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28 April 2024

Salvatore Barba   Sandro Parrinello

Marco Limongiello   Anna Dell'Amico

editors

D-SITE

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

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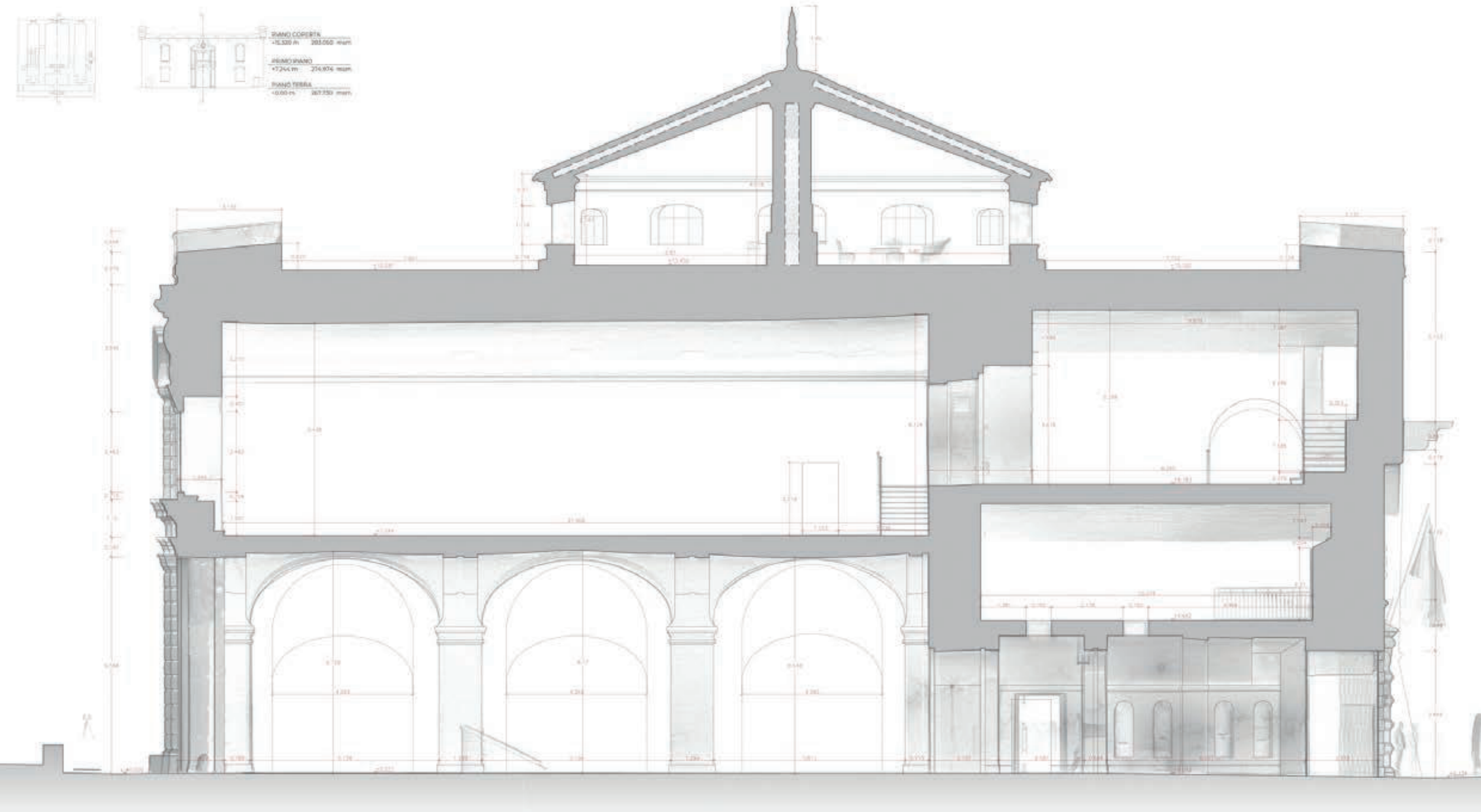

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ABSTRACT

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

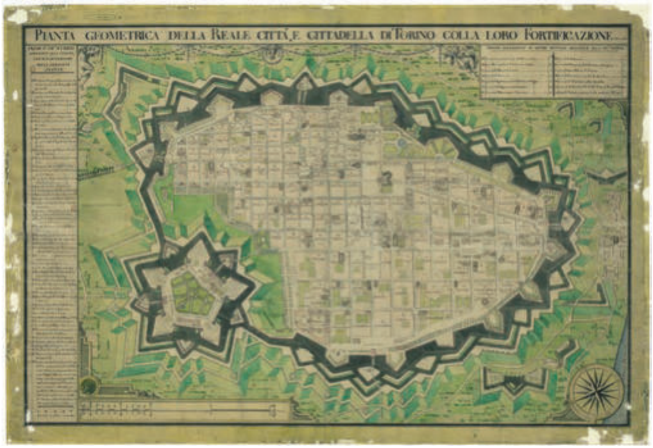


Figure 1. "Pianta geometrica della reale città, e cittadella di Torino colla loro fortificazione" (Galletti, 1790). Historical Archive of the Torino Municipality (Tipi e Disegni 64.2.13). http://www.museotorino.it.

