cultural Heritage, leading to a complete acquisition of the detailed architectural elements and decorative apparatuses, especially at a height whereby both ground-based photogrammetry and scanning using TLS instruments provide unsatisfactory results, placing various operational limitations. In parallel, the contribution highlights the use of the new software provided by the DJI manufacturer. In general, the final results showed high-resolution 3D polygonal models useful for the analysis and representation of architectural details. The quality control performed using the two different photogrammetric modeling software revealed a deviation in the order of a few millimeters, demonstrating good quality in terms of data accuracy and reliability. As for future developments in this research, it seems legitimate to continue the

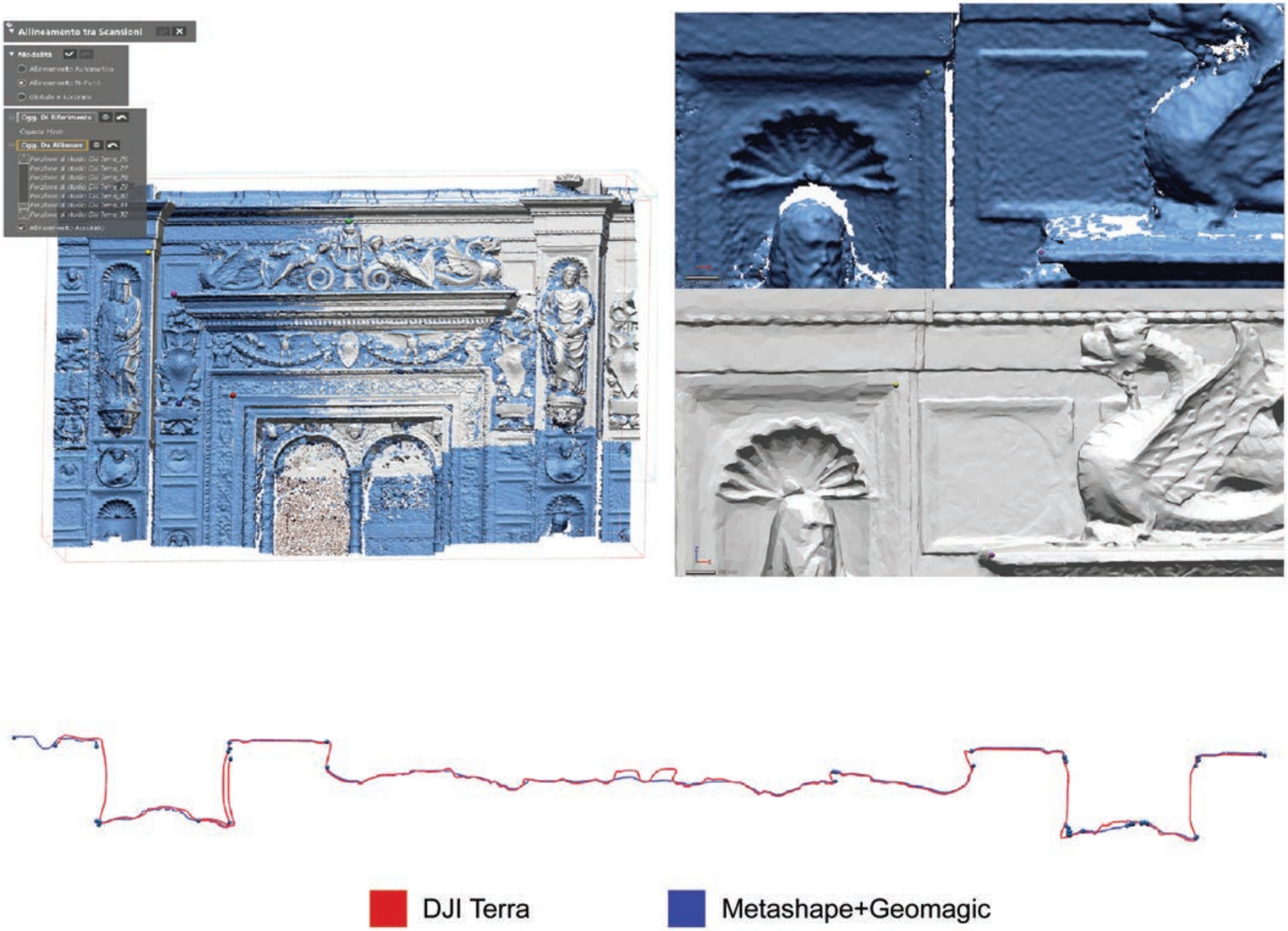

Figure 7. Alignment phase of the models through the tools made available by Geomagic Design X. The alignment, which took place by homologous points, was subsequently assessed through the creation of a section line passing through the window lintel. Through it, you can read the geometry of the architectural element and have a first comparison about not only the alignment of the models, but also on the level of detail of one model to the other. In the central portion, it is possible to read a difference in the construction of the DJI Terra model compared to the Metashape. In particular, DJI Terra has reconstructed more accurately details that Geomagic has not been able to elaborate on. This may be due to an error in the construction of the point cloud on Metashape, which failed to recognize differences in level on the facade near the sculptural details, despite the high degree of detail set during the image processing phase.

Figure 8. The average standard deviation of the model derived from DJI Terra compared to the model derived from Metashape with a tolerance range of 5 mm on a maximum deviation of 20 mm. It is noted that most of the surfaces included an irrelevant deviation, except for some areas where the deviation is substantially influential.

Figure 9. Critical issues encountered during the mesh comparison phase. On the left, the misalignment between the two meshes near the left sculptural apparatus is evident, on the right, some inaccuracies on the alignment of the models in the area on the right of the object of study, in which the maximum error varies between 7 mm and 12 mm.

experimentation phase in the production of 3D models of the *Certosa di Pavia* artifacts.
In particular, the modeling process will be able to experiment and compare the results of the numerous software on the market, evaluating which of these is configured as the most valid tool for knowledge of architecture and which allows to integrate an already consolidated metric reliability, a high degree of detail.

Credits

The research project on the Certosa di Pavia factory was developed within the DAda-Lab research laboratory of the University of Pavia (headed by Prof. Sandro Parrinello, scientific coordinator Dr. Francesca Picchio) which since 2016 has started numerous acquisition campaigns in the various rooms of the complex, aimed at the digital documentation of the religious complex, with an analysis that from

the large architectural scale descends to the greater detail of the stone sculptural apparatuses of the facade of Santa Maria delle Grazie. Those research were enforced in a collaboration between DJI Enterprise and the University of Pavia for the development of research activities, and the promotion of the different ways of using drones for cultural heritage. This collaboration is based on the "Agreement for the development of research activities about the digital documentation of cultural heritage and landscape using drones" between the Department of Civil Engineering and Architecture of the University of Pavia and iFlight Technology Company Limited, signed in February 2020, lasting three years.

The writing of the paragraphs 1 and 2 is due to Silvia La Placa, and the writing of the paragraphs 3 and 4 to Francesca Galasso.

Note

1 Cfr. Lo Brutto, M., Garraffa, A., & Meli, P. (2014). U*AV PLATFORMS FOR CULTURAL HERITAGE SURVEY: FIRST RESULTS. ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences*, 2, 5, 2014, pp. 227-234.

2 Cfr. E. Marchiafava, *Assessorato al Turismo della Provincia di Pavia,* (2012). La Certosa di Pavia (pp. 2 -15).

3 The RTK (Real-Time Kinematic) system provides satellite positioning in real-time, and today it is used (among others) for hydrographic and surveying surveys, achievable thanks to the GPS, GLONASS, and Galileo signals, where a single reference station Delivered in real-time with centimeter-level accuracy.

4 The façade documentation activities were carried out with a terrestrial Z + F IMAGER® 5006h scanner with phase difference acquisition technology. In particular, the point cloud, recorded through the use of the Leica Cyclone software, presents a diagnostic report which highlighted an average collimation difference of the targets of 3 cm taking into account the entire complex of the Charterhouse (See Becherini, De Marco 2016).

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ABSTRACT

The use of drones has the potential to reduce the time and costs of conventional techniques employed for field survey of cultural heritage buildings. This research explored the processes necessary to convert the most iconic building of the University of California, San Diego, the Geisel Library, into an H-BIM model. The main result findings of this work is to create a model can be used for two main purposes: to collect information which can protect the cultural significance of the building and achieve a virtual tool that can be used to better define a restoration strategy.

Keywords:
Geisel Library, drone, UAV photogrammetry, H-BIM, Modelling, Cultural Heritage.

UAV for mapping historic buildings: Geisel Library of University of California, San Diego

1. Introduction

The need to preserve Cultural Heritage and to have a complete documentation of historically significant buildings is an ever more current necessity. Unmanned Aerial Vehicles (UAV) systems can be used to document existing structures, in particular for structures characterized by areas with difficult access (Newcome, 2004). Born in the military sector, in recent years the use of drones has spread mainly in the architectural and archaeological survey sector.

The most advanced studies currently focus on the image processing phase due to the high number of images necessary for a complete coverage of the study areas, comparing software deriving from Computer Vision and classic photogrammetric programs.

Digitization methods and the creation of 3D models can be employed safeguarding cultural heritage. In particular UAVs, equipped with high-resolution cameras, represent an emerging technology for the collection of survey data useful for construction of photogrammetric models (Vacanas et al. 2015). The processing of the images captured with drones, processed with SfM algorithms, results in the generation point clouds that can be used as a reference for the creation of an H-BIM model (Historic Building Information Modeling) (Oreni et al. 2017). In this case, Agisoft's Metashape software was used for image processing. This study aims to create a digital model that can be used as a repository of all information useful for the complete description of the artefact, such as: geographical location, geometry, properties of materials and technical elements, the construction phases described over time, the operations of planned maintenance and all the collection of material that can be useful for the perfect understanding of the building. The case study identified is the Geisel Library, a library located within the University of California's San Diego campus (Figure 1). Being an existing building and not a new construction, it wasn't possible to use preset

Figure 1. Geisel Library, located within the University of California's San Diego campus.

parametric objects but it was necessary to build new objects to create a library of data useful for the construction of the model. In addition, some analyzes were performed in this work to assess the metric accuracy of the orientations based on the variation of the image acquisition scheme to verify the 3D models and orthophotos produced. This is the new challenge of 3D digital modeling: the modeling of information on existing and historic buildings.

1. Case of study

The case study identified deals with the most iconic building within the University of California campus: the Geisel Library (Figure 2). Geisel Library is located in the center of the UC San Diego campus and it houses more than 7 million volumes to support the educational and research objectives of the university. The Geisel Library was designed in the late 1960s by William Pereira, an American architect from Chicago known for his futuristic designs. As a young man, Pereira worked as draftsman and architect's assistant, and supported himself as a painter and illustrator. He graduated from the University of Illinois School of Architecture in 1931. After graduation, at the beginning, Pereira worked for the firm of Holabird and Root and subsequently he opened the firm of Pereira and Pereira with his brother Hal.

The captivating shape of the building is inspired by a tree, from whose roots, in the basement, the entrance has been obtained, whose cultural life leads the visitor to visit the upper floors. The Geisel Library building is a composite reinforced concrete structure with eight floors with a height of 110 feet (34 meters) and at the widest point of 248 feet wide (76 meters). The site for the Geisel Library was located at the geometric center of the campus at the crest of a small canyon. The canyon, planned to be kept as an open reserve, is visually exposed to the Pacific Coast Freeway to the northeast. For this reason the library is a visible and symbolic landmark of UCSD.

The structure of the building incorporates a frame of reinforced concrete cast on site on a square module for all floors.The overall finish is in unfinished exposed concrete with anodized aluminum window walls, containing 38,000 square feet (or approximately 3520 square meters) of flat glass. The building was built with 17,000 cubic yards of concrete (around 13,000 cubic meters). To support the load of this cantilevered building, there are four massive tapered pillars per side. These pillars tilt upwards 45 degrees to the sixth level and are literally linked to the rest of the building structure both on the fifth and sixth levels with 300 1/4 inch high-strength post-tensioned steel rods in diameter (equal to 6.35 mm in diameter). Much of the structure is exposed to view with ribbed ceilings that support the large glass walls (William L. Pereira & Associates, Planning & Architecture,1969).

2. The survey procedure

The survey campaign was carried out with drone photogrammetry (conducted by Eric Lo). The photogrammetric survey with drone is operated through Remote Piloting Aircraft Systems (RPAS,

Figure 2. Geisel Library.

commonly assimilated to the term "drones"): the aim is to provide a photogrammetric model, or a three-dimensional model measurable, in scale, of the detected object, which reports all the geometric, chromatic and material characteristics (Aicardi, Chiabrando, Grasso, Lingua, Noardo, Spanó, 2016). Digital photogrammetry with drone is the survey technique that allows one to obtain metric and geographic information, shape and position, of three-dimensional objects, such as land and buildings by processing digital photographic images (Anderson, Gaston, 2013). The point is the fundamental entity on which the photogrammetric survey method is based. The recognition of so called "homologous" points in the frames, in fact, allows their alignment and subsequent processing of a "point cloud" model: a model in which each point is uniquely determined by three spatial coordinates X, Y, Z and three RGB color coordinates (Themistocleous et al. 2016). In particular, for the survey of the Geisel Library, the brand of drone is DJI and the model is Phantom 4 RTK (Figure 3) with the firmware version 02.01.0012, released on 22-05-2019, was used, the latest available on the market at the time of the survey.The innovations introduced by the new firmware released are an option to control the terrain rendering map display in the app.

When planning a terrain awareness operation, users can enable or disable the display in general settings and fixed the issue where the waypoint operations could not include the absolute altitude when exporting the operations.

The main technical characteristics of the aircraft are: takeoff weight, 1391 g; diagonal distance, 350 mm; max service ceiling above sea level: 19685 ft (6000 m); max Flight Time Approx., 30 minutes.

The main technical characteristics of the camera are: sensor: 1″ CMOS; effective pixels, 20 MP; lens, FOV 84°, 8.8 mm/24 mm (35 mm format equivalent: 24 mm); photo Format, JPEG; supported SD Cards MicroSD, Max Capacity: 128 GB. The flight plan parallel to the ground surface was planned for 25 m of AGL[1] to obtain a GSD[2] of 0.68 cm / px at takeoff height.

Figure 3. Drone DJI Phantom 4 RTK.

Altitude (m)	Gimbal pitch (deg)
5	13
9	5
12	0
16	-8
22	-15
30	-24
39	-30
52	-40

Table 1. Inclinations of the gimbal according to the altitude of the drone.

The gimbal was aimed downward 60 degrees from the horizon to provide oblique views and both front and side overlap set to 80%. Since it is no possible to plan a flight model parallel to the vertical facades or to define 3D flight paths in GS Pro, a manual flight of a path in orbit around the Geisel Library has been chosen, keeping it centered on the camera body (Zhihua et al. 2014). More specifically, the flight carried out provided for semicircular arches at approximately 8 different altitudes with specific angles of the gimbal to make the best photographic coverage. Below are the inclinations of the gimbal according to the altitude of the drone, repeated on the four facades of the building (Table 1) (Figure 4, Figure 5, Figure 6).

4. Processing images

The processing of the images acquired for the purpose of generating the point cloud was carried out through

Figure 4. Survey campaign with drone.

the Agisoft Metashape software (new release of the Agisoft Photoscan software) Metashape allows for the creation a polygonal models. Through feature extraction and matching operations, as the recognition of Tie Points which are common to more images, and their gathering thanks to Scale-Invariant Feature Transform algorithm we achieved a three dimensional model composed by TiePoints. This model is useful for the orientation (sparse point cloud) from which the dense matching followed: during this phase the algorithm allowed to generate a points made model of the interested object called dense point cloud, once analysed orientated photograms with an established field partition (Rodríguez-Moreno, Reinoso-Gordo, Rivas-Lopez, Gomez-Blanco, Ariza-Lopez, Ariza-Lopez, 2018). Then the scaling and referencing of the model was done by means of measurements or known points recollected in the field, with mesh creation and projection of HD oriented pictures on the achieved mesh model (Chiabrando et al. 2017).

The images that have been processed are 1668.

In particular, the phases that led to the construction of the point cloud, which was then imported into the Revit software, are as follows: align the photographs with each other producing a cloud of points (sparse cloud); camera calibration, adaptive camera model fitting; building dense point cloud: once the whole set is aligned and the error is distributed, it produces a dense cloud building, through the classic stereophotogrammetry formulas. Once the point cloud was generated, it was exported in a.rcp format model, compatible for importing into the Revit software (Figure 7, Figure 8, Figure 9) (León-Robles, Reinoso-Gordo, González-Quiñones, 2019). The accuracy of the model created from the survey with drones is highly variable, and the causes are still not fully understood. A number of factors may affect the precision of UAV-derived orthoimagery and digital elevation data, such as flight parameters, for example AGL and GDL, orientation of the camera, the camera's focal length, flight speed, direction, image quality, processing software, the morphology of the studied area, and the type of vehicle. Short focal length lenses used for low altitude flights introduce considerable geometric distortion into Unmanned Aerial Systems - derived imagery, risking to adversely affect accuracy. It has been shown that appropriate settings can reduce the positioning error of SfM products, but processing workflow and accuracy assessment methodologies need to be optimized and standardized. The model was compared to a previous model generated with lidar.

Overlapping the cloud of point generated with aerial photogrammetry with that generated by lidar, it appears that the difference is 0.80 inch (about 2 centimeters) on the edges of the different floors.

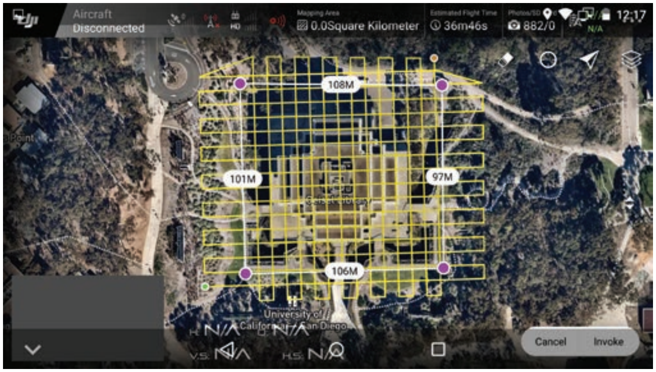

Figure 5. Double lawnmower pattern flown from the top of Geisel Library.

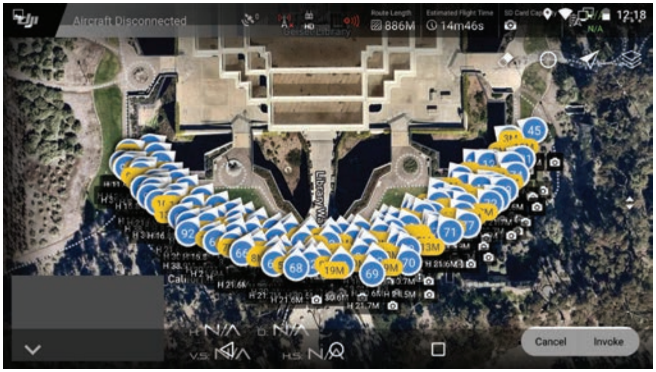

Figure 6. Flight from the south of Geisel Library.

The creation of a kind of model which is measurable and navigable is clearly a great advantage not only to document and monitor buildings, but also to the evaluation procedure, intended to prevent and reduce the vulnerability (Donato et al. 2017).

5. Conclusion

This document describes an integrative procedure for obtaining an H-BIM by integrating different detection techniques to obtain the best results in terms of precision of the parametric elements (DBA) (Fryskowska, Stachelek, 2018). The Geisel Library represents a very stimulating study object due to its particular morphology. By integrating the SfM procedure for UAV for the external survey and the use of known floor plans for the interior, the H-BIM model of the structure was possible overall (Angelini et al. 2017). But if the design in BIM has already been practiced in the field of new buildings for some years, totally changing the approach to the design, its application in the field of Cultural Heritage and historical construction therefore on the existing building heritage is still not widespread, although it is however increasing, both in research field both in professional field (Adami, Scala, Spezzoni, 2017). Much still needs to be studied in depth, but certainly the combined methodologies that involve surveys with drone and BIM parametric modeling can profoundly change the processes of knowledge, monitoring and intervention at all levels, from new buildings, to historic construction, to archaeological sites (Bianchini et al. 2016).

6. Future developments

The model case of study is in a preliminary phase which will continue in the coming months, with the generation of the internal elements starting from existing CAD drawings, generated following a recent survey of the building carried out in 2018. Various techniques will thus be merged generation of the BIM model: one starting from the photogrammetric campaign with drone and one starting from and existing drawings.
Moreover, although point clouds are typically meshed and textured, the point data can also support a versatile digital scaffold or 3D/4D database.
Viscore, a point-based visual analytics engine, is being developed at the Qualcomm Institute. Though not the first application, both the 100 Island Challenge Project and the Hoyo Negro Project are excellent examples of how Viscore enables research far beyond the visualization of point-data. The researchers used a data set, acquired at different times for the duration

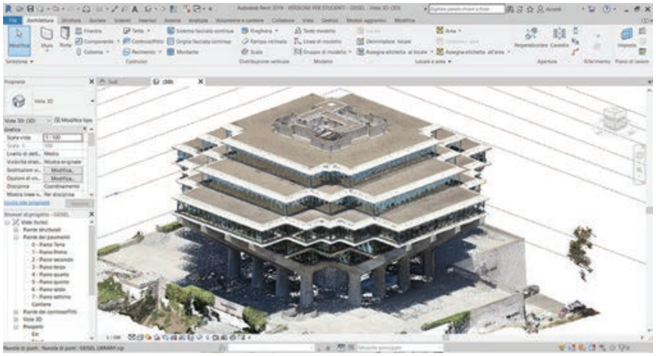

Figure 7. Cloud of point in Revit software.

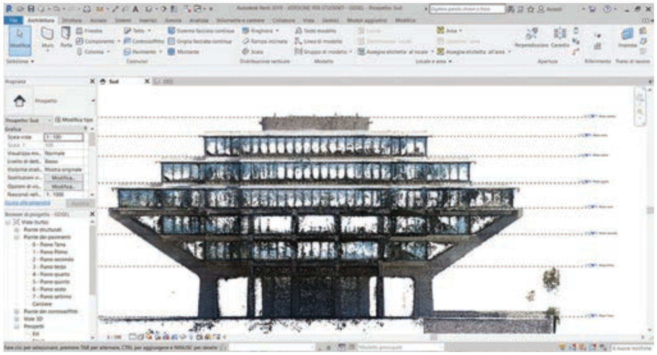

Figure 8. Cloud of point in Revit software.

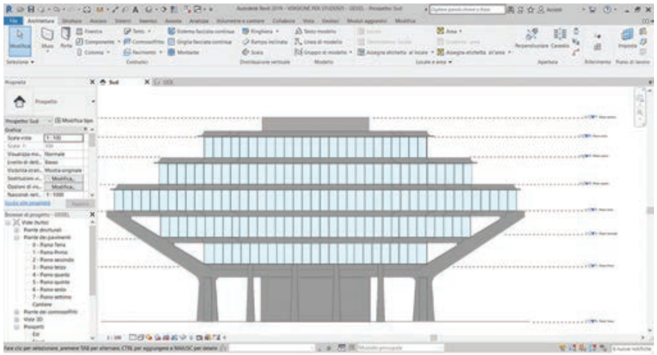

Figure 9. Model Revit software.

of 8 years, taking thousands of images of the same area of the coral reef. These images were processed with software to create 3D photographic mosaics of the ecosystem. The researchers combined this imaging technology with a new visualization software, Viscore, which allows users to review the thousands of photographs that make up the mosaics. The team of the Cultural Heritage Engineering Initiative of the University of San Diego initially developed Viscore to allow new forms of exploration and analysis of big data, allowing specialists and the public to be able to explore this heritage, however the potential that this software can have is clear, also on the built heritage. For this reason, the Viscore will be tested also on the Geisel Library case study.

Note

1 AGL (Height Above Ground Level) is the height measured with respect to the underlying surface of the ground.

2 GDL (Ground Sample Distance) is the distance of the soil sample and the distance between the central points of each sample taken from the ground. Since these are digital photos, each sample is a pixel. The GSD is therefore the size of each pixel on the ground.

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ABSTRACT

UAVs in architectural survey are nowadays widely used to collect detailed geospatial information. The ever-increasing diffusion of drones, however, is still often accompanied by a negative perception. This perception is related both to the object itself and to the privacy issues concerning the acquisition and storage of potentially sensitive data. These concerns and the cultural and social environment in which drones are used have a strong impact on how local communities perceive them. This paper wants to show how local communities in diverse urban contexts, such as the case studies of Pavia and Bethlehem, include similarities in the perception of UAV-conducted investigation operations.

My neighbour drone. The social perception of UAV survey operations in the urban contexts of Bethlehem and Pavia

1. Introcuction

In the last decade, the massive diffusion of consumer drones made them available to a broad public and for various purposes, from recreational to professional ones, such as the documentation and investigation on built heritage.
The innovations brought by this technology are mainly due to the simplification and inexpensiveness in the process of image and video data that can be easily stored and shared.
The main innovation is represented by the possibility of a different point of view for the acquisition, changing the standard one allowed by the size and sight of users. Traditionally all the operations of imagery acquisition (such as photography, documentation processes or surveillance) are mainly carried from a horizontal point of view, allowing to capture what is visible from the position of the operator (Figure 1).
Conversely, drones introduce a disruptive shift in the point of view that moves from the level of the street – or the standard height of buildings – to the sky: such

Figure 1. Drones invade the public space, for various reasons we are getting used to seeing small airplanes flying near monuments or places of value as well as near landscapes and particularly suggestive places.

Figure 2. The use for technical investigations allows the drones to approach critical situations that would otherwise be identifiable only with the construction of special scaffolding. In the figure: the surveys of the Central Palace of the University of Pavia for data acquisition for SfM photogrammetry and diagnostics.

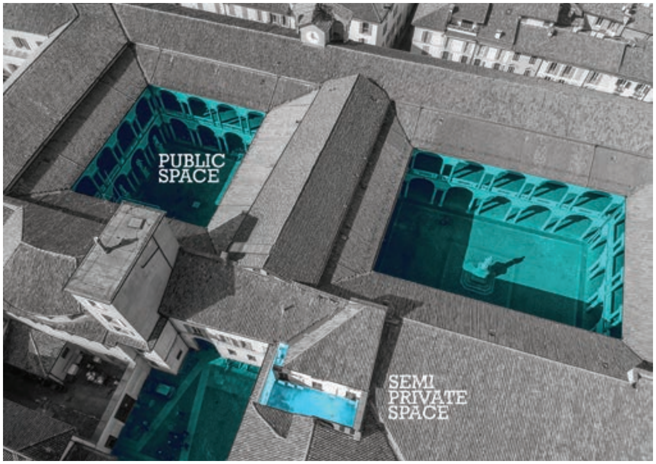

Figure 3. The change of perspective introduces the problem of flying with drones over private spaces. Legally, in Italy, the ownership of a land is not always related to the ownership of the airspace.

change provides the possibility to embrace a wider view and immerse into a vision inaccessible to common users before the advent of these technologies.

To begin with, a similar use of drones offers many opportunities for professionals and practitioners of the architectural and landscape survey, enabling access to an innovative point of view on the object to be surveyed. Moreover, it is possible to survey and analyse areas which are usually hard to observe because inaccessible from public spaces – such as roofs (Parrinello & Picchio 2019).

On the other side, shifting the level of acquisition alows to "relocate the boundary between what is public and what is private" (Choi-Fitzpatrick 2014): the result is a new level of permeability of those spaces that were believed to be "protected" from the observer's eye, and now become potentially visible, as any other public space.

Implications of the usage of drones in acquisitions and survey are to be considered on a social aspect as well, namely in the arise of concerns about privacy and usage of collected data. The feeling of vulnerability has a great impact in the social perception of drones, and it must be taken into account during survey operations, particularly in dense areas, historic cores and inhabited areas in general (Figure 2).

2. The social implications in the use of UAVs

Even though in recent years researches on this topic have risen in number, it is not appropriate to consider it a consolidated line of research in the academic field. A first assumption rising from the analysis of the state of the art is that the perception of this technology is not always positive, even when considering civilian applications; the population is concerned by privacy breaches and leakage or misuse of collected data.

A unified and coherent policy framework has not been developed yet, especially in regards of the collection and use of data, and this circumstance does not contribute to the feeling of privacy in the concerned communities.

In addition to privacy concerns, other factors affect the perception, be it negative or positive. Some of the most significant aspects on which recent researches have been focusing are the semantic and the usage of sensitive data: the first aspect relates to how different terminology defining UAVs have an impact on their perception; the second one aims to determine how people perceive their privacy to be undermined by the unregulated use of drones (Figure 3).

2.1 State of the art: semantic and perception

Until now, systemic studies on the characterization of public perception of drones and their main concerns are yet to be conducted (Clothier 2015). Despite this, a line of research concerning the variation of risk perception according to the terminology used to define UAV technology is being developed in academic and research field. Different terms can generate different responses on common perception therefore configuring people's acceptance as one of the main factors in both the widespread use of drones as tools and for the definition of objectives of the safety rules.
One of the researches (Clothier 2015) aims at defining how differences in risk perception are associated with differences in psychometric risks. According to the research, people have a different perception of risks depending on the different classes of drones: risks associated to small drones and bigger drones can be distinguished.
The perception is described as an elaboration of "physical signals and/or information on potential risks associated with a specific technology, and the shaping of a judgement on gravity, probability and acceptability of this technology" (Renn 2013).
Another research (Sjöberg 2012) suggests that terminology and semantics have a significant impact on determining how the public perceive risks.
Terminology is a significant factor in the drones' industry: common terms used to name drones are unmanned aerial vehicle (UAV), remotely piloted aerial system and autonomous aerial vehicle. It is widely recognized in the industry that negative concepts are more commonly associated with the term drone. It is no coincidence that the most popular drones' manufacturers name their products with terms such as aerial cameras, flying cameras or aerial photography system.
The research by Clothier, 2015, focused on this aspect by analysing press articles about drones and the various names used to define them.
A text analysis tool has been used to inspect the images, determine the themes represented and their relationship with the concepts contained. The study demonstrates that many potentially negative concepts are associated with drones: apparently, the most common theme emerging in the examined articles is "killing", and there are more chances that the words attacked, killed, death, war and strikes coexist with the term drone than with the term unmanned. Supposedly, the public will operate the same association with the various terms proposed by the media, and these mental associations will affect the public perception of risks. Besides, an Italian research (Ferretti 2018) addresses "the objective to investigate the debate on the topic of drones in the Italian press in the period between 2015-2017". Some Italian newspaper have been selected, namely La Repubblica, Il Giornale, La Stampa and Il Fatto Quotidiano, in order to cover nationwide and politically different views: the study proves that "semantically speaking, the military dimension is still predominant", even if with different intensities. The statistical analysis shows that there are "occurring and repeated parts relating to the military dimension, that characterize the language used in the public debate regarding the topic of drones", this strongly influences the common perception in regards to the terms used.

2.2 State of the art: sensitive data

During a research carried on in 2017 in the United States (Chang 2017) questions have been asked to a group of 20 people about how they perceive drones as affecting their personal privacy and safety expectations. The results of the respondents' interactions with drones confirmed the conclusions derived from the previous

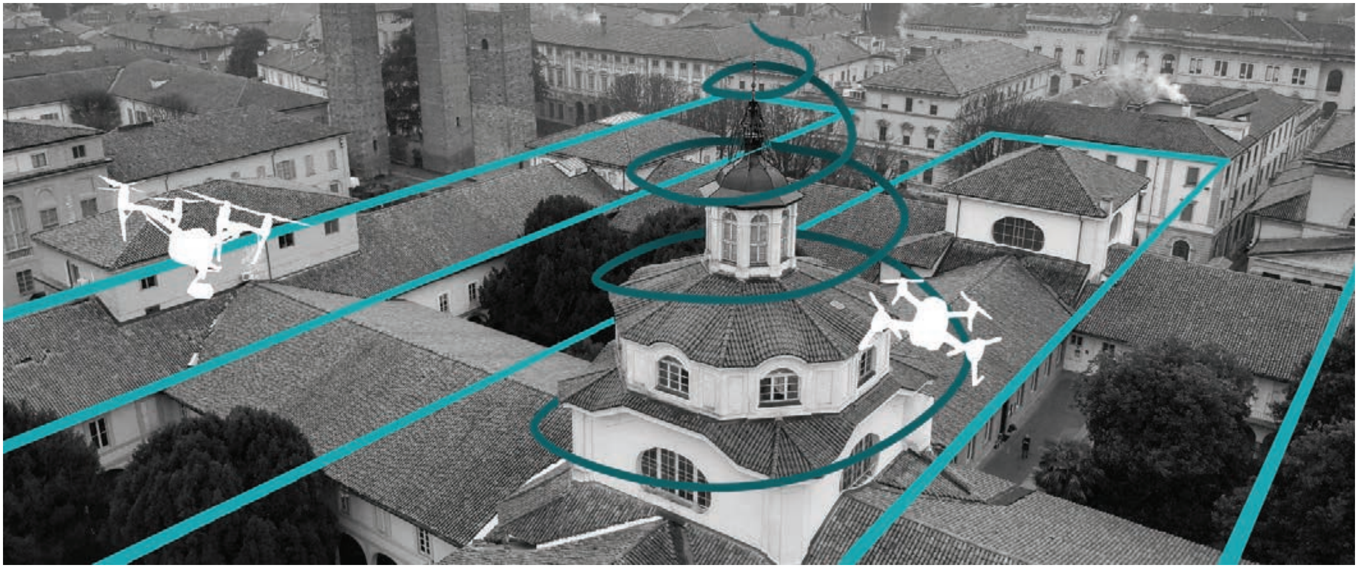

Figure 4. Compliance with the principles of the GDPR is guaranteed by the choice of tools and from the principle of minimization of privilege, which requires the use of the data collected only within the limits of the achievement of the purpose for which they were requested and only by the people involved in such work. The need to respect these limitations is one of the factors.

studies (Wang 2016): concerns about invasion of privacy, fear of personal injuries and unwillingness to disclosure personal information in presence of drones are the most common negative responses found during the study. Moreover, the feeling of reluctance is amplified by the design, colour, size, speed and noise emitted by the drone. All these features influence the people's perception regarding privacy and safety.The traditional concept of privacy, as "the right to confidentiality of the person's private life" is affected not just by visible and close threats like people and objects, but also by civil drones (Rao 2016). In addition to that, the person's attitude towards the drone depends not only on the object itself, but also on where the interaction takes place: when in a public space, citizens do not expect the same privacy as they do in private space.

Drones disrupt privacy expectations, especially in the context of urban survey, since even if they operate in a public space, they are able to capture images and sounds that are not usually accessible to the public. The legal gap could allow for an unjustified and unpunished surveillance on private spaces. Current privacy laws state that it is not allowed to collect images of the inside of a private space or building, even if the camera is located on the outside. In the architectural and urban survey this circumstance requires a strong attention: uncareful use of drones, even if they are at sight and flying over the operator's property area, can bring to privacy breaches because of a monitoring activity which is not allowed by law (ENAC 2013) (Figure 4).

3. The case studies: Bethlehem and Pavia

Research projects about survey and documentation of urban fabric are case studies that effectively demonstrate how the relationship between the community and UAV instrumentation can generate critical issues in the practice of data acquisition.

The two cities chosen as reference, Pavia (Italy), and Bethlehem (Palestine), are the setting in which different experimentations are taking place: although different in project objectives they have in common the need to acquire aerial imagery of particularly large areas (Morandotti 2019; Parrinello 2019)[1].
The two urban contexts are profoundly different both from the social and cultural point of view, but common behavioural aspects have been observed in the interaction between citizens and drones used in the survey operations. The political and social situations of the two case studies offered evidence of what the aforementioned research pointed out about the social perception of UAVs: in the city of Bethlehem public reactions are amplified and the concept of “safety risk” appears to have a tangible significance.
The citizens demonstrated suspect towards the drones: the suspect was amplified when the survey operations

Figure 5. The morphological context of Bethlehem is very complex compared to Pavia with a mixing and compresence of private and public spaces; the survey required high-altitude flight plans for large-scale photographs and punctual investigations with close-up shots of the buildings.

Figure 6. From the drone is possible to carry out a census of the technological aspects investigating some degradation realities concerning private space.

took place in areas with a strong private character (cfr. previous research), that are not usually investigated for cultural purposes.

In the case of Bethlehem this aspect is particularly evident: the concerns towards the instruments remark the fact that in this territory drones are perceived mainly for their military purposes.

Reluctance towards the instruments has also been expressed: despite the use of ultralight models (e.g. DJI Spark), physical attacks via throwing stones and objects have been carried out in order to damage the drone (Figure 5).

It has been observed that the perception also varies according to the age, as resulted from several researches (IMECHE 2019, Choi-Fitzpatrick 2014).

While younger population usually accept the use of the instrument with curiosity and ingenuity, elder population is less aware of the instrument and its functioning remaining culturally distant from previous experience (Figure 6).

UAV instrumentation has been used for the documentation of important and culturally valuable complexes both in the city of Pavia as well as in Bethlehem (Morandotti 2018).

The case study of the research is set in particularly dense and populated urban contexts. In the Lombard city the results of the observation have highlighted a different reaction in the local community, showing in most cases a positive attitude towards the instruments. A general perception of safety with regards to the potential threats deriving from their use have been observed: local community showed interest, willingness to question about details on the instruments and the purpose of the operations, and in some cases, curiosity about the images being acquired.

This case study showed, such as in Bethlehem, a variation in people's perception according to their age: younger and adult population is particularly interested and curious about the drones itself and the object of the survey. In some cases, elder population showed concerns about safety and risks of injury, but they demonstrated neither concerns about privacy issues nor hostility towards the use of the drones.

In general, it has been evident that communities living in a peaceful and quiet socio-political contexts perceive the survey activities with drones as the documentation of a public space, with less concerns on the invasion of private spaces is a minor concern (Figure 7).

4. Conclusions

While UAV instrumentations provide undoubted advantages in accurate and rapid imagery acquisition,

issues and concerns about the ethical implications of their usage are rapidly growing. In the context of urban and architectural survey the topic of privacy and storage of collected personal data is a critical issue to be considered when planning documentation processes. The case studies pointed out that the concept of privacy – also intended as control over activities and behaviours of the population – varies according to the geographical, socio-political and cultural context.
The ongoing researches in this field show that the vision of drones brings an initial lack of confidence, both in public and private situations.

Figure 7. The urban and morphological context of the city centre of Pavia has a roman structure and compresence of private and public spaces clearly separated from each other; in this case too, we proceeded with high-altitude flight plans and close-up shots of the details of the buildings.

Furthermore, as stated by several researchers (Chang 2017; Clothier 2015) both the semantics, the aesthetics and sound features of the drone affect the perception and can guide the public opinion towards a negative meaning of the instrument.

This misalignment between perceived and real use of UAV instrumentation (Geavert 2018) can bring to reluctant responses and, in extreme cases, to hostility towards the documentation operation, as observed in Bethlehem.

In order to mitigate and improve the common perception of drones, a possible action of is via an action of divulgation of objectives and collected information as to raise the awareness about the usefulness of the documentation operation.

The ability of drones to offer a new point of view of familiar places can offer the population a reason to get involved with technology. Architectural heritage is experienced in everyday life by local communities from the point of view of the human eye: a new vision of these places can help raising the awareness of their value, their critical issues and, consequently, the need to properly conserve and manage them.

The empowerment process has a strong potential, especially in complex urban contexts, where private edificatory actions sometimes have a negative impact on the image of the city.

That said, raising the awareness of the community and the perception of their active role in the determination of such image can contribute to the quality of the planning and management action of the city.

Note

1 The research laboratory DAdaLab of the University of Pavia is carrying two research projects concerning the urban investigation of the two case studies discussed in the paper. One of the Pavia-based projects is the documentation and analysis of the monumental complex of University's Central Palace. Its size makes it comparable to a urban context (cfr. Picchio F., Doria E., Miceli A., University of Pavia's Central Palace as a place of identity and connection. Documentation and definition of databases for its valorisation. 42° Convegno Internazionale dei Docenti delle Discipline della Rappresentazione. Congresso della Unione Italiana per il Disegno, 2020. In course of publication). The other one concerns the monumental Basilica di San Michele, in the heart of the city's historic area. The case study of Bethehem, Palestine, is the research and cooperation project "3D Bethlehem. Management and control of urban growth for the development of heritage and improvement of life in the city of Bethlehem", in which extensive documentation operation took place on the entire historic fabric of the city (Cfr: Parrinello S. (2019). (a cura di) *3D Bethlehem. Management and control of urban growth for the development of heritage and improvement of life in the city of Bethlehem*. Vol. 1.Firenze: Edifir Edizioni Firenze s.r.l., 2019. ISBN: 978-88-7970-946-0).

Those research were enforced in a collaboration between DJI Enterprise and the University of Pavia for the development of research activities, and the promotion of the different ways of using drones for cultural heritage. This collaboration is based on the "Agreement for the development of research activities about the digital documentation of cultural heritage and landscape using drones" between the Department of Civil Engineering and Architecture of the University of Pavia and iFlight Technology Company Limited, signed in February 2020, lasting three years.

Credits

The writing of the paragraphs 1 and 3 is due to Alessia Miceli, and the writing of paragraphs 2 and 4 to Elisabetta Doria.

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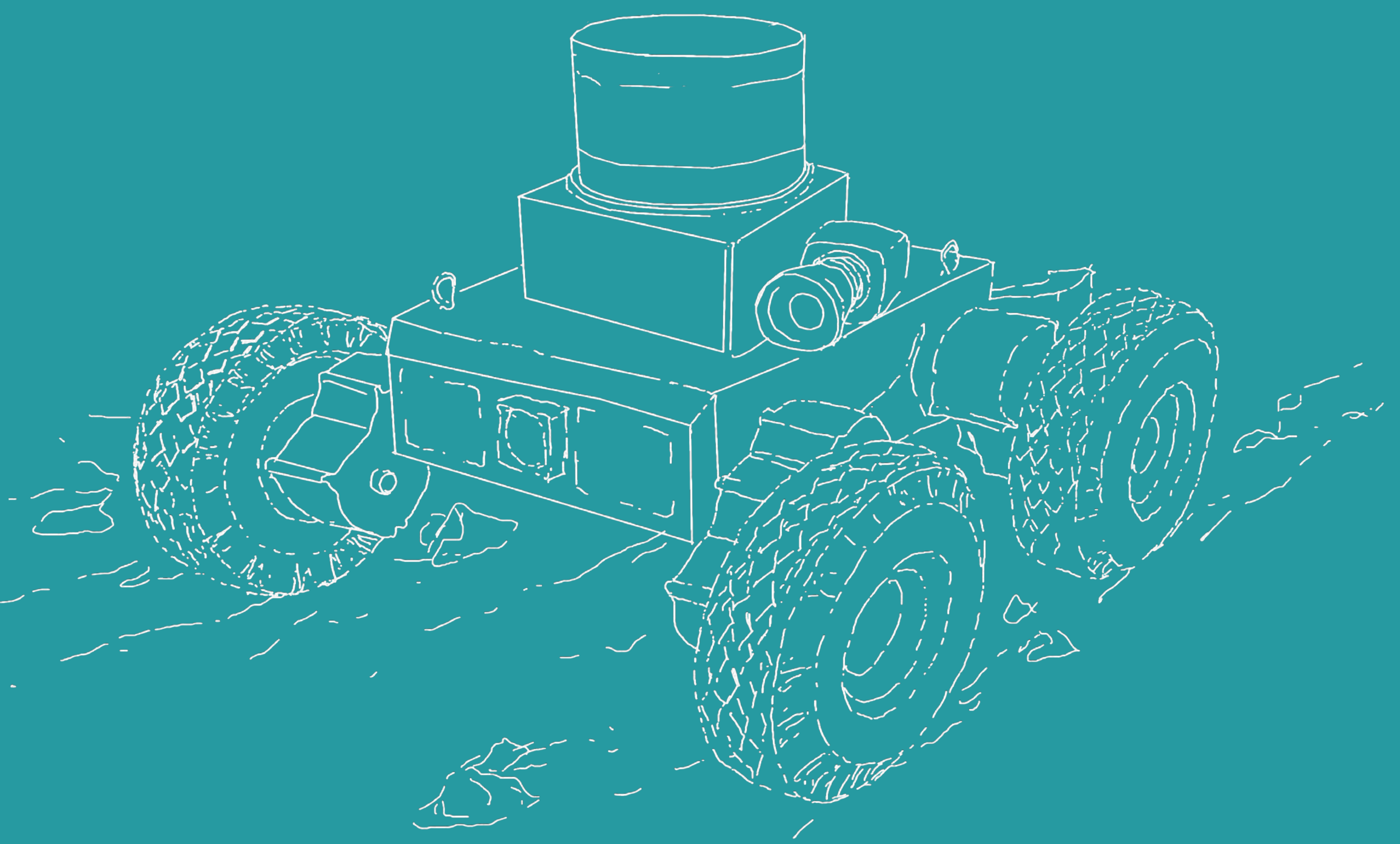

TOPIC

Acquisition systems for critical and emergency areas, UAS monitoring and indoor inspection operations. New approaches to fast, low-cost and open sources survey

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SfM survey, point cloud comparison, structural diagnosis, medieval towers, Pavia.

ABSTRACT

The application of UAVs amplifies the potential for documentation and monitoring in the context of historic buildings, permitted by the competitive characteristics of acquisition and expeditious analysis of morpho-metric data. This possibility assumes a particular key role in those contexts of emergency due to structural instability which represent a risk for the safety of buildings and users in the urban context. The case study of the Clock Tower of Pavia, in the historical complex of the Central University, experiences integrated surveying and monitoring processes with UAV in the urban critical scenario for the mapping of structural surfaces, the certification of instrumental morpho-metric reliability and the diagnosis of deformations and structural instabilities present on the masonry block.

Mapping solutions and reliability control in UAV's photogrammetry for structural emergency. The multi-instrumental survey of the Clock Tower in the historical complex of University of Pavia

1. Introduction: historical structures, emergency and UAVs

The requirement of frameworks for survey and non-invasive documentation of historic architectural structures has established an emergent strength and growth in recent decades, as a good practice of knowledge of the built heritage for the safety of buildings and of their users (Will, Meyer 2007; Moropoulou et al. 2013). The coexistence of the realities and transformations of built heritage in the context of the historic centres, especially in the cultural landscape of European cities and their infrastructures, has highlighted the risks associated with historic constructions, their stratifications and functional adaptations, often also due to a neglected maintenance on the integrity of resistant systems and for the overloading of mechanical constraints (Binda et al. 2006; Roca et al. 2010) or for the dangers associated with the occurrence of seismic and environmental events (Bruneau et al. 2003, Syrmakezis 2006; Elyamani et al. 2017). In this way, the protection of urban environments through the control of its buildings and monuments has oriented the administrations and technical committees in a renewed attention to appropriate monitoring practices of architectural structures. The products of the documentation on built heritage are expected to "anticipate", and not only "assist", the occurrence of damage events, such as failures and collapses, through the mapping of evolving damage and deformation states on the buildings surfaces.

The instabilities affecting an architectural structural system, linked to the lability of the building by mechanical phenomena developed during its lifecycle and state of conservation of the structure, often manifest an evident alteration of the materic continuity of the surfaces closely to the moment of crisis, when the emergency for the risk is maximum and the intervention opportunities are yet critical (Giuffrè 2000).

The attention to a planned monitoring practice, established as a prevention rather than an implementation service, is however marginal to the actions of management of the architectural heritage due to the considerable time and costs for its implementation, aimed at guaranteeing useful levels of precision and reliability for a correct diagnosis.

Within this framework of requirements, digital survey practices have faced in recent years an emerging request for methodological expeditiveness, acquisition and management of documentable data to produce information useful for safety and intervention operations. The provision of professional sensors for morpho-metric measurement, such as Laser Scanner, continues to support these practices in the scientific goals achieved on the reliability of the extended spatial data (Pancani 2017) and on the analysis of shape as a diagnostic investigation parameter (Parrinello, De Marco 2018).

At the same time, it is developing a finalization of photogrammetric terrestrial and aerial acquisition procedures (Multiyroso, Grussenmeyer 2017) advantaged in the capability of global overall documentation of complex built configurations with expeditious methods and economic tools (Parrinello, Picchio 2019). This is the case of the application of UAVs for geo-referenced

Figure 1. Aerial view of the historic center of the city of Pavia, where the dense urban aggregates, by Roman urban plan, are characterised by the punctual presence of the medieval towers, closely related to the surrounding building and residential area.

Figure 2. The Clock Tower between 1935-1940, incorporated within the south part of the Menabrea military station, built in expansion of the historic university complex of San Matteo Hospital. Today, together with the Fraccaro Tower (left) and Maino Tower (right), it represents one of the tallest medieval towers in the city, characterizing the urban space of Leonardo Da Vinci Square. the dense urban aggregates, by Roman urban plan, are characterised by the punctual presence of the medieval towers, closely related to the surrounding building and residential area.

photogrammetric mapping to the masonry structures of monuments, infrastructures and urban aggregates (Sankarasrinivasan et al. 2015; Bacco et al. 2020), that with the precision of location and photographic quality can lend themselves to adequate instrumental calibrations for the control of the acquired data and its certification of measurement (Guarnieri et al. 2005; Friz et al. 2013), approaching the threshold and reliability standards of the structural legislation[1]. Another aspect concerns the operation of these acquisition tools in the context of flight regulations and critical areas[2], such as urban or congested ones, where the vehicle classes and the necessary qualifications cause heavy constraints on the personnel authorized for the operations.

In this sense, the production and availability on the market of light UAVs[3] that maintain high performances of camera and sensors[4] has opened the field of experimentation on data acquisition and processing protocols from non-professional tools, while expanding the users and the administrative operators enabled to apply widespread and frequent monitoring practices on specific built contexts, with bureaucratic expeditiveness and low risk on the field.

2. The case study: the medieval clock tower in Pavia

The case study offered by the medieval towers of the city of Pavia[5] highlights a particular risk context for the safety of the surrounding built heritage and urban life. The large structural masses set on reduced resistant sections are subjected to compression and crushing frameworks, that generate mechanisms of rapid propagation of instability along the vertical walls with widespread cracks, precisely where the documentation and monitoring operations are more difficult due to the high altitudes of development. The Clock Tower represents one of the main medieval towers preserved in the city of Pavia, whose construction dates to the 11th-12th century. With a square base of 5,2 meters on each side, it has a brick wall structure with a thickness of more than 2 meters[6], with regular courses of constructive holes on each side, and an elevation of 37 meters[7]. The compact block of walls, erected for noble prestige, owes its name to the presence of a plastered two-sided clock built between 1775 and 1792, still functional. The tower, with reduced openings on 3 entrances (one original walled on the north side, two more recent on the east side, walled, and west side, practicable) and 1-2 windows on each front, has undergone several building interventions on the external envelope, as the incorporation in the structures of the architectural complex of the Menabrea military station and then the subsequent isolation, with the demolition of the southern part of the complex from 1959 for the arrangement of Leonardo Da Vinci Square, in the management program of the complex and spaces of University of Pavia[8]. Following the unexpected collapse of the Civic Tower in 1989, the Clock Tower together with the other medieval towers of the city of Pavia was subjected to a monitoring program with fixed dynamic sensors, installed at the base of the tower, for the control of possible static movements of the block. In December 2019, following an intense atmospheric cycle, some portions of plaster and brick collapsed at the foot of the tower, with a high risk for people, and highlighting the danger on the state of conservation of the surfaces and top apparatuses. The Technical Office of the University of Pavia, responsible for the monument to the local Superintendence, required to define risk control and large-scale monitoring actions on the monument, thus DAda Lab. and PLAY laboratories of the Department of Civil Engineering and Architecture have been called for the organization of a documentation and analysis campaign of the masonry structure, requested as expeditious (acquisition and processing in less than 2 months) and with a low impact on the activities of the surrounding urban area.

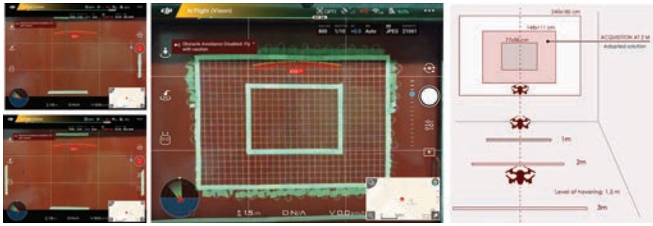

Figure 3. Indoor acquisition set for the planning of flight modes and distances to be implemented on site. The arrangement of a dense grid (5 cm) made it possible also to evaluate the distortion parameters present in the photographic frame of the DJI Spark, usually applied for sporting and non-professional purposes.

3. Activity and parameters planning for the site acquisition campaign

The documentation activity on the structural block of the tower provided for a specific multi-instrumental calibration and integration plan of digital survey practices. The main objective was to ensure the transposition of an adequate shape quality and precision of data to the description of the tower external surfaces, from the base to the top of the structure, with a photogrammetric survey from UAV[9].

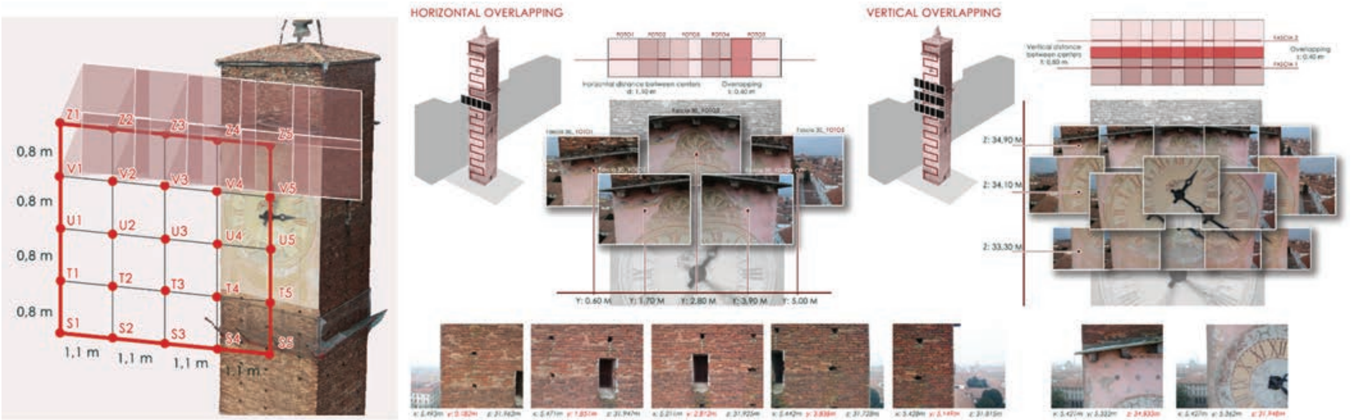

Figure 4. Arrangement of the geo-referenced grid for aerial survey and management of the acquisition trajectories, planned to guarantee a sufficient overlap of the photographic image for the subsequent SfM alignment of data.

The control of the density and the referencing of spatial data was central in the management of the on-site acquisition activities, characterizing on the one hand the resolution required in the geometric and colorimetric analysis of the single specific morpho-metric data, on the other the containment of the metric error and the global mapping correspondence between partial data in relation to the specific acquisition context, also guaranteed by the integration with spatial data by Terrestrial Laser Scanner (TLS). The survey activity with UAV was managed with the application of a light drone DJI Spark, which developed a high-resolution photo-mosaic campaign for each front. The choice of the UAV, linked to the requirements of fast survey and critical urban scenarios near the tower, provided for a careful preliminary planning of the acquisition strategy to be adopted on site, tested and calibrated with a simulation within the university laboratories. Through the arrangement of a specific acquisition set, it was possible to pilot the UAV in indoor mode at a height of 1,5 meters from the ground and with controlled distances of approach from the target surface, evaluating the photographic data acquired in positional hovering. The considered characteristics concerned the photographic detail required (distinction of the brick profiles and of the cracks), the geometry of the on-site acquisition context (radius from the tower block mainly less than 5 meters, and the presence of safety bulkheads installed at 25 meters altitude of the tower), the number of photos considerable with respect to the dimensions of the fronts (193 square meters each) and the autonomy times of the UAV (10-12 minutes per flight). The adopted set has provided for an acquisition distance from the wall surface of 2 meters, capable of guaranteeing a 148x111 cm coverage for each hovering acquisition. In this way, the photographic campaign has provided for flight plans along the fronts of the tower according to horizontal trajectories of 5 camera positions each level, at 1,10 meters of distance for an overlap of 40 cm between each photo (30% of the width of the photographic framework). Vertically, the survey has provided for 47 acquisition levels, at 80 cm of distance and with an overlap of 40 cm between each camera (30% of the height of the photographic framework). The camera stations have been controlled by setting a metric control grid, generating a mesh of localized coordinates for each survey position of the UAV; during the flight, the pilot interface allowed the control of the camera positions and the altitudes through the altimeter and visual grid on RC monitor. The photographic data collected and corrected in the distortion parameters (with FC1102 profile) were processed on a Structure from Motion platform for their alignment according to tie points, and for the subsequent processing in a dense point cloud supporting the mesh surface, generated with a detail increased up to 5 mm for polygonal edge.

4. Comparison test and data certificationfor diagnostics

The multi-instrumental campaign conducted on site allowed to qualify the most suitable products of the digital survey to acquire and transpose the geometric and formal specificities for the documentation of the tower according to the purposes of structural and conservative diagnosis. The survey campaign with Terrestrial Laser Scanner, limited to the acquisition from the ground, was configured as the main metric archive for the greater dimensional reliability of data. The measurement strategy has been particularly calibrated to increase the density of acquired points even in the highest wall surfaces, with a thickening of the scanned points for specific more dense acquisition cones oriented on the tower block, which have optimized the quality of the TLS point cloud on local morphologies. Despite this measure, it was not possible to solve the problems related to the shortened angle of acquisition, particularly influential for the high size of the tower (37 meters) compared to the practicality of the acquisition space on the ground (sometimes even just 5 meters of distance of the scan position from the tower).

The analysis of TLS data on the specific profiles of the masonry was therefore significantly influenced by the

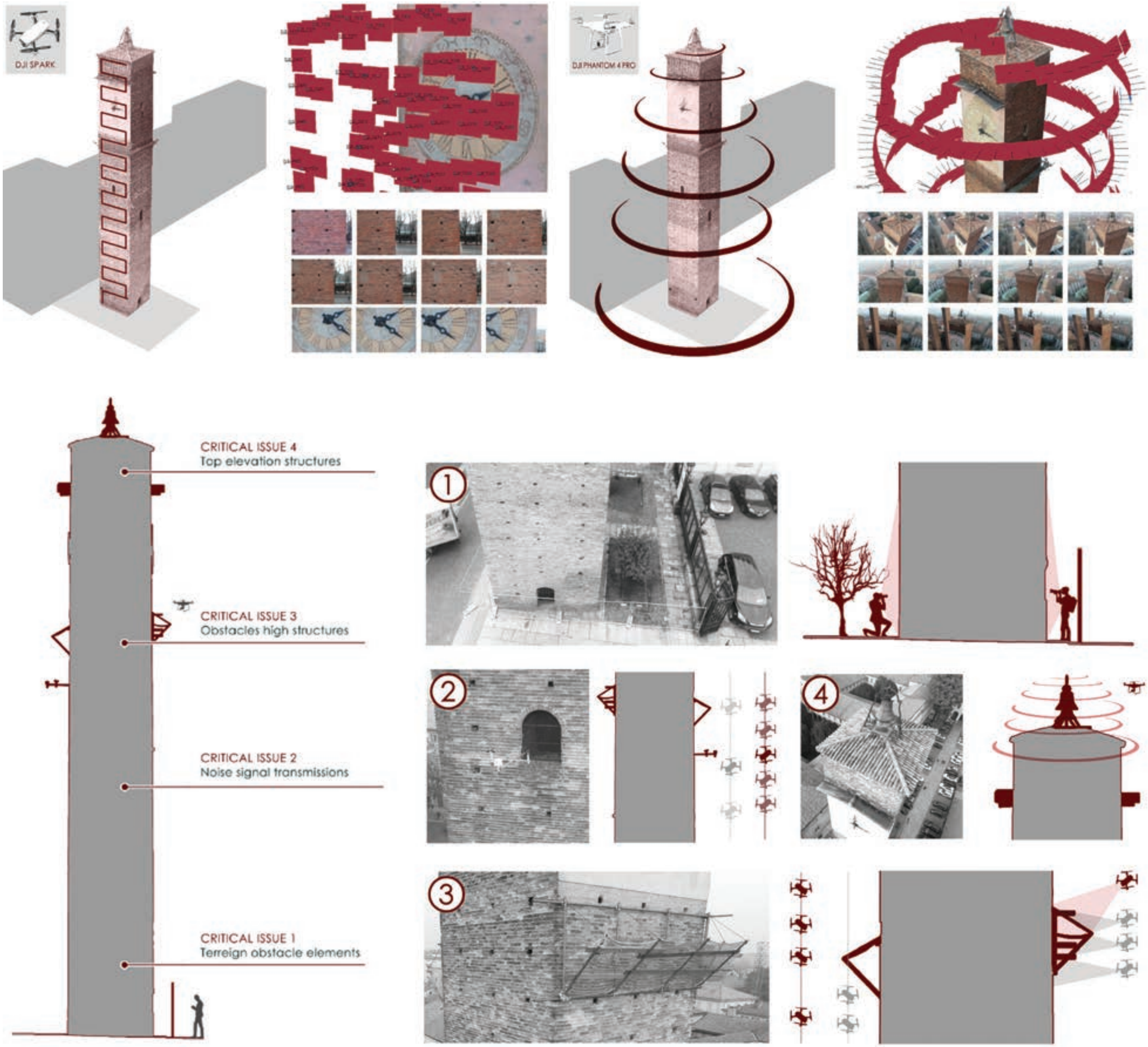

Figure 5. On-site acquisition modes (grid and point of interest mapping, with support from DJI Phantom Pro 4). Specific contextual critical issues and solutions adopted during the flight mission: 1) Integration of data at the ground level occluded by vegetation and obstacles, 2) Wider distancing due to signal disturbance from the reception antenna installed inside the tower, 3) Removal and inclination of the camera due to the presence of the safety bulkheads installed after the damage events, 4) Integration with point of interest mapping for the roofing elements.

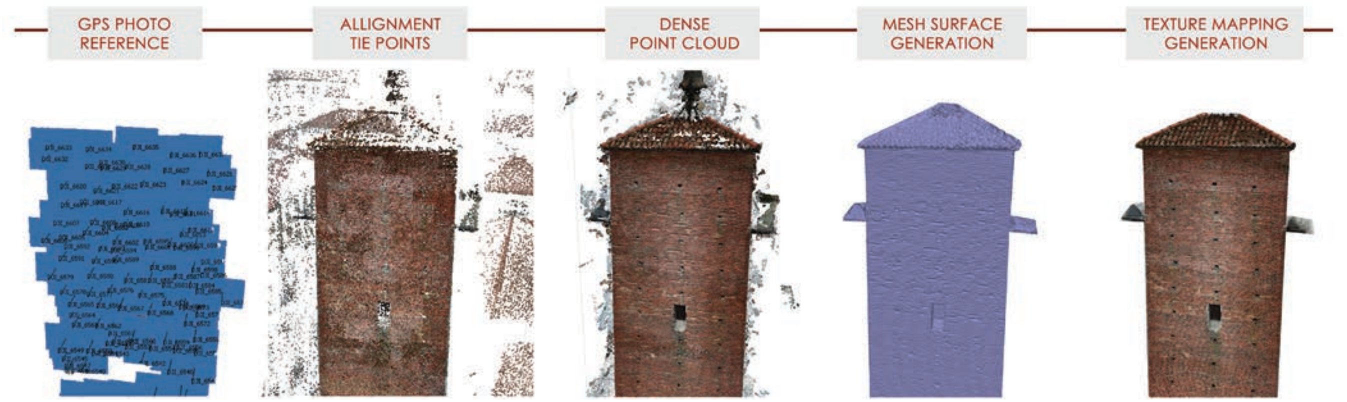

Figure 6. Photographic material from UAV camera mapping, also used for SfM photogrammetric reconstruction. The photographic detail on the morphological geometry and state of conservation of the surfaces in correspondence of both the masonry main surfaces and the plastered portions is appreciable.

shortened acquisition distance, and it has been possible to analyse and graphically represent the constructive quality of the structure only thanks to the integration of the high-quality materic ortho-mosaics obtained from the UAV survey. The single acquisition chunks, suitably aligned and textured, have been oriented towards morphological targets from the TLS archive, and they have been integrated to the main geometric profiles for the detailed drawing of the specific masonry structure, developed on the entire wall surfaces of the fronts.

Figure 7. Pipeline for the processing of mesh surfaces with Structure from Motion photogrammetry from the aerial survey performed with UAV: from the referencing with GPS coordinates of the cameras, to the photographic alignment and generation of the SfM point cloud, then triangulated with mesh and textured.

The analysis of the morpho-metric resolution developed by the different survey tools has demonstrated a geometric quality of excellence in the mesh surfaces triangulated from SfM point cloud generated by DJI Spark photos (with a detail of 1,5 mm of edge), confirming the practicality and convenience of data quality offered by the light UAV, compared also with an experimentation on the same site with DJI Phantom Pro 4.

Figure 8. Integration of the graphic elaborates of the architectural documentation of the tower from TLS digital survey database with the morpho-metric and materic information produced by the high-defined ortho-mosaics from UAV, necessary for the correct description of the wall textures and surface decay pathologies.

Figure 9. Final graphics integrated with materic ortho-mosaics applied on the fronts of the Clock Tower. Each front (5.2 m of base side for 37 meters of height) has more than 480 courses of brick masonry, each uniquely identified both in geometric-morphological and materic terms and for the surface conservation.

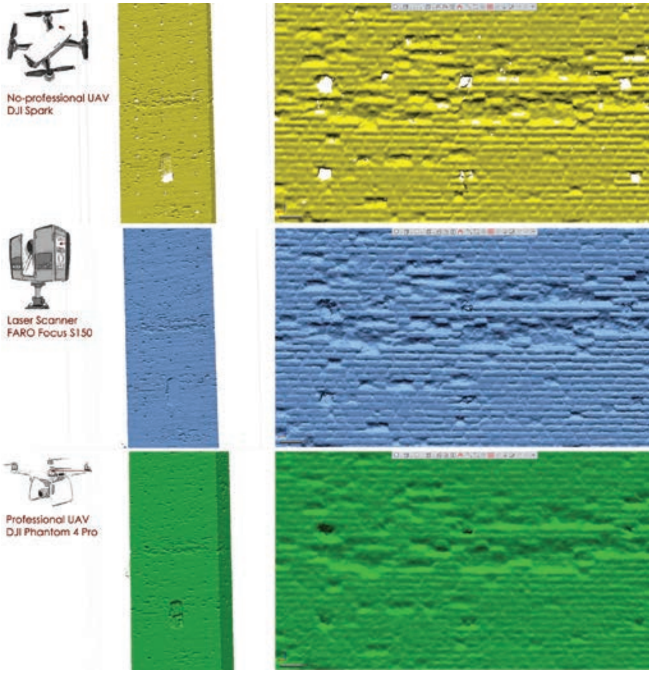

Figure 10. Morpho-metric mesh quality achieved by the different instruments applied on site.

The closer distance of acquisition, even at high altitude, and the possibility of manual piloting for the photo capture has allowed to achieve a more specific and targeted mapping of the wall structures, preserving the morpho-metric detail both at high levels (compared to TLS survey) and till the centimetre scale (compared to the professional UAV) and integrating it with the materic information. From the reliability of this information, it was possible to derive analysis maps on the specific variation of shape of the surfaces of the masonries, both structurally and in terms of surface conservation pathology. The mapping of the decays of damages and degradation present on the masonry has highlighted macro-areas of focused monitoring affected by extensive phenomena of cracking, detachment and erosion. These blocks have been evaluated in relation to the analysis of the plastic deformations present on the surfaces, interpreted as an elevation map of distribution with respect to the average plane of the walls and highlighting macro-blocks of kinematic instability and improper intervention characterizing the load-bearing structure of the tower.

5. Conclusions

Within the emerging monitoring requirements, the application of UAV for aerial photogrammetry has shown its potential for precision and reliability of documentation on the historical urban buildings and aggregates, in particular for monuments of specific interest and risk due to instability. The quality of data obtainable and interpretable by the photographic mapping from non-professional light UAVs allows to expand the planning of cyclical monitoring methods towards monuments and buildings, simplifying the procedures for the flight as well as the availability of operators suitable for the action. In this way, documentation and control campaigns are encouraged for the fast mapping, containment and prevention of structural instabilities related to cultural heritage and historical urban centres.

Figure 11. Mapping of the conservation and cracking framework from the tower's materic drawings and elaborates.

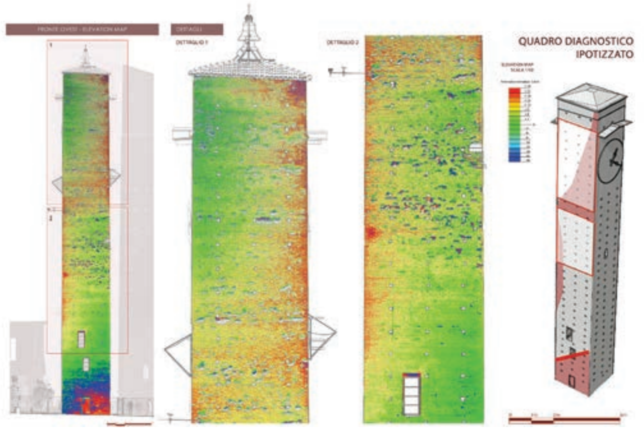

Figure 12. Structural instability framework derived from the morphological and materic analysis of the tower's wall surfaces.

Note

1 The Italian technical legislation for structural project (NTC 2018) incorporates the systematic scheme for Confidence Factors and Knowledge Levels in assessing the degree of reliability of surveys. The cap. 8 – "Existing constructions" does not specify well-defined control parameters, with an analysis framework still based on empirical calculation schemes and the absence of adequate references to support the digital morphometric value in the verifications. A reference is considered to the indications for design controls, which set a dimension of 5 mm of local error as an indicative value of the elastic threshold for the progress of further analysis, to verify the static resistance of the building.

2 The regulatory provisions on the application of UAV air cameras in urban areas are constantly updated, in relation to the safety guarantee for citizens and structures during flight operations. The ENAC regulation in 2015 defined the overflight of urban areas as Critical Operations in an urban scenario, which can only be performed by specialized personnel, with a permit to fly and requiring that the drone is equipped in accordance with the criticality and with technical solutions that ensure the reliability standards, such as a flight terminator system in case of signal loss. The alternative concerns the use of a light UAV (under 300 gr.) which reduces the dangers associated to flight anomalies. These provisions are waiting for the publication of the new EASA 2020 rules on the update of UAV flight in urban settings, balancing operational and commercial needs.

3 As the ENAC regulation defines them, these are aircraft weighing 300 gr. or less, which enjoy special facilities: the pilot is not required to have any specific training certificate or flight permit request, also considering the limited range of flight. Drones under 300 gr. can fly in urban areas as long as the location is not within an ATZ (about 5km from the airport) and not in Reserved or Prohibited areas. In addition, it is allowed to fly over people providing that they are not assembled. But the flight above humans on the occasion of concerts, demonstrations, village festivals is still forbidden.

4 It means camera quality suitable for high resolution survey with medium acquisition distance (2,5-7 m), with at least 12 MPixel frames. These characteristics are mediated by the qualities of manoeuvre for acquisition, requiring a smaller area, by the presence of sensors for approaching to the survey surfaces (which can also be set to less than 2 m) in addition to the availability of paraelics for safety in flight obstacles (birds, vegetation, buildings). Flight stability is assessed in relation to shutter speed, ensuring an hovering levelling for at least 10 seconds of fixed acquisition.

5 Considering the documented towers in the medieval historic center of Pavia from the 12th century (more than 100 in 1522, testified in the fresco of the church of San Teodoro by Lanzani), today only 60 are still present, of which only 6 intact with the original height. A common practice has concerned their levelling, for reasons of safety and stability, and the integration of the blocks in the built aggregates, transforming their interiors with residential or commercial functions.

6 The documentation campaign carried out in 2019 could only focus on the external envelope of the masonry block.
The internal environments, very small in size due to the high thickness of the walls (about 2 meters) were inspected only on sight in compliance with the operator's safety, with the presence of a vertical connecting staircase not sufficiently stable to develop a campaign of instrumental survey. From the inspection, it was possible to verify how the brick walls are tapering by rising levels, lightening the load on the basement walls, and suggesting the original subdivision of the wooden floors present inside.

7 Similarly to other towers in the city, it seems that the Clock Tower was destroyed at the top, with an original height of 50-60 meters like the nearby Maino's Tower.

8 The Menabrea military station was established to expand the premises of San Matteo hospital starting in 1933, when it was moved from Verona. From 1943 the military station fell into disuse and in 1945, after the activity was suspended, it welcomed the homeless after the bombings in Pavia in 1944. The dismantling of the southern part of the complex began in 1959 at the behest of the Magnificent Rector prof. Plinio Fraccaro, and it promoted the overall enhancement and restoration of the medieval towers in the square. Cfr. Bossaglia R. (1959) Torri civili del Medioevo Pavese. Arte Lombarda, 4(2), 1959, pp. 198-201.

9 Those research were enforced in a collaboration between DJI Enterprise and the University of Pavia for the development of research activities, and the promotion of the different ways of using drones for cultural heritage. This collaboration is based on the "Agreement for the development of research activities about the digital documentation of cultural heritage and landscape using drones" between the Department of Civil Engineering and Architecture of the University of Pavia and iFlight Technology Company Limited, signed in February 2020, lasting three years.

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HeritageBot, Cultural Heritage, survey, robotic arm, robotic tripod legs.

ABSTRACT

The contribution briefly illustrates the HeritageBot project, currently in the prototype phase, which concerns the construction of a drone structure with robotic legs. The system is equipped with high dexterity locomotion mobility and the possibility of small flights. Its platform, structured in modular mode, allows to host various sensors, both commercial and specially developed, in order to intervene in the processes of knowledge and detection of Cultural Heritage, in critical situations and conditions and particularly difficult accessibility.

Hybrid knowledge devices for Built Cultural Heritage

1. Introduction

"*Knowledge*" is the key element for the protection and enhancement of Cultural Heritage. The objective of documenting, analysing, interpreting and contextualizing Cultural Heritage is the basis of this work. The intrinsic nature of monumental emergencies cannot be fully understood without integrating different disciplinary competences. These competences require the possibility to explore the object of investigation with multiple instruments. Any activities with the objective of studying archaeological, architectural elements, on an urban scale or in dangerous situations are based on the construction of an articulated system of knowledge. The latter, if properly structured, concerns several elements: historical, cultural, quantitative, qualitative, etc. While the qualitative elements are based on a rigorous scientific approach, the others are related to the sensitivity and interpretative capacity of the researcher/operator which often allow him to reach levels of knowledge that go well beyond the codified instrumental measurement operations. In the study of Cultural Heritage this process proves to be particularly evident as it is necessary to understand, structure and integrate information from various scientific fields. Increasingly often, we are called to operate in emergency and dangerous situations, for a first phase of knowledge of the damage, aimed at making the Good safe. It is therefore fundamental, in any case, that the database structure always responds to criteria of a scientific approach, commonly accepted by the community of scholars.

The information for the knowledge of the Good must be well defined and correctly set up. In this context, the methodology and procedures for the survey constitute a guiding tool for a profound analysis of the artefacts, in accordance with the various specificities of the reality under investigation. Both in relation to the methodologies for data acquisition and the procedures for the selection, elaboration and restitution of the acquired information. This approach has fully characterized the phases of the survey, an activity in which there is a real duality between the phase of data acquisition and the modalities with which the study of the analysed object is carried out. In the usual survey processes, direct or instrumental, the acquisition phase is always subject to a careful preliminary study phase. This phase allows to guide and optimize the field operations, initially choosing the most significant aspects and discontinuities that will then be the object of measurement.

Often, however, in sites of large dimensions or characterized by complex geometries or situations, traditional procedures have sometimes encountered difficulties in adequately completing the integral mapping of the asset under examination. On the other hand, recent technologies, such as 3D scanning or SFM (Structure for Motion)[1], make it possible to acquire millions of points, necessary for a better description of the surfaces, without having to establish beforehand which ones to measure[2]. Within this framework, the use of mobile instrumentation guided at a distance is a considerable advantage, about some peculiar monumental emergencies and for all those situations in which accessibility to places is limited, dangerous and/or precluded. The possibility to operate remotely allows to work in safety and investigate spaces otherwise not visible. However, precisely because of the different characteristics of each architectural, archaeological or crisis context, it is not possible to identify an absolute rule to follow in order to carry out measurement operations. Therefore, so that the survey process - which is mainly instrumental and semi-automatic - can return the metric characters and the information necessary for the knowledge of the Good, it is necessary to operate according to a careful operative methodology, the only one that can guarantee the quality of the data to be used for the realization of reliable and scientifically valid elaborations. It is precisely in relation to this particular context that the idea of designing a hybrid drone was born, designed not only for data acquisition aimed at surveying, but also as an integrated tool - with specific mobile devices - for particular operations and movements, managed remotely.

2. Robot, Drone, HeritageBot

The examples of robotic structures and drones that can be used until now in the field of Cultural Heritage knowledge, although tending towards miniaturization, are still characterized by considerable dimensions, or by movement structures based on tracks or wheels of various sizes and weights. Each system can operate at a distance within inaccessible areas, however, not all of them are able to meet some specific requirements in particularly complex investigation environments.

Within this framework, this paper proposes a solution called HeritageBot, consisting of components that can be integrated and scalable according to the demands and needs of the survey context. The system, equipped with propeller module, mechanical legs and control unit for the management of communication and sensors, can operate a short flight and locomotion on legs. The set is specifically designed to meet certain demands for mobility and accessibility, paying attention to integrated handling.

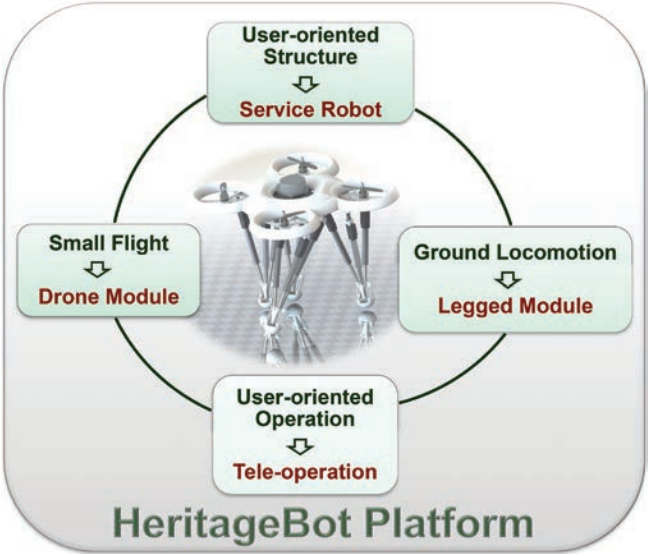

Figure 1. The design of the HeritageBot Platform, Scheme for the conceptual design.

The latter guarantees the use of the system both in dangerous conditions and in areas to which access is restricted for logistical reasons (Figure 1).

The project currently in the prototype phase called HeritageBot is part of a FILAS Regione Lazio research project carried out by the Department of Economics of the University of Cassino and southern Lazio and involving researchers from the DART, LARM, IMPRENDILAB and FINLAB laboratories. The project also includes the participation of the Faculty of Architecture of Roma Sapienza and the Faculty of Engineering of the University of Rome Tor Vergata. In short, the current project involves the interaction of three cultural souls. In addition to the economic one, for the verification of the productive feasibility of the system, the mechatronic partners - for the structural apparatus from the platform - coordinated with the scholars of the archaeological and architectural survey are substantial and fundamental partners of the company. In particular, the latter have transferred their know-how to the project and highlighted the possible

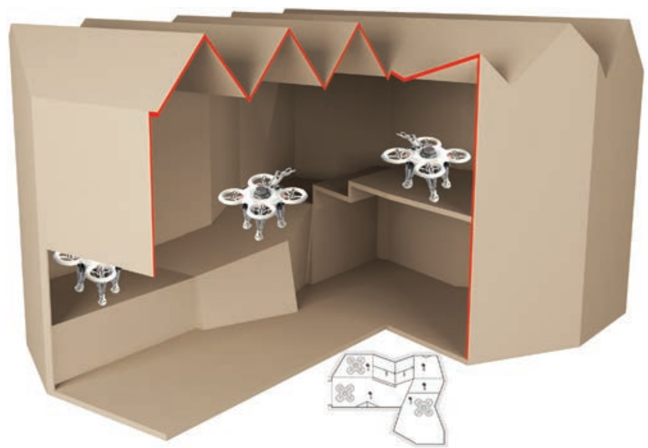

Figure 2. Experimentation field for the mobile platform handling tests.

peculiar problems that can be encountered in the operations of knowledge of the Cultural Heritage. This collaboration has also allowed a progressive evolution in the design of the platform, precisely in function of the first experiments carried out with the prototypes made, simulating - in the laboratory - critical situations of operation of the system (Figure 2).

3. The platform

The project therefore foresees the development of a suitably sensed robotic platform, with mobility in locomotion and small flight with wireless management for monitoring and intervention operations on BBCC. The system has the purpose of data acquisition also with on-board storage capacity.
The structure of the platform is modular both for mobility with innovative modules for high dexterity leg locomotion and to make a short flight with drone system, and for the instrumentation provided, aimed at monitoring and intervention in Cultural Heritage environments and products.
The modules are designed as independent but integrated structures to easily adapt the platform to a wide range of applications. In particular, the equipment can be provided for different functions, using commercial solutions or specially developed. The demonstration prototype includes a sensor system for monitoring using LIDAR cameras and sensors. The HeritageBot platform is also designed to have a high autonomy in mobility and duration of operation (Figure 3).

4. The Legs

The choice to create a locomotion module with legs to match to the propeller module is the great advantage of the platform. In fact the movement through robotic arts, allows to overcome a great limit still not solvable through the use of only propellers, that is to supply the possibility of a movement at low speed but able to be compatible with the problems of vision by the operator as well as for overcoming micro-obstacles difficult to solve by using the most invasive tracks or wheels. The movement on the legs allows to keep the structure under control and in balance thanks to the supports, guaranteeing a very low energy consumption

Figure 3. Left: render of the full conceptual design; right: wireframe of the prototyp's shell, Patent Application no. 402017000025062-2017.03.07 (in Italy).

Figure 4. a: Tripod leg; b: embedded anthropomorphic arm.

which contributes to the possibility of the prototype remaining inside the building for several hours without the need to recharge or replace the batteries. All these features come from the mechanical structure of the Leg that is composed by three linear actuators converging in one point thanks to the mechanism described in the patent IT201600093695 (A1), this structure creates a tripod leg described in the patent IT201600097258 (A1). This tripod configuration has several advantages starting that can be added to the already mentioned ones. The step length is greater than the 100% the height of the leg improving the walking feature of the robotic platform. Another feature is the high payload capability with a small size.

These two characteristics merged together gives another important one that is the small impact to the ground that is very important to avoid damaging a potentially important floor (Figure 4a).

5. The propeller module

The propeller module is the element able to guarantee fast movements within the environment through the possibility to operate a short flight. The propellers, sized to guarantee the necessary payload for the installation of the sensors, allow a better accessibility to all the structures at height but at the same time guarantee the necessary support to the leg module for the efficiency of the system also allowing, if necessary, a transport of a higher payload or a lower impact on the ground using the propellers to lighten the weight of the structure giving it a “floating” characteristic. In fact, the propeller module can be used not only for displacement but also to lighten the weight of the prototype to the supports operating at low speed, as well, can be used to straighten the prototype in case of accidental fall, or as a simple tool for overcoming all those obstacles otherwise impossible to overcome (Figure 5).

6. The robotic arm

Given its nature as a tool for knowledge, the prototype presents a further innovation, namely the presence of a robotic arm embedded in the body. The anthropomorphic arm can be guided remotely, constituting an additional aid instrument aimed at solving various problems related to the knowledge with different uses ranging from taking samples, to transporting and positioning sensors of different nature, to the physical movement of possible obstacles. The anthropomorphic arm a 4 Degrees of freedom structure with a two-finger gripper at the end.

This mechanical structure has been chosen since it is very simple to reproduce and to control remotely by an operator but at the same time is very reliable (Figure 4b).

7. Sensors

The system allows multiple sensors to be used if necessary. Video and telemetry can be collected from the environment through onboard sensors, allowing bi-dimensional 360° and immersive photo-video mapping while additional sensors can be installed if required. The prototype is equipped with a main controller that is interfaced with all the other controllers of each sensor module and the transmitter for manual operation. It receives feedback from each module together with the

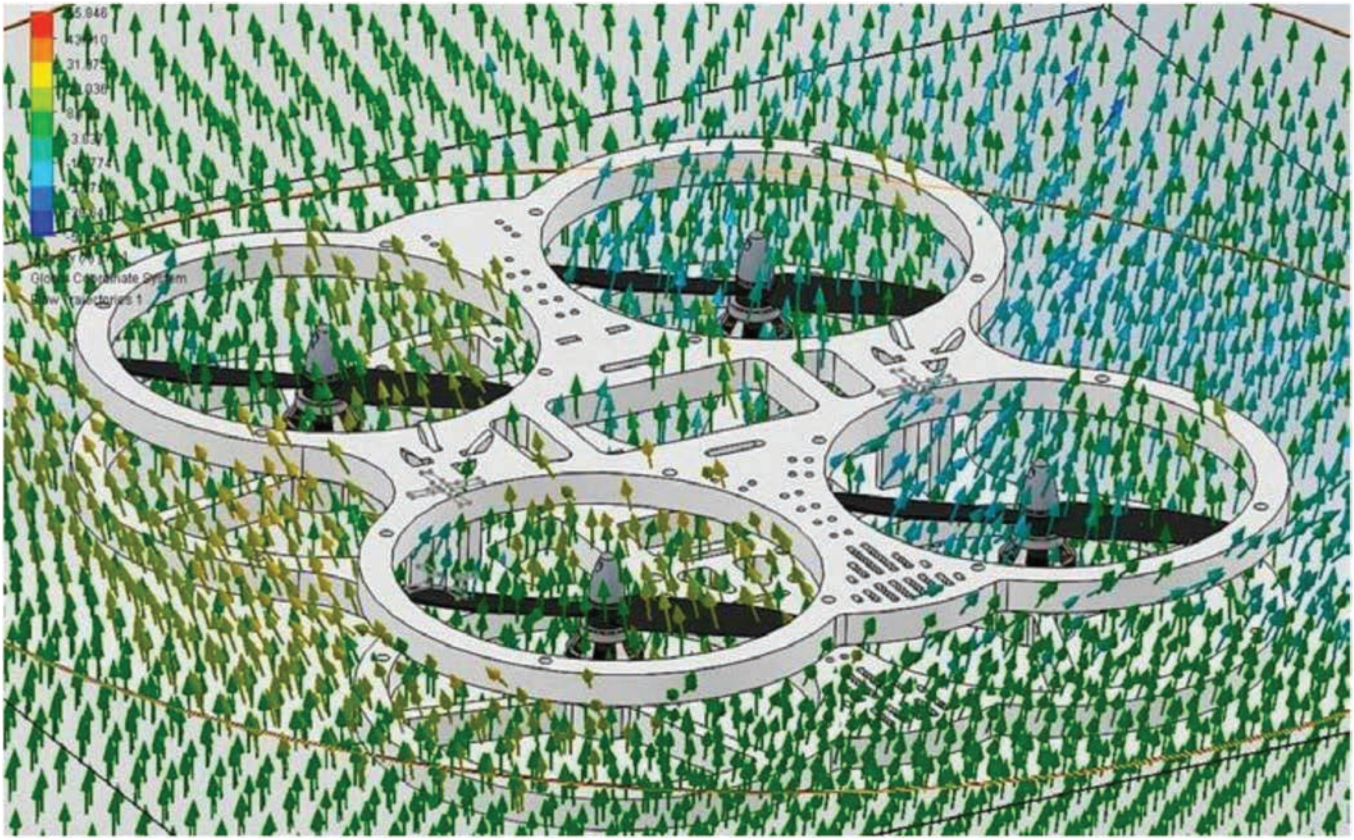

Figure 5. A computational fluid dynamic analysis for the operation of the drone module in the designed platform.

input from the manual control by the user and manage the joint operations to achieve the desired task. In terms of hardware, to help the balancing HBIII an IMU sensor including a three-axis accelerometer, gyroscope and magnetometer has been used. In addition, the used IMU device has an embedded barometer. As the name implies, the accelerometer measures linear acceleration in up to three axes X, Y and Z. A very important parameter that allows a multicopter to stay stable is the detection of gravity done by the three-axis accelerometer. The 2D mapping is done using RPLIDAR 360, the mapping 3D is guaranteed by a Velodyne Portable Laser Scanner and the Video streaming is performed by a GoPro camera.

8. Test carried out for support device design on Built Cultural Heritage

Tests were carried out in an archaeological environment that is difficult to access to support the design fases of our device. The tests analysed the ability of a Parrot mini-drone on wheels to move and be controlled remotely in various experiments. These tests were conducted in the Roman Theatre of Ancient city of Cassino, inside the Archaeological Area (Figure 6). The tests highlighted the difficulties in controlling the movement of the platform on wheels in a real environment: the presence of obstacles, even small

Figure 6. Tests for support device design.

ones, and its poor ability to perceive their presence are important limits for all vehicles without leg-type structures.

The second series of tests conducted for design definition of our prototype focused on the evaluation of the sensors.

This was carried out in controlled environments aimed of defining the level of uncertainty and the ability to return data with a good degree of approximation. In order to evaluate the possibility of using a camera as a means of data acquisition for structure from motion procedures, operational tests were conducted to verify the significant frame survey processes and the operational difficulty of collecting data in inaccessible environments. This was carried out with the help of the Parrot mini-drone through the application of a commercial action camera. These tests supported the design of the remote-controlled robotic platform. It was possible to explain the different issues related to movement with legs and the choice of specific sensors for data acquisition for Built Cultural Heritage under specific operating conditions.

9. Conclusions

All the part of the assembly is designed to be 3D Printed to achieve a low-cost and easy to reproduce structure. The experimentation carried out so far by the working group, has given satisfactory results and of sure interest for the research.

The HeritageBot prototype, even though its nature is still being defined, has made clear how the development of a mobile medium, able to explore environments that are difficult to access in order to investigate the intrinsic nature of the artefact, is an important goal that, by exploiting innovative technologies, is able to increase the level of knowledge of what has been examined. In addition, the HeritageBot project foresees the definition of a methodological path specifically articulated in the procedures and methods of analysis and knowledge of Cultural Heritage.

In second order it will be possible to obtain as a further objective the training of an intermediate professional class between detectors and robotics.

This figure of operator, close to the skills related to the analysis and restoration of Cultural Heritage will also have skills on the design and operation of integrated robotic systems. The value and the need for a connection between the various cultural souls are witnessed by the programs presented by the work team which, particularly with the HeritageBot project, has made it possible to fund various scholarships for young researchers with different cultural backgrounds. These young people, working together for the common goal of designing an integrated system for Cultural Heritage, have acquired multidisciplinary experiences, with a flexible professional training ready to the different demands of the working world. In this way, skills are formed between the worlds of restoration and robotics, able to contribute to the development and advancement in the analysis, conservation and restoration of Cultural Heritage, in line with the progress of technology.

Note

1 Photomodelling (Structure from Motion) develops from the theoretical assumptions of photogrammetry and allows the restitution of three-dimensional graphic models through the integration of the phases of survey, modeling and representation, extracting from the RGB coordinates, chromatic data, distances, vertices and profiles.

2 This statement is not intended to identify the methods for the massive acquisition of points as totally automatic processes, carried out without being filtered by the operator's choices. In fact, laser scanning, in addition to the appropriate positioning of the instrument, presupposes a priori the choice of the scale of return of the processes, because this objective is linked to the specific definition of values linked to certain parameters (sample spacing and probe). In photomodelling, on the other hand, the number of shots, the quality and homogeneity of the photographic sockets in relation to accessibility and lighting conditions, the typology of the photographic socket scheme based on the morphology and geometry of the object under study, the level of detail of the model to be built are to be considered. See: De Luca L. 2011. *La fotomodellazione architettonica*. Rome: Dario Flaccovio Editore; Gaiani M. (ed.) 2015, *I portici di Bologna. Architettura, modelli 3D e ricerche tecnologiche*, Bologna: Bononia University Press.

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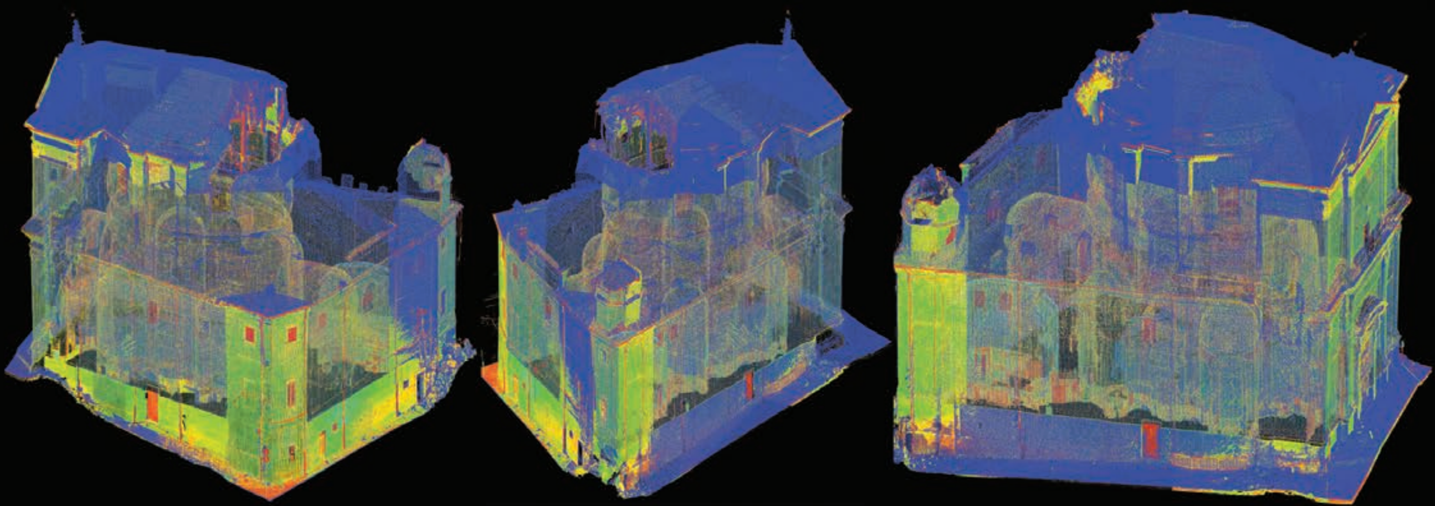

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Keywords:
Integrated surveying, 3D data merging, UAV, point clouds approach, SfM processing.

ABSTRACT

In situations where some portions of a building are inaccessible (particular architectural conformations or earthquake damage) it is necessary to adopt an integrated approach that combines range-based data acquired from terrestrial laser scanning and image-based 3D data acquired using an UAV equipped with a digital camera. This paper presents the results of a point-cloud-based survey made on two different case studies. The goal is to define a workflow for processing dense 3D models that can be used to describe complex buildings for different purposes (high-/low-poly 3D models, specific 2D representations).

The contribution of drone photographic acquisition in risky survey conditions: a comparison of two experiences

1. Framework and Goals of the Studies

In the last decade, the practice of surveying has solidified into a combination of different reality-based methods, that is, the integration of range-based and image-based acquisition technologies (Remondino 2011), enabling a unique dataset of processable information to be obtained more easily. The state of the art includes many cases that document how the use of aerial photogrammetry with digital cameras mounted on unmanned aerial vehicles (UAV) has been combined with surveys based on terrestrial laser scanning (TLS) to acquire 3D data related to the cultural heritage. The result is more detailed and more complete knowledge of architectural buildings characterized by complex geometries (Binda et al. 2011; Colomina 2013; Saleri et al. 2013).

In this context, the article presents two different integrated survey experiences made on two different buildings in which the use of aerial photogrammetry plays a fundamental role (Remondino et al. 2014). This is an irreplaceable tool without which it would not have been possible to completely acquire the data or therefore provide adequate documentation related to specific planned studies (Kerle et al. 2019).

Given this, the objective of the research was to experiment with and develop a hybrid workflow that combined the advantages and best features of each sensor (Fiorillo et al. 2013) in order to obtain sufficiently accurate three-dimensional data. These 3D data are useful not only for producing various representations aimed at documenting the buildings in question, but also for subsequent analysis, such as the study of seismic risk based on finite element methods (FEM) or to assess damage after an earthquake in order to secure the building.

2. The Church of Santa Maria in Via after the Earthquake of 2016

This religious building is located in the historical centre of Camerino (Province of Macerata). From outside, the church shows a trapezoidal layout resulting from the unification of pre-existing buildings. The more complex structure of the interior is composed of an elliptical hall covered with a dome. The hall is surrounded by four semi-circular chapel niches and two small choirs on the minor axis, while the ends of the major axis host the entrance and a deep chancel apse. The bell tower, likely built at the time of the church, was located at one corner of the rear façade (Mariano 2009).

The original building, consecrated in 1654, was the object of several modifications regarding the roof in particular which, after its collapse in the earthquake of 1799 (Moreschini 1802), was replaced by a gabled roof supported by wooden trusses and, within, by a false dome in camorcanna (reed and plaster). The church unfortunately experienced considerable damage in the earthquake of 2016. The bell tower situated on the rear façade collapsed along with part of the roof, with the consequent collapse of a good part of the camorcanna dome and part of the drum. Damage affecting the body of the façade that is detached from the hall, with a loss of structural consistency of the masonry.

Figure 1. The Church of Santa Maria in Via after the earthquake: collapse of the interior camorcanna dome, roof, and bell tower.

Within, the collapse of the roof and dome littered the entire floor area of the church and parts of the body of the façade were completely inaccessible. Outside, significant piles of rubble blocked access to the side streets and the rear façade while the ruinous collapse of the bell tower on the southern corner blocked access to the adjacent Piazzale della Vittoria (Figure 1). Considering the critical aspects of the site, a point-cloud-based survey campaign was defined. In an integrated reality-based approach, terrestrial range-based data acquired using laser scanners was combined with image-based data taken from a UAV equipped with a remote-oriented camera to produce the most detailed visualization possible of the extent and the locationing of collapses in the roof, trusses, dome, and bell tower. The range-based survey was carried out using the Leica HDS 7000 3D laser scanner. Despite the reduced safety of the site, 15 stations for high-density scans were managed (made) - 10 outside and 5 inside the church along the perimeter of the oval (the only accessible space) - adopting'high' and'superhigh' scans quality and with variable sampling densities in relation to the working distances from the surfaces (6.3 mm and 3.2 mm spacing between the points at a distance of 10 m). This setting of density and quality in data acquisition has aimed to obtain an accuracy (metric precision) such that representations corresponding to a scale of detail of 1:50 can be achieved. The image-based survey made for photogrammetry purposes was carried out with a DJI FC6310 (Phantom 4 Pro Plus) quadcopter with incorporated camera equipped with a 1" sensor and 20 Mp resolution with mechanical shutter to eliminate rolling shutter distortions. The photographic campaign was carried out with different acquisition schemes relating to the different portions of the building: vertical with regard to the'plane' of the roof about 10 m away from the ridge; and pseudo-vertical (axis inclined with panoramic view) along the entire perimeter of the roof at a distance varying from 15 to 20 metres. The snapshots were made with f/5.6 and f/5 apertures, a shutter speed from 1/200s to 1/400s, and ISO 100 to reduce noise. The entire campaign yielded a total of 301 snapshots.

The goal was to obtain as much data as possible in the form of point clouds in order to accurately and adequately process 2D representations as well as suitable 3D display modes (with orbitable textured views of the point cloud) of the state of the church after the earthquake, i.e. to document types and objects of the damage and therefore compose reliable graphical bases for the subsequent project to secure the building. The data-processing phase primarily regarded the creation of a homogeneous database. The range-based survey campaign resulted in a total set of 522 million points. With regard to the photographic data acquired using the drone, qualitative analysis of the photos resulted in 150 snapshots chosen for processing. Using a structure-from-motion (SfM) tool, all the selected photograms were oriented and the absence of alignment errors was verified, followed by extraction of the dense cloud with a'high' setting, resulting in a cloud consisting of 44 million points. This dense cloud was then converted into a polygonal model (3.8 million faces) using a proprietary algorithm in the software that works via interpolation. Since the drone was georeferenced during shooting (snapshots equipped with geotags in the WGS84 reference system), both the point cloud and resulting mesh model were already scaled appropriately (Figure 2). The two separate point clouds were aligned and merged by identifying two reference lengths (vertical

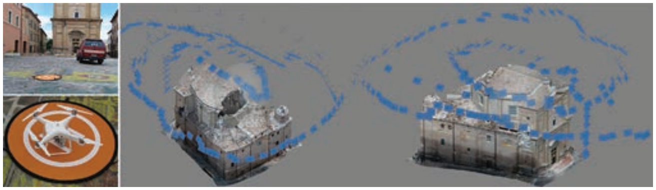

Figure 2. The image-based survey and processing of the snapshots made with the camera axis tilted with respect to the roof area.

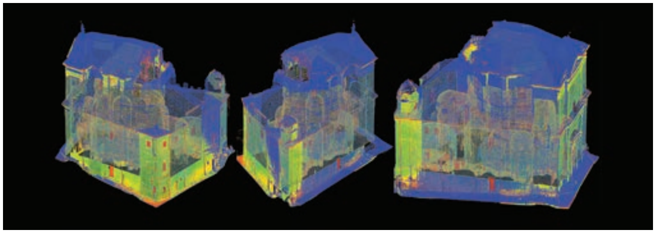

Figure 3. Views of the entire data set obtained after aligning and merging the two point clouds: photogrammetry point cloud (blue), laser scanner cloud (coloured).

and horizontal), that is, a series of points distributed on the different sides of the church that were recognizable in both the laser scanner cloud and the cloud obtained from photogrammetric processing. The coordinates of the points were obtained from the laser scan and then appropriately inserted as markers in the cloud resulting from photogrammetry (Figure 3).

Once a single data set in the form of a point cloud was obtained, the next step concerned the data processing phase. The team of structural engineers in charge of the subsequent safety project has therefore identified and defined types, quantities and scale of detail of the necessary and useful representations. First at all, was indicated as indispensable 2D drawings relating to: all external elevations with the detailed representation of damage, gaps and collapses; four levels of plants; a complete longitudinal external-internal section; two profiles on the macro element of the facade aimed at analyzing the extent and importance of the displacement from the vertical alignment (off-plumb) of some portions of this front (Figg. 4, 5).

From a three-dimensional point of view, it was defined as necessary for the study of process of securing not so much the elaboration of a model (considered in itself not useful given the huge percentage of collapses) but rather a processing that allowed to visually explore the state of the collapses at height. To this end, by re-projecting the shots on the mesh model elaborated with SFM systems, a 3D orbitable and zoomable overview has been produced in order to explore the state of the collapse in elevation (Figure 6).

3. The Complex of San Francesco for Analysing Earthquake Risk

This convent complex is located in the historic centre of Monterubbiano (Province of Fermo). From its foundation (1247) up to the most recent restorations carried out following the earthquake of 1997, the entire complex of San Francesco has changed in use several times (currently a museum) and has undergone substantial formal modifications that have defined its current structure.

Internally the church, choir, and base of the bell-tower form a single body. The church consists of a single nave covered by ogival groin vaults; the choir, covered by a groin vault, is situated at a higher level on the counter-façade and facing the nave of the church. The slender, soaring bell tower is located to the left of the church entrance. Within of the bell-tower a C-shaped staircase, with access on the choir level, is located to reach the higher levels (Figure 7).

A laser scanner survey was also combined in this case with photographic survey using a UAV, which allowed for control of shadowed areas from above and photography of high parts that would otherwise be unreachable (roof and bell tower). The range-based survey to acquire 3D geometrical data both inside and outside the complex was designed using multiple resolutions. Eighty-three scanning stations were carried out, of which 26 were outside and 57 were inside. A total of 421 million points were acquired.

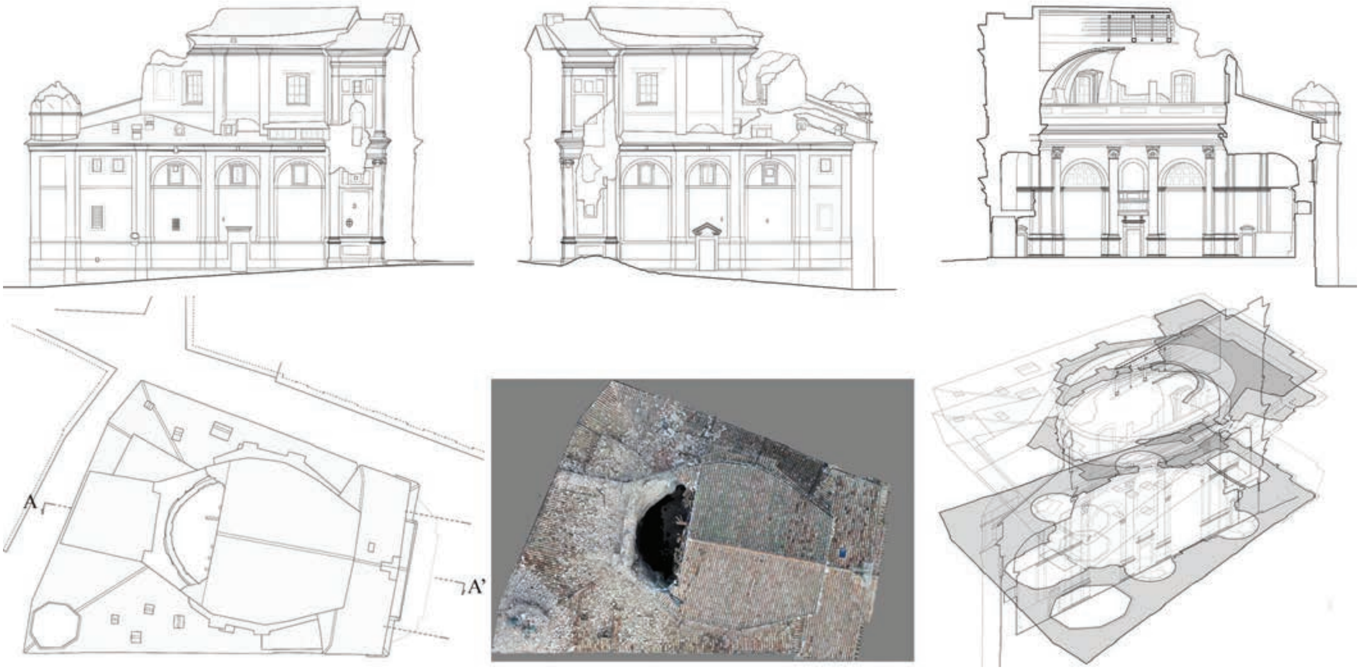

Figure 4. Some 2D representations: elevations of the left and right sides, longitudinal section, to-scale textured orthophoto and related plan of the roof, axonometric view of four plan levels.

The image-based survey — of fundamental importance for acquiring data relating to the horizontal and vertical configuration of the roofs and the structure of the richly moulded bell tower — was made using a UAV powered by six 400 KV brushless electric motors and 15’’-diameter rotors.

Figure 5. Some pictures of the operations to secure the church: interior drum and dome, corner and top of the bell tower, left side of the façade.

It was equipped with a Sony NEX-5R camera with a fixed 22-mm focal length and an APS-C sensor (23.4 mm x 15.6 mm) with a maximum resolution of 4912 x 3264 (16,032,768 pixels), yielding a physical pixel dimension of 0.004763 mm (p = 23.4 mm/4912). For the entire photography campaign, the main shooting characteristics required by the software used to process the images (minimum overlay, convergence, etc.) were considered.

The flight paths were primarily linear except around the bell tower, where the motion was more circular on several different horizontal planes. The views in the snapshots (one every 2 seconds) were tilted with respect to the building’s vertical surfaces to control shadowed areas from above. The UAV campaign resulted in 517 photographs in RAW and JPG format. An initial look at the lighting conditions in all the photographs showed

Figure 6. Orbitable 3D model obtained from the processing of aerial photos taken by drone: overall views and detailed views of damage to the roof and façade.

that the JPG images could be used directly without corrections via RAW processing. Therefore, a qualitative analysis of the photos was made; 129 were initially selected in which radial distortions were eliminated. After an initial orientation with SFM tools, additional problematic shots were identified, reducing the overall image count to be processed to 93. Once no alignment errors were found, extraction of the dense point cloud began with the'high' setting. The resulting point cloud cleaned of all outliers and points not pertaining to the building, consisted of around 39 million points (Figure 8). In order to align the point clouds from the two campaigns (TLS and UAV), it was necessary to scale the point cloud produced by processing images taken by the drone. We then proceeded to identify a reference length for both point clouds. The extreme points of the straight line were identified near corners of the building (unaligned, distant enough, and visible to both systems). The clouds from the two campaigns were aligned using the Geomagic software for which a reference length was identified. This program allows for a 'best-fit' alignment only between one mesh and one point cloud.

Figure 7. Orbitable 3D model obtained from the processing of aerial photos taken by drone: overall views and detailed views of damage to the roof and façade.

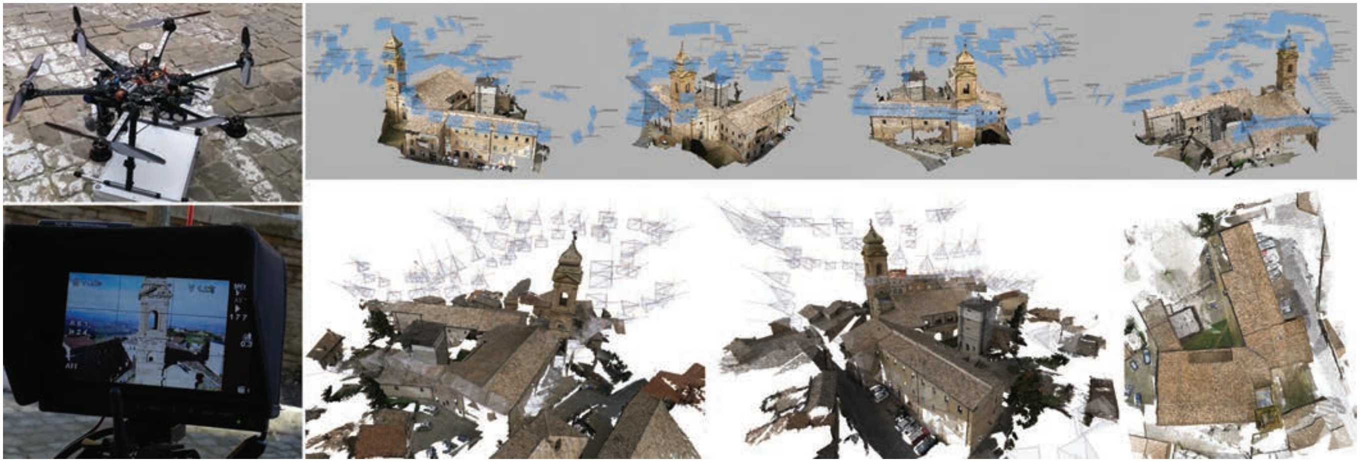

Figure 8. The image-based survey and the photogrammetric processing of the shots: coloured point cloud and position of the pictures taken from the UAV.

Therefore, the point cloud from the laser scan was tessellated using the proprietary meshing 'Wrap' algorithm in Geomagic.
This algorithm is better adapted to reconstructing architectural shapes than other meshing algorithms ('Poisson', for example), which would have generated a model with corners that would be too soft and smoothed.
Once alignment using the best fit was completed, an additional adjustment was made to decrease the deviation between the two point clouds. The resulting average deviation was 5.5 cm.
To better establish and verify the accuracy of the alignment, different parts of the model were analysed using complete data from the two point clouds without applying any decimation (Figure 9).To merge the two clouds, the laser scanner data were left unchanged while all superimposed parts in the drone point cloud were eliminated, leaving only the parts necessary to fill in the scanner point cloud gaps. The portions of the drone point cloud to be merged with the scanner cloud were determined by identifying the gap edges on the mesh derived from the laser scanner.
These contours were converted into curves, which were then transferred to the mesh derived from the drone data. These curves were then used as a boundary to identify the parts useful for filling in gaps in the scanner data. This procedure yielded a complete model of the roof that was almost entirely absent from the laser scanner data (Figure 10).
The textureless 3D model thus obtained was used to assess the seismic risk of specific large elements (Meschini et al. 2015), including the bell tower (Figure 11).
Furthermore, a textured 3D model was developed by using a mesh with a low number of polygons onto which the aerial photos were reprojected and merged. This model is useful for making more realistic and overall representative views (pdf 3D, 3D player on-line) (Figure 12).
Finally, with respect to the 2D representations and the generation of orthographic images (Ippoliti et al. 2015) useful for analysing wall materials or crack patterns, both aerial and other additional ground-based photographs were reprojected onto portions of a non-decimated 3D model (Figure 13).

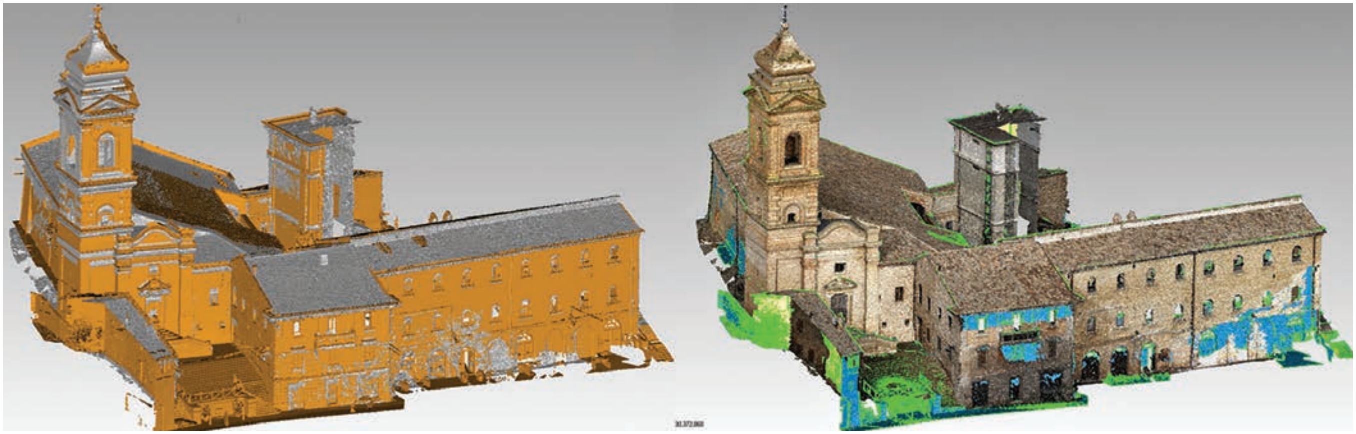

Figure 9. Best-fit alignment (reference length in red) of point clouds captured using UAV and TLS (tessellated using the'Wrap' meshing algorithm).

4. Conclusion

The applications described in this paper aimed to identify an operational framework (phases, survey tools, and tools to produce the most suitable representations) that may potentially also be adopted for other objects of historical/architectural value, that is, for contexts with similar characteristics. In both cases, contribution of photographic acquisition from a drone was fundamental in capturing portions of the buildings that could not be accessed using other tools, thereby reducing risk exposure for on-site surveyors and allowing satisfactory data to be obtained.

The cloud-to-cloud procedure to process the data enabled dense 3D models to be constructed.

These models yielded both 2D representations (geometric/metric renderings, scaled orthographic images) and 3D views (models textured with aerial images from the drone) that document a complex architectural object with different levels of visualization and detail; they are also useful for various analytical processes.

It is clear that only with additional applications may fundamental feedback be provided to verify the validity of the methodological approach in its different phases in relation to the quality of the results.

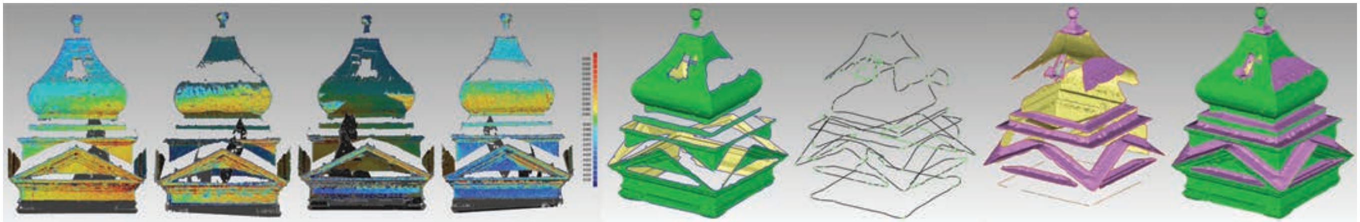

Figure 10. Merging phase (example): hole edges highlighted in LS data; hole edges extracted; UAV data to fill in holes in LS data (extraction after projecting the edges); merged LS and UAV data.

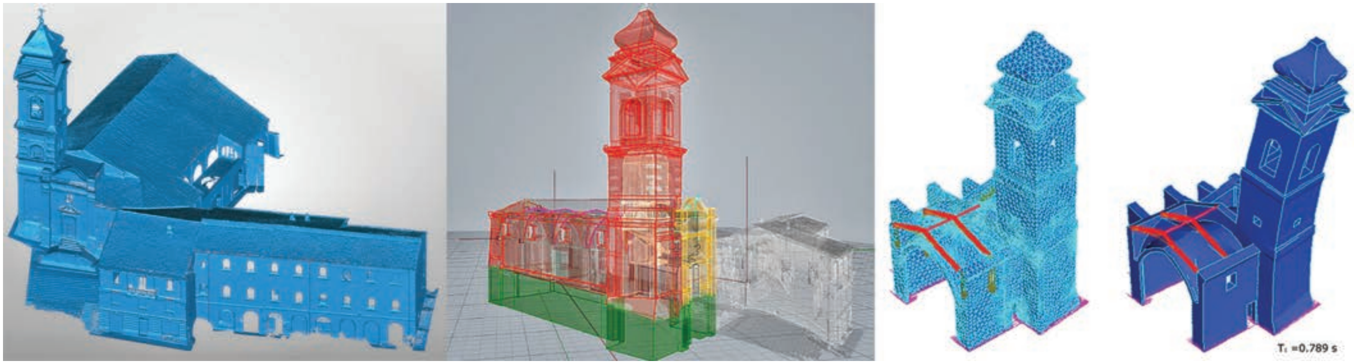

Figure 11. 3D mesh model obtained by merging LS and UAV data. Modelling: union of 865 surfaces into a single closed polysurface. Solid mesh and geometry (low number of polygons) for structural analysis.

Figure 12. Textured 3D model (explorable pdf 3D) for realistic representations: overall views and detailed views of the bell tower and facade.

Figure 13. Scaled orthographic rendering and related elevations of the east and south sides.

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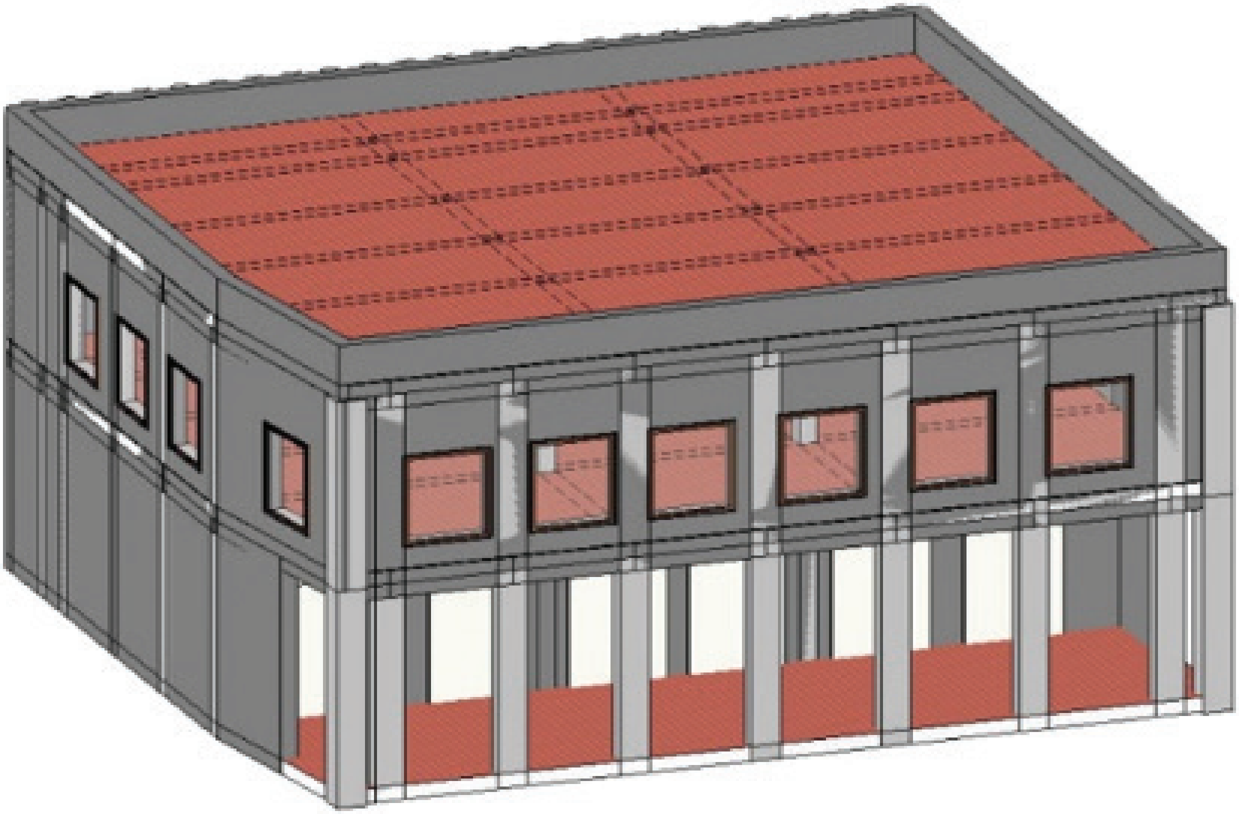

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Keywords:

Natural risks, photogrammetry, BIM model, structural analysis.

ABSTRACT

The Philippines is an area suffering of several natural risks, such as seismic events, typhoons, floods and storms. Moreover, the lack of information about the buildings make even hard their management. In the paper is illustrated a digital procedure that take into account all the steps that go from the data acquisition to the safety assessment of the buildings, through standardized forms, innovative tools and techniques. An application on a case study shows the relation between photogrammetry, digital platforms, BIM, and structural analysis software.

A workflow for structural tasks with digital tools, a case study in the Philippines hazard-prone area

1. Introduction and presentation of the case study

The safety assessment of existing buildings is a matter of primary importance in natural hazard-prone areas as the Philippines (Su S.S., 1988), where most of the buildings were built without taking into account any seismic criteria. The determination of the safety level of these structures is important both for identifying the buildings suffering higher risk in the territory and for planning retrofit interventions to restore safety, particularly for Cultural Heritage (CH) assets. In fact, the Philippines are frequently affected by earthquakes and typhoons, as well as floods and storms. The aim of this work is to define guidelines for the evaluation of seismic vulnerability of some buildings in Iloilo, one of the oldest cities in the country. For the data collection phase, a Rapid Visual Survey (RVS) form has been used, based on three levels of information, that corresponds to an increasing degree of accuracy in the estimation of structural vulnerability and even to structural risk. The data collection has been carried out on a large scale, thus including 25 heritage buildings in Iloilo City, through innovative and non-invasive techniques and tools for the improvement of investigations (Figure 1); in particular, the thermal and omnidirectional cameras has been used for the collection of structural data and the drones for roof inspection, i.e. one of the most dangerous sources of vulnerability of the Philippines CH assets. The activity presented in the paper is part of the of the CHeRiSH research project, aimed at the definition of a multi-hazard risk assessment for CH assets in natural hazard-prone area (Sevieri et al. 2019) One of the 25 building, the Villanueva Building, has been designated as target building to carry out the structural analysis to evaluate seismic vulnerability. It consists of two stories reinforced concrete frames, where the first is 4 m high, and the second 3,5 m.
Placed in the corner, it was built in 1970s for commercial use (Figure 2).

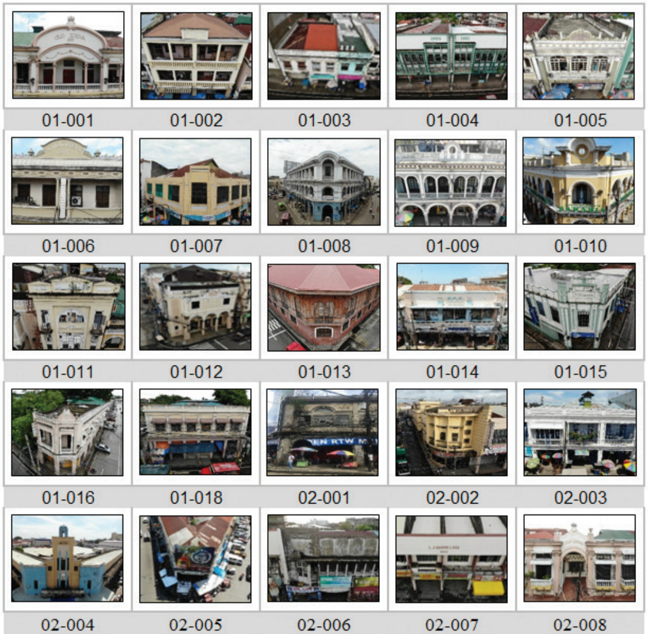

Figure 1. Iloilo City buildings.

Figure 2. Case study: Villanueva Building Facades and roof.

2. Data collection

The multi-risk assessment of structures is of great importance in natural risk areas, for the implementation of Disaster Risk Reduction strategies (DRR). Among the most vulnerable buildings, cultural heritage (CH) assets are particularly significant because of their value, the lack of any risk-resistant design and the material degradation due to the ageing. For these reasons, the data collection has been carried out on the 25 buildings in a standardized way, through a Rapid Visual Survey (RVS) form based on three levels of knowledge, highlighted with different colors.

The RVS form contains information for the characterization of a given hazard profile thanks to parameters contained that are related to specific characteristics of the building (Gentile et al. 2019); it is used during the field investigation and the and consists of six sections as shown in Figure3. The information required at the first level of accuracy (white color) can be collected with an external survey of the building in about 30-40 minutes by a team of engineers. For the second level of accuracy (light grey color) more detailed data on the structure are required (e.g. presence of non-continuous structural walls, their type and quality of connections to the roof, diaphragm) which can be obtained from both an internal and external investigation of the building.

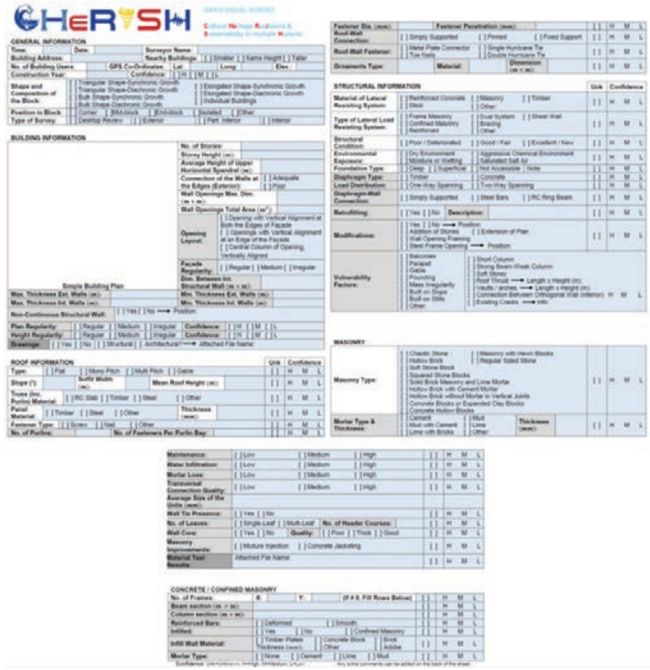

Figure 3. RVS Form.

The information acquired allow to reach a knowledge Level 2 (KL2), useful for performing structural analysis.

The third level of accuracy (dark grey color) requires more efforts but allows a more detailed analysis from the structural point of view, useful to obtain more accurate numerical models.

Thanks to the standardization of the data collection phase, some statistics have been obtained, that allow a simpler and more intelligible reading of the degradation level and the lack of maintenance of the Iloilo city CH assets (Figure 4).
In 60% of the surveyed buildings some pathologies have been inspected that may moderately affect the structural condition, such as small cracks concentrated on a limited number of elements and infill panels; moreover, one of the most dangerous source of vulnerability of the Filipino CH assets is the roof.
Indeed, several non-engineered roofs built with low quality materials can be frequently found and the degradation can even worsen their structural performance. The collection of roof data is usually very difficult because of their inaccessibility.
For the purpose, the use of drones has turned out to be particularly comfortable for the roof inspections (Irizarry et al. 2012).
In this regard, it has been experienced that the use of new technologies drastically increases the stream and amount of information which can more comfortable to manage.
The data collected has been necessary to build a mechanical model, representative of the structural behavior of the building. It has been useful to perform a gravitational load analysis for the performance of a simulated structural design based on the Filipino code of 1970 "Uniform Building Code building" (UBC) for the definition of constructive details, basing on the calculation methods used at the time of construction. After that, a modal analysis and a non-linear static analysis, was performed to obtain the push-over and the fragility curves.

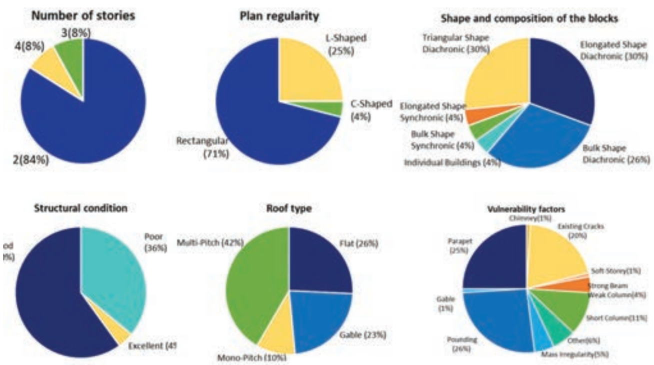

Figure 4. Statistics of the surveyed CH in Iloilo City.

3. Innovative tools and digital platform

In order the develop the whole process in a digital way, and at the same time as fast and cheap as possible to facilitate the extension on a large scale, the photogrammetry technique and omnidirectional cameras have been used to generate point clouds from the outdoor.
In order to obtain all the data needed to develops the specific task, some other innovative tools have been necessary, i.e. drones for the inspection of roofs (an important element of vulnerability for local buildings), room 360° for the inspection of the indoor environments and the RVS forms, an important and innovative aspect, to collect the information in all the buildings but in a standardized way.
All the data acquired on site have been introduced in the BIM model thanks to the implementation of the usBIM.platform, developed by ACCA Software (https://www.acca.it/bim-collaboration-software), in which all data collected on site as photos and RVS forms have been uploaded.
Thus, the Common Data Environment (CDE), is the single source of information used to collect, manage and disseminate documentation, the graphical model and non-graphical data for the whole project team (Preidel et al. 2017). The creation of this single source of information facilitates the collaboration among project team members.
Moreover, thanks to the information developed directly in a digital way, the use of paper work is significantly reduced as it was a source of confusion among the multiple figures who interacted with the process causing damage in terms of time and costs (Figure 5).

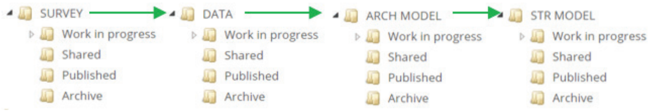

Figure 5. Common Data Environment structure.

Figure 6. Villanueva Building Point Cloud.

4. Scan-to-FEM process

This process performed is a very simple, non-invasive process called Scan-to-FEM (Bassier et al. 2016). This is a gradual process, in which, starting from the data collected, the structural analysis is performed.
It is made up of three steps:

-Scan
During the photographic survey some rules have been taken into account to ensure the best quality of the point cloud elaboration. For each of the building about 50-60 photos have been taken by UAV for the roofs inspections but not all of these have been used due to disturbing factors, like the weather conditions, the traffic and the incorrect execution, so that they have been filtered. The time needed for the flight operations have been of approximately 20 minutes for each building. Some other traditional shots of the external and the internal surfaces have been taken by omnidirectional camera and smartphones in an additional time of about 30 minutes. All these photos have been uploaded directly in the CDE, where they were organized in different folders according to the tools used for each building. High percentage both of overlap (70%) and sidelap (60%) have been taken into account during the photos acquisition, in order to ensure the best quality for the photogrammetric point cloud, generated with the Photoscan software (Unger et al. 2014). First of all, a scattered point cloud has been obtained and then dense one, which was not lacking of noisy points that need to be eliminated. For the purpose, the dense point cloud was moved to CloudCompare, an open-source software for the point cloud post-processing, where it was cleaned and scaled fixing several measurements and verifying the final point cloud comparing the measurements taken from the point cloud with real ones in the three orthogonal directions (Figure 6). For the following elaborations an approximation of 2 cm in the measurements have been considered acceptable, because of the focus on the structural matter; indeed, the point cloud has been considered both as a source of information for filling in the RSV forms and as a reference for the identification of walls, openings and structural elements recognizable on the façade.

- BIM
The point cloud constitutes the input data for the definition of the architectural BIM model, build with the Revit software, in which grids, levels, structural, non-structural walls, columns and openings have been modelled. It has to be noticed that for the indoor environments the traditional way has been chosen to acquire the measurements while the laser-scanning was not taken into account due to the simplicity of the buildings (most of them are two-stories buildings) and because of the big amount of data not necessary for structural purpose. Basing on the architectural model, a structural model has been developed, containing the identification of the elements that have a load bearing function. The BIM model has become a source of information pertaining several aspects of the building, such as diagnostic analysis based on

destructive and non-destructive elements inspections, material information, interconnections of elements, architectural and structural considerations. After generating the architectural and structural model, a Clash detection analysis (set on a 1 cm tolerance level) has been performed in Autodesk Navisworks to detect accidental errors and/or interferences within the models (Guangbin et al. 2011). After importing the two models in the open format.ifc, they have been compared for the identification of errors that may have occurred for their correction thus avoiding additional time and needed for the remedy in more advanced stages of the project (Figure 7).

- Fem

Thanks to the BIM interoperability, the FEM model was moved into Midas gen, in order to perform the structural analysis. For the purpose, some missing information have been added, i.e. the stiffness and the strength of the material, the constraints (base joints, rigid diaphragms, rigid arms) the loads, the load combinations and the response spectra (Figure 8).

5. Structural analysis

Thanks to the FEM model, a non-linear static analysis has been carried out, using a concentrated plasticity model and assuming the formation of plastic hinges at the columns and beams endings. Indeed, in the framed structures subject to horizontal actions those induced by seismic events, the maximum bending moments occur at the ends of the beams and columns. Therefore, it is in these points that, once the elastic threshold is exceeded, inelastic deformations are concentrated. The main advantages of this model are its simplicity, computational efficiency and the short time required for the analysis. Once defined these the plastic hinges, they have been assigned to the beams and columns. After that, once the elastic and inelastic spectra, called Acceleration Displacement Response Spectrum (ADRS), related to the specific site have been loaded into the software in terms of acceleration and displacements, and the load cases proportional on to the acceleration and the other to the mode have been defined. The push-over curve obtained, is related to a multi-degree of freedom system (MdoF) so that, thanks to the modal participation factor G, it has been scaled to an equivalent Single-degree of freedom system (SdoF), as shown in Figure 9. The push-over curve has been bi-linearized through the N2 method so that the characteristics of the system have been obtained (Fajfar P. & Gaspersic P., 1996).

6. Fragility Curves

From these curves some parameters have been deduced, in particular the Base Shear (in kN) of each column of the building and the Displacement (in m) of each plane from top to bottom, for the definition of the fragility curves for different limit states of damage using the Fracas software (Joskowicz et al. 1998). Differently from the typical approach, in which the fragility curves relate to a specific building with its own features, the approach here proposed is focused on typological classes, represented by group of buildings of a certain area with generic features that characterize all of them. In this case, each class of buildings can be represented by macroparameters such as shape, size,

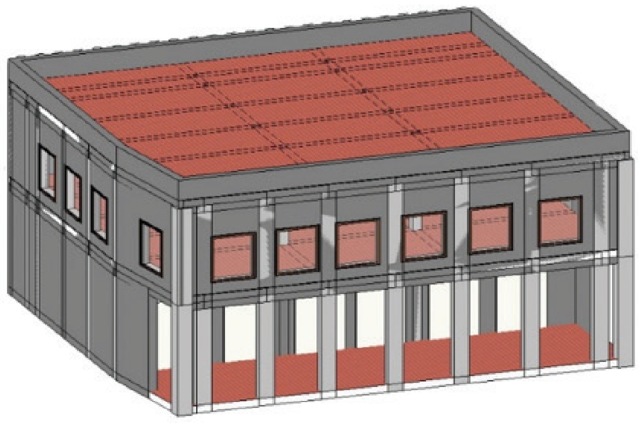

Figure 7. Architectural BIM model.

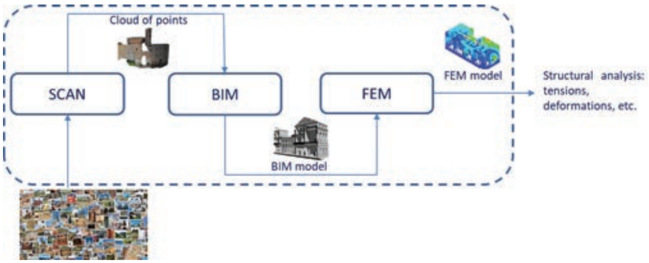

Figure 8. Scan-to-Fem process.

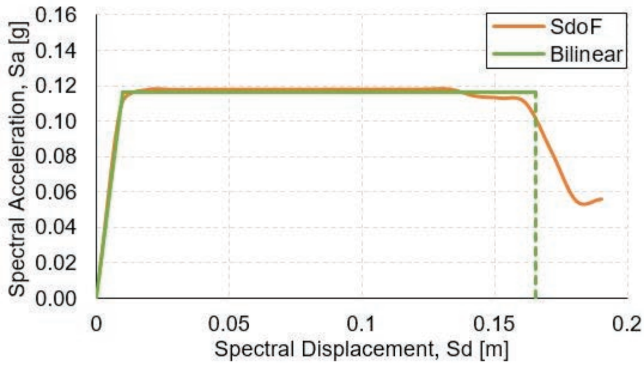

Figure 9. Bilinear and Push-over.

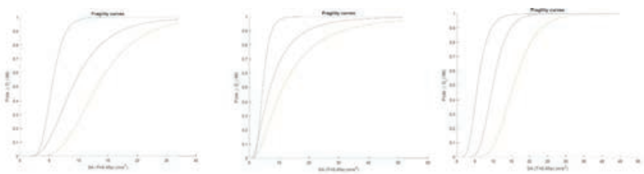

Figure 10. Intermediate fragility curves.

year of construction, etc., so that in this study is an "average" building has been taken into account.
It follows that some difficulties have derived in relation to the analytical approach, for the definition of the influence of all macroparameters on the seismic behaviour of the structures.
For this reason, the empirical approach has been preferred taking into account statistical analyses of the data concerning the behaviour of buildings, all of which are traceable to the specific classes. Inserting all the necessary information in the Fracas form, eight Fragility Curves have been obtained in terms of Spectral Acceleration (Sa), for 150 ground motions, divided into 8 steps (the first for ten Ground Motions and the other seven for twenty Ground Motions), as shown in Figure 10. The several curves have been joined to get a single curve for three different limit states of damage (Figure 11).

7. Conclusions

The approach here presented consists in a sequence of operation in which, starting from a very simple input consisting of photos and information collected in standardized forms during the survey, aim to define the seismic behaviour of buildings on a large scale. 25 buildings have been inspected to find the vulnerability sources and all the data collected have been introduced in a CDE, so that the information have been stored in an orderly manner and will always be available, avoiding any loss of information. In particular, the Villanueva Building has been chosen as a case study for the definition of guidelines for the local people, making them in condition to replicate the process of seismic assessment for the remaining buildings.
This concept goes under the name of Capacity Building.
The suite of software employed for the purpose

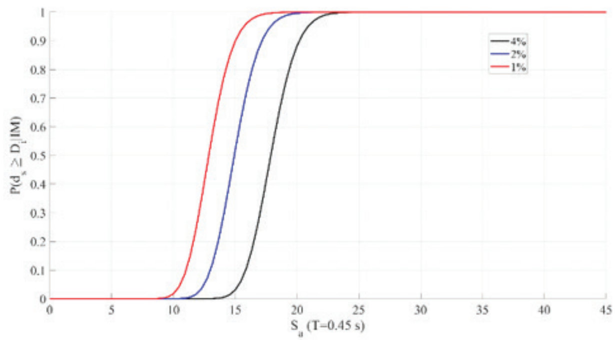

Figure 11. Definitive fragility curves.

is shown in Figure 12. For the purpose, the photogrammetry technique and the utilization of UAVs turned out to be time saving, compared to the traditional methodologies.
The procedure can also be extended to define whether it is necessary to design retrofit intervention. So, through the model itself, it's possible to understand where and how to intervene so that also the local people will be able do it.

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This study was performed in the framework of the "CHeRiSH: Cultural Heritage Resilience & Sustainability to multiple Hazards" project funded by the UK British Council. The University of the Philippines Visayas (UPV), the Central Philippine University (CPU), and the De La Salle University (DLSU), Manila, are acknowledged for the technical support during the fieldwork. In particular, Prof. Andres Winston Oreta (DLSU), Prof. Mary Earl Daryl Grio (CPU), Prof. Rhodella Ibabao (UPV), Mr. Richard De Jesus (DLSU) are gratefully acknowledged for helping in planning and executing the data collection. The graduate students from CPU who participated in the fieldwork are also gratefully acknowledged.

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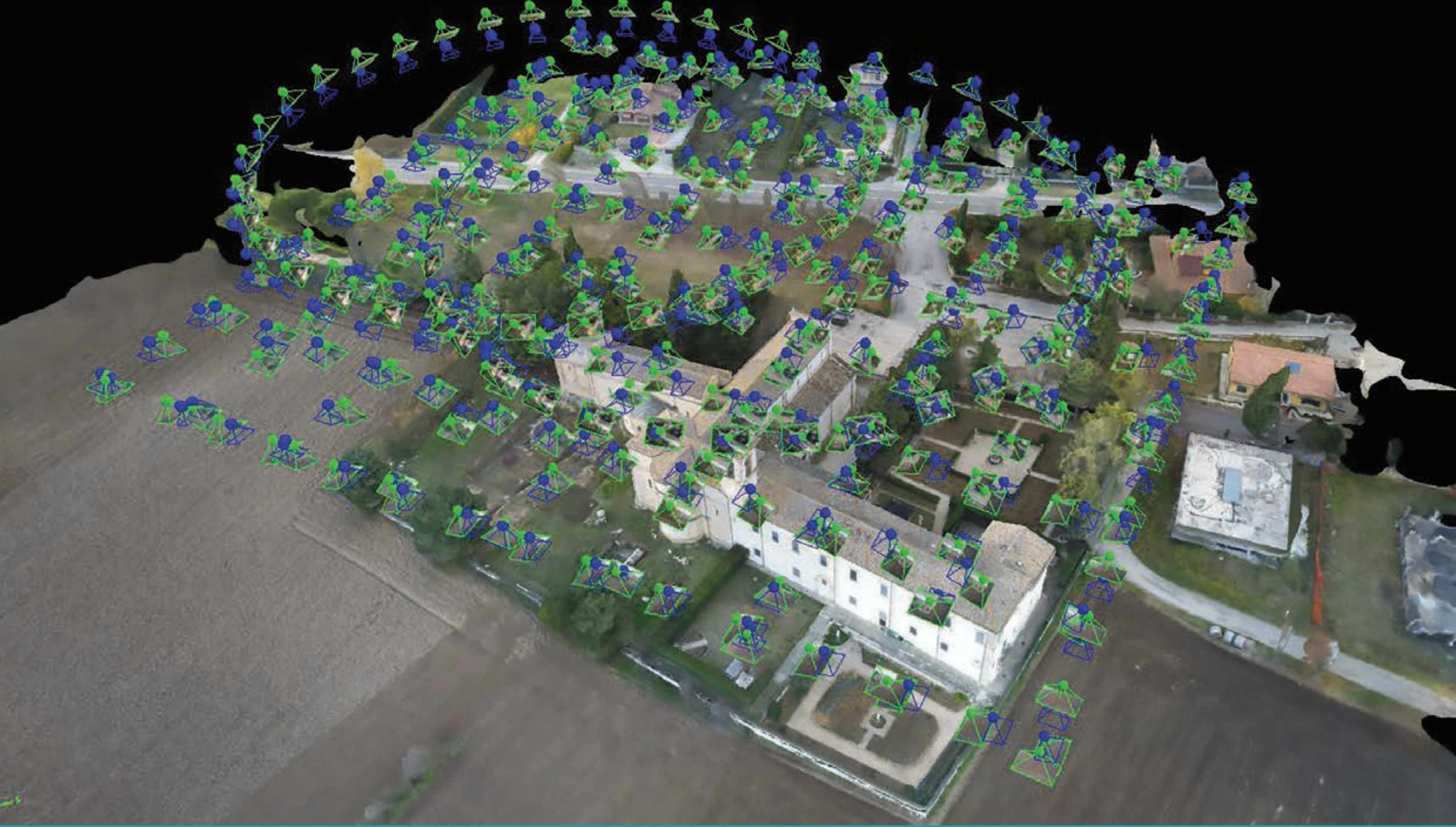

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Survey, photogrammetry, Meshroom, Metashape, heritage.

ABSTRACT

The contribution reports a research experience, aimed at the documentation of Cultural Heritage in Abruzzo, conducted with the help of drones, with the combination of methodologies of acquisition and processing data acquisition and photo-modelling, integrated in a comparative and experimental way. Specifically, the study themes suggested by the conference concerned the Valvense Complex, which has been little analysed from the point of view of architectural survey, and which is one of the most important Romanesque monuments in the Peligno area, near Sulmona (AQ), located on the remains of the ancient Italic capital, on the access axis to the Roman town of Corfinium. The research focuses in particular on the comparison of two photomodelling methodologies, one open source and the other commercial, where the advantages and criticalities are highlighted by analyzing workflows and results.

The UAV survey of the Valvense complex in Corfinio, comparison between two photomodelling methods

1. Introduction

The use of IUAV instrumentation for surveying in the last period has increased considerably, at the same time there is an improvement in the software for the processing of photogrammetric data aimed at three-dimensional photomodelling, which over time become increasingly accurate and easy to use. Also, open source applications that offer good results almost superimposable to those obtained by the commercial counterpart are multiplying. The contribution compares two different processing workflows structured from a single three-dimensional dataset, based on photographic images and obtained with Structure from Motion drone methods, with the aim of verifying, starting from the same acquisitions, the correctness in terms of results of the two different methodological approaches applied to a particular case study, the ancient Romanesque Valvense complex, a very large area consisting of several related compartments. The survey thus illustrates a twofold development, related to the dynamics of data acquisition by exploiting the drone system and the comparison between the two different workflows, of which the open source one, Alicevision Meshroom, which is developed through a node system, very interactive but with less precise results, and the commercial one, Agisoft Metashape, more solid and cumbersome but with more accurate metric results. The planned study of the different levels of depth, starting from the recognition phase necessary for the knowledge and documentation of the cultural and artistic heritage, is oriented towards the aspects of relief typical of geomatics and architecture, aimed at the conservation and territorial enhancement of culture.

Figure 1. Valvense complex, facade of San Pelino.

2. Historical background on the case study area

The area where the architectural structures created in memory of the martyr Pelino are located reveals the presence of fortified structures dating back to the 5th and 6th centuries, within which there was a large palace, as evidenced by the studies conducted on the archaeological site (Giuntella 1990) and on the building traces found under the episcopal complex started in 1075 by Bishop Trasmondo with recycled materials, as attested by the Chronicon Casauriense. (ChCasaur, coll. 866). The stratified structure is currently composed of several buildings connected to the Basilica of San Pelino, which for its historical importance plays the role of co-cathedral of Sulmona. The articulated complex houses the Cathedral Basilica to which on one side, towards the middle of the right aisle, connects the oratory of St. Alexander and the tower of the same name and on the left, at the height of the transept, the bell tower and the eighteenth-century Episcope, now the seat of the cloistered monastery. Historical and archaeological studies (La Salvia, Somma 2015) confirm several interruptions suffered during the construction started by Trasmondo; a first suspension dates back to 1092, which identifies the first church dedicated to Saint Alexander, which has remained unfinished and probably erected together with the square tower used for the site's sighting and defence (Fucinese 1971). The completion of the Cathedral of San Pelino dates back to the 12th century, with several consecrations, the first of which was attributed to Bishop Gualterio (1014-1128) and the second, when the work was completed, to Bishop Odorisio (1172-1181). (Vinegar 2007) The survey data confirm construction inhomogeneity, successive reconstructions derived from earthquakes, baroque renovations and subsequent restoration work in 1970 that forced the Romanesque structures to come to light (Fucinese 1974). In this sense, the survey methods used provide an objective basis to support the historical complexity of the controversial construction phases (Paura 2018) and allow a three-dimensional analysis of the architectural complex from the whole to the detail, finally allowing to monitor the important cultural heritage.

Figure 2. Valvense complex: 1) tower of Sant'Alessandro 2) oratory of Sant'Alessandro 3) Church of San Pelino 4) bell tower 5) eighteenth-century episcope6) Archeological area.

3. Plan preparation

The photogrammetric 3D survey through IUAV instruments is generally divided into three phases, a phase of data acquisition, in which it is essential to define the areas of interest that directly influence the path of the drone and the shooting modes, by placing a specific survey plan, a data processing phase in which photomodeling software is used and a post-production phase relating to mesh correction and the definition of a 3d model. In the case study, before embarking on the data set acquisition phase, it was essential to take some macro-measures relating to some of the complex's perimeter walls with the aim of obtaining a return in scale of the architectural artefact in the second instance. The weight of the drone used, Parrot Anafi, is about 400 grams and during takeoff it has a flight autonomy of 30 minutes in normal conditions of absence of wind. Through remote control via smarthphone, it was possible to control the flight of

Figure 3. On top, flight plan, Pix4DMapper interface.

Figure 4. On right, flight plan remote system.

the UAV (aircraft system remote pilotage) by managing the camera stabilizer so as to direct the inclination of the camera itself. Another possible function is to take single photos or to start/stop video recording. The main advantage in the use of drones for surveying works is related to the possibility of scanning parts not visible from the ground or inaccessible, flying at low speed near the objective. Thanks to the help of cameras consisting of focal lengths with variable pixel size, it is possible to obtain high resolution images, with a sampling distance on the ground (GSD, pixel size on the ground) of the order of centimeters. The video from which 5344x4016 frames were extracted was obtained, getting a GSD (Ground Sampling Distance) calculation of 1.17 cm / pixel, useful for processing the point cloud. For flights carried out by the drone, some rules have been taken into account that allow to determine the flight height of the drone, the frequency with which to take the frames and the variable distance from the object of study according to the return scale. The fundamental parameter to be defined in the design of all the steps necessary for the correct execution of an aerial photogrammetric survey is therefore the choice, based on the objective of the survey, of the representation scale, that is the final definition of the obtainable drawings. This factor is always contained in the GSD which briefly expresses the "quantity of territory" represented by 1 pixel of the 2d image. It is essential to prepare a well-structured survey program to better define the paths to be carried out by UAV tools, keeping in mind the rules and calculations we discussed earlier. The aim is always to provide, through the use of specific equipment, a measurable and scaled 3d photogrammetric model of the detected object which reports all its geometric, chromatic and material characteristics. During the flight about 300 frames were taken, useful to elaborate the point cloud of the survey area. The flight plan was structured using Pix4DCapture apps for smartphones and the flight phase and the acquisition of aerial images were almost completely automatic, providing data with a permissible error in centimeters, considering the flight altitude and the resolution of the optics. The breadth of the analysis area required the use of two datasets, in particular

Figure 5. Definition of the cameras based on the acquisition data set within the Meshroom interface.

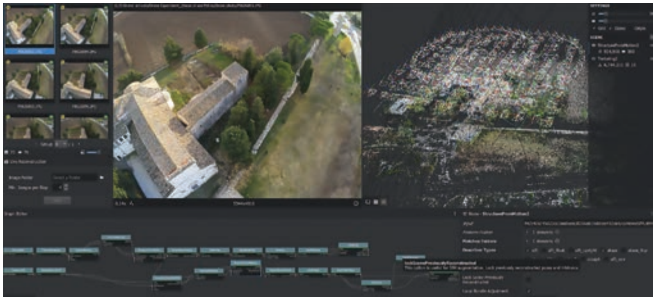

Figure 6. On the right top, Meshroom, processing of the dense point cloud through the fluid node-graph workflow.

one acquired at close range following a "convergent photocentric" path, the other one instead following a linear checkerboard path with zenithal framing[1]. The results obtained from the various acquisitions were then compared and examined to verify the level of accuracy of the data useful for the achievement of the required purposes, with the consequent elimination of the data that cannot be used in the survey such as photographs with excessive motion blur or particularly under or overexposed.

4. Data processing through the comparison of two photomodelinf software

Moving on to the data processing and photomodeling phase, two well-known photogrammetry software were used to survey the monastic complex, Agisoft Metashape, one of the most used commercial programs in the field of territorial and architectural survey, and Alicevision Meshroom, open source software, using the full hd frames from drone, in order to make a subsequent comparison between the two 3d models obtained from the same data set. The use of systems that work with photography, using passive sensors and using precisely the light present in the environment, allows to obtain models of a remarkable level of detail, both at a metric level, in relation to the restitution of geometry and proportions of the compositional elements, both aesthetically and chromatically, in relation to the material information. Image-based detection systems are mainly based on SfM algorithms, Structure from Motion, through which an automated 3D digital reconstruction is generated from frames acquired in motion sequences where a pixel matching condition occurs, and therefore an overlap, between the various images acquired in progression. Being a system based on the image, it is therefore essential to define a data set in an optimal condition of diffused lighting and a rapid data acquisition timing in order not to change the light conditions.

4.1 Data processing and analysis using Agisoft Metashape commercial software

Following the workflow of Agisoft Metashape commercial software, the photos were imported (http://www.agisoft.com/) (Aicardi et al. 2016) to start the alignment steps and generate the dense point cloud by structuring a procedure that is divided into four main steps. The first one, after entering the photographic data in the computer, consists in the alignment of the different camera shots: in this phase the software analyzes all the photos, looking for the homologous points in relation to the chromatic peculiarity and the light exposure factor; for each image the camera orientation and the related calibration parameters are identified, from which the lens distortion coefficient is also obtained. From this processing is generated, through an automatic collimation, a "Point Cloud Based", i.e. a diffused point cloud composed by the "Key Points" necessary to hook in a Cartesian coordinate system the spatial model of the detected object: in this phase, we can start outlining the contour of the object in a three-dimensional environment with the indications related to each single shot of the camera capture[2]. In the second phase of the workflow a thicker "Dense Point Cloud" is configured, obtained based on the positioning of the estimated shooting points, from which the program extracts information about the color and plastic details of the object. The Dense Point Cloud, which requires several hours of computation using the CPU and GPU together, can be modified, cut and optimized according to the next step, i.e. mesh construction using meshing-triangulation algorithms, which "wraps" the point cloud with a network of triangles to generate a mesh surface, or TIN " triangulated irregular network ", considering each point in the cloud as a vertex of a triangular contiguous and irregular polygon with a Z coordinate, effectively transforming the point cloud into a polygonal model[3]. The two photographic datasets, one relating to the photocentric-convergent shooting, the other obtained following a linear checkerboard path, are then unified in Metashape using the chunk alignment technique through the use of markers. Topology was also addressed[4] of these self-generated 3D models and their polygonal density based on the desired graphic-visual quality in relation to the scale of the investigation required. It is therefore necessary to make some corrections, reducing the polygonal density of the mesh, removing unnecessary disturbing components, accidentally calculated because they are present in the frames or closing the mesh holes. So we opted for the inclusion in the workflow of Pixologic Z-brush, a program used in the film and art industry that can exploit the power of Voxel algorithms to easily manage hundreds of thousands of pixels. Among the various features of the software were used automatic retopology, digital painting, detail projection and corrective sculpting through polygonal subdivision. The result at polygonal weight level is a model of about 20,000,000 polygons and after the optimization of about 800,000.

4.2 Fluid workflow thorough node editor of the open source software AliceVision Meshroom

The other 3d photogrammetry software used in the project is Meshroom, which despite being a completely free open source, turns out to be a really interesting software with innovative features, despite using essentially the same open source algorithms common in other three-dimensional applications of photogrammetry. The substantial difference in the executive pipeline consists in the fact that the various phases of work are structured through a graphic node editor that allows to simplify the quick management of each step. The visual interface is suitable for different levels of professional knowledge, from the already

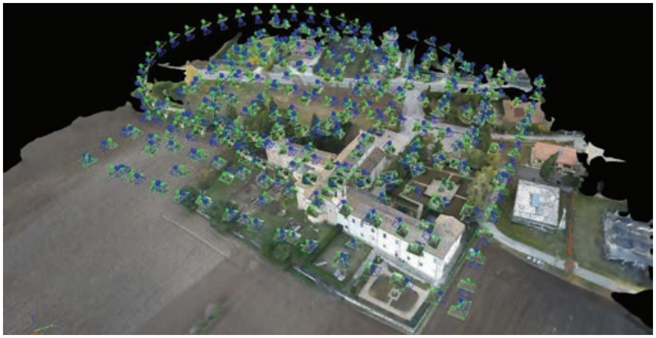

Figure 7. On the right bottom, definition of the cameras based on the acquisition data set within the Metashape.

Figure 8. Metashape Mesh result.

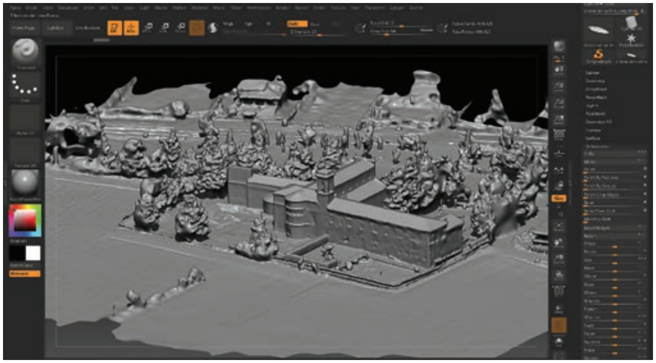

Figure 9. Zbrush optimization of Metashape mesh model.

pre-compiled standard, which allows anyone to use Meshroom without the need to modify anything, to a fully configurable structure based on personal creative needs. The first step of the workflow is the classic image acquisition where the quality of the photographic dataset is the most important part as the software seems to work better with less high resolution images as it is able to detect pairs of homologous points very well. The system displays all the steps of the photogrammetry pipeline as nodes with configurable parameters, while all the steps will be recorded by the program and saved in a "Meshroom Cache" folder that can be recalled at any time. The software, based on a database where the characteristics of the camera sensors are stored, through which you can determine the internal parameters in the form of metadata, simplifies the steps by automatically implementing configuration presets. Fortunately, for the case study, the metadata has been clearly recognized and processed node by node for each step of the process.

The photo modeling pipeline also in Meshroom consists of two main steps, managed by specific algorithms.

SfM: It provides the rigid alignment structure of the scene (3D points) with the position and orientation of the filmed objects and the internal calibration of all cameras.

MVS: The MultiView-Stereo (dense cloud reconstruction) uses the calibrated structure from motion cameras to generate a solid geometric surface. The result is a structured mesh that can be exported in OBJ format with corresponding MTL and texture files.

For the Sparse Reconstruction the features present in the default pipeline have been used such as "FeatureExtraction", able to recognize the correct number of cameras involved in the project, and "FeatureMatching" with "Guided Matching" enabled, which allowed a second more accurate step in the matching procedure: once the descriptor matching has been performed (with a global distance ratio test) and a first geometric filtering, the software identifies the most substantial geometric transformations.

In doing so "Guided Matching" uses this geometric information to perform the matching descriptors a second time, but with a new constraint, improving the search for further homologous points.

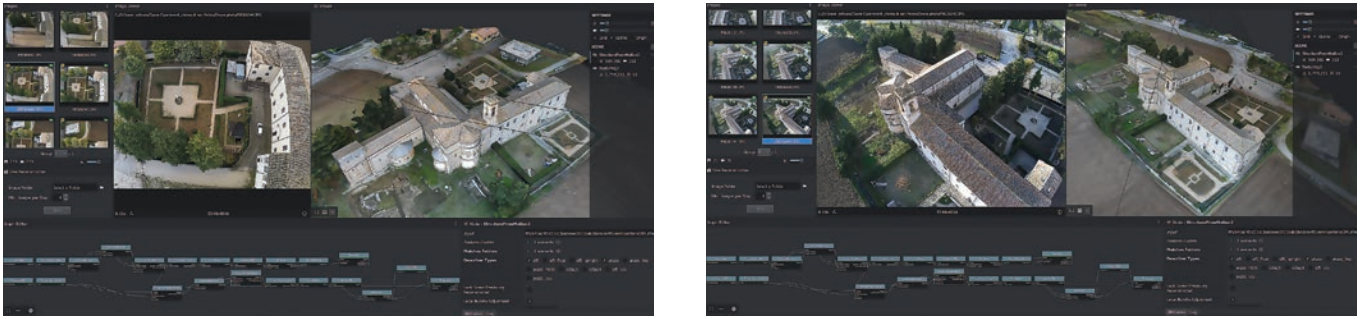

Figure 10. Open source meshroom software interface, calculation of the textured mesh model.

This geometric approach prevents the early underestimation of fundamental matching points and improves the number of matches, particularly with repetitive elements.

For the Dense Reconstruction, Meshroom provides other algorithms, such as the fundamental DepthMap, Dephtmap Filter, with which based on the potential of its graphics card it is possible to calibrate the final quality of the reconstruction of the dense point cloud, obtained on the basis of interpolation, managed by the AII of the program, of the points of the scattered cloud. In the case study it was necessary to divide the dataset into two parts relating to the two photographic acquisition methodologies, exactly as happened for the calculation of the chunk session in Metashape, so that the software, when uploading the photos, used an advanced recognition system named "Augmented Reconstruction", involving not only the standard SIFT algorithm but also the new AKAZE algorithm, capable of recognizing over 60000 + 60000 homologous points thanks to the metadata of each shot such as GPS indications.

The software was thus able to complete autonomously, following two independent workflows initially and then reunited, rejoining the point clouds, generating the complete model during the meshing phase without having to use any manual recognition marker. The result is a 758,000 polygons model.

5. Conclusions

On a visual level, a comparison of the two mesh models, generated with standard settings using the same computer, immediately reveals more details for the Agisoft product mesh than the denser but less detailed model generated by Open Source software. A technical comparison between the two systems was then performed to verify the validity and the obtained results in the specific case. For this purpose and with the help of the Cloud Compare software (http://www.danielgm.net/ccl), we were able to verify the actual distance of each vertex between the two meshes using Octree calculations[5], which define in specific units the amount of mesh or point cloud overlap compared. After the alignment of the models carried out through the overlap obtained with the convergence of three clearly visible points, taken in specific areas such as the tops of the roofs and edges of the structures, the software proceeds providing a numerical feedback from which we can infer a good correspondence between the two models at macro level, i.e. the proportions and heights seem to coincide despite a greater lack of details evident in the model generated by AliceVision's product. The results show a general Compute Distance of about 0.191625/ std deviation equal to 0.641589, so a coincident result for meshes generated by different software and workflows. For the complexity and extension of the survey an error of this size can be

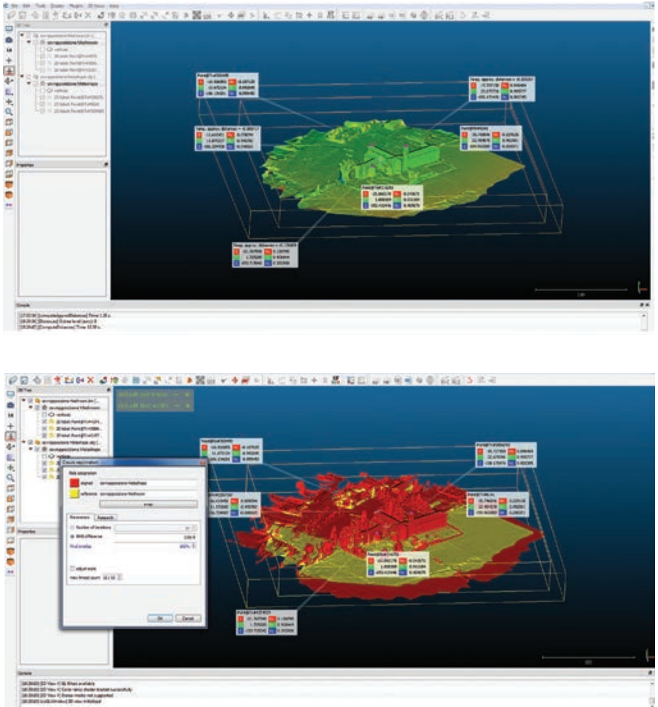

Figure 11. CloudCompare, calculating the marker for both models and distance of overlap Octree.

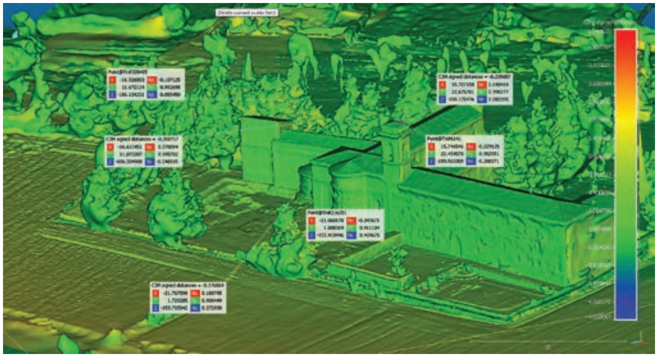

Figure 12. Cloud Compare, Cloud-to-mesh distances, color gradient graph.

considered acceptable, also considering that the cloud points processed by Metashape seems to be much more complete and clearer than the one processed by Meshroom, without some parts. It must be underlined that with the use of textures the models improve and maybe the quality of the textures of the open source version seems to be higher. The images show what is exposed and document the related steps.

Note

1 The management of the drone flight plan and the acquisition of the photographic dataset for the elaborations were carried out in collaboration with Franz Lami.

2 The alignment phase is essential to understand, before starting other calculations, the problems related to the images inserted, the error rates and any distortions to be corrected.

3 It is useful to underline that, unlike the Laser Scanner, from which you get an "ordered" point cloud with a scanning phase consisting of rows and columns, image-based systems create a very dense but "messy" point network, producing polygonal meshes with irregular topology, configured according to a calculation logic produced by the data and photographic information entered.

4 The topology is to be considered in computer graphics as the hidden geometry of a 3d model identifiable in the mesh configuration. Re-Topologizing thus means replacing the mesh conformation without modifying the apparent geometry of the 3d model.

5 An octree corresponds to the recursive partition of a cubical volume of space. From an initial box, octree cells are formed by dividing cubes into 8 equivalent sub-cubes. By default, the octree subdivision is initiated from the square bounding box of a cloud, but it can also be computed from an arbitrary cube is space (to optimize comparison algorithms such as distance computation for example).

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ABSTRACT

At the heart of the debate regarding the serious traumatic events that can affect cultural assets is the need for procedures for handling the rubble in order to better manage the reconstruction phase well in advance of construction phase.

The planning and implementation of UAV activities during rubble removal provides a useful support for the reconstruction. The organization of databases that allow data on rubble to be filed not as a simple counts, but instead based on the morphology of its constituent elements, makes it possible to devise a reconstruction plan based on the actual elements recovered.

Keywords:
Rubble survey, rubble analysis, virtual 3 reconstruction, cataloguing procedure, database construction.

Post-earthquake rubble management: the potential contribution of UAV for architectural heritage restoration

1. Introduction

There are several phenomena that can have an impact on buildings, particularly historical buildings, resulting in the caving in and/or collapsing of parts of or entire structures. When one looks at the historical series of traumatic events associated with natural phenomena, a noticeable increase in terms of intensity and frequency since the beginning of the last century is evident both locally and globally. While the disasters arising from hydro-meteorological and biological phenomena have grown exponentially due to the sharp increase in risk (climate change), the slight increase in destructive events caused by geological events, particularly earthquakes, is most likely caused by an increase in vulnerability and exposure. Furthermore, in Western Europe, in the second post-war period, traumatic events linked to conflicts or actions of a terroristic or, in any case, criminal nature have had various ups and downs, with a slight recovery in the last two decades.

After such events, whether natural or man-made, it is essential for a complex but accurate debris management system to be consider multiple instances that will set off the operating procedures to be put in place by the structure appointed for the purpose of emergency situations. In Italy, the seismic events of the last ten years (Abruzzo 2009, Emilia 2012 and Central Italy 2016) have slowly led to the definition of specific measures (government Ordinances) and procedures for assessment of outcomes related to the management of collapsed or demolished buildings. In this context, particular attention is being paid to the activation of differentiated procedures for handling rubble from collapsed buildings of cultural interest. However, it has been challenging to apply these procedures in post-earthquake contexts, highlighting the need to study additional strategies that involve the classification of rubble for the purposes of restoration of the site. These must be closely related, not only to the relevance of the destroyed architectural asset, but also to its precise placement before and after the traumatic event (Figure 1). To this end, photographic data from drones, even if acquired for purposes other than those linked to the future reconstruction, can be a useful aid for the subsequent intervention phases.

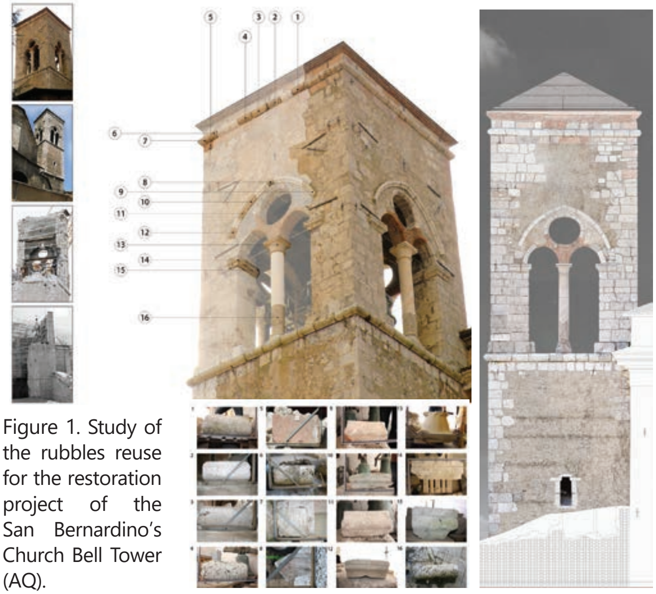

Figure 1. Study of the rubbles reuse for the restoration project of the San Bernardino's Church Bell Tower (AQ).

2. Recovering the rubble-collapse analysis and initial provisions

A collapse causes, on the one hand, the presence of material on the ground and the consequent formation of rubble[1] and, on the other, the presence, of incomplete wall structures, often in a condition of precarious equilibrium, i.e., ruins[2]. The kind of phenomenon that produced the rubble will significantly affect the type of damage that it causes. In the event of an earthquake, for example, the damage is often '*systemic*' affecting usually the entire building, but is manifested with greater or lesser intensity depending on the level of vulnerability of a building or, rather, a the single structural unit in its own context. Furthermore, related to the stresses affecting the wall structure with out-of-plane action, collapse mechanisms of overturning, vertical bending or horizontal bending frequently occur. In Italy, these types of destructive events have led to reflections focusing on how to regulate reconstruction of the ruined architectural elements on the ground or, in any case, displaced with respect to their original position within the framework of the restoration, one of the most interesting topics of debate in the second post-war period[3]. This is not the place to investigate the complex relationship between the quality of the recovery of the collapsed elements and the possibility of recomposing them by completing the missing parts, but when it comes to the importance of the methods used for recovering rubble, the reflections by Alfredo Barbacci appear to be fundamental. In 1956 he underlined how "*the first guide for the re-composition is given by the position of the various elements*"[4]. Subsequently, as a result of the Friulian experience, Alba Bellina, when drafting the analysis sheets of numerous reconstruction interventions carried out in Gemona and Venzone, integrated the reading of the damage suffered and the methods of collapse with analysis of the methods of clearing the rubble, and recovery and cataloguing of stone elements. The aim was to evaluate in a "*scientific*" manner what the author defines as a "*recoverability index*"[5] (Figure 2).

The importance of the rubble removal procedure is reaffirmed strongly by both Alba Bellina and Francesco Doglioni.

They emphasise that the anastylosis intervention should begin as soon as the collapse has occurred, and indicate the "*archaeological method*"[6] as a reference for the removal and sorting of rubble.

According to the two authors, the analysis of the position of the elements on the ground is particularly relevant to the study of how the building collapsed [7](Figure 3). It was not until the end of 2013 that the first regulatory provisions were issued by MiBACT concerning the management of actions to secure and safeguard cultural heritage in the event of emergencies arising from natural disasters[8]. The same Ministry then issued a specific directive on "*Procedures for the removal and recovery of rubble of protected assets and historic buildings*"[9] pertaining to the seismic events recorded from 24th August 2016. This Directive provides for the acquisition of photographs taken from above using drones before and during the removal of the rubble.

Although the case of the Church of Saint Benedict in Norcia (PG) revealed several critical issues regarding

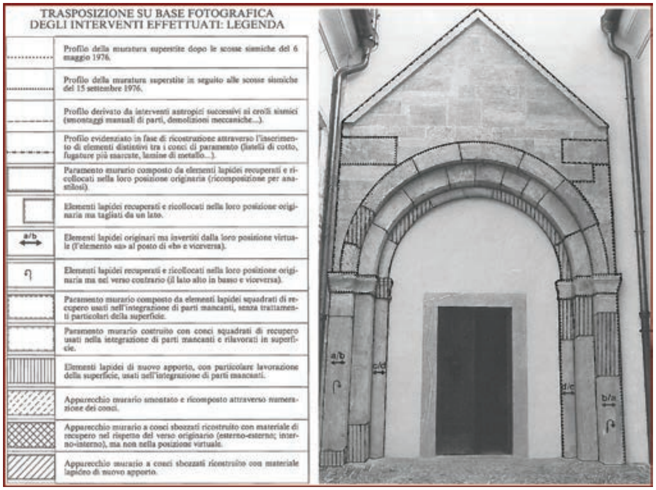

Figure 2. Example of Alba Bellina analysis of reconstruction intervention in Gemona.

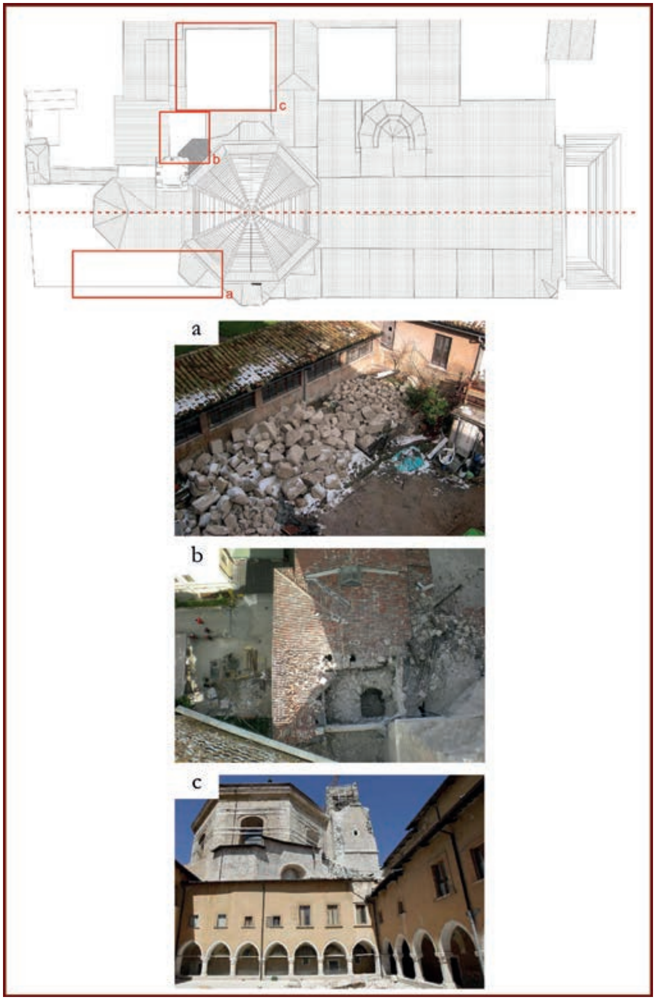

Figure 3. Bell Tower of San Bernardino's Church (AQ): identification of the drop points on ground of the structure.

the application of the ministerial decrees[10], it did provide an opportunity for qualification of the methods of removal and recovery of rubble in the construction site.

Specifically, drones, or UAVs, were used to create an orthophotographic base for the purposes of geo-referencing the removed fragments and documenting the work, considering the impossibility of applying the stratigraphic method for reasons related to the safety of the workers. Though singular situation (few other post-earthquake sites have seen the use of remotely piloted aircraft since 2016), the case of the Church of Saint Benedict highlighted several limitations in the exploitation of the potential offered by these tools, which are widely present on the market today. Retracing the different operational phases that followed the traumatic event allows us to promptly verify the possible strategies of integrating the use of drones. The ultimate aim is the continual improvement of the quality of the recovery of the collapsed elements which, it should be emphasised, cannot constitute the only condition for allowing the same elements to be recomposed.

3. Handling the rubble in the emergency phase

In the immediate aftermath of a collapse event, the immediate action of the authorities is solely aimed at rescuing people involved in the collapses. This type of intervention generally requires delicate manoeuvres, often manual, to excavate and remove debris from the ground. The only factor governing such removal operations is the need for them to be carried out as quickly as possible without causing further harm to any survivors.

Simultaneously, and immediately afterwards, initial work begins on clearing accessibility/connection infrastructure so as to allow an effective throughway between emergency areas and strategic sites (e.g. recovery centres and hospitals). In medium to large cities, these routes may be the oldest roads, normally typified by the presence of important historical buildings, even of a specialised nature. In this case too, the speed necessary for operations of debris removal caused by collapses that often involve such buildings, usually facing the road, does not enable control of what is being moved. Finally, and always under extremely tight deadlines, controlled demolition[11] of buildings or parts of buildings (towers, bell towers, chimneys, slender wall structures that are not near the road, etc.) can be carried out. This can jeopardise the safety of rescue operations and subsequent inspections by experts in order to verify and assess the damage done and by the residents themselves in their own homes. Even though the time required for such interventions should enable the so-called *"controlled dismantling"* of the wall structures, the lack of specialised human resources usually entails decidedly less rigorous procedures (Figure 4 and Figure 5).

During these delicate phases, drones are already being widely used by first responders. Several flights are performed in order to assess the need for rescue interventions aimed at saving people trapped under the remains of the buildings, before continuing with the subsequent phases of removing and/or moving the rubble.

Once the phase of extreme urgency is over, having taken note of the overall damage level, a Legislative Decree is issued.

This establishes how the subsequent emergency phase should be managed, with particular reference to the procedures, at a national level; the institutional players involved; and, above all, the human and economic resources to be deployed.

The player having the greatest influence in the management of the emergency is the Commissioner for the reconstruction, who is appointed by the National Government.

The Commissioner then decrees the actions to be taken via one or more Ordinances[12].

The management of the rubble is generally one of the main subjects outlined in the Legislative Decree[13], but it is dealt with in more precise detail in the subsequent Ordinances.

In this phase, a plan should be created to survey the area using drones, in relation to the activities to be carried out on the ground. The aim should be to be able to put in place data collected in a more or less finalised way that allows the creation of a rough database to be used in the reconstruction.

Figure 4. Palazzo del Governo and Sant Agostino's Church (AQ): in red and in yellow the exemplification how rubbles are moved during the emergency phase.

Figure 5. Church of Sant'Andrea (Campi di Norcia - PG) before and after the earthquake in 2016. The rubbles were moved to allow the vehicle passage.

Drone flights are especially useful when architectural elements have already been removed, without their being associated with their own area of collapse (the aforementioned uncontrolled removal), but also when they have; in the latter case they enable the real roto-translation of each element within the'Stratigraphic Units' to be pinpointed.

4. Information managment

4.1 Removal of rubble – land and air activities

To analyse the collapse and plan the reconstruction, we must be able to relate each element removed (to be surveyed via photogrammetry later on) with the portion of the building that it originated from, and to refer them to their respective collapse mechanisms (Figure 6). The activities required should take place according to a logical sequence that involves alternating drone flights with rubble removal on the ground.

This allows us to obtain frames for each'Stratigraphic Unit' being monitored (Figure 7). Each sequential "*macro-phase*" (drone flight + rubble layer removal), carried out in a consequential manner, has the aim of surveying, through photogrammetry, the architectural elements in the context of the collapse.

The large number of elements to be surveyed, as well as the compulsory expeditious nature of the operations, means that the metric references required for the post-processing phases need to be carefully planned and prepared; it is also necessary to conduct accurate and timely classification and indexing of the frames.

This will enable a reading of the frames that will be "*linear*" (i.e. in chronological order) but, above all, "*closed*" (i.e. with frames associated with their respective areas of collapse).

4.2 Creation of the database

The time interval between the removal phase and the processing of the data (years, even in the best-case scenario) makes necessary to begin work on database construction during the first phases.

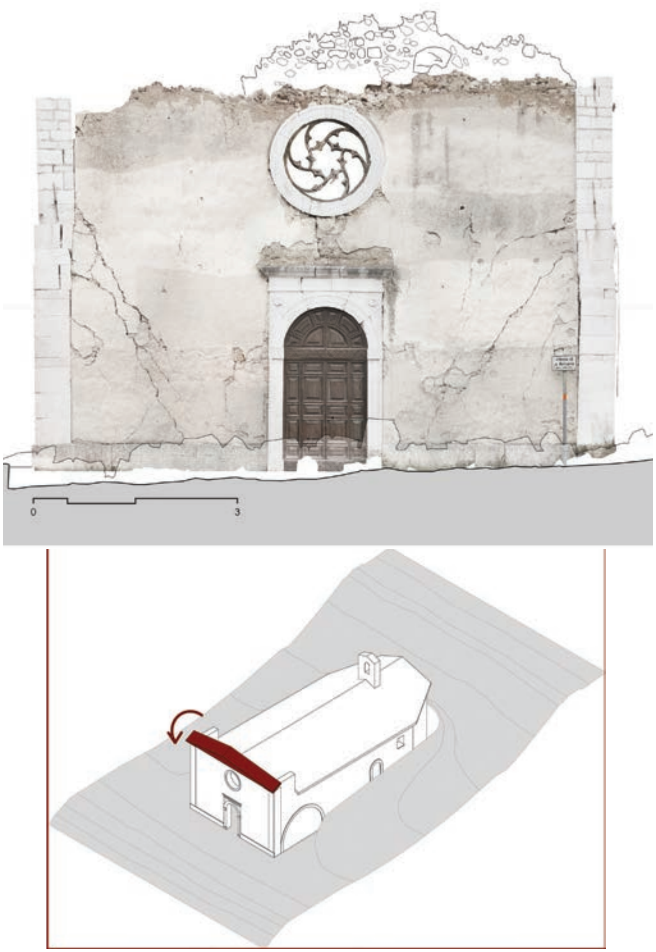

Figure 6. Identification of the collapse mechanisms that generate the presence of rubbles in front of the façade of Sant'Andrea Church. (Credit: M. Agnelliti, M. Venturoli Gabriel)

This initial database - Database 0 - must be able to be eventually implemented and as such it should contain the following information:

- Drone images and footage taken during the emergency phases.
- Flights performed during the emergency phase enable the positions of the architectural elements in the immediate aftermath of the collapse to be

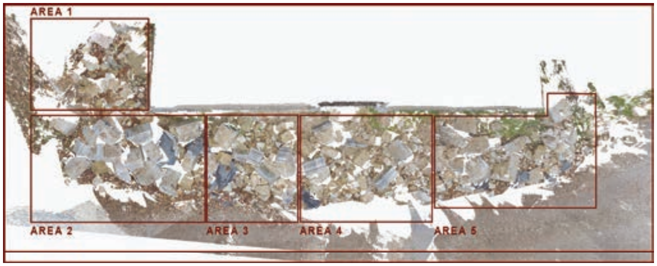

Figure 7. Planning of the Stratigraphic Units for the rubbles survey of Sant'Andrea Church.

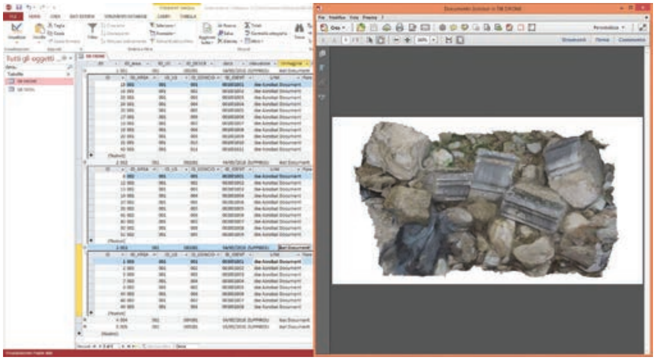

Figure 8. Sant'Andrea database 1: the database contains elaboration of the point cloud per each area of collapse planned.

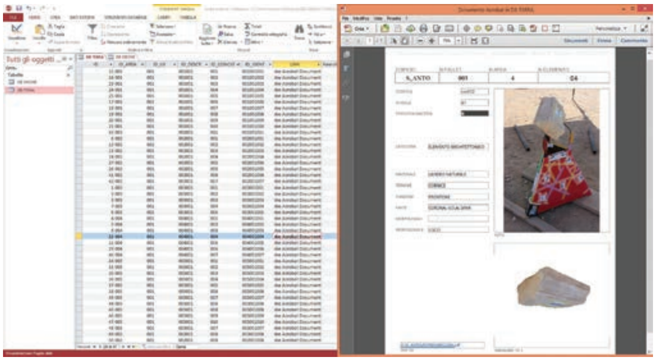

Figure 9. Sant'Andrea database 2: the database contains the catalogue of each elements surveyed on ground.

identified, and the movement of the rubble to be "mapped". These positions will be different from those surveyed later on, and drone footage thereby makes it possible to trace back the various phases of rubble movement and to identify the real points of collapse of the displaced elements.

- Drone footage frames taken during the rubble removal phases.
- These will be useful for photogrammetric survey of the rubble in the extraction phase (phase 4.1).
- Images of architectural elements taken from the ground for the photogrammetric survey of the single elements[14].
- Two different databases will be created later on. One, Database 1, will contain the point cloud of each area of collapse (drone photogrammetry) (Figure 8), while the other, Database 2, will be completed with the point cloud pertaining to each element (on-ground photogrammetry) (Figure 9).

Other useful sources of information that could add to to the data are:

- Laser scanner survey of the post-earthquake state (Figure 10). The laser scanner survey is useful both for a more accurate metric reference of the rubble pile (software able to process together photogrammetry and point clouds from a laser scanner), and to refer the elements on ground with their exact position within the monumental building (the metric accuracy of laser scanner survey allows more precise correlation with the features still present in the building).
- Surveys of the pre-earthquake state (if available).
- Historical photographic documentation.

4.3 Database Correlation

The next stage is to link up the two databases in order to correlate the various elements catalogued in Database 2 with the data contained in Database 1, which records the morphology of each element in the '*Stratigraphic Units*' (Figure 11). Correlating the two databases makes it possible to:

Figure 10. Laser scanner point cloud of Sant'Andrea Church.

- Identify the area of collapse (Database 1) for each of the surveyed elements (Database 2), data which is never included in the documentation pertaining to uncontrolled removal.
- Establish the roto-translational movements of the elements during the collapse, information which helps us to better understand collapse mechanisms.
- Recognise the pre-earthquake positions of similar and consecutive elements.

The use of comparable elements which compose architectural features (cornice, architrave etc.) does not permit the univocal re-collocation of the elements through identification of the number of area they belong to alone.

To define the correct position of each element belonging to a set of similar elements within the area of collapse, correlation of the elements in Database 2 with the information in Database 1 is required (Figure 12). Other information that may be useful are the lithotype, surface treatment, and state of decay, amongst other factors.

4.4 Virtual reconstruction

The above procedure became a starting point for the virtual reconstruction (Figure 13) of the collapsed architectural elements on the ground[15].

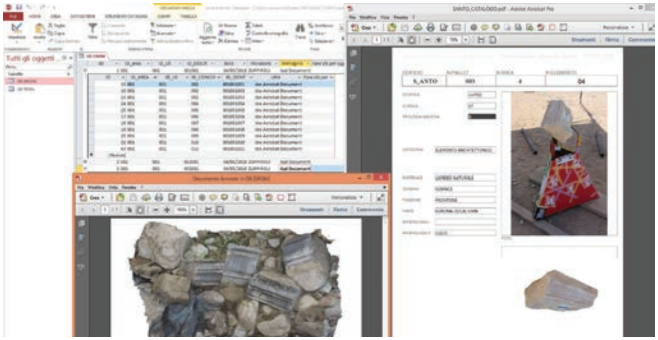

Figure 11. Correlation of database 1 and 2 of Sant'Andrea Church. Each component of database 2 is related to its own area in database 1. The correlation was realised manually by the operator recognising the morphology, the degradation and other aspects.

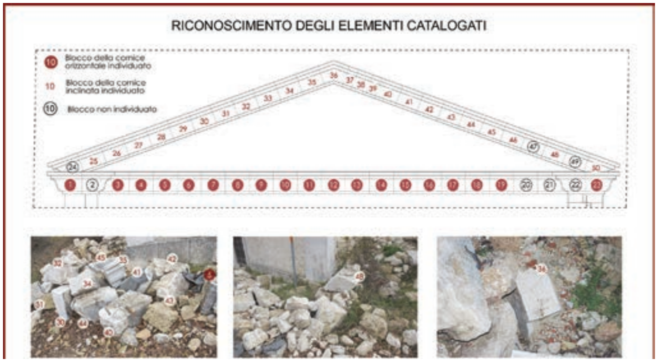

Figure 12. Example of correct positioning of each elements belonging to a set of similar elements for the cornice of Sant'Andrea Church. (Credit: M. Agnelliti, M. Venturoli Gabriel).

5. Conclusion

The different aforementioned uses of the drone's images during the removal and cataloguing procedure underline the needs on the one hand to improve drone flights, especially in the emergency phase, the phase in which the rubble has not yet been moved, and on the other to coordinate and plan the activity on the ground with the UAV.

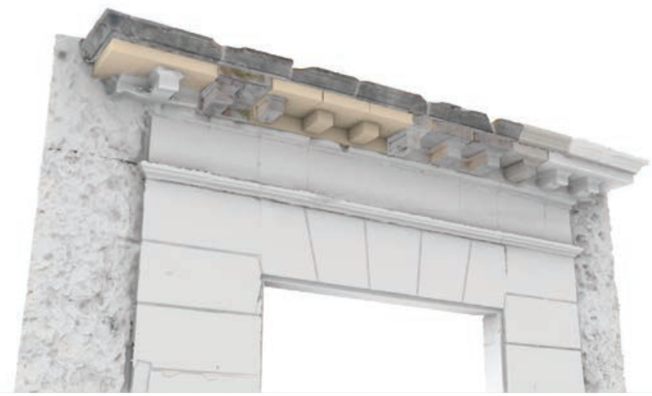

Figure 13. The virtual re-collocation of the elements recognised in the rubbles of Palazzo del Governo (AQ). The different colours identify the elements still in situ, the elements virtually re-located and elements definitely lost which are represented through simplified forms.

Secondly, the creation of a photographic database (Database 0), structured according to space and time ("*closed*" and "*linear*" reading of the frame, as shown in in 4.1), enables construction of Database 1 and Database 2 to be postponed until requirements related to the restoration and/or reconstruction project arise. As additional consideration, the databases correlation expressed in point 4.3 is currently carried out by a human operator, who manually identifies and connects the different databases elements; in the future this process will likely be automated thanks to the implementation of software based on AI and neural networks.

Note

1 The Italian term "maceria" (meaning rubble) seems to refer to the Greek noun "makaria" meaning "flour dough and broth". Therefore, it does not seem related to the type of material but rather to the chaotic way in which it is destroyed and to the fact that it is impossible to distinguish its constituent elements.

2 The term "ruin" comes from the Latin "*rŭīna*" and means both the material that falls to the ground and the remains and surviving structures of buildings and urban complexes that have suffered partial or total collapse. The term is often used in connection with the parts of ancient buildings that are still standing. In the context of this report, we use it in its general meaning.

3 For more information on this theme, with particular attention to the second post-war period, see M. P. I. *Direzione Generale delle Antichità e Belle Arti*, 1950, pp. 47-48; De Angelis d'Ossat G. 1957, passim; Bonelli R. 1953, pp. 54-58; Barbacci A. 1956, pp. 97-101; Brandi C. 2005, pp. 150-179; Bellina A. 1988, in particular chapter 1 "*L'anastilosi nell'ambito della teoria e storia del restauro*", pp. 19-38; Dalla Negra R. 2012.

4 See Barbacci A. 1956, p. 98. As example he provides two specific cases: "*collapsed portico rovesciato will present itself, even with some reciprocal movement of stones, as a projection of the untouched work on the ground [...] and it will be possible to identify each column with its own capital and base, the arches or the lintel of the subsequent spans, crowning cornices, etc. Similarly, in a fallen wall, the different horizontal rows and the moulding will be identifiable from the position of stones overlapping it, albeit with inevitable uncertainty, especially if they are small elements*" (Translated by the author).

5 Translation of the author from Bellina A. 1988, p. 47.

6 See Bellina A. 1988, in particular "Final notes, by Alba Bellina and Francesco Doglioni" pp. 209-214. (Translated by the author).

7 Ibid, p. 211.

8 Directive of 12th December 2013: Directive of 12th December 2013: "Procedures for management of safety and safeguarding of heritage in the event of emergencies and natural disasters." (GU Serie Generale n. 75 dated 31/3/2014, revised by the Directive dated 23rd April 2015) (Translated by the author).

9 Carried out by the Preservation and Restoration Institute (ISCR) - architect Gisella Capponi, and General Directorate for the Archeology, Fine Arts and Landscape, (DG-ABAP) - Caterina Bon Valsassina and architect Alessandra Marino. (Translated by the author).

10 See Argenti S. et al.. 2017.

11 For example, the demolition of the bell towers at Poggio Renatico (with the use of explosives) and Buonacompra, of the chimney at Bondeno and the Parisio mill in Bologna are mentioned in the context of the 2012 Emilia earthquake.

12 Ordinances by the delegated Commissioner are governed by art. 5, paragraph 2 and 2 bis of Italian Law n. 225' Establishment of the National Civil Protection Service', dated 24th February 1992, and fall into the category of contingent and urgent measures; they may

derogate the laws in force (in compliance with the general principles of the system) and do not have pre-established content.

13 For the 2009 Abruzzo earthquake, please refer to Legislative Decree n. 39 dated 28th April 2009, "Urgent measures for communities affected by earthquake in the Abruzzo region on April 6, 2009 and other urgent operations of civil protection" (Translated by the author), which was converted into Law n. 77 on 24th June 2009, with specific reference to Art.

14 A procedure for the management of the rubble is illustrated in Zuppiroli M. 2019 (part 4).

15 See Zuppiroli M. 2019 (part 4-5).

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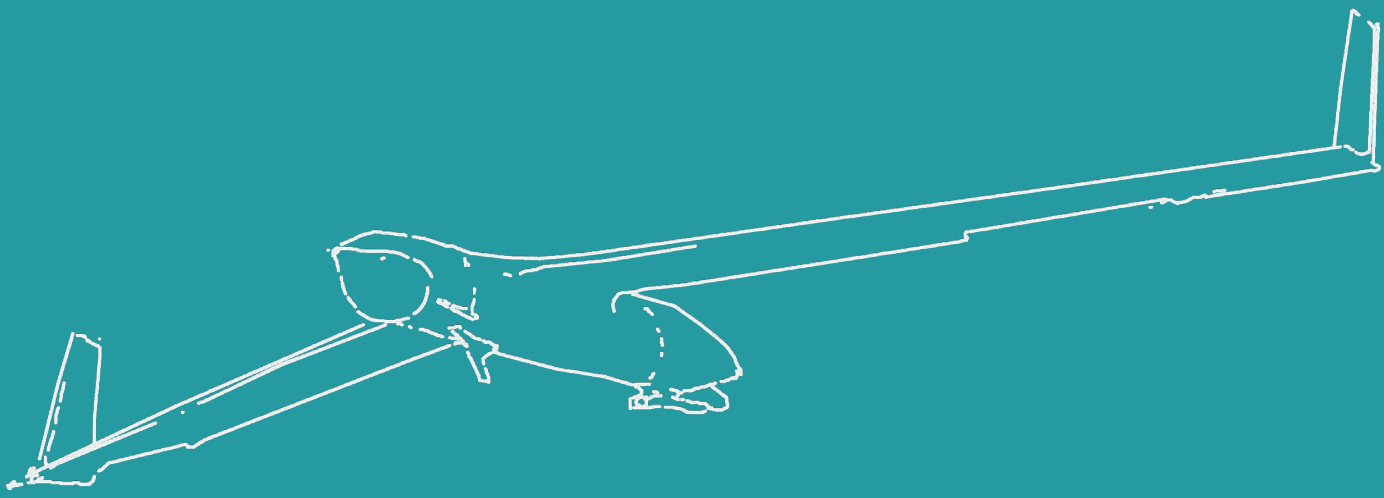

TOPIC

UAVs REMOTE SENSING FOR THE ANALYSIS OF TERRITORIAL ASPECTS: GEOLOGICAL, AGRICULTURAL, FORESTRY

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Keywords:
Cultural Landscape Heritage, UAV, photogrammetry, integrated 3D metric survey, environmental 3D model.

ABSTRACT

In the last decades, the technology progress in the cultural and environmental field has had a loud growth. The authors applied drone and terrestrial photogrammetric techniques for a complete survey on a complex Cultural Landscape Heritage, requiring protection and promoting actions. These technologies were used to obtain even more detailed 3D point clouds, terrain models, orthophotos (also new quasi-vertical product) with a centimetre accuracy, for tourism development and landslide hazard prevention on road and villages, also reducing survey costs in a complex and limited orography site.

UAV data acquisition and analysis for a Cultural Landscape Heritage: the emergency area of the Vallone d'Elva

1. Introduction

In recent years, the study of Cultural Heritage (CH) in Italy has undergone a considerable increase. In this perspective, different detection technologies have been developed and used for mapping and monitoring artificial and environmental issues, such as image-based UAV (Unmanned Aerial Vehicle) technology and terrestrial photogrammetry (Watts 2012; Balletti 2019; Barba 2019), associated with traditional topographic techniques.

The article aims to enhance the environment-territory system from a tourist and safety point of view (Parrinello 2018), using a multi-sensor approach to rebuild the landscape heritage of the Vallone d'Elva in Piedmont (Italy), investigating the persistent rocky slopes vulnerability along SP104 road, still closed to traffic, leading to Elva hamlets. In the literature, monitoring and documenting of landslides case studies in complex and inaccessible environments using geomatics technologies are manifold, testifying the importance of this issue. With this in mind, classical topographic techniques such as TLS (Terrestrial Laser Scanning) (Artese 2015 & Kaspersky 2010) for monitoring the large impact landslides were employed, associated with UAV (Lindner 2016) and terrestrial photogrammetric techniques, as well as global satellite technology (Gili 2000) in orographically complex environments subject to landslide events at different scales. Given this orography complexity, an "*ad hoc*" acquisition and processing methodologies have been developed (Fissore 2017), to generate the 3D model.

Nadiral and oblique images (Lingua 2017) have been acquired, in order to obtain a more exhaustive and correct 3D model (complete, accurate, precise) for the greater landslide hazard as witnessed by the event occurred in 2014 which led to the definitive closure of the route. As performed in a similar case (Bassani 2019), a specific Mobile Mapping System (MMS) with LiDAR, GNSS and other synchronized sensors mounted on a car could allow the extraction of detailed 3D model of the sub-vertical rock walls. Here, this investigation could not be carried out due the poor GNSS satellite visibility for kinematic applications caused by complex orography. To overcome this, high resolution terrestrial photogrammetric survey of the whole road has been performed, obtaining dense point clouds and vertical orthophotos, useful for geostructural analysis and tourism landscape purposes. High-resolution images by UAV and terrestrial photogrammetry were analysed using photogrammetric software (Agisoft Metashape Professional), generating surface data at different survey scales with a multiscale approach (Bemis 2014), obtaining 3D models at different levels of detail along the road axis, or focusing on the landslide event. The models obtained enabled the generation of the DSM (Digital Surface Model) and orthophotos (Li 2004); further analyses were carried out to classify the vegetation on rocky slopes, generating a high-resolution DTM (Digital Terrain Model) useful for the planning and landslide risk analysis. Data obtained through the SfM (Structure for Motion) computation of UAV images, allows also to calculate the rock volume possibly subject to collapse, in continuity with field analysis (Tucci 2019).

2. The case study: Vallone d'Elva road

The case study is the road of Vallone d'Elva. The village of Elva is sited in Maira Valley in the province of Cuneo (CN). The historical small centre is the 10th municipality for altitude in Italy, 1700 m a.s.l., it is composed by 22 hamlets (mostly abandoned) and it is famous for its richness of artworks. The church contains paintings of the 14th century realized by "Maestro d'Elva" Hans Klemer, a baptistery of XIV century and a wooden crucifix of XV century. For all these reasons the connections with other valleys have always been important for this area. The local people have tried to design a road in order to easily connect Elva to the lower Valle Maira main road. Some documents reported the necessity of an easier route and in 1838 a municipal resolution declared to design a path between Maira and Varaita Valleys, opened in 1934 as mule-track and suitable for vehicles in 1950. The road is composed of 10 km of paved road, enclosed by walls of living rock, flanked by twelve tunnels dug into the rock. From the beginning, it was characterised by landslides and rock falls events causing long periods of isolation for Elva villages. After a huge landslide event in 2014 the road was declared closed due to its dangerousness (Figure 1). Today, the inhabitants of Elva are claiming the re-opening of the road for its cultural and historical value and for its attractiveness. For these reasons and due to its history, the road could be considered a CLH (Cultural Landscape Heritage) to take in consideration for different type of analysis (spatial, morphological, geological,…).

In the UNESCO definition and classification, it is possible to consider as CH "monuments, group of building and sites and as natural heritage (NS) natural features, geological and physiographical formations and natural sites" (eg. Convention Concerning the protection of the World Cultural and Natural Heritage 1972). Afterwards, a more recent definition in the UNESCO documents of 1992 add the Cultural Landscape definition to the previous one, in order to identify combined works of nature and humankind (WHC-92/CONF.002/12 point IV).

Figure 1. 2014 landslide's event which closed the SP 104.

The cultural value of the road could also be underline by the fact that Maira Valley is included into many projects and objectives of the RLP (Regional Landscape Plan), which represents the main tool for establishing the quality of landscape and the sustainable development of the entire regional area. The RLP places within its main strategies the "Revitalization of the mountain and of the hills" that can be reached contrasting the abandonment of the territory, the redevelopment of the Alpine landscapes and the enhancement and re-functionalization of the itineraries historical and scenic routes. Moreover, the Maira Valley has considered as strategic guidelines the protection of elements of geomorphological interest, land monitoring and tourist enhancement of the typical landscapes.

3. Data acquisition

The Vallone d'Elva route is a complex environment which characteristics require a careful flight planning. Using standard criteria of terrain resolution and accuracy of photogrammetric products (Piras et al. 2017), it has been chosen to perform manual flights with skilled UAV pilots to guarantee a higher level of safety. To guarantee a rigorous approach in terms of accuracy and precision, a crucial step involved

the realization of a topographic network by using both GNSS (Global Navigation Satellite System) and traditional topographic techniques.
The coordinates of 22 vertices have been measured through a geodetic GNSS receiver in static mode (1 hour for each point). The coordinates have been estimated considering a multi-base solution (through the Leica Geo Office® software v.8.4) with the Ostana and Demonte permanent stations of CORSs (Continuous Operating Reference Stations) network by Piedmont district (Figure 2), obtaining a high level of accuracy (σmax=3 mm in vertical direction).
Starting from the reference vertices with RTK GNSS survey, some photogrammetric control points has been acquired on markers, both on horizontal street surface and on vertical rock facades (Figure 3).
The coordinates were estimated with a precision of few centimetres (σmax= 3 cm) with fixed-phase ambiguities for all points.
Finally, the positions of 54 vertical markers (Figure 3c) and 120 natural target points were measured by a total station (Leica Image Station) located on the reference vertices. All measurements were subsequently adjusted with the MicroSurvey StarNet v.9.0 software tool, in order to obtain the final coordinates: the RMSE (Root Mean Square Error) of the estimated coordinates was less than 1 cm.

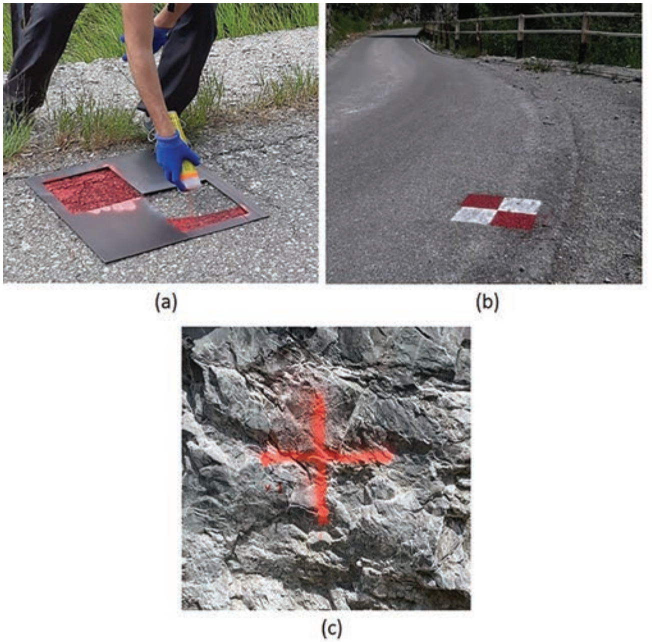

Figure 3. Control points materialization: (a) colouring of highly visible markers (30x30 cm) along the street, using a specially made template; (b) a horizontal marker; (c) a vertical marker.

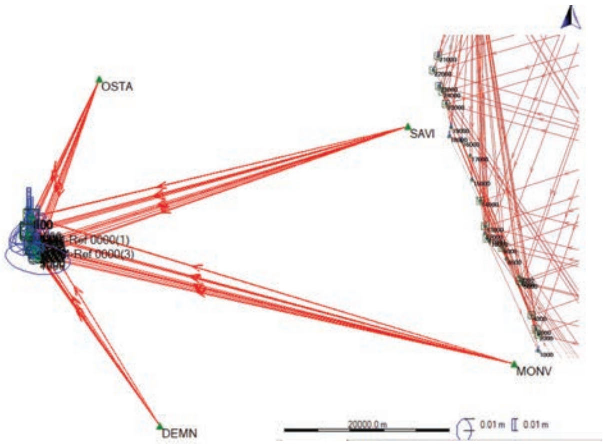

Figure 2. CORSs permanent stations network used as reference.

Figure 4 shows the final topographic network. The image acquisition has required two days considering winds and weather conditions, for 11 flights (Table 1).
The "almost vertical" rock facades suggested the use of a mixed approach for the block geometry, combining nadiral images, about 100 meters far from the street level, and oblique images with a mean distance of about 50 m from rockfaces. Two commercial UAVs have been used (DJI Phantom 4, with a FC6310 camera, 20 MP CMOS sensor, focal length of 8.8 mm).
In order to cover all ten kilometres of the road, the survey was divided in three different areas, namely "High part of Road (HR)", "Low part of Road (LR)" and "Large Landslide (LL)" (Figure 5).

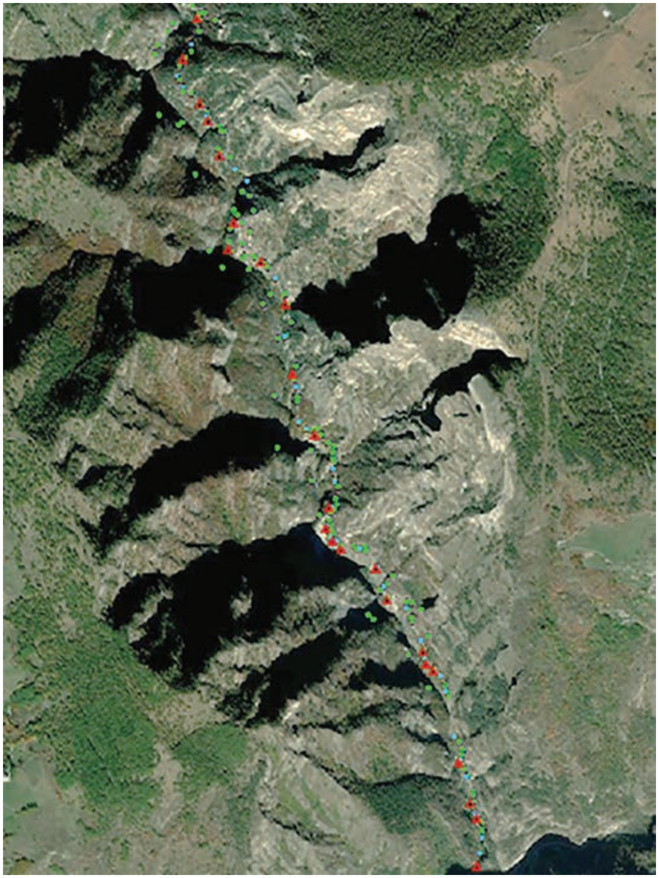

Figure 4. The topographic network with reference vertices (red), horizontal markers (blue), vertical markers and the natural points (green).

Area	Nadir	Oblique	Total
HR	3 flights 505 images	5 flights 395 images	8 flights 900 images
LR	4 flights 340 images	3 flights 259 images	7 flights 599 images
LL	2 flights 48 images	2 flights 137 images	4 flights 185 images

Table 1. Flights and images in different areas. For the location of the HR, LR and LL areas, please refer to Fig. 5.

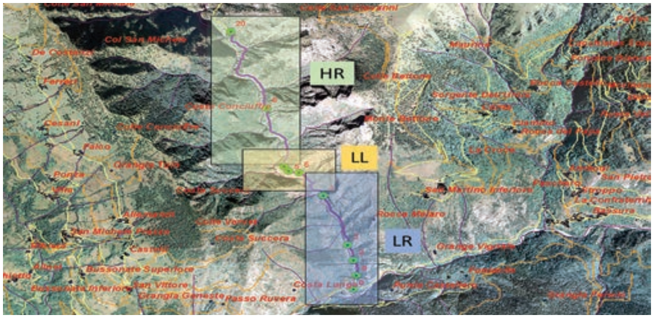

Figure 5. The three different areas of Vallone d'Elva route.

4. Photogrammetric data processing

The photogrammetric processing has been carried out with SfM algorithms using the commercial software AMS (Agisoft MetaShape professional), dividing the total amount of the gathered data in 3 different chunks. Nadiral and oblique images have been aligned together, setting up the "high" level of accuracy of AMS (i.e. using the photos at the original size). Then, some GCPs (Ground Control Points) used for georeferencing 3D models, and CPs (Check Points) to validate the obtained precision, have been collimated in all the images, obtaining the results shown in Table 2 and Table 3.

Three 3D dense point clouds have been produced with the "high" details level of AMS (which means that the original images were downscaled by a factor of 4 – i.e. 2 times by each side) in order to obtain some products suitable for a large-scale purpose (1:200), as shown in Table 4.

	n. GCPs	ΔX [mm]	ΔY [mm]	ΔZ [mm]
HR	17	39 **16**	29 **13**	53 **17**
LL	9	10 **5**	19 **9**	10 **5**
LR	13	20 **10**	15 **7**	34 **14**

Table 2. Max/mean (bold) residuals on GCPs.

	n. CPs	ΔX [mm]	ΔY [mm]	ΔZ [mm]
HR	7	33 **14**	13 **8**	16 **10**
LL	4	12 **8**	7 **5**	10 **7**
LR	5	13 **9**	17 **9**	26 **15**

Table 3. Max/mean (bold) residuals on CPs.

	N° points [millions]	Processing time [hh:mm]	Density [points/dm^2]
LR	199	05:49	8
LL	47	00:24	10
HR	268	03:46	6

Table 4. Millions of points, processing times and densities of dense point clouds.

High density point clouds (about 1 point each 4 cm) and a moderate level of noise have been obtained: some noisy points, caused by vegetation and border effects have been removed manually. The triangulated 3D models have been obtained using the setting "high" of AMS (i.e. using 1/5 of the number of points of the source dense point clouds), generating high resolution meshes in terms of faces and vertices number, as summarized in Table 5.The final steps had regarded the generation of the DSM and the relative orthophotos in the coordinates system WGS84 – UTM 32N using the relative meshes (detailed in Table 6), as shown respectively in Figure 6 and Figure 7.

5. DTM generation and multiscale GIS

Although filtering and segmentation of clouds from airborne flights is now a fairly consolidated procedure, the use of such high-detail clouds in complex environments with slopes and irregularities, makes it necessary to experiment "*ad-hoc*" workflow that supports the specific characteristics of the point clouds and the thick vegetation recognizing objects to be extracted, such as trees and buildings (Spanò et al. 2018). In this case, to obtain a DTM (Digital Terrain Model - without vegetation), two different filtering and classification approaches with AMS were tested (one completely automatic and another one semi-automatic). The first approach was not completely successful because of the complex orography of the area.

	N. faces [millions]	N. vertices [millions]	Proc. time [hh:mm]
LR	40	120	02:04
LL	0,1	0,1	01:26
HR	53	27	02:09

Table 5. Numbers of faces and vertices against processing times of the generated meshes.

	DSM process. time [mm:ss]	Orthophotos process. time [mm:ss]
LR	02:44	25:58
LL	00:09	00:14
HR	03:39	33:50

Table 6. DSM and Orthophotos processing times.

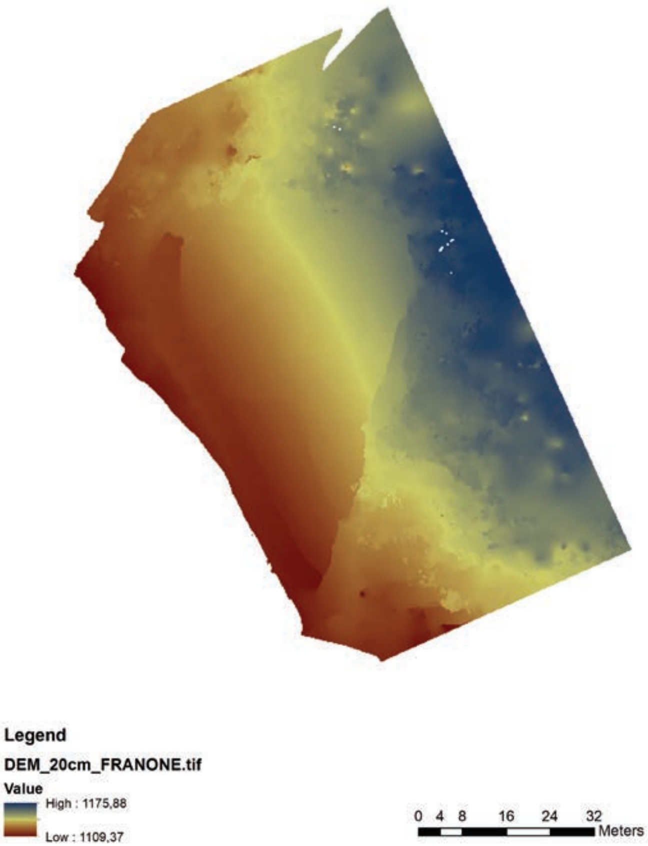

Figure 6. DSM generated on the LL site.

Figure 7. Orthophoto extracted by LL site.

The results of semi-automatic classification were acceptable: 75 % of the vegetation points were correctly detected, while were wrongly classified ground about 11 %, and the rest was unclassified; besides, 85 % of rock wall were correctly detected as ground, while 9 % were wrongly classified like buildings in "*quasi*" vertical parts. In the following (Figure 8) are reported the different between them and the critical issues found.
Starting from the ground classify points obtained, 3D surfaces have been generated to compute a DTM with a GSD of 20 cm. Analyses and post-processing phases have been developed using a multiscale approach, optimizing gradually the elaborations according to the operative aims. Specifically, we started with a regional analysis of the cultural and geological features of

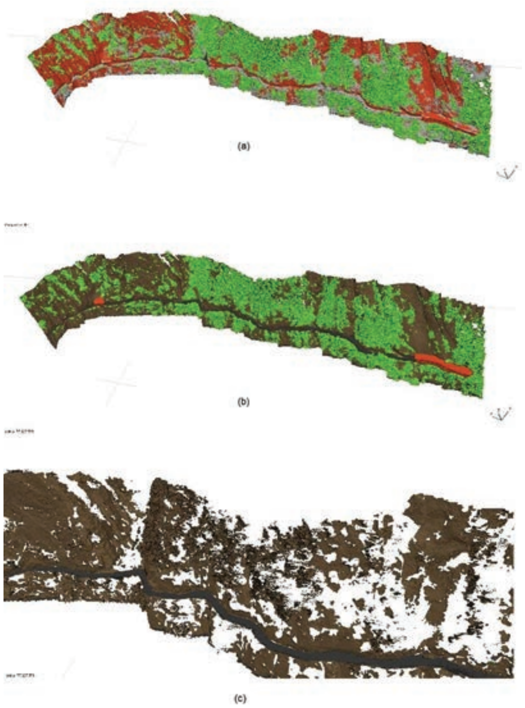

Figure 8. Classification map reporting classifying results: a) Automatic classification by "Classify Points" tools; b) Semi-automatic classification in AMS; c) Critical issues found cause of complex and steep geography. Red, green, brown and black points represent building, vegetation, ground and road respectively.

the entire valley of the Elva stream, establishing a GIS platform, show in (Figure 9). Finally, they allow an enhancement of all the landscape aspects of the Vallone d'Elva in order to create virtual tours (Bronzino et al. 2019).

6. A new product: the side road orthophoto

The larger scale data have been produced using terrestrial photogrammetry to obtain even more detailed 3D results, with a resolution in order to perform geological analyses on individual fractures/rock-walls

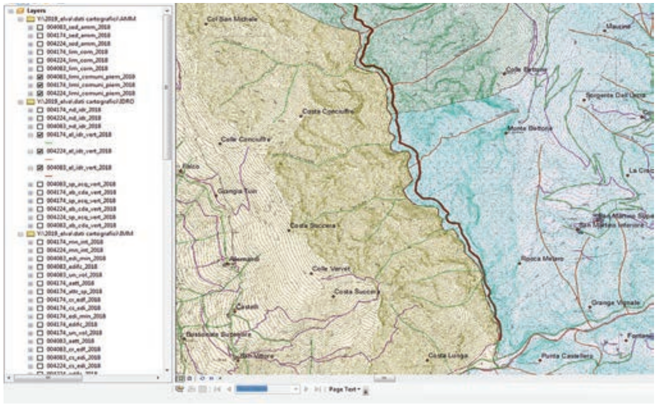

Figure 9. GIS platform for multiscale data visualization and analysis approach.

for landslides hazard and for touristic purposes and valorisation of this CLH. For an easier representation of geostructural features (such as sliding mechanisms, rock-wall fracture analysis, etc.) some vertical orthophotos were performed, as shown in (Figure 10). These orthophotos constitute an important aid in the design phase for feasibility studies, general and executive planning.

7. Conclusions and perspectives

For the CH study and validation regarding the Vallone d'Elva road, the most recent and current 3D detection technologies have played a significant role. The use of nadiral and oblique images from UAV was employed on a complex orography with a limited accessibility allowing to reduce survey costs in respect to more traditional survey technologies. Moreover, a terrestrial photogrammetric approach was used to exploit the pre-existent dense point clouds, obtaining an even more detailed feature of the landscape and cultural value of Vallone d'Elva, allowing to obtain an high level of detail and providing consistent and valuable material and results for the study of landslide hazards

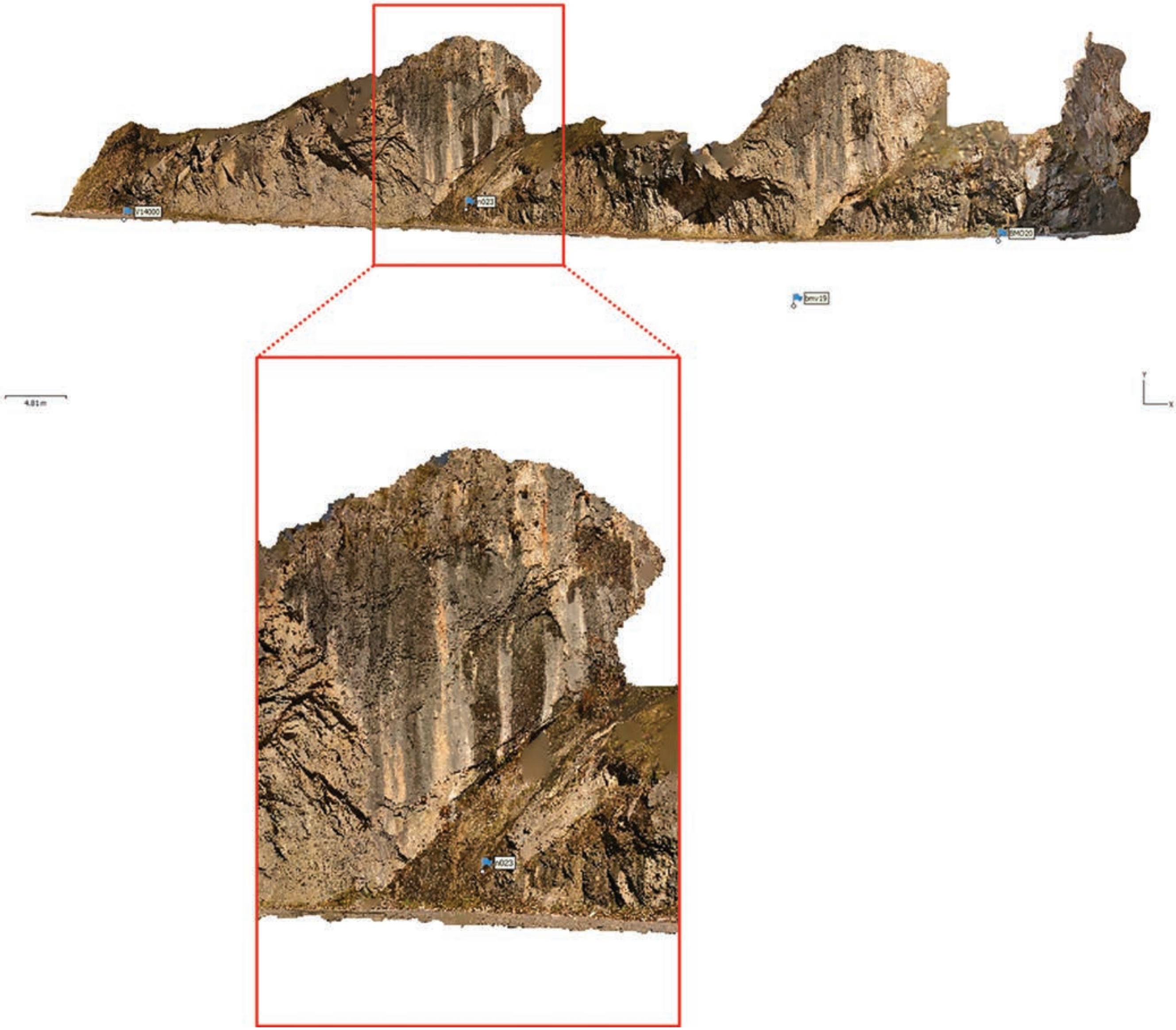

Figure 10. Vertical orthophoto on a particular side of SP104 rock-wall. Note the even more detail on the rock wall (red box).

and tourist valorisation of the road, the hamlets and the villages. The multiscale approach supply an effective representation of this complex object, useful for the aforementioned different purposes.

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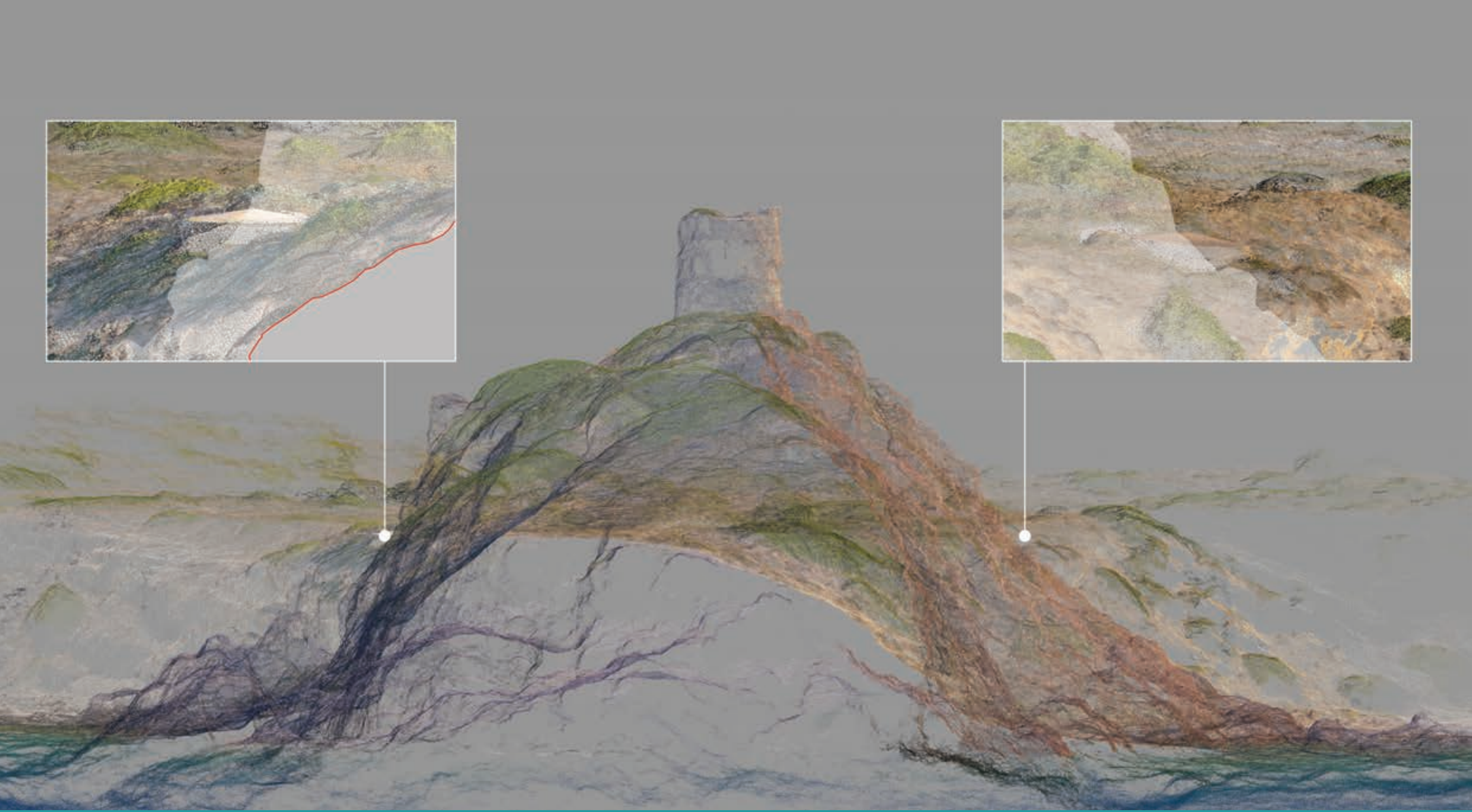

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Keywords:

Drones, photogrammetry, bunkers, Sardinia, Italy.

ABSTRACT

The proposed study is part of a broader multidisciplinary research involving Italian and Spanish universities on the topics of the "modern wars" heritage. The presence of towers and bunkers unites the coasts of Spain and Sardinia and offers the opportunity to start a process of knowledge for the protection and enhancement of the historical landscape entrusted to integrated survey and representation methodologies. The territorial size of the research field and the multiscale character of the landscape bring a documentation activity in which integrated (digital and traditional) graphic techniques are employed and the use of the drone supports the acquisition of data and the construction of digital models of the investigated context functional to create cultural itineraries.

UAVs and photogrammetry for landscape analysis of Sardinia's "modern wars architectures"

1. The "sentinels" of modern wars[1]

A catalogue of the military architectures (military architectures' catalogue) located along the coasts of the Sardinia and the Spanish Levant, their comparison (aimed to create a repertoire) with (by) graphic models

Figure 1. Aerial view of Planargia costiera (coastal Planargia): red circles indicate Columbargia and Turas areas, red points indicate bunkers locations. On the right side zenithal views of surveyed bunkers are shown (drawing by A. Pirinu & R. Argiolas).

identified in the archive documents and a particular study on the dimension of the military landscape that characterizes the study cases, represent the main objectives of the research.
The large number of examples that characterize the contexts of study (Figure 1) lead the choice of sectors of greatest interest and their subsequent reconnaissance in the field.
The entire coastal perimeter of Sardinia and the Mediterranean coast of Spain from Cadiz to Girona shows the presence of numerous towers built from the sixteenth century and bunkers built during the Spanish Civil War (1936-39) and the Second World War (1942) for air, sea and land control.
The system of bunkers designed to protect the "Coastal Planargia" -along the western coast of Sardinia (Figure 1)- is specifically the subject of this contribution and a piece of a mosaic on which the survey operations were started in Sardinia in the territory of Cagliari, Quartu Sant'Elena, Bosa (Martínez-Medina & Pirinu 2018) and in Spain along the defence line of the territory of Alicante (Martínez-Medina 2016, Martínez-Medina et al. 2019).

2. Survey and representation methodologies for the historical-cultural heritage

One of the main problems faced working on cultural heritage is the lack of information or their availability, creating issues not only in the process of analysis of the assets but also in the formulation of programs designed to preserve or manage the assets itself.

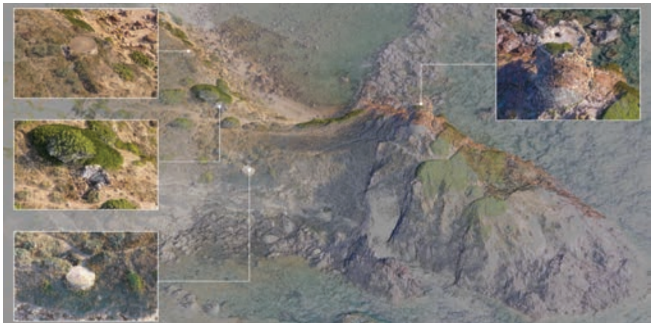


Figure 2. Environmental section of the Columbargia area and planimetric schemes of the bunkers (drawing by R. Argiolas, C.G.I. by N. Paba, scientific coordinator A. Pirinu).

Furthermore, it is not unusual for some fields of application to be devoid of truly valid intervention protocols for the documentation and safeguarding of historic heritage.

A fundamental tool for the data acquisition, analysis and communication of information in this sense is the 3D survey that allows, through three-dimensional databases, to represent the heritage maintaining its morphological characteristics and making constructive stylistic comparisons. This is a necessary procedure in particular for Spanish case studies, for which -unlike the models designed by Italians and Germans in Sardinia- there is no archival graphic documentation, as they were made without planning on the occasion of the "civil war". The analysis would however be incomplete if limited to the single bunker, decontextualized from its natural environment. In addition to this, there is also the need to study and interpret understand realities that belong to the different scale levels (territorial and architectural) and identify the relationships between different architectural objects and between the objects and the landscape context that hosts them (Toniolo et al. 2015). There are many examples of research that underlies the geographical and typological identification of the sites; often there has also been the involvement of subjects belonging to different social and cultural realities, such as the case of the UNESCO's World Heritage List which is recognized as a real reference for identifying the characters to be preserved (Rao 2010). The identification and classification phases are therefore the foundations on which begin effective monitoring and knowledge collection actions. In this sense, the digital survey -through the creation of interoperable models- allows an ever more in-depth understanding of the heritage by offering the possibility of carrying out not only the study of the actual state of the artefacts but, of being able to carry out simulations of hypothetical reuse of the individual artefact and/or

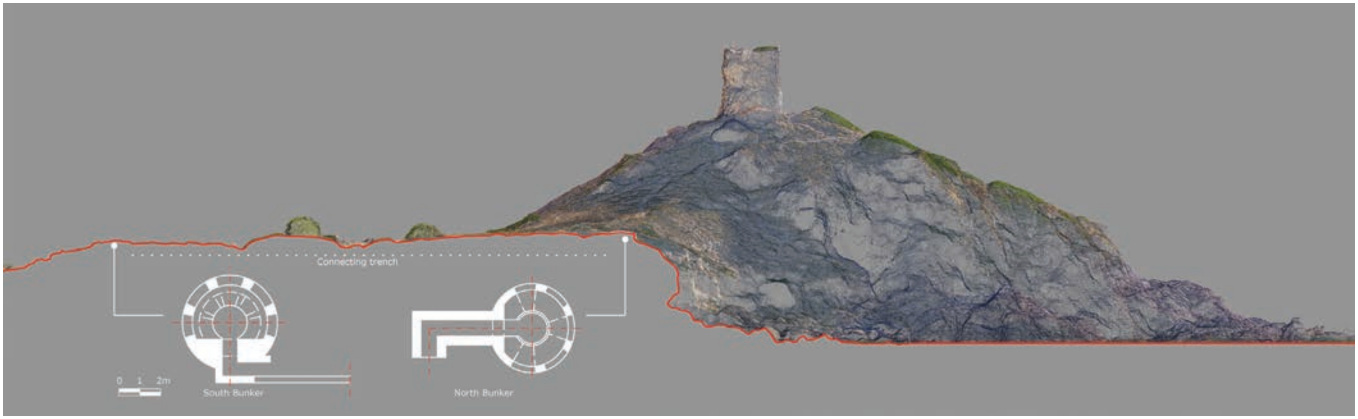


Figure 3. Environmental sections of the Turas area and planimetric schemes of the bunkers (drawing and C.G.I. by N. Paba, scientific coordinator A. Pirinu).

creation of cultural itineraries (Parrinello et al. 2019), both in terms of performances and uses.

However, the field operations require that the product be reachable, a condition not always guaranteed. In fact, the artefacts to be surveyed may reside in areas that are difficult for man to reach, especially if you decide to use special instruments whose overall dimensions are in all respects an obstacle to the mobility of operators. In other cases, despite having sufficient physical accessibility, the site to be studied may present risk factors for people, making it impractical (e.g. areas affected by instability, degradation of structures or unsuitable environmental and sanitary conditions); furthermore it can happen that the area to be studied has an extension that makes difficult to survey with traditional methods, which would require high timing both in the survey phase and in subsequent analyses.

It is therefore essential to define documentation strategies that select the most suitable procedures and instruments, planning the different operating phases and the different levels of information and in-depth analysis. Analyses that are aimed at producing a graphic and informative documentation functional to build a database capable of representing (at different levels of analysis) the complexity of the investigated system. The result of this process is a multidisciplinary and implementable 3D information system functional for the management, maintenance and enhancement of architectural and landscape heritage within cultural itineraries.

A methodology that is increasingly being used as a solution to the limitations/goal described is photogrammetry through the use of drones; the improvement of drones technology allows to contain costs while maintaining relatively high performance levels (Fernández-Hernandez et al. 2015, Brumana et al. 2013), especially when compared with equipment such as laser scanners. The high mobility allows drones to have access to areas that are difficult or completely inaccessible to humans, both in physical and environmental terms (Westoby et al. 2012); moreover, if we take into consideration the drones in their common conception, those therefore capable of flying, it is evident that the possibility of shooting at altitude makes work on very large areas, as well as on individual case studies, extremely easier.

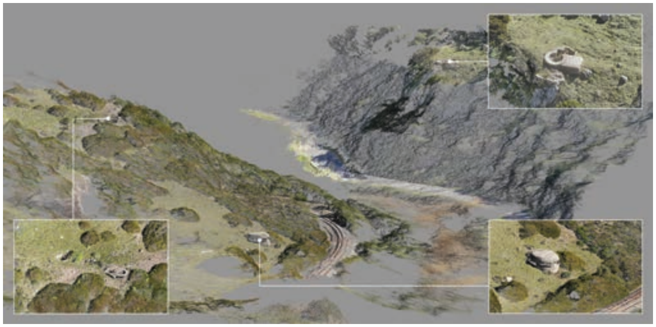


Figure 4. A global view of Turas area obtained from photogrammetry dense point cloud. White points indicate the bunkers locations (drawing and C.G.I. by N. Paba, scientific coordinator A. Pirinu).

This is combined with the possibility of flight programming and the high mobility of the cameras mounted on drones, making them instruments of exceptional flexibility of use (Aicardi et al. 2016).

The fields of use are ultimately manifold, from stratigraphic documentation to the possibility of making reconstructions, to static and structural analyses (Fiorillo et al. 2013), with the possibility of passing from the architectural to the territorial scale (Ebolese et al. 2019).The database acquired through the photogrammetric survey with the drone can also be supported by others survey instruments and GPS references and integrated by the direct measurements and by shots taken from the ground with the possibility of acquiring information on the dimensional and material characteristics inside and outside the artefact.

The digital models thus obtained through the processing of the data provide drawings characterizes by different levels of detail which can be "communicated" through integrated (traditional and digital) representation methods.

3. Data acquisition, processing and definition of graphic models through UAV and terrestrial photogrammetry. The case studies of Turas and Columbargia in Sardinia

Within the defensive system of the Bosa along the north-western coast of Sardinia, two sectors have been identified in which to apply the investigation methodology set on the use of the drone.

The first selected sector consists of a promontory which preserves a 16th century tower and two pillboxes in reinforced concrete mainly built to supervise the two nearby coves (Figure 2-3).

The conditions of decay of the Columbargia tower and its topographical and morphological position make it necessary different procedures that minimize contact with architecture. Furthermore, the high value of the landscape context requires an extension of the survey area that includes two small bunkers and another small building positioned along the trench that originally connected them.

The second selected sector is characterized by the presence of a "barrier" consisting of several bunkers positioned at different altitudes along the sides of the Turas river, the railway and the road route that runs parallel to the river bed a few kilometres from the centre of Bosa (Figure 4-5).

Both sectors -due to the high landscape value of the sites- can constitute an important part of a tourist/cultural itinerary that offers, in addition to the interest in military architecture, the opportunity to enjoy wide and evocative views of the coastal landscape of Bosa.

Operatively, for the survey of the Columbargia promontory, a DJI Phantom 4 drone flight was carried out (operated) with a flight plan at an varying altitude with a max of 80 meters (from the take-off point close to two small bunkers) with parallel stripes at a distance of 40 meters, cruising speed 7.6 m/s (27.36 km/h) and a 4-second interval shooting so as to guarantee a lateral overlap of 70% and a longitudinal one close to the 70%.

For the shots, a camera equipped with a 1/2.3" sensor with an aspect ratio of 4:3 and a resolution of 12.4Mpx was used. The accompanying lens has a FOV (Field-of-View) of 94°, equivalent to 20mm (compared to the 35mm format).

The flight characteristics determined an investigation area at 80 m of 135 m x 100 m with a ground pixel resolution (GSD) of 3.4 cm/pixel. The nadiral photos have been integrated by a series of oblique photos taken at a suitable height, to better capture the sides

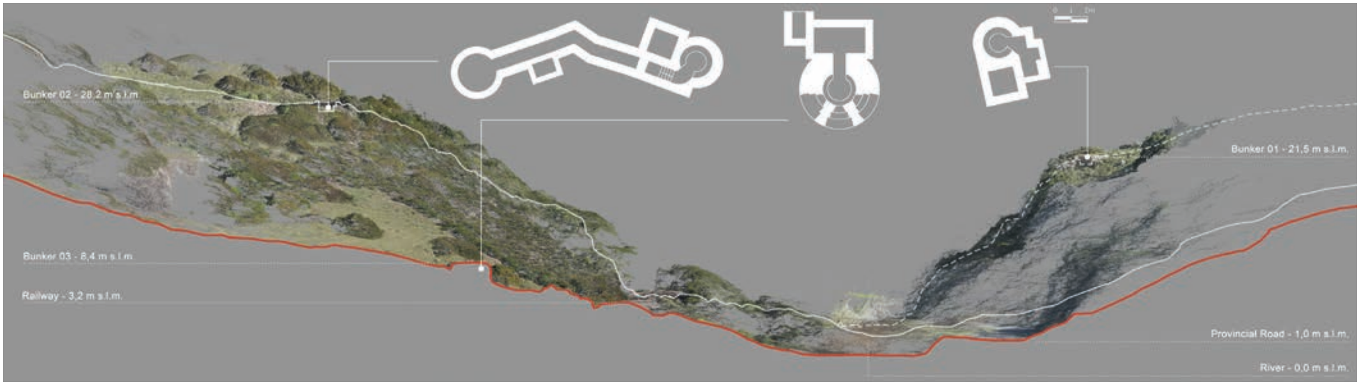


Figure 5. Some views of the dense point cloud of one of the bunkers in the Columbargia area. On the left an isometric view and on the right a top view (drawing and C.G.I. by N. Paba, scientific coordinator A. Pirinu).

of the promontory which are very steep and another series of aerial photographs of the bunkers and the small adjacent building taken at a lower altitude (about 30 m).

In this case study the images taken by drone were integrated by images taken on the ground level, which -for the extremely shorter shooting distance- guarantee a suitable definition for the architectural scale of representation. At this stage a mirrorless Sony NEX-5 camera was used, equipped with a sensor in APS-C 23.5 x 15.7 mm format, with an aspect ratio of 3:2 and a resolution of 14.2 MP with wide angle Sony 16mm fixed focal length and maximum aperture F/2.8.

The images were acquired outside and inside the small bunkers, with the set objective of maintaining a high overlap between the shots and allowing the reconstruction of a complete and defined three-dimensional model.

For the Turas sector, a DJI Mavic Air drone flight was carried out, programming a flight plan at 40 meters above sea level on a trajectory with parallel strips at a distance of 16 meters, maintaining a constant speed of 3 m/s (10,8 km/h) and an interval between shots of 4 seconds in order to guarantee a sufficient overlap between shots of 70% in both directions. The camera on board the APR (remotely piloted aircraft) is equipped with a 1/2.3 "and 12MP sensor, and a lens with an 85 ° FOV, corresponding to 24mm on the Full Frame format (35mm). The GSD planned for the flight is 1.4 cm/pixel, with a footprint of 54.5 m x 41 m.

The described procedure -applied in Turas and Columbargia area- was also integrated with 360° panoramas aimed at inserting the three sites of interest within a single three-dimensional model in order to observe the relationships between them.

Once the field operations were completed, data processing was carried out with the support of the Agisoft Metashape Professional 1.5.3 software and once the image quality was estimated, in order to exclude the blurred or out of focus photos, it's possible to proceed with the "Structure from Motion" process with which

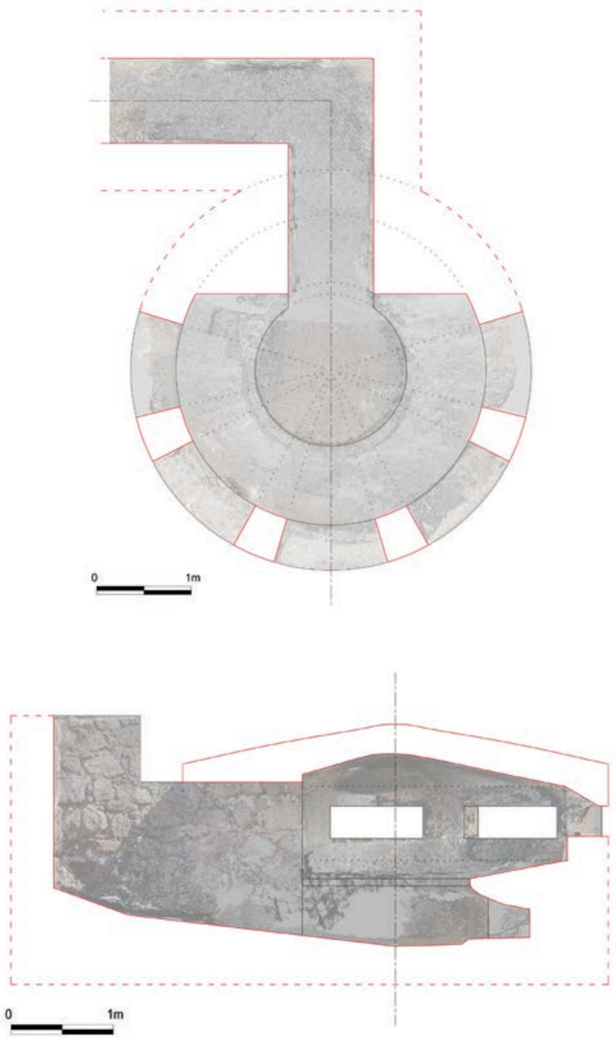


Figure 6. Pill box projected to control the south bay in Columbargia area. Horizontal (on the left) and vertical section (on the right) of the 3d model (drawing and C.G.I. by N. Paba, scientific coordinator A. Pirinu).

-starting from the recognizable elements (key points)- allows the matching points (tie points) to be defined; that have produced a scattered cloud, which has been analysed and treated so that all the images inserted in the process were correctly aligned. In particular, during the procedure aimed at documenting the individual bunkers, special care was taken to ensure that the images of the exterior and interior were aligned in a single chunk, to avoid alignment and resizing on the dense cloud. Once the process was over, it was possible to positively evaluate the position and alignment of the cameras.

The scattered clouds obtained following the SfM process, net of treatment and optimization, measure 320.000 points for Turas, 207.000 points for Columbargia and 730.000 points for Columbargia's bunkers. Subsequently, the dense cloud was calculated with 49.000.000 points for Turas, 28.000.000 points for Torre Columbargia area and 79.800.000 points Columbargia's bunker (Figure 6); each dense cloud was processed with Cloud Compare software (subsample, noise reduction and "SOR Filter"). Starting from these graphic models it has been possible to analyse architectural and geometric aspects of the bunkers and represent them through plan scheme and sections (Figure 7).

4. Objectives pursued and achieved

Through the processing of the data offered by the photogrammetric survey and the study of the archive sources we reach an good level documentation consisting of two-dimensional and three-dimensional graphic models with a deepening of the knowledge of the current state of architecture, its geometric/architectural and construction features; we also obtain a first estimate of landscape values, useful and necessary tools for conscious protection and enhancement of the historical heritage investigated through a cultural itinerary also guaranteed by the conservation of historical and visual routes. The main scale of the investigation field is that of the landscape because the study was directed to the analysis of the relationship between the design of military architecture and the landscape. The documentation produced (Figs. 8-9) consists of overall and detailed zenith views, partial views of the digital models, environmental sections and insights aimed at highlighting the design "reasons"

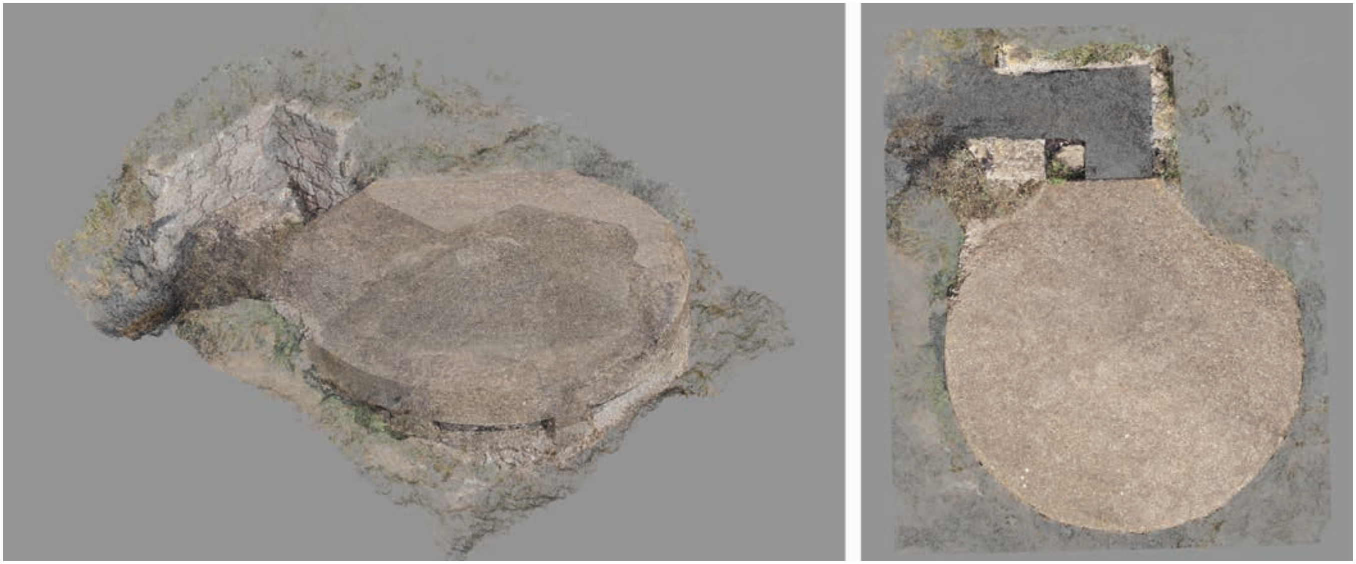


Figure 7. Some views of the dense point cloud of one of the bunkers in the Columbargia area. On the left an isometric view and on the right a top view (drawing and C.G.I. by N. Paba, scientific coordinator A. Pirinu).

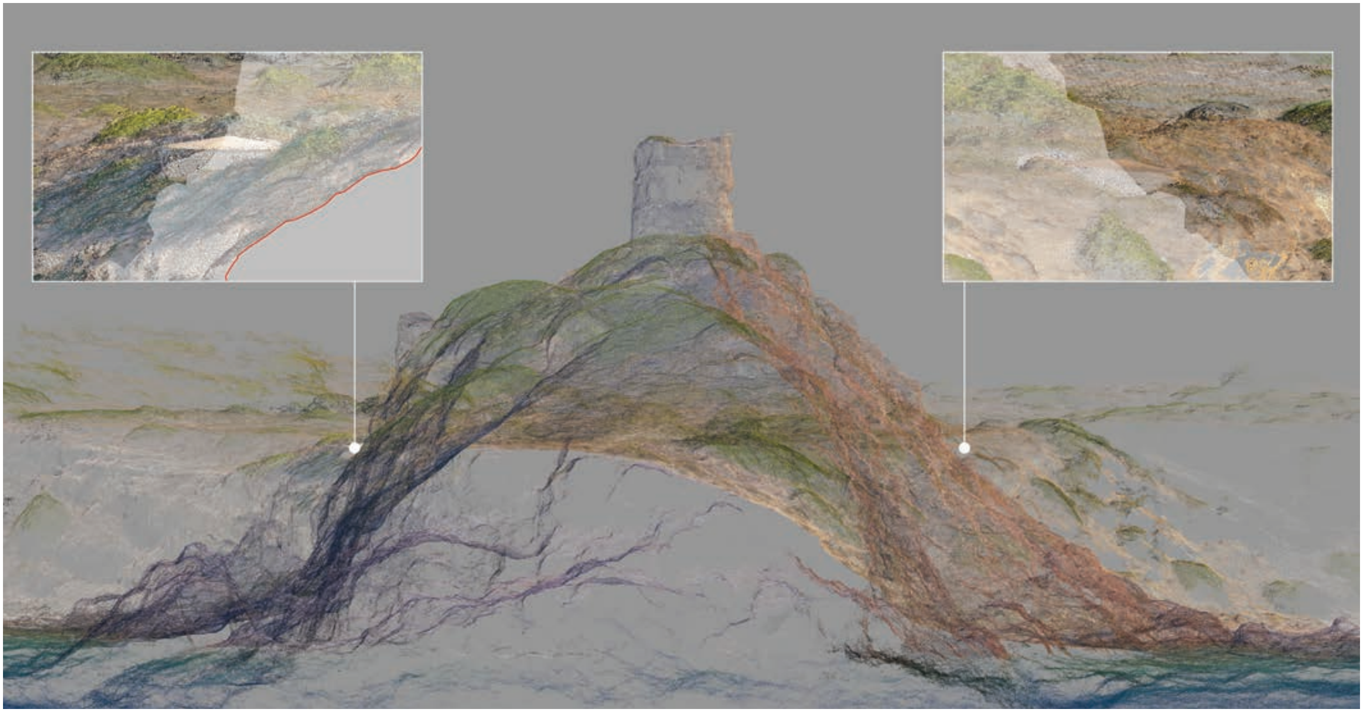


Figure 8. A simulation on the point cloud of a frontal view from the sea of the Columbargia tower. On the sides it's shown how the promontory hides the bunker to potential invaders coming from the sea (drawing by R. Argiolas, C.G.I. by N. Paba, scientific coordinator A. Pirinu).

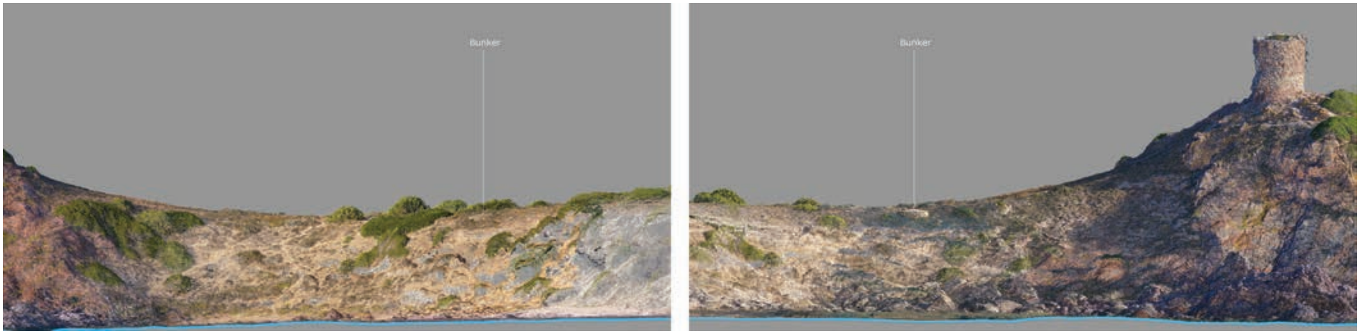
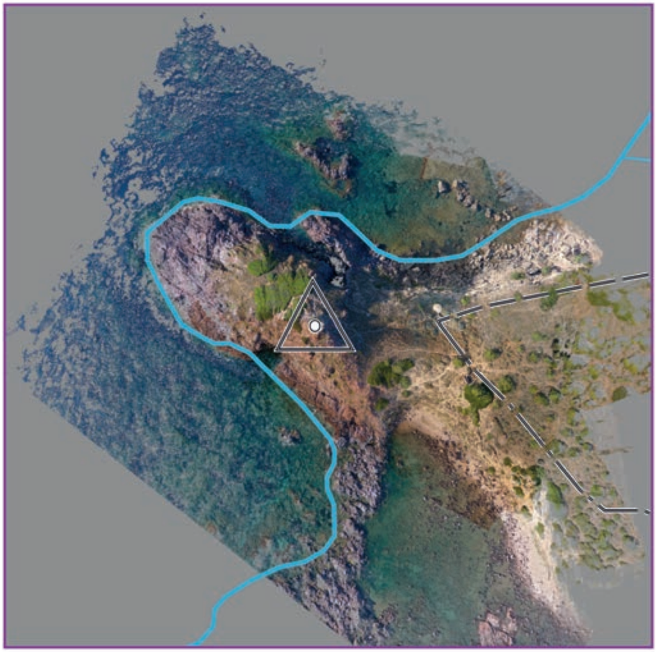


Figure 9. Simulations of views from the sea of the south bunker (on the left) and the north bunker (on the right) in the Columbargia area (drawing by R. Argiolas, C.G.I. by N. Paba scientific coordinator A. Pirinu).

Figure 10. Overlay mapping between "point cloud "and historical map (IGM 1958) in the area of Torre Columbargia. A good compatibility is shown (drawing by R. Argiolas, C.G.I. by N. Paba, scientific coordinator A. Pirinu).



(choice of site) necessary for the mimesis and control of the coasts and land routes, as well as the architectural and structural characteristics of the artefacts.

The level of accuracy required -at least in this phase of the research- is that of the territorial scale, a level (Figure 10) necessary for a comparison with the IGM (Military Geographic Institute) historical cartography however the procedures implemented guarantee an accuracy of the survey at the architectural scale.

In conclusion, the construction of a digital database become the way to start a virtuous process of knowledge, protection and enhancement of a historical and cultural heritage of the "modern wars". A knowledge that nowadays can rely on new information technologies and tools for the survey of architecture and landscape, including drones.

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Note

1 The writing of the paragraphs 1 is due to Andrea Pirinu; the writing of the paragraph 2 is due to Andrea Pirinu and Raffaele Argiolas; the writing of the paragraphs 3 is due Andrea Pirinu and Nicola Paba; the writing of the paragraphs 4 is due to Andrea Pirinu, Raffaele Argiolas, and Nicola Paba.

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ABSTRACT

The stonewalled settlements of the Mpumalanga Escarpment could be described as one of the most remarkable archaeological sites in South Africa. To validate the historical significance of these forgotten structures, the project follows and interdisciplinary approach. It unites two universities from different continents through the contribution of available resources and the purposeful alignment of different, often colliding sectors including, among others, graphic engineering, landscape archaeology and architectural composition. Innovative tools, hardware and software are employed simultaneously to generate an accurate set of documentation. The result is a 3D digital reconstruction of the Mpumalanga archaeological site that can be compared with the available knowledge and exported for two purposes: planning of interventions and dissemination of expertise.

Documentation and enhancement of the cultural landscape of South Africa

1. Introduction: Case study and project organization

The settlements and relating terraces, in the province of Mpumalanga, represent an extraordinary archaeological testimony of South Africa. Long before the arrival of the European coloniser, these environmental engineering works were constructed around the 1650 by the Bokoni, an extinct African community, not only to provide shelter in its most primitive form, but also to assist in food production in the most "innovative" way. The need to preserve the traces of a civilization that has now disappeared led researchers, from the University of Salerno and Tshwane University of Technology, to collaborate in a project that aimed, through the dissemination of knowledge, to enhance and preserve the site.
The whole project is developed in three main phases. In the first phase, specific methods and approaches to landscape archaeology are developed; by analysing the historic landscape, as much information as possible are collected and every attempt is made to place this evidence in its original historical context (Brogiolo et al. 2012). The second phase is developing in the field of the several collaborations, summer schools, workshop and seminars, organized with the contribution of the Italian Embassy and the Italian Ministry of Foreign Affairs and International Cooperation. The required data are obtained using close-range and UAV photogrammetry and the results, in the form of a complete 3D reconstruction, are compared with the available and historical information (Rinaudo et al. 2012; Themistocleous et al. 2015). The repository is then exported for two purposes: project and diffusion. The third and final phase, still in development, attempts to recover the archaeological site and recognize the value of a "cultural landscape".

2. Methods: Landscape Archaeology and possible readings of the rocks

In recent decades there has been a lot of speculation about the nature and history of the archaeological site. The best known and most substantial of the exotic explanation has been offered by Cyril Hromnik. He has long maintained that most of the significant innovations and social systems in Africa are the result of Indian influence, a perspective which has led him to argue that the Mpumalanga stone-walled sites are Hindu temples, edified some time before AD 1200 or 1300. Interpretations like this have proliferated and diversified but most of them are based on speculation rather than credible evidence and share the assumption that African society was incapable of innovation without decisive external influences.
Other researchers all agree that the site could be attributed to Pedi society because in their view the settlement layout indicate a close cultural affinity with modern Pedi patterns, and in the eighteenth and nineteenth centuries they controlled the area. The most accredited theory today is the result of interdisciplinary methodical work. For archaeologists and Historians who study these ancient settlements, the fact that the stone was used for buildings is a great help.

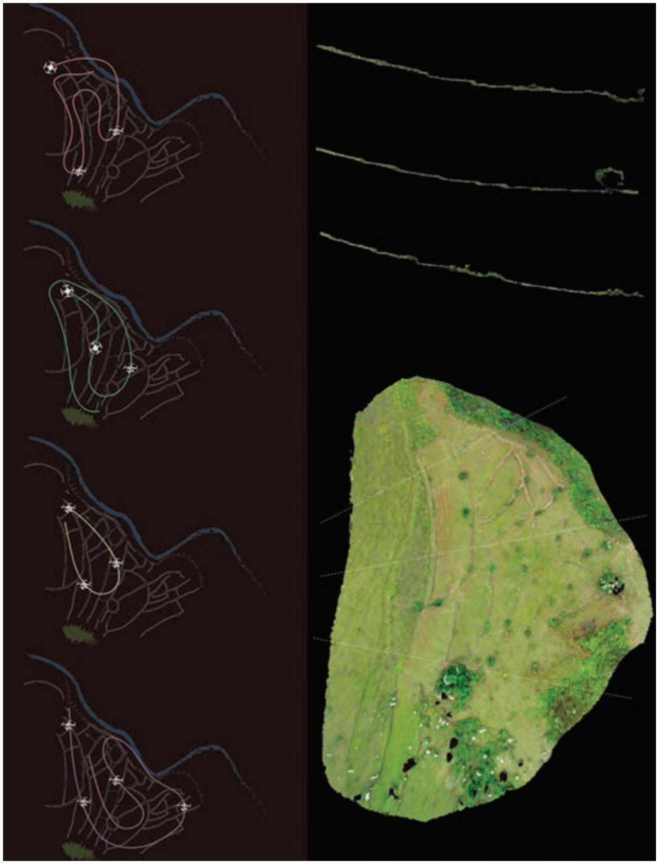

Figure 2. Representation of the main flight plans, with nadir and oblique captures - orthophotos and profiles, output from Analist Cloud of the Verlorenkloof site.

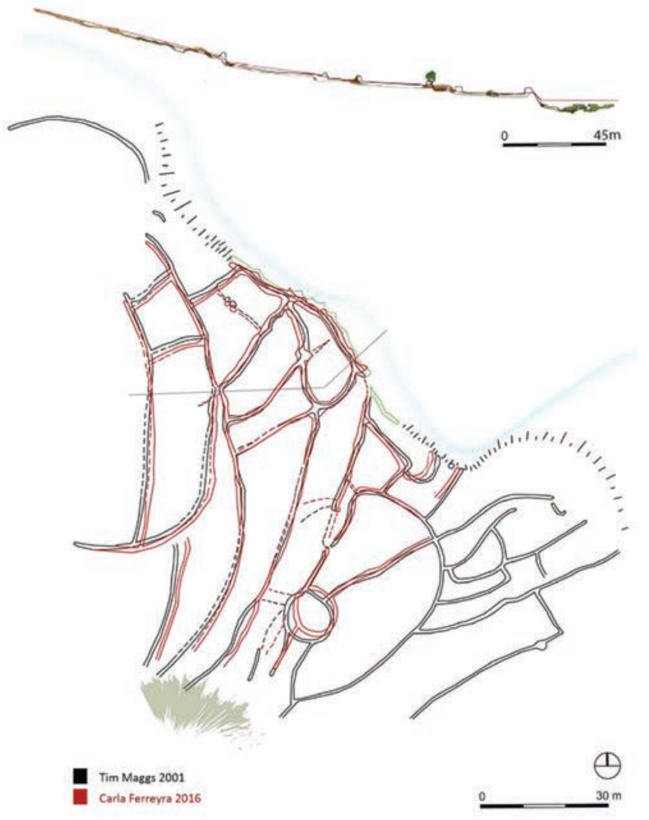

Figure 3. Overlap between the existing documentation of 2001 and the first digital survey in 2016 of the Verlorenkloof site.

We can find out what kinds of structures the people built and the ways in which the buildings were arranged in relation to each other to produce the distinctive settlement pattern which characterises Bokoni society and distinguishes it from other black farming communities in southern Africa (Coetzee 2008). Bokoni (meaning "land of the people from the north") was a pre-colonial, agro-pastoral society found in north western and southern parts of present-day Mpumalanga province between approximately AD 1500 and 1820.

Iconic to Bokoni sites is the presence of significant stone terracing and stonecrafting (Delius 2007). Locally-sourced stones both surround and compose a number of features: including homesteads, roads, and a variety of enclosures for animals; as well as other, less common features that have been seen to vary on a site-by-site and region-by-region basis (Delius et al. 2009; Joubert 2009). The possibilities offered by the techniques of digital 3d photogrammetry have consented the planning of the posterior study, providing all that necessary information for the successive activities of protection, starting point for the procedures of material defence of the heritage. The main objective of this dissertation has been knowing the past – to transmit it to the future – recovering how much more information possible to try to place the evidence in the historical original context, as survival in the current landscape plan.

3. Digital Documentation of the site Acquisition campaigns

The present work aims to propose a new and effective documentation approach for the heritage, not exclusively addressed to specialists in the sector but conceived, above all, for the dissemination of the results to a non-technical audience, with the intention of stimulating the population to recognise, through knowledge, their own history and roots in the heritage to be protected, laying the foundations for the development of tools for valorisation and defence against oblivion (Brunetaud et al. 2012). The entire study moves from the search for an identity through the exaltation of the historical-cultural value of these landscapes, inducing local community initiatives for their conservation and enjoyment.During the pilot phase of the project, the research groups of the universities involved focused on the creation of cartographic drawings for a classification of the areas of interest. In fact, there was almost no map and graphic documentation that could represent, in an exhaustive way, the morphological and non-morphological aspects of the sites to be investigated. For this reason, the Verlorenkloof site was selected as a sample. The first applications made use of the UAV photogrammetric technique (Remondino et al. 2012). The instrumentation used is a DJI Phantom 3 Pro drone, with a 12.4 MP 1/2.3″ CMOS sensor, equivalent focal length of 20 mm, f/2.8 aperture and 94° FOV (Field of View). The total of 500 frames are divided into 5 swipe blocks, three of which are acquired with a flight height of 30 m (about 300 frames) and two with a height of 60 m (200 frames), ensuring a GSD (Ground Sample Distance) of 5 cm. For each block,

Figure 4. Topographic support with Spectra Precision SP 60 and first flights.

Figure 5. DJI Phantom 4 with MAPIR NIR and RGB sensors.

acquired at constant aircraft speed and in manual mode, an overlap of 60% and a sidelap of 40% is guaranteed. GCPs (Ground Control Points), necessary to complete the photogrammetric process, were acquired with a pair of GNSS receivers operating in RTK mode (base + rover), with a horizontal accuracy of 10 mm + 1 ppm and vertical accuracy of 20 mm + 1 ppm (Agnieszka et al. 2018). A network of 14 artificial checkerboard targets,

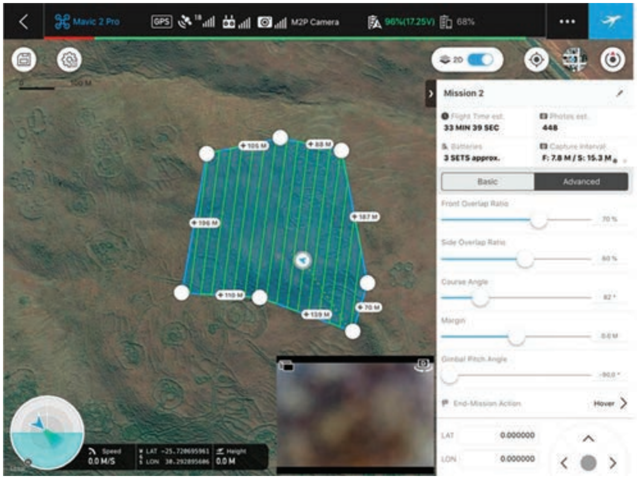

Figure 6. Single grid flight plan of the Mavic 2 Pro.

distributed in the scene before the acquisition, was used for geo-location. From the first restitution it was possible to make comparisons with the historical documentation and above all to define the relevant strategies for the following phases. The focus shifted to the Moxomatsi site, characterized by elements that are more significant for historical and archaeological investigations. The new location became the perfect benchmark for close-range photogrammetry applications (Arias et al. 2005; Lerma et al. 2010; Yilmaz et al. 2007). Groups of students from Tswane University of Technology were also involved in the campaign operations, transforming this technical phase into an open-air laboratory that could be used to share the necessary knowledge for the correct organization of a photogrammetric survey. The formalization of a schematic procedural pipeline in the acquisition and management of photogrammetric data represented a fundamental moment to define the basic concepts, with the purpose to make them easily accessible for all those who approached this technique. The instrument used most in this phase was a carbon fibre telescopic rod, extendable up to 10 metres and provided with a three-axis gimbal. The system, stabilized and remotely controlled, is equipped with a Sony DSC-QX30 camera featuring a 20.4 MP Exmor R CMOS sensor of 1/2.3”. The experience was divided into two acquisition campaigns. The first, with the capture of 300 frames (5184 x 4356), was used to verify the applicability of unconventional multi-image photogrammetry for the documentation of the site and for this reason the data collected were promptly processed in Agisoft Metashape 1.5.1, highlighting a good quality of the results. Starting from these assumptions, in a second campaign, 1500 frames were acquired in order to comprehensively document an entire residential nucleus, part of the vast Moxomatsi complex. Also in this case the GCPs were acquired with a system of two GNSS receivers operating in RTK mode (base + rover), in order to geo-localize the model and ensure an appropriate connection with the models resulting from future surveys. The network was organized with 10 artificial chessboard targets. This experience also served as a basis for planning the third and final phase of the acquisition. Based on the characteristics of the site, it was decided to acquire the images with a UAV photogrammetric approach: a DJI Mavic 2 Pro and a DJI Phantom 4 were employed. The first one, weighing about 1.4 kg, has an integrated 12 MP camera with 94° FoV, 1/2.3” CMOS sensor (pixel size of 1.55 microns) and equivalent focal length of 24 mm; it allows to take pictures in RAW format. and is equipped with a remote control with a range of 3.5 km. The other UAV, the DJI Mavic 2 Pro, which weighs about 900g less, is equipped with the brand-new Hasselblad L1D-20c camera with exclusive Hasselblad Natural Color Solution (HNCS) technology. The sensor is still a CMOS, but 1” in size with 20 MP resolution (pixel size of 2.4 microns), 77° FoV and 28 mm equivalent focal length, allowing RAW photography. The remote control has a range of 8 km.
With the DJI Phantom 4 were captured only nadiral images, organised in a flight plan with a dual grid. Thus, 198 images (99 for each grid) were acquired, detecting a territorial extension of about 5 hectares, whose centre of gravity coincides with the pattern on which photogrammetric experiments were conducted with telescopic system.

The flight plan was designed taking into account the general requirements of the project - for example, a minimum GSD of about 2 cm - and with the aim of ensuring a high level of automation in the subsequent data processing phase. The first nadir grid developed from East to West, with an average flight height of 45 m, medium speed of 3.8 m/s, overlap of 70% and sidelap of 60%. The second nadir grid developed from South to North, with an identical average flight altitude, medium speed of 4.2 m/s, constant overlap and sidelap. Even with the DJI Mavic 2 Pro only nadir images with flight plan in a double grid were captured.

In this case, 452 images were acquired (226 for each grid), detecting the same area: the higher number of images compared to the previous overflight is due to a lower flight height (30 m instead of 45) and a reduced FoV (from 94° to 77°). According to the previous grids, the vehicle speed was of 4 m/s, for a design GSD of about 7 mm. Finally, a NIR (NearInfraRed) sensor installed on the DJI Phantom 4 was tested. The relative flight mission, planned to cover the area with sufficient longitudinal and lateral overlap (i.e., overlap and sidelap), made it possible to simultaneously record the NIR and RGB data. For the acquisition of this information, Mapir Survey 2, with 1/2.3″ CMOS sensor, 12 MP resolution (pixel size of 1.34 micron) and 4 mm focal length, were implemented. The frames were captured in aperture priority (with f/2.8), variable shutter and constant ISO at 200, according to a path identical to previous flight plans, but single rid, with a flight height of 30 m, average speed of 3 m/s and time-lapse mode (at 2-second intervals). Photogrammetric data acquisition was supported and combined with GNSS positioning techniques. In this test we proceeded to the diachronic measurement, in NRTK mode, of a network consisting of 16 artificial targets placed on the ground (flat forex panels, with a size of 40 x 40 cm, fixed by means of topographic nails). The instrumentation used to measure each target consisted of a receiver Spectra Precision Survey Pro SP 60, in order to verify the propagation of errors and for the exact georeferencing of the survey by UAV.

4. Data processing

The data collected in the three acquisition campaigns were processed in the Agisoft Metashape environment, both for unconventional close-range and UAV photogrammetry.

The workflow used is what the literature presents as best practice.

Focus was put particularly on the optimization phase of the orientation of the cameras, both as regards the implementation of GNSS geo-localization data and the filtering of tie points. With regards to the last aspect, two parameters are taken into account.

The first is the number of images. To reconstruct the three-dimensional position of a tie point this must be visible in at least two images. In this case, however, the positioning accuracy is very low and this was the reason only the points visible in at least 3 images have been retained. The second parameter considered is the reprojection error.

This represents the distance between the point on the image where a reconstructed 3D point can be projected and the original projection of that 3D point detected on the photo and used as a basis for the 3D point reconstruction procedure. This error is expressed in pixels and for the case study all tie points with an uncertainty greater than one pixel are discarded.

5. Design and requalification

The data collected in the second phase was processed to build a repository to support the next modeling phase. In particular, raster data such as DTM (Digital Terrain Model) and DSM (Digital Surface Model) and vector data such as contour lines were exported to be processed in CAM/CAD environment and gave back a georeferenced reconstruction of the area of interest as the basis for the subsequent design.

In response to the existing circular forms on the site, the final design responses varied between straight lines and organic shapes.

The final presentations included conceptual drawings, plans, sections and a video rendering.

Figure 7. Orthophotos and trace analysis.

6. Results

The results obtained after the acquisition campaigns offered numerous opportunities for comparison and experimentation. For example, using the orthophoto processed from the photogrammetric data of the first campaign (5 cm GSD), a planimetric and topographic analysis was carried out on a survey carried out in 2001 by Tim Maggs, the only documentation available. It is possible to observed localized variations between the outputs up to 1 m. on the trace of the terraces.

For a general assessment of the accuracy of photogrammetric models, data acquired with GNSS systems were used. In detail, the artificial targets detected were divided into two groups, ensuring for each one a good distribution in the scene. The first group, containing the GCPs, was directly used in the process of optimizing the orientation of the cameras. The second, containing the QCPs (Quality Check Points), was employed for quantify the distance between the input source and estimated positions of the markers For both close range and UAV photogrammetry, the

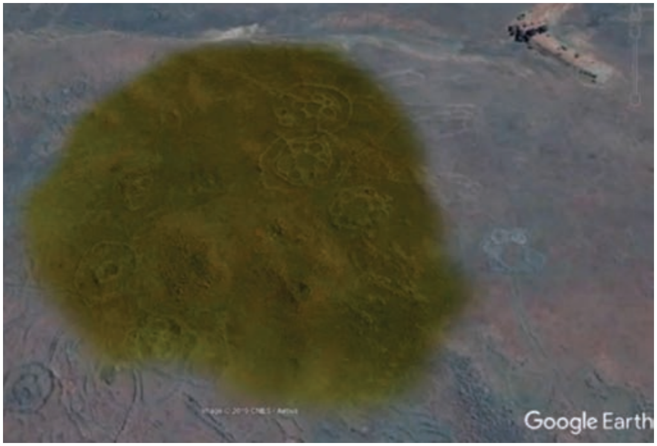

Figure 8. Georeferencing in Google Earth of the generated orthophoto.

maximum deviation recorded on QCPs is about 6 cm, while the average error is less than 3 cm, comparable with the pixel resolution obtained in the orthophotos.

7. Conclusions

The proposed project is aimed at seeking new forms of protection and enhancement of the heritage. In particular, the photogrammetric surveys prove to be effective tools for morphological and geometric reconstruction and an essential support for an interpretative analysis of architecture and landscape. They represent a rigorous reading instrument, a support to historical analysis, which lays the foundations for projects of restoration, protection, conservation, monitoring and enhancement of the heritage. In order to guarantee an adequate result of the survey, it was necessary to establish a rigorous methodology from the acquisition campaign to the data processing and subsequent dissemination of the results. An operational workflow was therefore developed, a survey procedure using rapid photogrammetric techniques that identify new frontiers for heritage documentation.

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ABSTRACT

The study was conducted to create a concept for the development strategy of the architectural complex of the 17-19 centuries in Usolye. The UAV was chosen as a data collection tool for urban planning due to the difficult hydrological conditions and the inaccessibility of some areas. As a result of aerial surveys, it was possible to identify and record coastal erosion, flood areas and the condition of buildings. These data significantly enriched previous urban studies obtained by classical methods of engineering surveys. Landscape analysis using UAVs allowed us to transform data into three-dimensional form. The accuracy and perception of space and elements has increased.

UAVs FOR STRATEGIC MASTER PLANNING

1. Introduction

Nowadays strategic spatial planning is especially relevant for Russian cities. (Tuzovskii 20019).The strategy defines a system of priorities for the territory development and expected results. (MLA+, 2017)
The main purpose of spatial strategy understands needs and values, the prerequisites of the current state, the role of the territory at urban or regional scale, and area structure. Therefore the key task of the strategic Master plan is to study a large territory and to represent it on maps, models and descriptions. The urban planning analysis is one of the most important parts of the Master-plan.
It has to include: hydrogeological, topographic, morphological features of the territory, a planning structure, and infrastructure and transport systems, requiring a large amount of source data.
The digital technologies allow to quickly and effectively get data about the urban environment. Photo shooting using unmanned aerial vehicles (UAVs) is a new tool in relation to the study of the territories and architecture in Russia. Before the use of UAVs, overflights in helicopters, airplanes or other manned aircraft were sometimes carried out (Shevchenko 2015). The method of aerial photography is quite well-known, but it has not received wide application in the urban planning due to the high costs of organizing and conducting flights. The drones and quadcopters, like new-generation unmanned remotely controlled vehicles, have made this method affordable.

Figure 1. Left: research area scheme. Right: research area general view.

Figure 2. View of central part from the west. Left: 1970s photo taken from an airplane. Right: Photo by V.E. Zarovnyanykh, 2010.

Figure 3. Upper: the project suggestion "Usolye-on-Kama". Lower: Usolye in spring flooding time, 2014 (Fpvperm.ru).

Drones can be defined as a platform for the remote research to provide urban planners with data necessary for analysis, such as: 1) spatial relationships and location in the urbanstructure; 2) the spatial spread of different types of territories; 3) transport and related infrastructure; 4) the ability of monitoring changes in the use of territories; 5) the impact of land use on the effectiveness of the use of territories. Such information is relevant and necessary for urban planning in General and for creating Master plans in particular.

2. Case study: Usolye

Photogrammetry using drones was used to collect data during the development of the Usolye' Master plan. (Perm Region, Russia).

The town of Usolye was founded in 1606 and is located on the banks of the Kama river.

Before the Kama reservoir was filled (1956), the territory was a flooded plain of a river with old lakes.

During the construction of the Kama hydroelectric dam in 1954–1956, the historic part of Usolye which is adjusted to the river, was flooded by the Kama reservoir. The water level in Kama rose by 2.3 meters. Nowadays the historical part of Usolye, where the architectural monuments of the 18th-19th centuries are located, is flooded during the spring floods and turning into separate islands in this time. A condition for preserving the disappearing architectural heritage of Usolye is the renovation of the territory and the searching for updatedand attractive functions for residents and businesses. A new master plan of the town is aimed at solving this problem. The landscape of old Usolye, formed by a gentle natural relief, landscaping, the location of the main architectural monuments, as well as the structure of the coastline are the greatest value of the territory. On the other hand, the complex size of the territory (386 hectares), hydrological conditions, inaccessibility of some coastal areas and objects, and specific morphology present major problems for study, especially in winter. Aerial photography in these conditions provides great opportunities and, as practice shows, is the most effective tool for research.

3. Method of research

In the process of developing the Master plan, we used old photographs (taken from manned aircraft), photographs from drones that were placed at different times in the public domain on the Internet, as well as the results of aerial photofixing obtained while working on the MarieSkłodowska-Curie grant and kindly provided by colleagues from the University of Pavia.Thus, aerial photographs of different years and different seasons were collected for analysis.

Overflights of the territory and architectural objects using drones were carried out four times: in May 2014 by Fpvperm.ru to test its microcopters; in the fall of 2018 - by the New Ground company which conducted geological engineering surveys at 9 objects of architectural heritage in the central part of the island; in August 2018 - employees of the University of Pavia;in the fall of 2019, non-professional photography of Usolye was posted on social networks by D. Beltyukov. All surveys were done for different purposes.

4. Results and discussions

At different times several renovation projects of Usolye by various organizations were developed. These projects were compared with aerial photographs in terms of the current situation on the islands. The archival materials made it possible to understand what happened to the territory over the past 50 years and why these projects were not implemented. The concept of “Usolye-on-Kama” (2008) suggested: the restoration of the lost objects of architectural heritage on the preserved foundations, the restoration of the Salt Baths sanatorium, built in the 1930s, residential low-rise buildings and salt boiling museums “Upper Industries” and “Lower Industries”. The understanding of possibilities to implement some solutions came after comparison the project with aerial photographs which demonstrate the flooding of the territory in the spring time. The restoration of the “Salt Baths” sanatorium in its former place, the new residential development of the complex cannot be implemented for current realities. At the same time the aerial photographs show the territory resistant to hydrological processes, which can be actively used for various types of tourism, leisure or business. In the orthophotos (plan photos), the state of the coastline is clearly visible. Together with ground-based research, it is possible to draw conclusions about the most suitable places for the use of coastal areas (as a beach, promenade, boat stations) and develop special water routes. With the different photo shooting angle and flight altitude it is possible to use drones both to determine the nature of coastal erosion and to assess the state of the architectural objects. For the architectural monuments, the problem of wild growth

Figure 4. Upper: the project suggestion “Usolye-on-Kama”. Lower: Usolye in spring flooding time, 2014 (Fpvperm.ru).

Figure 5. Rubezhskaya church. Left: View from the west. April, 2014. Right: view from the north-west. Summer, 2018.

Figure 6. Aerial view of St. Nicholas Church from the east. Left: St. Nicholas Church in spring time, photo by V.E. Zarovnyanykh, 2010. Right: St. Nicholas Church in summer time, photo of the University of Pavia, 2018.

on arches or on their preserved parts is relevant. Aerial photography conducted by New Ground and Pavia University staff made it possible to see the vegetation in the bell tower of the Transfiguration Cathedral, and the nature of its germination into the masonry. Analyzing aerial photographs of the Rubezhskaya Church, which is located far from the shore or the Abamelek-Lazarev house, located right near the water, the risks forthe reconstruction works were fixed.It shows the dependence of the implementation time on the magnitude of the spring flood, which should be taken into account in the design decisions and assessment of the effectiveness of flood protection.

A comparison of images from different years allowed us to see a slight change in the landscape. The area around St. Nicholas Church during the flood period is not steadily covered with water; therefore it can be filled of functions year-round. Subsequently, this was confirmed by topographical surveys and historical facts about the bulk nature of the soil under this architectural object.

5. Conclusions

The examples of comparison existing aerial photographs show the feasibility and effectiveness of using drones for collecting data to develop the Master plan.

Air-based survey enriches the data of urban studies which usually obtained by topographic surveys, laser technology, photogrammetry, and classical engineering survey methods. Landscape - visual analysis using drones takes on a three-dimensional form, expanding the perception of space and its individual elements.

Surveying by the drone makes it possible to “interpret and distinguish spatial relationships that are not perceived nearby due to the properties of the perspective” (Parrinello 2015).

The final document of Master plan is including a digital 3D model of the territory’s development.

The images obtained from the UAVs while development of the Usolye strategic Master plan allowed us to study areas to which never had access and to refine the parameters of the entire territory as a whole as well as each individual objects.

Photogrammetry obtained using UAVs made it possible to complete the roofs of three-dimensional models of objects, as well as obtain the relief of the adjacent territory.

Work on the master plan proved that UAVs have a great prospect in areas like Usolye, with annual water level fluctuations, inaccessible areas overgrown with ruderal vegetation, due to their ease of use and wide possibilities of adaptation to various types of tasks.

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ABSTRACT

The looting phenomenon is one of the most dangerous and devastating risk factors associated with archaeological heritage that affects the whole world. In most cases, it is concentrates in the illegal excavation of the necropolis, because they are, generally, the contexts richer in archaeological finds and better preserved. This violent practice creates a destruction of deposition contexts and artifacts, with the consequent loss of scientific knowledge and dispersion of archaeological material in the ever greedy black market. The actions aimed at identifying and monitoring the looting phenomenon are supported by the use of drones. As it attempts to demonstrate in this article, by analyzing two case studies between Peru and Italy, these innovative unmanned aerial system (UAS) would be a tool with significant potential, and one more weapon in the fight against the looting.

Locate and monitor the looting through the drones. Some examples of application in Peru and Italy

1. Introduction

Remote sensing technologies have been successfully applied in archaeological research for years, they allow us to monitor and preserve cultural and natural heritage (Stubbs et al. 2006; Iadanza et al. 2013; Spreafico et al. 2015; Hadjimitsis et al. 2020).

Among the latest methodologies belonging to the remote sensing family are the proximity analyses carried out by drones (Pecci 2015; Seitz 2018; Germanese et al. 2020). These are tools in rapid technological evolution, increasingly performing above all in terms of duration of performance and quality of the sensors mounted. Essentially, drones allow us to:

- take photos, in all periods of the year (weather permitting), at very high resolution and higher than that currently obtainable from satellite;
- perform a photogrammetric coverage of a territory, therefore being able to create 3d models through software based on Structure from Motion algorithms; - use different sensors (RGB cameras, thermal cameras, LiDAR) based on the needs derived from the type of investigation to be carried out;
- use low-cost and low environmental impact machines.

Thanks to the enormous potential derived from their use in the archaeological field (Campana 2017; Pecci et al. 2018), they are becoming almost indispensable tools in scientific research. As widely demonstrated, remote sensing plays an important role in the analysis and monitoring of risk factors (fire, hydrogeological instability, floods, urban sprawl, etc.) of cultural and archaeological heritage.

Among the most devastating types of risk is the phenomenon of looting, unfortunately always current and widespread throughout the globe.

Drones, thanks to their considerable potential, can make a great contribution in this field of research (Pecci, Donnici 2017), they integrate with the classic remote sensing analysis and allows to carry out further research and analysis thanks to their agility, versatility and performance.

The present contribution will show the results of some applications carried out on some sites in Italy (San Nicola, Ferrandina) and Peru (Paredones, Nasca).

2. Brief notes on looting in Italy and Peru

In Italy, the action of the grave robbers is aimed almost totally at the necropolis and votive deposits of the pre-Roman and Roman eras.

The reason for this specific interest is linked to the richness of the finds inside the tombs or sanctuary, which contain material of the highest quality and value, most of the times in excellent condition.

The objects found are mostly locally produced ceramic vases, imported from Greece or Magna Graecia, bronze weapons or jewellery.

With the spread of Christianity in Italy, the use of depositing rich objects of value or social status in the tombs slowly decreased until it almost disappeared completely. In fact, the action of the grave robbers aimed at medieval or modern necropolis is rarely

recorded, mainly because of the poverty or absence of funeral items.
As a result, the attention of antiquity buyers for the Middle Ages and later periods is turned to artefacts such as paintings, statues or jewels, often stolen from cathedrals or museums.
The antiquarian passion for the classical world and the consequent antiquity market has been the subject of a thriving literature (Iasiello 2017).
Between the end of the eighteenth century and until after the unification of Italy, there were numerous clandestine and non-clandestine excavations that mainly affected southern Italy, which contributed to the dispersion of thousands of archaeological finds or their context in the world of excavation.
After the unification of Italy the phenomenon has drastically reduced but not exhausted.
Since the second post-war period, the economic boom and the consequent phenomenon of urbanization and industrialization of a state that for millennia has based its economy on agriculture, has seen the urbanization of entire areas and the consequent destruction or stealing of archaeological finds in the object areas. of that action. Since that time, there has been a renewed interest in antiquities, with a consecutive increase in the black market (Graepler, Mazzei 1996; Campbell 2013; Giulierini et al. 2018), which, unfortunately, continues to this day (Repubblica.it).
Looting of antiquities is not a new phenomenon in South America but starts from the Spanish colonial period (Rødal 2017).
Since the second post-war period, this phenomenon has increased and has been mainly directed towards pre-Columbian sites, which preserve priceless finds such as goldsmith's objects, ceramic vases, textiles, often in an extraordinary state of conservation thanks to the particular climatic conditions.
The exhibits identified are still being sold, illegally, to collectors of antiquities from all over the world (Elia 1997; Contreras 2010), with the consequent loss of the context of discovery and the history of peoples.
This phenomenon, so intense and devastating, has seen the birth of real figures of looters of antiquity in Peru: the huaquero, definable as one whose work concerns the huacas (which means strange, special or sacred), a term that usually refers to pre-Columbian archaeological sites (Smith 2005).
Most of the time it is a local specialist, who knows a good amount of archaeological sites and who often consults archaeological books for his purpose. Huaqueros are not motivated not by moral decay, greed or ignorance, but most of the time they are motivated by poverty.
They often receive less than one percent of the retail value of their discoveries; in fact, profits on the black market of antiquities benefit intermediaries (Rødal 2017). An estimate of the extensive intensity and immense amount of looting in Peru and South America can be made by analysing public and private collections, and can be observed on the field in some archaeological sites and from above (satellites, aerial photos) so as to be visible also on Google Earth (Brodie, Renfrew 2005; Contreras 2010).

3. Case study: San Nicola (Ferrandina, Italy)

About 5 km NW from the city center of Ferrandina (Basilicata, South Italy), there is a large area rich in archaeological sites (San Nicola, Vaccareggio, Fonnoncelli, Caporre, San Giovanni and Coste dell'Abate), known in the past only through asystematic surveys (Patrone 1987; Pecci 2019), oral reports from citizens, and very short excavation tests of preventive archeology following the action of the tomb raiders as the site of Caporre (Bottini 1992) or linked to the construction of a San Giovanni wind farm (De Siena 2018). For about two years, after a long pause in archaeological research, the investigations have resumed in the territory of Ferrandina (Mt) by the "FArch – Ferrandina Archeologica" project of University of Basilicata - Department of Human Sciences DiSU (scientific director: Prof.ssa Maria Chiara Monaco; responsible archaeologists: Dr. Antonio Pecci and Dr. Fabio Donnici) in agreement with the Municipality of

Ferrandina and in concert with the Soprintendenza Archeologia, Belle Arti e Paesaggio della Basilicata.
In 2018, the research (excavation carried out under a ministerial concession regime DGABAP n. 16033-P of 10.06.2019) concerned a wooded area located in San Nicola where the presence of a furnace dating back to the 4th century BC had previously been reported (Patrone 1987). The presence of further archaeological evidence had already emerged with the preventive investigations carried out by the writer through the use of satellite images and LiDAR data, which had detected the presence of macro anomalies (Figure 1).
These field surveys preceded the aerophotogrammetric survey with drone that allowed to identify some micro-areas with a strong archaeological potential, on which it was desirable to operate with the excavation.
As already mentioned, the satellite images and the Lidar data (Figure 2) had allowed a first identification but did not allow, due to the low resolution (for both 1 m / pixel), to be able to better define and delineate the archaeological investigation of the features identified in the ground. Instead, the data obtained from the use of the drone and photogrammetry techniques presented a high level of detail, less than 2 cm/pix in aerial photos and 6 cm/pix in the DEM extrapolated from the 3D model.
These drone data have facilitated the archaeological interpretation allowing to hypothesize, before the archaeological excavation, the presence of a necropolis sacked in the recent past.
As can be observed in the orthophoto and in the DEM, in area 1 (Figure 3), there are holes in the ground at points A and B, while at point C there is an anomaly in

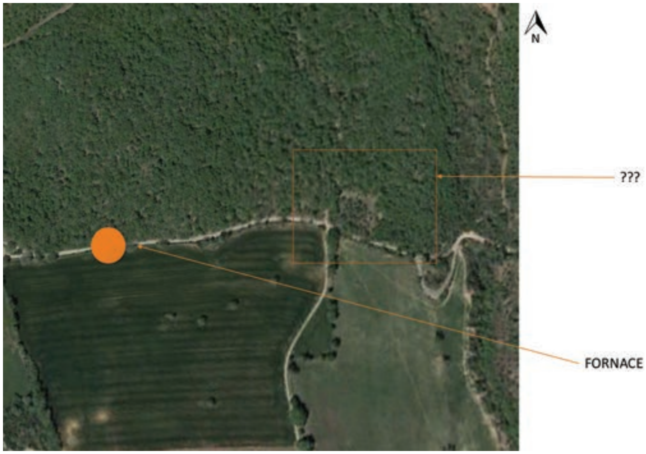

Figure 1. Study Area of San Nicola (Ferrandina, Italy).

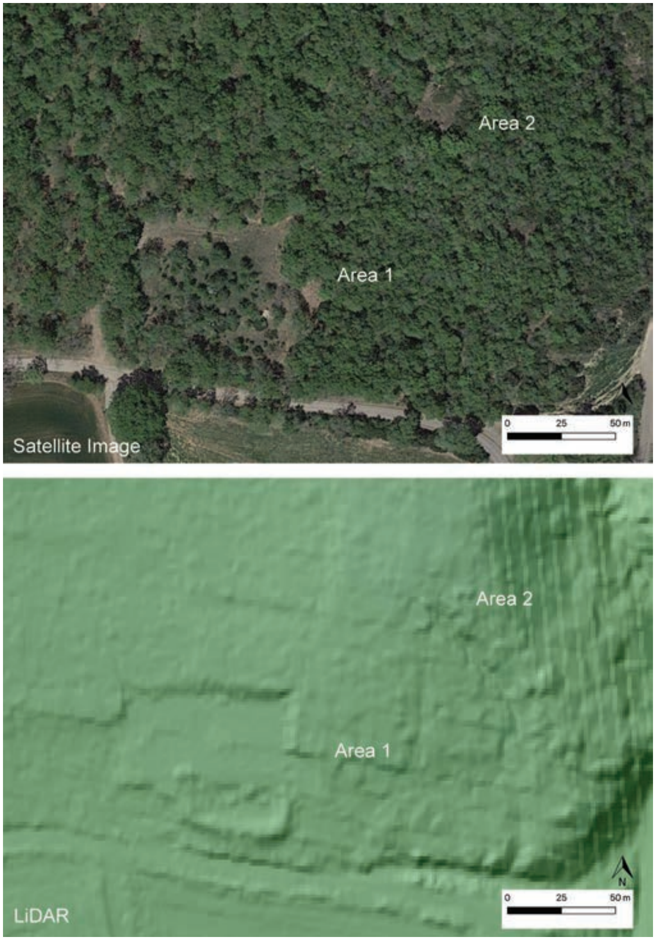

Figure 2. Satellite image and LiDAR of Area 1 and Area 2. Study Area of San Nicola (Ferrandina, Italy).

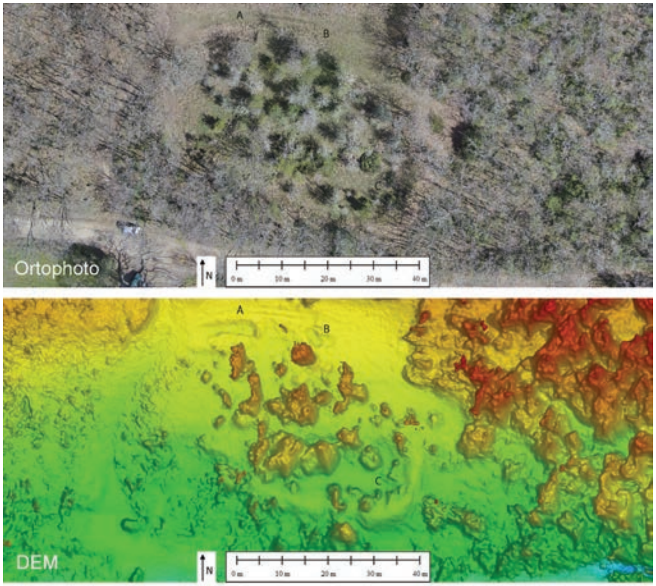

Figure 3. Ortophoto and DEM of Area 1. Study Area of San Nicola (Ferrandina, Italy).

Figure 5. Ortophoto and Photo of Area 2 after archaeological excavation of 2018. Study Area of San Nicola (Ferrandina, Italy).

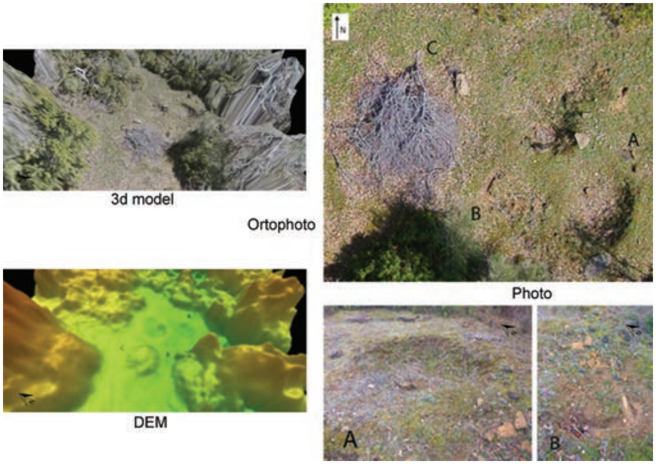

Figure 4. 3d Model, DEM, Ortophoto and Photos of Area 2. Study Area of San Nicola (Ferrandina, Italy).

the ground of a linear type, probably attributable to the presence of a building. While in area 2 (Figure 4), located in the woods and difficult to reach due to the thick vegetation, it is possible to notice other irregulars holes, some cleverly covered (Figure 4, point C) with the use of some branches.

The 2018 excavation (carried out only in Area 2), with a size of 7x7 m, led to the discovery five monumental burials with lithic cases already upset (Figure 5), completely looted by tomb raiders in recent times, confirming the goodness of the archaeological interpretation. Unfortunately, due to the clandestine excavations and the upheaval of the tombs, it is difficult at the moment to establish a dating for these structures, also because of the ceramic materials found which are quite rare. The only plausible hypothesis that can be advanced at the moment is that generally

the action of the looters is aimed at rich burials, in particular those of the hellenistic era.
In fact, it should not be ignored that a furnace has been identified near the excavation, dating back to the 4th century BC, which could be coeval with the tombs investigated.

4. Case study: Los Paredones (Nazca, Perù)

Los Paredones (Figure 6) is located in the Ica region (Nasca, Peru) halfway between the Pacific Coast and the Andean forest.
It is one of the best preserved archaeological sites (Orefici 2013) of the entire area. It is recognized as one of the most important administrative centres of Inca.
It covers more than twelve hectares and is characterized by rectangular architectures made in adobe built over stone bases.
The urban system spreads over several levels and artificial terraces. In the center of the site there is a large square of trapezoidal shape, around it are several administrative buildings, depots, housing, sacrificial and ceremonial areas. In the highest part of the site there is a large watchtower.
To the east of the site there is the presence of an extensive necropolis, partially damaged by robbers (Figure 7).
In the case of very extensive and dense looting phenomena, especially in the desert environment, it is often possible to identify even in satellite images the illegal action of the tomb robbers, where the violent action of the looting has created real "gruyere" extended over several hectares of land (Figure 8).
Here, the grave robbers dig deep holes and accumulate the earth on the sides of the hole, most of the time, without worrying about covering them.
In Peru, the areas affected by the looting phenomenon are very numerous, spread over the entire territory of the South American state.
The use of the drone allows to be able to carry out punctual analyses, to count the number of holes dug and to be able to monitor over time the possible

Figure 6. Location of the archaeological site of Los Paredones (Nasca, Peru). Google Earth.

Figure 7. Los Paredones (Nasca, Peru). An overview by drone.

Figure 8. The phenomenon of looting seen by Google Earth. Los Paredones (Nasca, Peru).

presence of new illegal excavations for the purpose of preventing the area.

During the ITACA mission of 2015 (Masini, Lasaponara 2016), led by prof. Nicola Masini of IBAM-CNR in Tito Scalo (Pz), a drone survey was carried out by the entire area of the Paredones site.

A very high precision was obtained for the 3d models, around 1.20 cm/pix in aerial photos and 5.2 cm/pix in the DEM. The site is characterized by the absence of vegetation and, therefore, the bare soil induced an almost homogeneous colour throughout the whole area.

In these conditions no archaeological crop-marks are perceptible except in some particular points related to the ridges of the buried walls or to the holes left by robbers.

The overlapping of DEM with the relative orthophotos (of the 3d model) made the interpretation of the contexts much easier compared to the analysis of the single data set. This is because the topography of the site appears much clearer and sharper.

In the Paredones study case, the DEM actually provided a real radiograph of the entire site (Figure 9).

This is due to the presence of buried structures that were terraced on a different level compared to the others, abandoned and also covered by the wind action over the centuries.

One impressive aspect is the clear evidence of the looting features the signs of robber actions also identified and investigated through remote-sensing techniques.

Appendix. Data acquisition and processing procedure

For both case studies, 3D models were created using a Phantom Vision 2+, produced by DJI, a Chinese multinational. It is a quadcopter, weighing 1242 grams, with 4 brushless motors equipped with a compass, altimeter, GPS, with an autonomy of about 20 minutes, with a standard 14 Megapixel camera. Based on the resolution of the drone camera, the altimetric curves of the places, and to reach a GSD of no more than 3 cm / pix, photogrammetric shots were taken flying at no more than 30 m from the ground. For both sites, the flights were carried out manually and not automatically due to the presence of some obstacles that prevented safe work (trees and branches, mountain walls). During the planning of the survey campaign, several flights were carried out, of which the first to create a zenithal coverage and the second for the oblique one taking the object of study at 360 degrees, shooting photos at 3-second intervals, checking the framing the camera on the smartphone. The photos, after being corrected using the Adobe Bridge Camera Raw plug-in, were processed through Agisoft Photoscan; in order to create 3d models with a high level of detail and precision, high processing parameters were used, the results of which are shown below (table 1).

3D MODEL	San Nicola	Los Paredones
N. Photos	210	721
Point cloud (point)	32.765.483	54.564.783
Mesh (faces)	26.432.745	46.567.834
Ortophoto precision (cm/pix)	2	1.20
DEM precision (cm/pix)	6	5.2
GCPs	7	20
CP	3	6

Table 1. Parameters in Agisoft Photoscan.

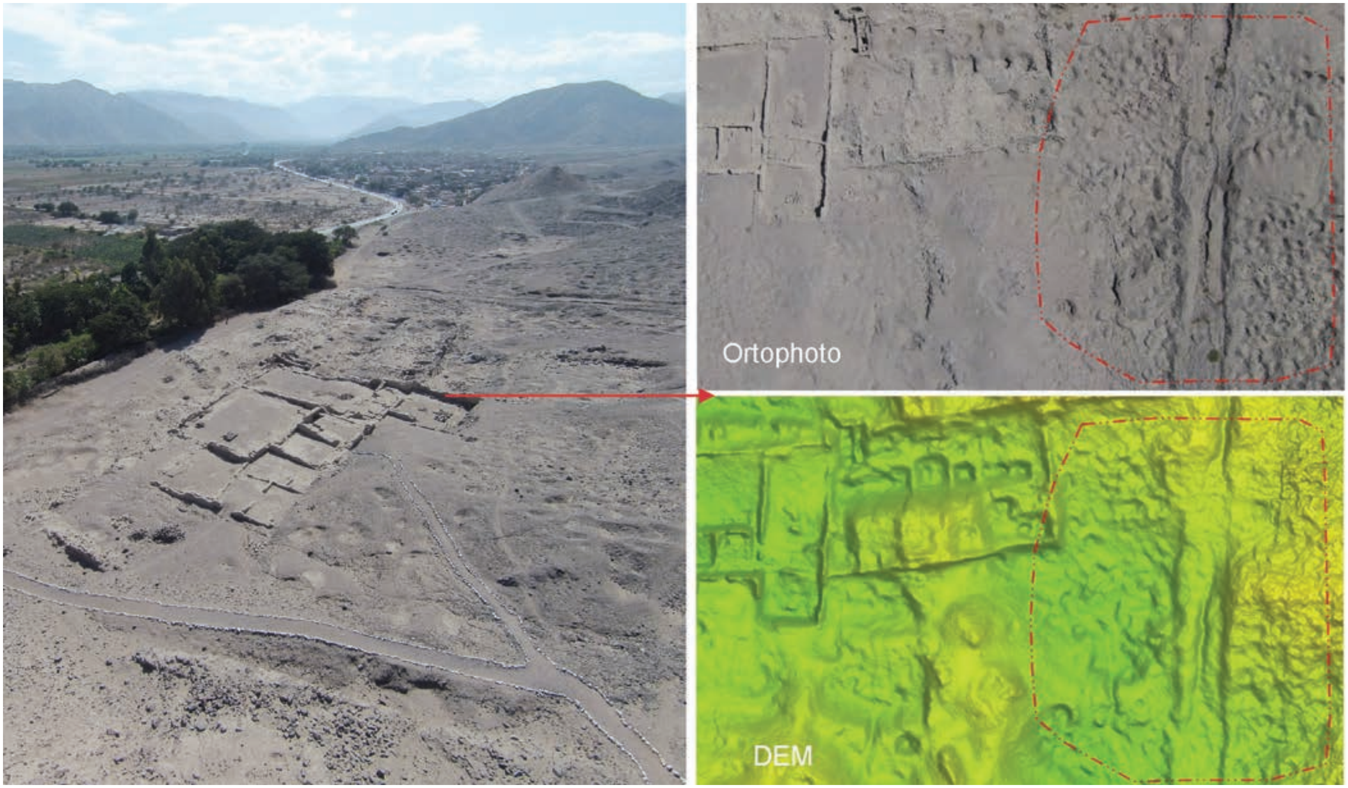

Figure 9. The looting observable on Orthophoto and DEM. Los Paredones (Nasca, Peru).

This software is based on a semi-automatic workflow that manages the entire work phase, consisting of the orientation of the photos, the generation of a cloud of points, the creation of a mesh and the final 3d model covered by a textured very high resolution.

The 3d models obtained, the details of which are shown in the table (tab. 1), have been georeferred on the basis of a technical cartography on a scale of 1: 2000. Finally, from the 3d model created and through Agisoft Photoscan, it was possible to create final outputs such as orthophotos, DEM (Digital Elevation Model) and Google KMZ, which can be managed within GIS and CAD software.

5. Conclusions

In certain geographical areas and in specific cases, the sign of the violent action of the tomb raiders is easily perceivable and identifiable in the ground through remote sensing analysis. In a desert environment, the phenomenon of looting is often represented by a sort of "gruyere effect" on the ground, caused by the holes and accumulations of earth on the sides of the same. This sign, definable as "looting marker" appears in Peru, for example, but also in Iraq or Syria, geographic areas for some similar characters. This occurs especially in those areas where the fight against looting is less strong if not absent, and especially in those areas subject to war conflicts.

Instead, in territories with much more restrictive laws and consequently with the phenomenon of looting less widespread and more fought, it is more difficult to identify illegal excavations.

All the more so if the grave robbers do not leave very tangible signs in the ground, if the excavation takes place mainly in an area covered by vegetation and in peripheral areas.

In conclusion, as highlighted in this contribution, the drones allow to overcome many limits of satellite images and remote sensing technologies, as it is possible to: obtain data at a higher resolution; investigate areas subject to a less extensive looting phenomenon, difficult to identify by satellite due to the type of soil in which the archaeological sites fall (vegetated area, uncultivated or affected by agricultural work) or the specific type of archaeological context (pit tombs, votive posts, abandoned villages); carry out a constant monitoring of the territory; cutting costs using low-cost tools; trying to create a series of case studies for the purpose of archaeological predictive investigations.

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Keywords:
Archaeological site, mounds, magnetometry, Unmanned Aerial Vehicles.

ABSTRACT

The paper presents the results of high-precision magnetic surveys by a quantum magnetometer using an unmanned aerial vehicle (UAV). The object of research was an area of 10 hectares at the archaeological site of Novaya Kurya in Western Siberia. Magnetic anomalies caused by ancient mounds with amplitude of up to 5 - 10 nT were revealed. The received information makes it possible to plan a strategy for archaeological study of this monument at a qualitatively different level. Same technology can be applied at any other archeological site.

High-precision magnetic survey with UAV for the archaeological barrows at Novaya Kurya monument in Western Siberia

1. Introduction

Trofimuk Institute of Petroleum Geology and Geophysics and Institute of Archaeology and Ethnography of Siberian Branch Russian Academy of Sciences have been cooperating for more than 20 years. Large amount of geophysical survey works (magnetometer and geoelectric survey) for the purpose of finding and studying of buried archaeological objects (Epov, 2016) has been carried out throughout this time. Usually ground magnetometer survey has been used for this purposes, which allowed to successfully locate magnetic anomalies as big as several nanotesla (nT) corresponding to archaeological objects of different type, such as entombments, ceremonial pits and middens, habitations.

They have also managed to locate more massive structures, such as mounds, visual traces of which were completely lost (Dyadkov 2015). Magnetic anomalies map analysis has allowed to determine the peculiar properties of their arrangement before the start of archaeological excavations. However, the conditions of ground survey carrying out are not always favorable (dense vegetation, marshiness, etc.), therefore there's a need for development and application of new alternative magnetometer survey technologies.It should also be taken into account that searching for archaeological objects requires higher measurement accuracy as well as sufficient proximity of survey to the ground surface (usually the first meters). Rapidly developing area of survey which uses unmanned aerial vehicles (UAV) opens up wide prospects for magnetic surveys including the archaeological ones. It is known that special equipment has been launched presently by Geometrics (USA) and Geoscan (Russia) in order to fulfill such tasks. Although the number of aeromagnetic surveys using UAV has significantly increased recently, there are still not many examples of their application at archaeological sites (Epov 2016; Tishkin 2017; Goglev 2018). A magnetometer survey with the help of UAV has been fulfilled within the framework of the present studies at the mound burial ground of Novaya Kurya. The site is located at the low ridge, in the northern part of the Kulundinskaya steppe (Karasukskiy district of Novosibirsk region, Russia).

Figure 1. UAV "Geoscan 401" (left) and a quantum magnetometer (right) when conducting magnetic surveys at the archaeological site Novaya Kurya, 2019.

It is represented by 8 rounded bourocks with diameter of 20 up to 35 meters and 0.2 to 0.7 meters high. The necropolis most probably dates back to the Nomads period (middle of the I millennium BC - end of the I millennium BC) The surface of the archaeological site has been repeatedly plowed up, this has considerably influenced the characteristics of the mounds and may have destroyed the external features of some of them. It was necessary to receive information about the boundaries of the site and specific features of mounds structure at the stage of preparation for archaeological studies as this would give the opportunity to plan the strategy of the named studies more carefully. The goal of the conducted works was to evaluate the prospects of using low-altitude aeromagnetic survey for locating and defining the structural features of mounds.

2. Methods and Devices of Magnetometer Survey

The aeromagnetic survey was executed at 2019 at mound burial ground Novaya Kurya by specially developed system "Geoscan 401 Geophysics" (Goglev 2018) which includes an industrial grade quadcopter "Geoscan 401", capable of performing flights at the assigned route as a vehicle.

A compact and high-precision quantum magnetometer, designed by the specialists of Geoscan Group of Companies, was used for the survey. The total area of survey amounted to 10 hectares (500 x 200 m) approximately.

Thus, total length of axial sections was about 100 km. The distance between the sections is approximately 1 m. The frequency of magnetometer measurements is 10 Hz, taking average flight speed as 5 m/s it amounts to the distance between the neighboring measurements, which is around 0,5 m. The measurement deviation tolerance of geomagnetic field induction vector module by Geoscan sensor does not exceed 0,3 nT.

In order to consider the influence of solar daily geomagnetic variations we used proton geomagnetic-

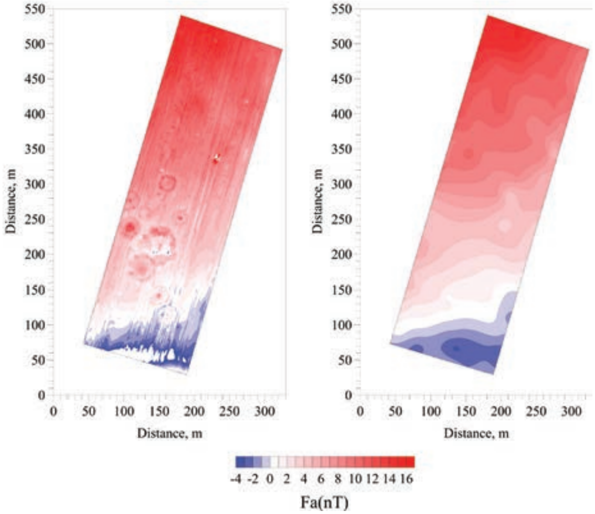

Figure 3. Primary Fa (raw data, on the left) and regional magnetic field Freg (on the right).

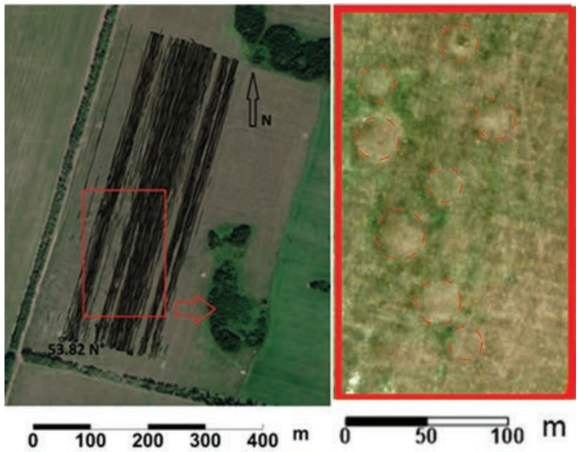

Figure 2. Google map with measuring points in a high-altitude window of 2-5 m (left) and its fragment with the designations of relief mounds (right).

variations system MB-07M, which has the accuracy of magnetic induction module vector registration not lower than 0,1 nT. The accuracy of GPS sensor complied with the submeter range (Figure 1).

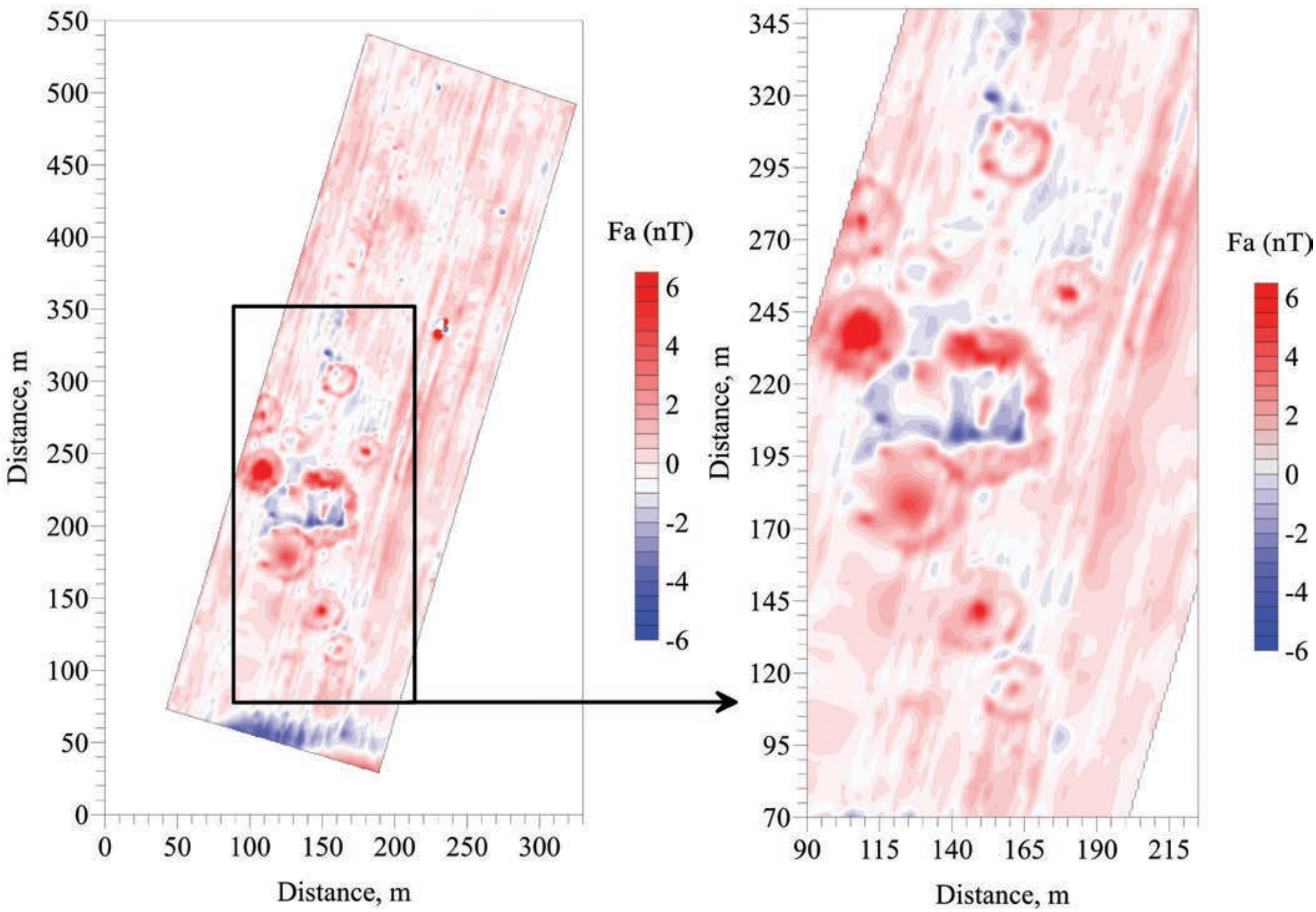

Figure 4. Map of the anomalous magnetic field Fa (after excluding the regional anomaly) at the archaeological site Novaya Kurya (left) and a fragment of the site (right) where the mounds are located, the numbering of which is shown in Fig. 2.

3. Obtained Results

Among all series of passages the ones which were made at the altitude of 2 to 5 meters were chosen as the closest to the objects and covering the studied territory to the fullest extent (Figure 2). The following operating procedures were chosen and executed in order to process the raw data.

First, the calculation of the external geomagnetic variations has been carried out by means of deducting the field values at the variation station from every measured field value at the section. Second, interpolation of the reported values (Fa) at 1m x 1 m grid was executed by means of Kriging method for about 100000 junctions.

Further, in order to register and eliminate the local magnetic field Fper we chose 300 points located beyond the local magnetic anomalies influence zones resulting both from archaeological objects and possible modern iron objects. In order to generate a map of local field with similar 1m x 1m grid a Kriging method was used, later the values of the local field Fper were deducted from the corresponding values of the field Fa.

To reduce local variations in the final field values caused by uneven tack of the quadcopter flight, the data array was smoothed using a 3 x 3 point floating window (Figure 3).

At the time when the magnetic survey took place the archaeological studies of mounds 5 were held.

This excavation site is being well documented on the maps.

The realization of the offered and described above methodological approach to data processing made it possible to greatly increase the detail of depicting separate elements of mound structure in anomalous magnetic field.

This has also provided the opportunity to detect the archaeological objects between the mounds 3 and 4 which cannot be traced visually and apparently are fully ploughed mounds. At summarizing final results, at the anomalous field one can clearly see the trenches traces of which are not visible at the surface. It makes it possible to precisely define the boundaries of the mounds. Positive anomalies connected with defects of bourocks caused by their plunder, clearly stand out in the center. Circular positive anomalies with diameter from 12 up to 14 meters are detected at the central part of several mounds (for example, of No 2 and 3). These anomalies are supposedly connected either with the bourock's structural features or with the arrangement of the area under the mound. Analysis of the anomalous magnetic field map obtained as a result of the study gives the opportunity to determine the boundaries of the archaeological site and confidently predict the absence of archaeological objects of this kind in the rest of the survey area.

This has a great significance for planning of archaeological works and putting the site on state records (Figure 3).

4. Conclusion

Usage of UAV for magnetic survey in archaeology makes it possible to achieve higher efficiency compared to the land survey. In addition, technical accuracy of the devices installed at the UAV is no worse than that of the ones used for ground-based surveys.

However, in order to achieve the same level of detailing one must use differential GPS receivers (RTK); only in this case the spatial accuracy of measurements will be close to sub-decimeter and that will increase the detailing of the anomalies under observation.

The magnetic survey method with the use of UAV applied at the mound burial ground Novaya Kurya made it possible to identify magnetic anomalies with a size up to 5–10 nT caused by archaeological objects - mounds.

The obtained resolution and detail of the anomalous field map allow us to evaluate the structural features of the mounds including those not visible in the terrain.

This method is universal and applicable also for a wide range of geological tasks including mineral, diamondiferous kimberlite, gold exploration, where the observed magnetic contrast of objects and host rocks has the following characteristics: anomalous magnetic field caused by them at least has the value of the first nT units, at minimum specified survey altitude determined by the relief and terrain features.

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Road roughness, distress, TLS, UAV, DEM.

ABSTRACT

Monitoring the state of damage of the road pavement plays a fundamental role with respect to the functionality of the infrastructure, and is necessary to schedule maintenance work, optimizing available resources and greatly enhancing the safety of users and infrastructure. The aim of our work is the three-dimensional reconstruction and analysis of the pavement surface surveyed using techniques different from the traditional ones used in road engineering. The test involved a 100-meter long road segment whose surface was surveyed by a Terrestrial Laser Scanner (time-of-flight) and by a UAV (Unmanned Aerial Vehicle) to analyze their performances and compare the results. The acquired data were interpolated to generate a DEM (Digital Elevation Model) representing a numerical model of the road surface on which the irregularities were measured. All the algorithms used in data processing were implemented in Matlab environment.

Characterisation of the road surface using integrated remote sensing techniques

1. Introduction

The road pavement condition has a significant impact on the life cycle of the road and the safety of users. Even today, vertical elevation profiles are used to assess the dynamic response of the vehicle and the roughness condition of the pavement. There are several indices that are used to estimate roughness along a longitudinal road profile. They can be divided into two groups: dynamic and geometric indices. The most frequently used dynamic index is the International Roughness Index (IRI); it provides an estimate of roughness based on the dynamic response of a standard vehicle moving along the profile (Gillespie, Queiroz, & Sayers, 1986). The geometric indices are based on the estimation of the standard deviation of the measured height values of the relative elevation points along the road surface profiles; a high correlation is found between the IRI and the standard deviation of the longitudinal roughness (Muniz de Farias & de Souza, 2009). Recently, starting from the survey data acquired with new technologies that allow to obtain data on pavement conditions in a more complete and efficient way compared to traditional survey methods, the pavement conditions can be analyzed on a three-dimensional model of the road surface (Guan, Li, Cao, Cao, & Yu, 2016).

For example, the elevation values of LiDAR (Light Detection And Ranging) data can be used to estimate the longitudinal roughness of the road. In particular, the survey with the Terrestrial Laser Scanner (TLS) allows a fast and highly accurate acquisition of dense point clouds. Its potential is now well proven; there are several guidelines in the application to infrastructure to take advantages of all its characteristics (Olsen et al. 2013; Puente, González-Jorge, Martínez-Sánchez, & Arias, 2013). Many researchers have proven the capability of estimating road roughness on LiDAR data and on reconstructed three-dimensional surfaces derived from them. Alhasan, White, and De Brabanter (2017) use dynamic indices on the reconstructed surface to measure the roughness of the pavement;

Chin (2012) studies the filtering of LiDAR data in order to render IRI values derived from road profiles with those measured with traditional instruments such as rods and levels, inclinometers and inertial profilers; Kumar, Lewis, Mc Elhinney and Rahman (2015) measure road roughness using a mobile laser scanner (MLS), which computes residual elevation values with respect to a reference surface. LiDAR data can also be used for the management of airport pavements; in better details, for the computation and analysis of faulting values of rigid concrete slabs (Barbarella, D'Amico, De Blasiis, Di Benedetto, & Fiani, 2018) and for the analysis of the geometry of flexible pavements (Barbarella, De Blasiis, & Fiani, 2017). In addition to the instruments using the LiDAR technique, UAV (Unmanned Aerial Vehicle) surveys are gaining ground and are having a great success in infrastructure applications, thanks also to the reduction of their weight and their increased payload capacity. To evaluate the road surface conditions, it is now possible to use 3D models obtained through UAVs. Tan and Li (2019) proposed an automatic method to assess road surface conditions using photogrammetric images acquired from UAVs.

Another important study is that of Pan, Zhang, Cervone and Yang (2018); they propose a new approach for the analysis of concrete pavement distress from MSI (multispectral imagery) UAVs using SVM (Support Vector Machine), artificial neural networks and RF (Random Forest) learning algorithms. Our research aims to compare the roughness values obtained on a test site with TLS and UAV surveys. The test concerned a 100 m long road segment whose surface was measured with the two techniques. The data acquired were interpolated to obtain a DEM (Digital Elevation Model) of the road surface on which the irregularities were measured.

2. Methods and material

The test survey was carried out on a section of a local urban road network (Figure 1). The road is a straight line about 100 m long. The cross-section consists of a single carriageway 11 m wide, each lane about 3.5 m wide. The test area is characterised by different types of distress. The TLS survey was made using a Riegl VZ-400, the TLS was placed in station on a tripod. We acquired three scans from three different laser stations. The angular scanning step was set to the smallest value of 0.01°, in order to obtain a dense point cloud.

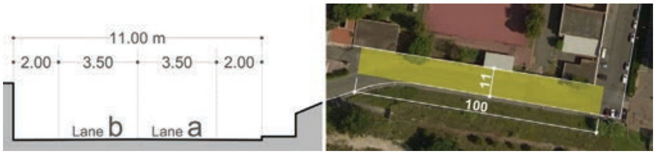

Figure 1. Test area.

Figure 2. TLS station, target and survey scheme.

To georeference the scans we used six spherical targets with a diameter of 15 cm, made of high reflectance polymer material, placed in station on the roadside on rods equipped with spherical level and supported by bipeds (Figure 2). The coordinates of the target's centroid were measured on-site with GNSS (Global Navigation Satellite System) receivers. Single scans with overlap ranging from 50% to 80% were co-registered and geo-referenced by using Innovmetric's Polyworks software package (ver.14). The georeferencing residuals were less than 1.6 cm, their average was 0.9 cm.

The UAV system used for this application is a BeeCopter (MicoGeo) with a net sensor weight of approx. 240 g. The mounted camera is a HERO4 Black with a 12 megapixel, 1/2.3" sensor with modified optics (Figure 3). An automatic flight plan has been set for the acquisition of the nadir photogrammetric shots. The UAV was set to maintain a flight altitude of 29 m above the take-off point. The flight plane was designed to produce parallel stripes where the longitudinal overlap of the images is more than 80% and the lateral overlap is more than 60%. Tab. 1 gives more details.

To georeference the photogrammetric shots a network of ground control points (GCP) measured using network Real Time Kinematic (nRTK) GNSS technique was used. The GNSS receiver used is GEOMAX Zenith 25, the planimetric accuracy is < 1 cm and the altimetric one is about 2 cm. Six artificial coded targets were used, placed near the TLS targets (Figure3). The geodetic reference system is the same as the TLS survey (UTM/ETRF00). For the processing of the photogrammetric data, Agisoft's PhotoScan ver.1.4.2 software package was used.

The inner orientation parameters were estimated using a self-calibrating beam adjustment including GCPs.

To analyze the accuracy of the photogrammetric model, the residuals on GCPs with the root mean square error (RMSE) associated and the reprojection error were used, the latter to estimate how much the adjusted coordinates of a 3D point correspond to its projection on the image.

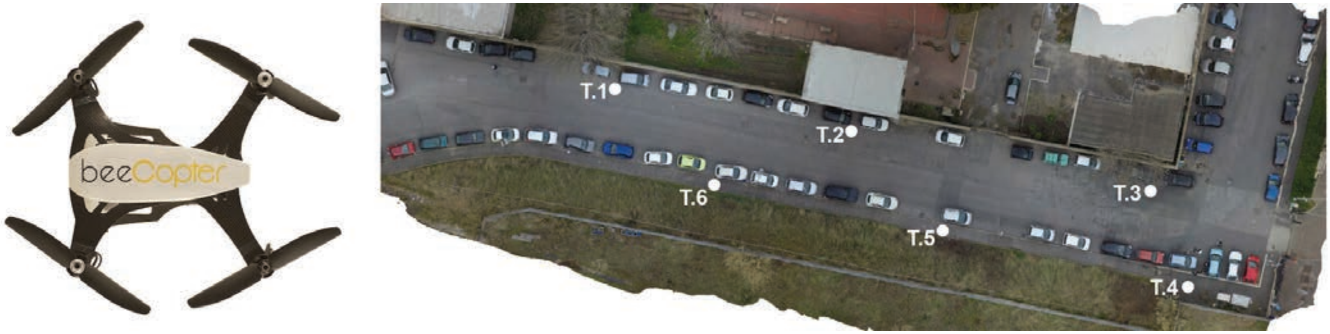

Figure 3. UAV BeeCopter (left panel); spatial distribution of the GCPs (left panel).

Camera	HERO4 Black (3 mm)
Focal length	5.4 mm
Pixel size	1.73 x 1.73 µm
Number of Image	97
Ground Sampling Distance	7.89 mm/pix
Ground coverage	6.45e+03 m²
Flight Height	29 m
RMSE (3D)	2.5 cm
RMS Reprojection Error	0.8 pix

Table 1. Main characteristics of the UAV survey.

	Riegl VZ-400	**UAV BeeCopter**
Number of Point [pnt]	56017749	864396
Mean [mm]	-3E-04	-4E-04
Standard Deviation [mm]	1.2	2.4
Skewness	2.69	-0.75
Kurtosis	24.05	35.15

Table 2. Summary statistics report of the residuals.

2.1 Digital Elevation Model building

Starting from a point cloud it is possible to build a DEM of the road pavement. There are several interpolation algorithms implemented in commercial software packages and the choice of the algorithm to be used is dependent on the type and density of the input data (Hengl, 2006).

A DEM has been built using the IDW (Inverse Distance to a Power) interpolator, power two, grid step 1 cm, suitable for the lowest density of input data. We analysed the residuals as the difference between the measured value and the interpolated value. Tab. 2 shows a summary statistics report of the residuals for TLS and UAV data. Figure 4 shows the map of the differences between the two DEMs.

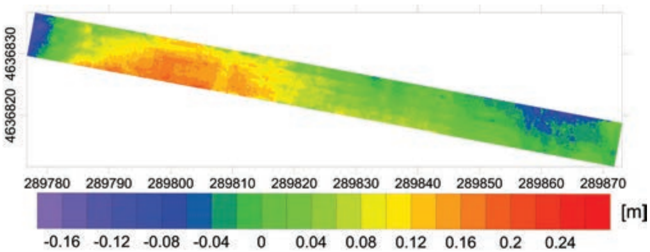

Figure 4. Map of the height differences (LST vs UAV).

2.2 Roughness Evaluation

The assessment of roughness was based on the study of the deviation of the paved surface from a reference plane. The process involves the creation of a two-pitched flat surface built to lie on the actual surface, taking into account that theoretically the cross-section of the road is double-pitched to allow the water to flow. The planes are built on road sections as wide as the entire carriageway and about 5 metres long.

To ensure that the pitch lies on the surface, an iterative algorithm has been implemented; at each iteration the algorithm removes the points below the plane obtained in the previous interpolation.

In this way, in the next cycle, the new plane will be constructed by interpolation based only on the data that were above the plane at the previous iteration; this method makes the plane orient itself according to the number of points remaining at each iterative cycle (Figure 5).

The adjacent pitches, in the direction of travel, are built in so as to be joined together.

The process has been implemented in a Matlab environment. The evaluation of the roughness value Δh of the road has been made computing the difference between the height value of the DEM nodes and the corresponding values of the reference surface (made up of the interpolated planes). To identify the downward displacements of the road surface, image segmentation algorithms were used; to remove or group isolated pixel regions (DEM nodes) with certain roughness characteristics morphological operators were used. This was implemented in Matlab environment.

The geometric parameters computed for each segmented region are: perimeter, area and volume. Tab. 3 shows the computed geometric parameters for some significant examples of identified downward displacements. Figure 6 shows the identified downward displacements.

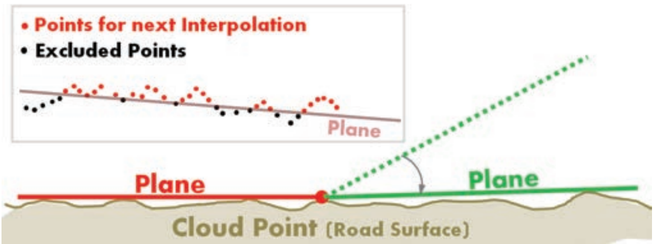

Figure 5. Iterative cycle to build the reference double-pitched cross-section of the road.

	TLS						UAV					
Zone	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
Perimeter [m]	2.83	2.20	32.23	5.51	263.21	3.90	4.59	37.05	25.82	18.38	18.78	16.75
Area [m²]	0.26	0.28	8.22	0.85	166.64	0.30	1.18	17.41	9.81	5.73	9.28	5.83
Volume [m³]	0.0109	0.0135	0.3984	0.0381	10.339	0.0124	0.0491	0.947	0.466	0.339	0.526	0.288

Table 3. Geometrical parameters of the segmented downward displacements.

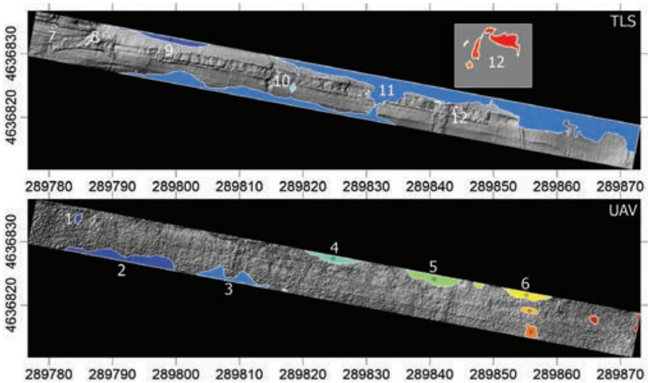

Figure 6. Segmented downward displacements.

3. Conclusions

The assessment of the regularity of the road surface plays a key role in ensuring the safety of users. The study is aimed at testing an alternative methodology to the traditional ones, which uses remote sensing techniques for the analysis of road roughness. One of the main objectives was to test a lightweight UAV system to study the regularity of the road surface.

Processing of LiDAR data was mainly used to validate the results. From the comparison, the results of the UAV are not perfectly in line with those obtained by TLS. One of the main reasons for this is the high noise level in the point cloud obtained by image matching. The noise is mainly due to the absence of a mechanical stabilizer (gimbal) and the homogeneous colour structure of the road surface. These problems can certainly be avoided by using UAVs with professional camera and mechanical stabilizer, which, however, are subject to normative constraints.

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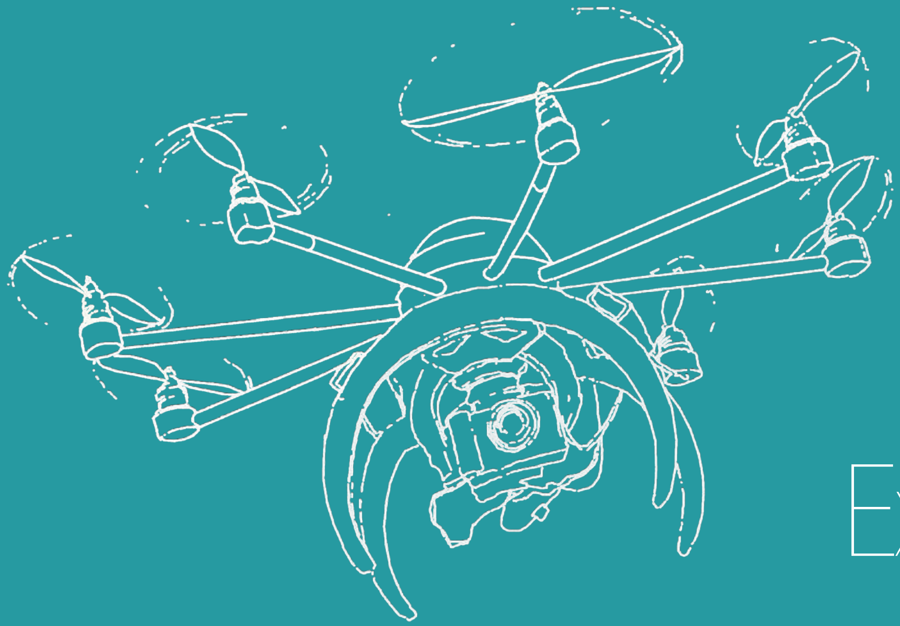
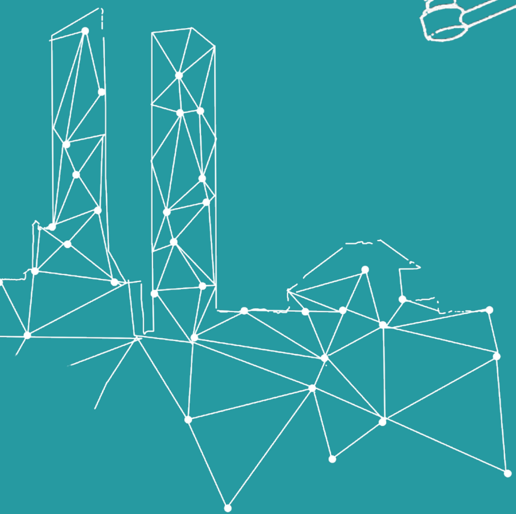




Exhibitions

Figure 1. Bird's eye view of the Old City of Mosul. (Iconem, 2018).

GIOVANNI FONTANA ANTONELLI

Mosul, faraway so close

REMOTE SENSING AND MAPPING AS KEY TOOLS FOR URBAN RECOVERY AND RECONCILIATION

The photo exhibition "*Mosul, faraway so close*" is the result of a photographic campaign that was undertaken in February 2018 in Mosul, few days after the re-opening of the Old City to its residents, and few months after the liberation from ISIL/Da'esh in July 2017. This photographic work was supported by remote sensing and mapping using Unmanned Aerial Vehicles (UAV) surveying to carry out the first damage assessment in the Old City of Mosul. The archaeological and religious heritage was deliberately damaged or demolished by ISIL/Daesh during a three-year occupation (2014-17), while 40 percent the historic urban fabric has been severely affected by the military operations to liberate the city. Ca. 550 historic buildings were destroyed, about 5,000 structures were damaged. The full digital documentation of the 250 ha. of Mosul's historic urban fabric is key to develop the cultural heritage post-conflict recovery and reconstruction.

An open-source GIS platform incorporating all data acquired through aerial and ground survey was also developed. A 3 cm/dpi orthophoto was produced, along with a 3D model of the historic town.

The combined use of the two imagery was essential for the team of experts to analyze the urban form, assess the damage and plan its restoration and reconstruction.

Figure 2. Street view of Al-Nouri Mosque and its Al-Hadba Minaret. (Giovanni Fontana Antonelli, 2018).

Figure 3. Ruins of an historic house in Mosul. (Giovanni Fontana Antonelli, 2018).

Figure 4. The courtyard of the Church of the Clock after bombardments. (Giovanni Fontana Antonelli, 2018).

BACKGROUND

More than 77 years after the end of the Second World War, historic cities and their citizens still experience massive destruction and devastation by wars and other types of conflicts. They have recovered and rebuilt themselves and have shown through their successes and failures that, despite the scale of the task, it is possible to recover, rebuild and reinvent oneself in various ways.

The wars that have ravaged Iraq since 1980 have caused, and continue to cause, immense human suffering. From 2014 to 2017, violent extremism sent Iraq into a downward spiral, adding to 35 years of war, human suffering, division and violence. It took root in the minds of part of its population and targeted rights, history, culture, education, cultural and religious diversity, and any symbols of prosperity. Since July 2014, Mosul's cultural and spiritual heritage sites and places of knowledge, as

Figure 5. Shops devastated in the Old City of Mosul. (Giovanni Fontana Antonelli, 2018).

well as its urban and social fabric and old city, have been systematically targeted and demolished under Daesh's occupying regime. It is estimated that over 40 percent of the city's historic urban fabric has been heavily destroyed by Daesh and subsequently to liberate the city from its extremists. More than 4.8 million people have been displaced in Northern Iraq, 860,000 of whom are from Mosul. The security situation remains precarious, in part due to the large number of landmines, booby traps and unexploded ordnance. While a large part of Iraqis is still in need of humanitarian assistance, internally displaced persons returned to Mosul Old City and started to resettle in its dense urban fabric, in spite of the lack of a coordinated mechanism that should address its recovery and reconstruction, enabling the return of inhabitants in dignified conditions. In the collective conscience, Mosul was the city of knowledge, exchanges, the plural identity of the Iraqi people, a

Figure 6. Interior of the Saint Thomas Church. (Giovanni Fontana Antonelli, 2018).

Figure 7. Mosul main street. (Iconem, 2018).

historical crossroads of trade and culture in the Middle East, celebrated throughout the Arab world for the vitality of its bookshops and second-hand booksellers. Its major monuments and cultural sites, such as the Great Mosque of Al-Nouri with its famous leaning minaret known as al-Hadba - the hunchback, the Tomb of the Prophet Jonah, or its museum containing objects from excavations of major archaeological sites in Nineveh Governorate, of which Mosul is the administrative capital, are all examples of the rich cultural heritage that makes up the identity of this city, the second largest in Iraq. Mosul is also known for its ancient manuscripts, safeguarded in its archive centre, churches, the Sunni Muslim library and the Central Library of the University of Mosul. The city and its region are imbued with the great diversity of their populations, having been home not only to Arab communities but also to Assyrian, Armenian, Turkmen, Kurd, Yazidi, Shabak, Sabian, Mandaean and other minorities. As expressions of the identity of the various populations and repositories of memory and traditional knowledge, cultural heritage is an essential component of a community's identity. Promoting respect for cultural diversity is crucial to prevent violent extremism, facilitate constructive dialogue and inclusion, and maintain lasting peace.

HOW REMOTE SENSING AND MAPPING IS KEY TO URBAN RECOVERY AND RECONCILIATION

The recovery and reconstruction planning frameworks were supported by remote sensing and mapping using Unmanned Aerial Vehicles (UAV) surveying to carry out the first damage assessment in the Old City of Mosul (2018-19). Ca. 550 historic buildings were destroyed, while about 5,000 structures were damaged. The full digital documentation of the 250 ha. of Mosul's historic urban fabric convened into an open-source GIS platform incorporating all data acquired through aerial and ground surveys. UAV surveys were key to inform the programme's components:

1. *Analysis, design, planning, database monitoring (City profiles, Data platforms, etc.)*

City and neighbourhood profiles: This component aims at providing crucial information on the social, economic and physical status of targeted areas for urban diagnosis and planning to guide prioritization of interventions. It aims at identifying priority actions for reconstruction interventions. Data platforms: are important tools for planning, monitoring and evaluation of recovery and reconstruction efforts. It will be hosted at the regional level and utilized at country level as an evidence-based decision tool.

2. *Debris Management (rubble management and recycling)*
Debris/rubble management is an important component in the reconstruction efforts, and is a major source of local economic revitalization. Debris/rubble management includes the following: rubble removal;identification of the kind of rubble, and separation; collection and transportation; rubble recycling to separate the items that can be used for reconstruction, raw material, and items that can be used for other purposes; reuse. The above requires a holistic plan for rubble/debris management, and will include guidelines for durable environmentally-sustainable related to debris and rubble management.

3. *Housing Rehabilitation and Reconstruction*
This component targets housing rehabilitation and reconstruction, based on damage assessments and includes innovative approaches of (a) core housing rehabilitation; (b) low cost housing construction; and (c) structural adjustments for housing.
This will be based on the available tools and mechanisms for reconstruction, coupled with monitoring.

4. *Urban Livelihood Revitalization (including youth employment in the different sectors)*
All interventions are based on an inherent objective of local economic revitalization, including the local economy and livelihoods restoration. This includes an in-depth analysis of target groups, includes demographic composition, available skills, location dynamics, economic opportunities, among local economic market analysis. It looks at a holistic human resource management for livelihoods creation, mainstreaming community engagement and ownership. In parallel, available skills will have a comprehensive on-the-job training for skilled and unskilled local labour, focusing on marginalized groups, including the youth, for reconstruction efforts.

5. *Urban Cultural Heritage, Environmental sustainability of reconstruction*
Reconstruction needs to mainstream the principles of 'building back better' through utilizing three main categories in reconstruction efforts at two levels, including at the governorate level (master planning, guidelines, methodologies), and implementation: cultural heri-

Figure 8. Ruined building. (Giovanni Fontana Antonelli, 2018).

Figure 9. Al-Qattanin Mosque viewed from a top. (Iconem, 2018).

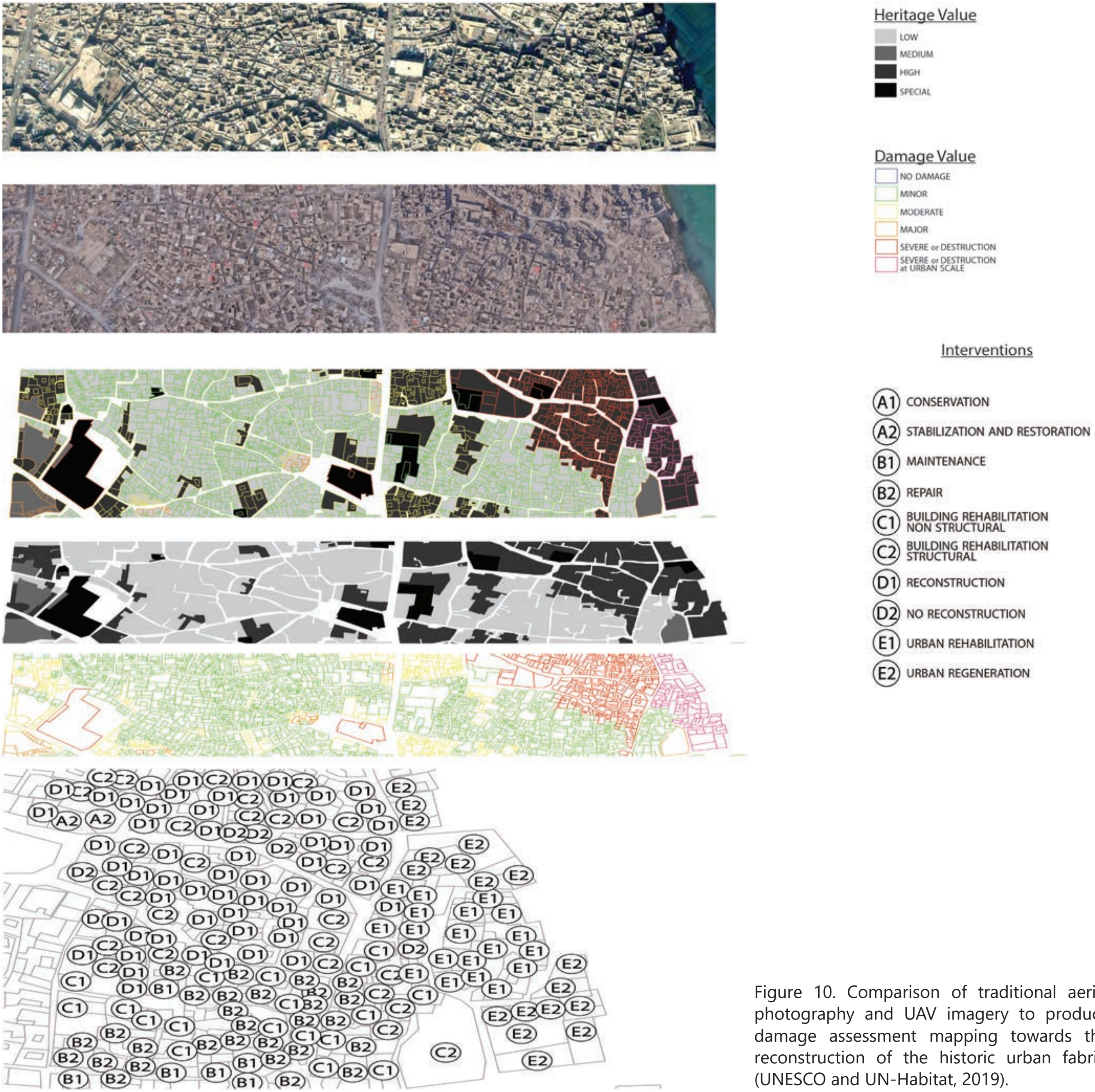


Figure 10. Comparison of traditional aerial photography and UAV imagery to produce damage assessment mapping towards the reconstruction of the historic urban fabric. (UNESCO and UN-Habitat, 2019).

tage: preservation and rehabilitation of cultural heritage sites; energy efficiency and renewable energy: street lighting, public facilities, municipalities, housing bulbs, solar water heaters; water efficiency, water conservation, grey water treatment; solid waste management, recycling and re-use.

METHODOLOGY

Two specialised companied from France (Iconem) and Italy (Risviel) were contracted to carry out respectively the UAV survey / data processing and the creation of a web-based open source GIS.

To facilitate the survey, the Old City of Mosul was divided in 15 zones, targeting a 3 cm resolution. Two zones (using 5 flights each) were tested before applying a protocol that would ensure the quality results of the entire area of the old fabric. For several areas, technical problems arose, and additional flights were necessary to complete their scan.

All in all, 90 flights were necessary to scan the 15 zones of the Old City – leading to an average of 6 flights per area. Altogether, these flights account for 25,000 aerial pictures of the Old City, taken at 75 meter-high with the camera pointing down (one flight) and 60 meter-high with the camera tilting at 45 degrees (5 flights). Each of the five flights were performed along the main compass directions to get a full scan of the vertical elements. The survey produced an ortho-photograph at 3 cm resolution, which was complemented by a vector Plan, as well as a 3D model reconstruction of the entire historic fabric. The 3D model was particularly helpful to understand the degree of destruction of each compartment of the old city, which presents a high degree of density and complexity.

Nine high-resolution 3D models of historic buildings (exterior and interior at 1 cm) were also produced, along with an interactive 3D viewer accessible locally and online. Six buildings out of nine, notably the Al-Nouri Mosque, the Al-Hadba Minaret, the Al-Tutunji House, the Museum of Mosul, the Old Al-Tahera Church, and the Church of the Clock are currently under restoration through different projects. All the data gathered during the survey and initially processed and included in an open-source GIS platform. A single reference system and georeferencing all the data according to this system was set up, in spite of the absence of benchmarks on the ground. The system collected a series of available raster image data; in particular, satellite maps of different periods that visually indicate the transformation of the urban fabric over time; subsequently, all these data were georeferenced on the orthophoto specifically produced for this programme. Acquisition of more than 14,000 single building units were gathered from the 2007-08 urban fabric census and a new ID card system was developed. The ID cards component will benefit the survey of historic buildings, and their archival documents (maps, drawings, photographs etc.). The system is being regularly updated by the insertion of new vector layers, already geo-referenced on the system indicated in previous points, such as: the neighborhoods, the streets, the cadastral maps, sewerage maps, etc.

CONCLUSIONS

The combined use of the digital tools (UAV surveying and GIS platform) was essential for the team of experts to analyze the urban form, assess the damage and plan its restoration and reconstruction. A first set of documents towards the recovery and reconstruction of Mosul was prepared in 2019 under the page heading of Initial Planning for the Reconstruction of Mosul, with a specific chapter focusing on the historic town. The “Mosul Old City: Reconstruction Priorities” document is a summary from key recommendations and actions. It should therefore be seen in the context of the overall framework for all of Mosul, as many challenges that the Old City face are shared with the wider city. Multiple local government actors have expressed their concern that reconstruction without an overarching and holistic plan may be counterproductive to long-term sustainable development of Mosul, and do irreversible damage. The document provides the first priorities to be endorsed by the Prime Minister’s Task Force for Reconstruction of the Old City to support the self-reconstruction process and prevent damaging recovery and reconstruction activities in the Old City. It draws upon earlier studies of the Old City; “Reconstruction of the Old City of Mosul Preliminary Study” (October 2017) and the “Reconstruction of Mosul Action Plan” (2018), both by the Engineering Consulting Bureau of Mosul University as well as recommendations of the Iraq’s Engineering Union. Building on these reports, the following implementable actions are recommended:

1. Protect the heritage from further destruction;
2. Recover the Old City through a block approach;
3. Clear the city from debris and unexploded ordnances;
4. Ensure reconstruction respects the city’s historical character;
5. Support the self-reconstruction process;
6. Support the small-medium enterprises in commercial streets;
7. Bring back schools to the Old City;
8. Reconnect the Old City to the rest of Mosul;
9. Assist Old City residents with property documents;
10. Implement pre-crisis plans to build-back-better.

Figure 1. Agrigento.

THE USE OF DRONES IN DOCUMENTARIES

While we are still trying to fully discover and understand our territory, our history, the ancient and the modern masterpieces, the technological elements and the nature, a new point of view has allowed us to start over this journey never ended. But this time, it can be done with different eyes.In recent years, thanks to the use of drones, air shooting has experienced a broad spread and the continuous improvement of its quality has fostered the transformation of this new technology into an always more adopted communication mean.Indeed, nowadays any TV broadcast, documentary, audiovisual or commercial includes at least one shoot made with a drone. Moreover, now the videos recorded show an incredibly high resolution, since the devices utilized range from fairly simple model to more professional ones, capable of lifting cameras like the RED. In my case, talking about TV broadcast connected to archeological parks and areas I am using light drones, such as the Mavic Pro and the Xiaomi X8, that are in any case able to record in 4K. The main TV broadcasts that I have directed and shot utilizing drones are the "Cronache dal Mito" and "Viaggio nella Bellezza" produced by Rai Storia and in both cases their use has been fundamental in showing in an incredible way the archeological finds and sites or to better understand the architecture, the settings or the morphology of the territory. Back in the days, this type of shots was unconceivable for the costs and the difficulties associated with its realization, done with aerostatic balloons, helicopters and airplanes. Now, instead the use of this new and truly spectacular communication mean is finally affordable and feasible.

"The voyge of discovery is not in seeking new landascapes but in having new eyes."
Marcel Proust

Figure 2. Lemnos.

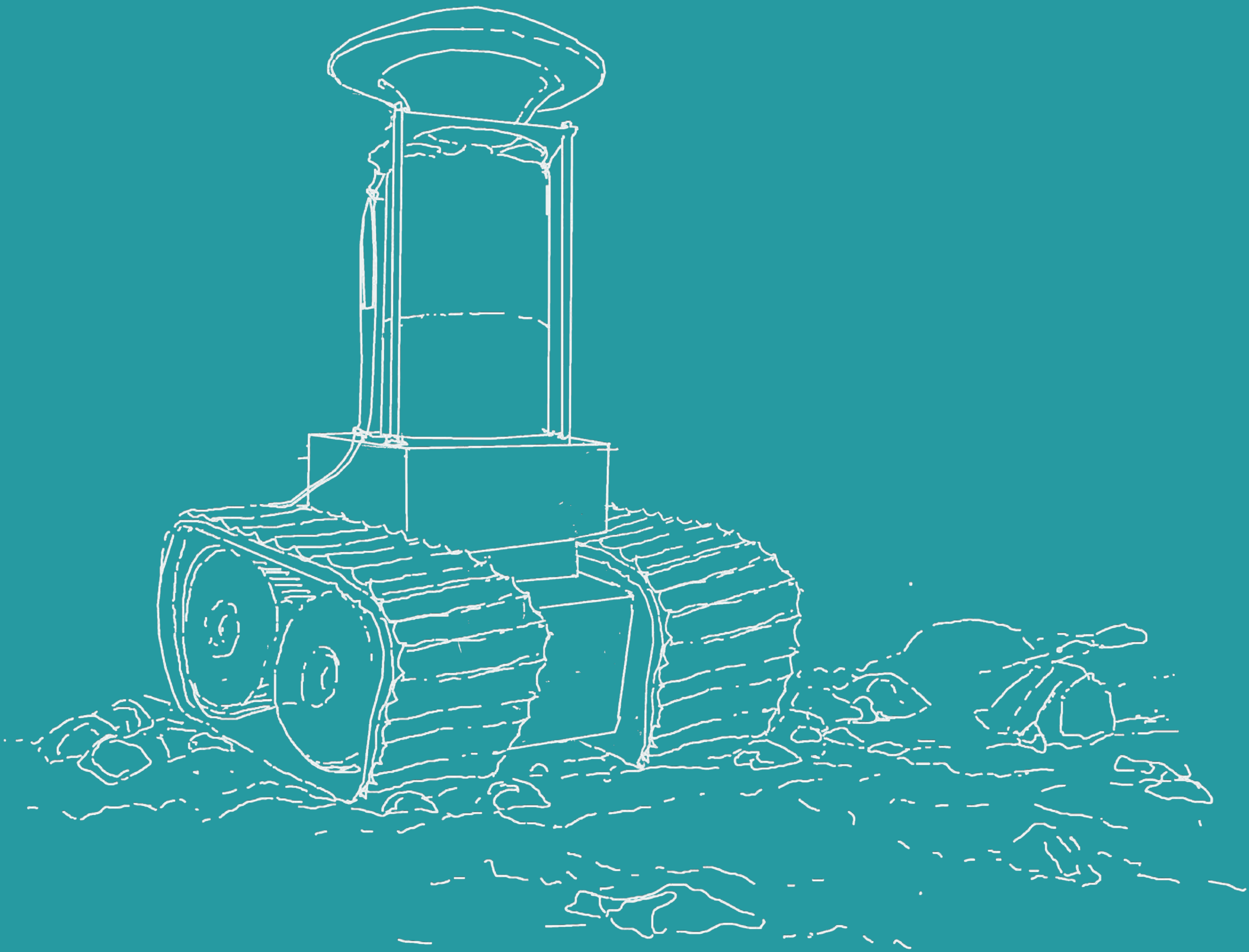
Figure 3. Athene.

Figure 4. Athene.

Figure 5. Delphi.

Drones and archeology is definitely an always more common pairing. Moreover, in addition to the documentary intent they can be used to explore areas hardly accessible, to locate underground structures with thermographic and multispectral sensors or to collect data for the processing of digital maps and 3D models. In the archeological documentary, even in terms photographic style, the changes have been substantial. The uniqueness and the freshness of this new point of view allows us to appreciate those monuments, constructions, geoglyphics and areas as if we were those Gods to which these great works have been dedicated to. Similarly, at this stage we can get close to certain details that are not even accessible and visible from the ground. Moreover, now with the drone it is easier to correlate different environments with a single frame and compared to the past, when mainly the JIB or the Crane were used, there is a reduction of the costs and the time associated with the realization of this type of video. However, drones or Jib/Cranes are two sets of tools whose communication styles and languages differ significantly; therefore, when looking at a documentary, the audience expects to see images realized with both technologies and this is especially true for archeological sites. In addition, thanks to the reduced danger and noise produced by drone's propellers, it is now feasible to record a presenter talking with an overall good audio quality. I still remember years ago, when deploying the first drones, that one could not shoot videos and simultaneously record the voice of the presenter. To conclude this brief presentation, I would like to stress once more the fact that drones represent one of the most disruptive change in the movie and documentary industry but for the future, technologies such as the VR or the 360 videos have the capability of providing the audience with an even more immersive and engaging experience.

Figure 6. Paestum.



Afterword

Rocco D'Auria from RDIGTAL and Marco Limongiello from DICIV, during the last drone survey in South Africa for a spatial and social investigation at Mpumalanga. Project "Youth Exchanges 2018-19" co-funded by the Italian Ministry of Foreign Affairs and International Cooperation.

Afterword

Salvatore Barba
University of Salerno, Vice Head DICIV - Department of Civil Engineering

As part of the initiative "D-SITE, Drones - Systems of Information on culTural hEritage. For a spatial and social investigation", the whole research material developed by the Italian and international universities has been published in this volume. The work aims to take stock of the tools and methods used to document the Cultural Heritage; it represents an insight into of the state of the art on the use of UAV (Unmanned Aerial Vehicle) for the survey and monitoring of the territory and the built environment.

Today, digital tools offer a multitude of new opportunities for the collection, analysis and dissemination of knowledge. The technological progress has facilitated the acquisition phase, which has become common practice in many disciplines. The recording of geometric and non-geometric characteristics of the architectural-archaeological sites, landscapes, etc., is now a fundamental and consolidated step that precedes any other activity: a 'rigorous' documentation based on the object to monitor changes and somehow modifies the object of study itself. The relative technological evolution is well illustrated in this volume. The various applications, as demonstrated, represent, in many cases, the most effective response, in terms of speed and potential, even in emergencies.

In the field of heritage documentation – be it cultural or natural – the use of drones, alternatively known as UAVs, is thus increasingly widespread, allowing for surveys, inspections or simple acquisitions of image and/or video. Their diffusion is due to the possibility to obtain images of the area under investigation from privileged points of view, with the consequent advantage of being able to map areas that are difficult to access: generally gaining imagery with a higher resolution than the one obtainable from classic aerial photogrammetry – due to the lower flight altitude – while also lowering the costs in the data acquisition phase.

The multirotor, in fact, can fly even at very low altitudes and has the ability to hold the position in mid-air – also called hovering ability – which are necessary to counteract the effects of rolling shutter (this is a disturbing element in any type of image processing). Therefore having greater flexibility in the image acquisition, allowing both nadiral and oblique shots. In the different applications it has not been overlooked that the multirotor is able to transport, depending on the respective maximum payload, a wide range of sensors – active and passive – up to thermal and multispectral cameras (the latter notoriously used in precision farming and in the archaeological field for the study of cropmarks), or even LiDAR instrumentations.

On the other hand, fixed-wing do not have hovering capabilities, sacrificed for the benefit of better aerodynamics that allow for greater wind resistance and longer autonomy: these are the reasons they are almost exclusively equipped with "compact" cameras, for purposes essentially related to the monitoring of the territory of medium-large extensions. Generally, these fixed-wing systems have flight heights higher than 100 meters and can almost exclusively acquire nadiral shots according to the classic aerial photogrammetry scheme.

In this perspective, the published works have been grouped in three principal sections that focus on different issues related to the use of UAV devices: the visualization and conservation of Cultural

Heritage; monitoring and internal inspection operations through new approaches with the aim of carrying out quicker and lower cost investigations; eventually, an overview of the possible applications of UAVs for the analysis of territorial, geological, agricultural and forestry aspects. Many of the case studies also focused on the integration of three-dimensional data generated by different sensors. The widespread aero photogrammetry from UAVs is notoriously high performing, in terms of data acquisition speed, metric quality of the final elaborations and colorimetric result, especially about external documentation. On the other hand, due to the reduced space and or low luminosity, it is more difficult to apply this technology indoors. The studies carried out, however, shows new lines of research in this direction as well, with an integration of data from both active and passive sensors. With different paradigms are proposed, from TLS (Terrestrial Laser Scanner) to SLAM (Simultaneous Localization And Mapping) technology. More and more often, of these types of integrated surveys culminates in H-BIM applications, with the return of "Digital Twin".

Another field of in-depth research is the digital visualization, where some original experimentations, such as hybrid drones or installations of magnetometers or other sensors on UAV means, find their own space. There are several examples that deserve mention, in particular the research "UAV multi-image matching approach for architectural survey in complex environments". This work concerns the use of a small UAV for the documentation of an historical architectural complex, in which space constraints arises. The adoption of a rapid mapping workflow using frames extracted from videos is discussed, together with the exploitation of an automatic procedure for the acquisition of 360° shots, used for ensuring the minimum required overlap for a reliable and accurate image orientation.

The paper of *Chiabrando et al.*, instead, investigates the integration of data acquired by a very light UAV and with the ones coming from different range-based sensors for documenting a historical and stratified fortified architecture. The problems related with the flight authorization and the strategies for data acquisition using the UAV and the employed range-based sensors are then explored: all the achieved metric products and the analyses are reported.

The study from *Banfi* is another noteworthy work. This paper outlines a multi-stage method to improve Historic Building Information Modelling projects using unmanned aerial vehicle based photogrammetry data. The digital reconstruction of semantic models is based on the application of novel GOG (Grades of Generation) and the integration of data coming from the use of different type of drones, with which it is possible to improve the LOD and LOI (Level of Detail and Information) of different types of architectural.

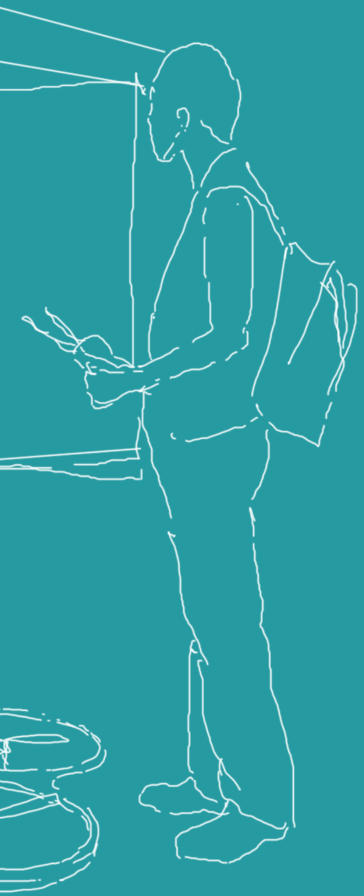
The working group of *D'Andrea,* has developed the drone-based photogrammetry survey of Paestum.

From the final geo-referenced model, a high-resolution orthophoto has been extracted to update the map of the visible structures, while the point cloud has been used to create an A-BIM (Archaeological Building Information Modelling). The 3D model supported the reconstruction of this insula, scarcely studied.

Pirinu et al., develops a broader multidisciplinary research involving Italian and Spanish universities and offers the opportunity to start a process of knowledge for the protection and enhancement of the historical landscape entrusted to integrate surveying and representation methodologies.
The territorial size of the research field and the multiscale character of the landscape leads to a documentation activity in which integrated (digital and traditional) graphic techniques are employed and the use of the drone supports the acquisition of data and the construction of digital models of the investigated context, with the additional purpose to create cultural itineraries.
The work of *Massari* reports the results of a research project aimed at the survey, historical knowledge and archaeological understanding. An extensive use of digital photogrammetry with the employment of UAVs and DSLRs, alongside some topographic instruments such as a total station and a GNSS receiver, provided a complete survey and eventually brought to the discovery of the borders and walls of an ancient castle.
The study of *Liuzzo et al.* looks at the numerous ruined fortified medieval sites throughout the Sicilian territory. The methodology chosen required a primarily image-based drone survey and a subsequent elaboration of data aimed at obtaining both 2D and 3D drawings as well as a virtual reality application to provide an instrument of knowledge and a virtual use of the sites.
The contribution of *Palestini et al.* represents another research experience, aimed at the documentation of Cultural Heritage conducted with the help of drones. The methodology combines the acquisition, the data processing and the photo-modelling, integrated in a comparative and experimental way. The research focuses on the comparison of two methodologies, one open source and the other commercial, where the advantages and criticalities are highlighted by comparing the workflows and the results.
Within the papers, it is also possible to meet projects of robotic drones to support Cultural Heritage, such as the project developed by *Cigola et al.* The contribution briefly illustrates the HeritageBot project, currently in the prototype phase, which concerns the construction of a drone structure with robotic legs. The system is equipped with high dexterity locomotion mobility and the possibility of small flights. Its platform, structured in modular mode, allows to host various sensors, both commercial and specifically developed, in order to intervene in the processes of knowledge and detection of Cultural Heritage, in critical situations and in conditions with particularly difficult accessibility. The proposed studies represent, an overview of three-dimensional survey techniques employing drones. The volume aims to give back some sort of guidelines, focusing on the planning phase and contributing to validate from the scientific point of view the complex process of measurement. In fact, the same survey, while constituting by itself an operation of 'knowledge', still requires an in-depth preliminary 'knowledge'.
It is trivial to observe how a mastery of the digital restitution modalities and the relative algorithms will guide in the very first place the choice of the quantity and quality of the necessary data.

From the comparison of said published research experiences, however, it emerges the opportunity to promote a discussion on the need for standardization of the survey. The multiplicity of topics and the presence of many researchers, coming from different sectors, has granted us – thanks to the work of the committee and scientific secretariat – a more global vision of the state of the art, as well as of the future perspectives related to the world of drones, each time more closely linked to that of the digital representation.

A spatial and social investigation at the Moxomatsi village.



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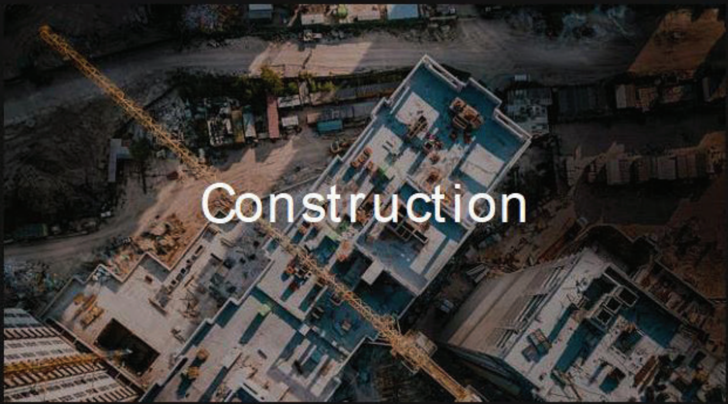
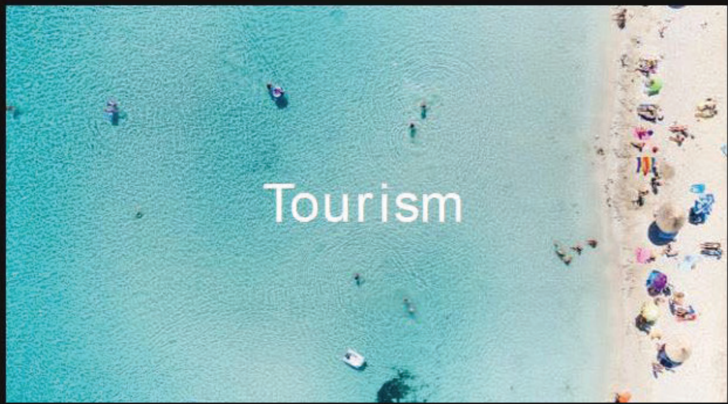
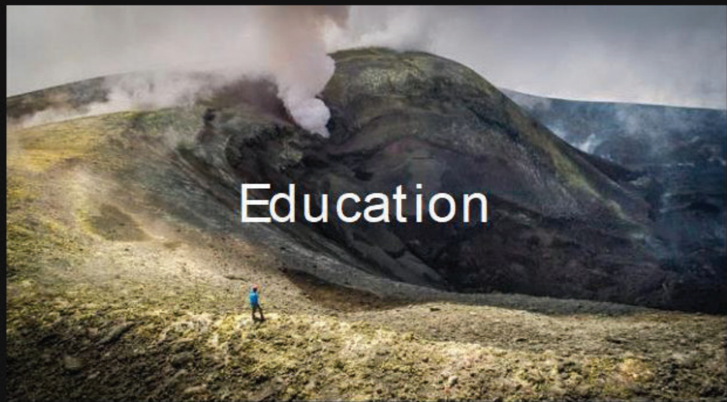
Attiva Spa is the main distributor of DJI Enterprise products in Italy thanks to the consolidated synergy between the excellent logistics structure and the vast ecosystem of System Integrators.

REVOLUTIONIZING INDUSTRIES








Sports


News
Broadcasting


Wildlife Monitoring


Archaeology


Industry facilities

Many more...

Enterprise solution - components

Platforms

Consumer

Enterprise

Payloads

In-house sensors

Third-party payloads

PAYLOAD SDK

Software

Developed by DJI

PILOT

Developed on DJI SDKs

MOBILE SDK

End-user

DJI Enterprise

Channel

Research & Development

Customs clearance

Engineering

Open source development partnership

Warranty

Branding

RF certification

Strategic partnerships

Trade shows

Quality certification

Online publications

Sales

Press interactions

Production

Resales

Business Development

Training

Repairs

Local certification

Key Industries Networking

Solution Engineering

Product partnership

Customs clearance

Stocks management

Account management

Customs clearance

System Integration

Enterprise verticals Mapping & Surveying

Solution 1: Connect the Phantom 4 RTK to the local NetRTK service with an NTRIP account.

Solution 2: Connect the Phantom 4 RTK with the DJI D-RTK 2 Mobile Station.

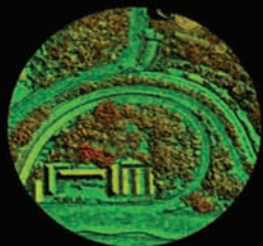
Solution 3: Connect the Phantom 4 RTK to a third-party RTK database with a NTRIP account via a 4G or Wi-Fi network.

Solution 4: Have the Phantom 4 RTK natively store all satellite observation data for image post-processing in PPK (Post-Process Kinematic) software, then compare data results with the offline data captured by the D-RTK 2 mobile station / third-party base station.

Ancient building

Tel Tower

City Planning

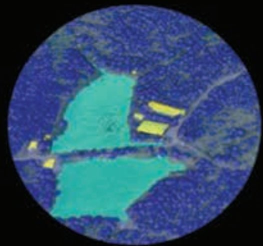


Surveying

Small scene modeling

Construction

Property management



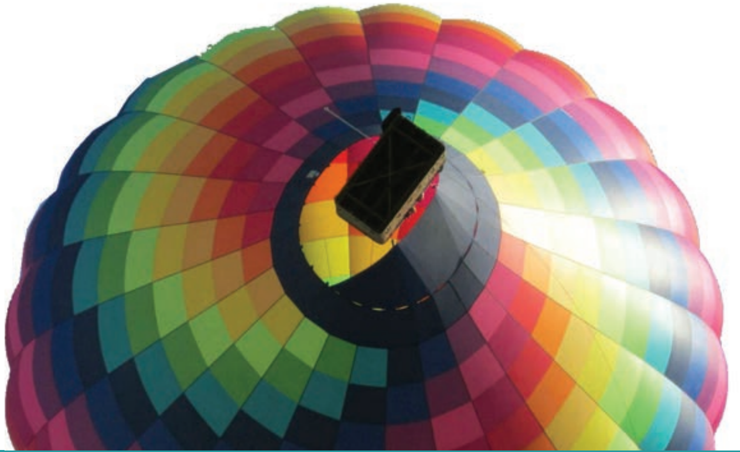
Digital agriculture

Milano droni s.r.l.
Milano mongolfiere s.r.l.

MILANO DRONI avails itself of the technical structure and know-how of MILANO MONGOLFIERE, a company certified by ENAC as an operator for the transport of passengers in hot air balloons and as a flight school authorized to provide instruction for this type of aircraft.

Since 2015 MILANO MONGOLFIERE has also made its expertise in education available to those who wish to become professional UAV operators. Therefore, it is certified by ENAC (CA.APR 023) as a training center for drone pilots. At our structure you will find a team of professionals able to guarantee a complete training course and to help the new operator in the drafting of the manuals necessary and required by current legislation on UAVs.

ENAC CERTIFICATIONS:
APR Training Center: CA.APR 023
Air Work Certificate: I-080.L.A
Air Operator Certificate: B151
Flight school no. R I / RF / 161 / N



UAV CRITICAL OPERATIONS PILOT CERTIFICATE COURSE (VLOS)

The course is addressed to the UAV pilot who wishes to obtain the critical operations qualification (CRO). This qualification is required for those who wish to fly closer to congested areas or groups of people.

Prerequisites:

Pilots with valid APR Pilot Certificate for Non-Critical Operations are admitted to the qualification course. Before the start of the practical part, the CA will submit the UAV pilot to an assessment of his skills to determine the number of missions required to obtain the certificate.

THE COURSE PRICE INCLUDES:

- Course registration
- Educational material
- 10 hours of Theory
- 4 hours of Practice with UAV
- Use of school drones
- Examination and certificate issuing costs

AEROPHOTOGRAMMETRY COURSE WITH UAVS

Surveyors, engineers, architects, builders.

Milano Droni S.R.L.
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Etruria volo s.r.l.

Etruria Volo S.r.l. is a company founded in 2015 and provides technological and professional services based on the use of Unmanned Aerial Vehicles. It was not born from nothing to exploit the "drone boom", but from a long and consolidated experience of the founders in the aeronautical world, ranging from teaching to design and construction, aeronautical research and development since the '80s, and in remote piloting since '91. As it is natural that, over time, collaborations with numerous and important private and public bodies have developed, including UNIFI, UNIFG, UNICH, CNR di Firenze, ANMIL, Versalis S.p.a., Eurallumina S.p.a., Raffinerie di Roma, Icaro S.r.l, Publiacqua S.p.a., ThyssenKrupp Italia, Timiopolis (BS), Polizia Municipale di Scandicci, Polizia Municipale di Prato, AREU Lombardia, etc. Our company is located in Castiglion Fiorentino, in the province of Arezzo, at the Aviosuperficie Serristori, former home of the VDS school and a particular love for flying, which in '94 realized the desire to modify its airplanes in order to be able, finally, to pilot people with motor disabilities in Italy, from which the association "Baroni rotti" was born. Etruria Volo is a company certified by ENAC for aeronautical education.For general aviation we have therefore set up an ATO (with identification IT.ATO.0084); based at the Aviosuperficie Serristori, where we use our 2 Cessna, a 180 (L-IUMM) and a 150 (I-CMAO). For remote pilot training, we have the UAV Training Centre (ENAC.CA.APR.030), also based at the Aviosuperficie Serristori and, in addition, secondary offices in Massarosa (Lucca), Montemelino (Perugia), Foggia and Tortolì (near Dorgali, Sardinia). In the Training Center we do training for both multiplane and fixed wing pilots, in basic, critical day and night operations, and we train Flight Instructors. We do both traditional training (for those who need to obtain flying qualifications), that training focused on operations, generating specific courses to be able to train in the pilot the knowledge and experience necessary to carry out specific types of operational missions, both for acquisition and inspection activities.

This type of teaching is possible through the classic courses of photogrammetry (RGB, IR and multispectral), and special courses in which we focus particularly on the specific activity that pilots will perform. Particular were the courses for AERU Lombardia, where we trained the Alpine and Speleological Rescue of Lombardy Region to operate efficiently with drones in the impervious alpine areas; or for Publiacqua S.p.a. (Florence). In addition to be instructors, we are also operators, and in order to be able to perform acquisition operations different from what is ordinary, it is spontaneous to use our decades of experience to create aircraft, sensors and procedures that adapt efficiently to the need of the activities that are required. Typical example is the use for years of IR sensors to carry out scans for structural verification, or to verify the geomorphology of the soil, or energy efficiency; or the combined use of typical and atypical sensors to verify the state of water, soil and air. Doing both Instructors and Operators and Builders, helps us to see what we do in a broad way and without losing sight of the objectives, imagining the "drones" as a convenient aerial stand that we can place where we need, it comes spontaneously to imagine and create an efficient "stand" that we can stop where we like, equipped with sensors suitable for the needs and duly modified, with the aim of acquiring multiple reliable data that can be used concretely. If one adds knowledge, love, passion and tenacity, the results are the natural consequence.

EtruriaVolo

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Microgeo s.r.l.

MicroGeo guarantees solutions and expertise in the fields of surveying, measurement and non-destructive testing PnD for almost twenty years, with the aim of improving and organizing technical and commercial skills in some important fields of precision "contact less" measurement.
MicroGeo is partner of the main global brands operating in the field of instrumentation for UAVs systems and LiDAR sensors. As a DJI Enterprise partner, MicroGeo guarantees an accurate and careful analysis of DJI drones and on-board sensors for professional use in the Photogrammetry and LiDAR sectors.
One of MicroGeo's solutions for the LiDAR UAVs survey is the combination of the new DJI 300 RTK Matrix with the LiDAR YellowScan Surveyor sensor.
The Matrice 300 RTK is the new industrial drone of DJI's house that gets its inspiration directly from modern aeronautical systems. With over 55 minutes of battery life, integration of advanced IA, six-directions sensing and positioning, and many other features, the M300 RTK sets a new standard for intelligence and reliability combined with performance never before available.
The Matrice 300 RTK has a payload capacity of 2.70 kg and up to 3 instrument loads simultaneously. The new H20 series of ZENUMUSE sensors also brings a completely different meaning to work efficiency. The unique intelligence and integrated design offer unprecedented aerial imaging capabilities for a wide range of applications in the UAV world.
Because of its considerable load capacity, MicroGeo believes that the 300 RTK Matrix is perfect as a drone LiDAR survey solution.
A survey solution, therefore, that makes the DJI Matrice 300 RTK the most competitive of the moment in the world of industrial drones.
Another equally valid solution is the combination of the DJI Matrice 600 Pro with the LiDAR MiniVux2 from Riegl.

Riegl company has always been distinguished by the use of the highest quality instruments in the field of terrestrial laser scanners and LiDAR sensors.
The MiniVux-2 is compact and lightweight (1.55 kg) with a measurement speed of 200,000 points per second, achieving up to 100 scans per second with a field of view of 360°. The sensor can include, in addition to the laser head, an IMU/GNSS System and up to two RGB cameras.
There are many fields of application among which are listed:

- Agricultural and forestry;
- Glacier and snowfield mapping;
- Archaeology and Cultural Heritage;
- Construction site monitoring;
- Landslide monitoring.

For photogrammetric and laser scanner data processing MicroGeo offers as 3DF Zephy Aerial software from the Italian software house 3D Flow.
With Zephyr it is possible to reconstruct 3D models starting from photographs. The reconstruction procedure is completely automatic and does not require any particular instrumentation. The software has multiple surveying tools, such as orthophotos, contour lines, georeferencing of the point cloud using GCP. The possibility, moreover, to integrate point clouds from Photogrammetry (terrestrial and drone) and point clouds from Laser Scanner allows Zephyr to be one of the most complete software in the field of Geomatics.

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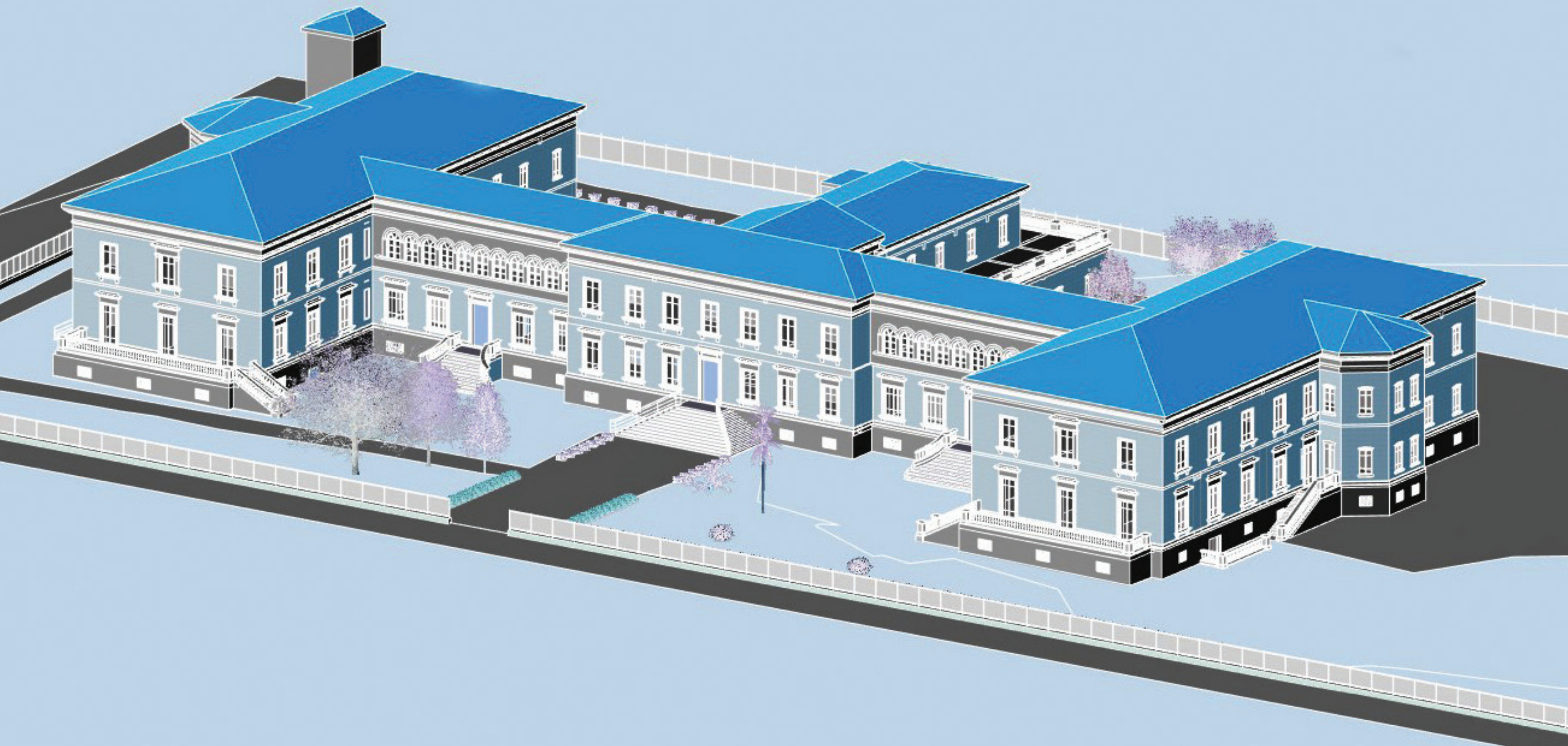
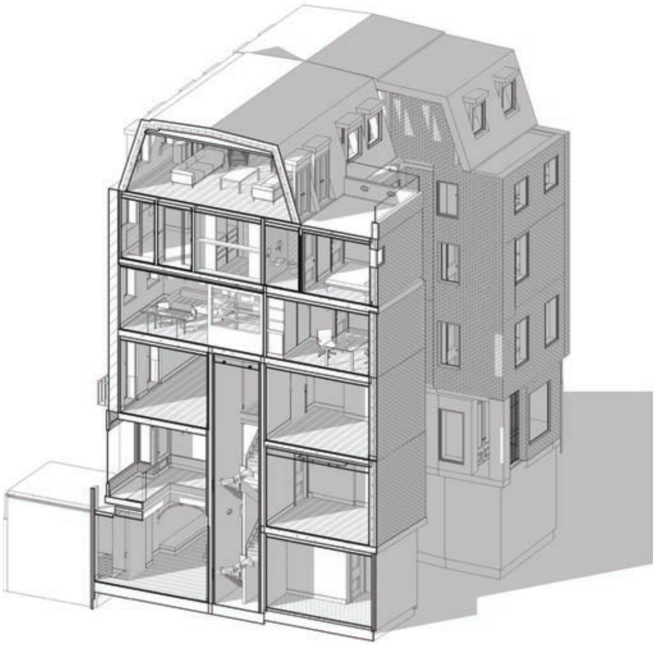
MODIT S.R.L.



Since 2016 Modit Studio operates in the field of engineering and architecture with a young team with a high degree of technological innovation, able to offer integrated design services up to turnkey realization. The studio, one of the first in Italy, makes use of the potential offered by BIM (Building Information Modeling) technology: through BIM tools it provides a high level of control over the project during all its phases, as well as complete interoperability between the figures involved and optimization of time and costs. With our consulting service we also develop new strategies for the company applying the principles of industrial production to the construction field.
We invest in new ideas, team training and the development of new technologies. Our Mission is to guide the client through a concrete project, designing innovative solutions thanks to a multidisciplinary team united by a working method based on BIM design.

OUR METHOD
Building Information Modelling allows us to optimize the planning, construction and management of buildings with the help of software.
All information relating to the building process is managed, collected and combined using an informative three-dimensional graphic model.
The facilitation of interoperability between the figures involved in the process is the key feature of BIM management. The updating of the fundamental information is instantaneous.
The containment of errors is consequently greater than traditional building design and management methods thanks to clash solving analyses and simulations of site procedures, so as to solve interference problems before the construction of the work.
In addition, the BIM extended to Facility Management allows the control of maintenance and management of the building accompanying the entire life cycle until its eventual discharge.
It also facilitates cost/benefit analysis with regard to extraordinary maintenance operations. An integral part of the innovation of Modit Studio is the Off-Site technology that allows the design and construction of modular solutions, complete with systems, both on project supplied by the customer and through custom designs.
The off-site construction, uses the potential of BIM technology and the logic of industrial production with a guarantee on quality and product, time and cost savings and a customer care service that facilitates the project management and maintenance of the building.



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engineering architecture & bim solutions

Modit S.R.L.
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