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).

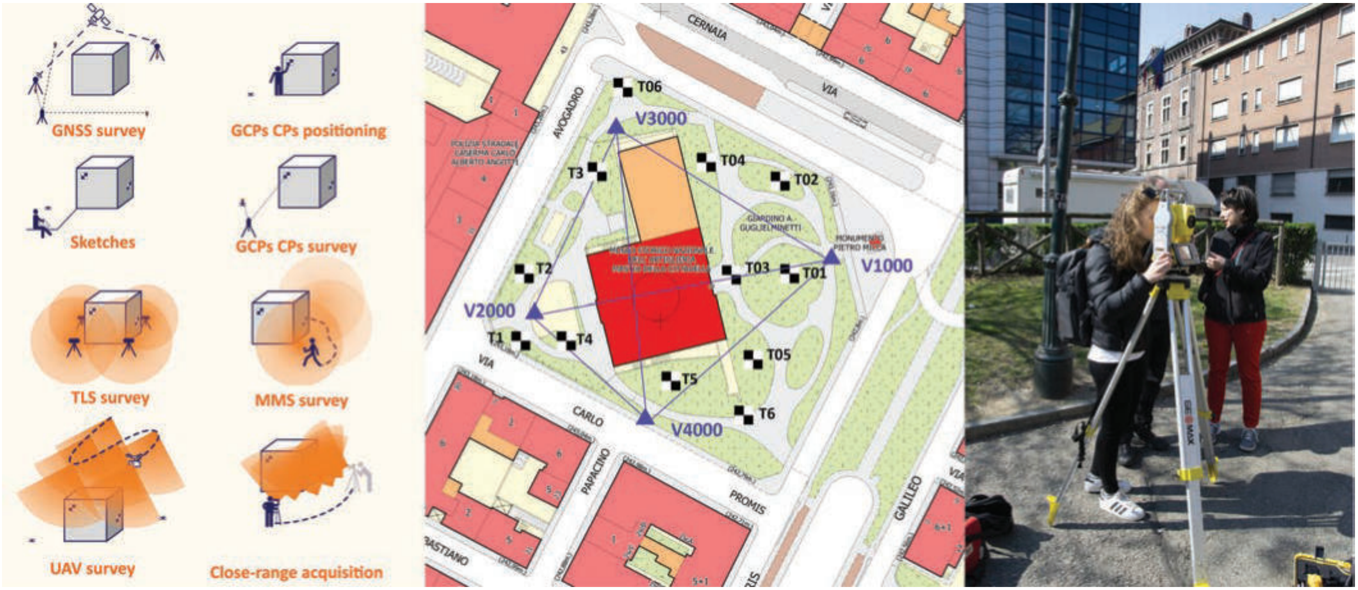


Figure 4. Workflow of the on the field survey (left), schema of the GNSS network and the position of the ground marker used for the photogrammetric UAV processing (center)). Topographic measurements total station (right).

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

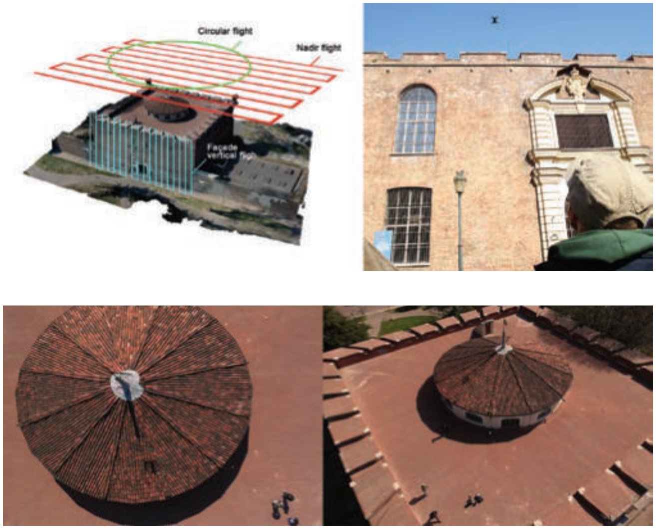
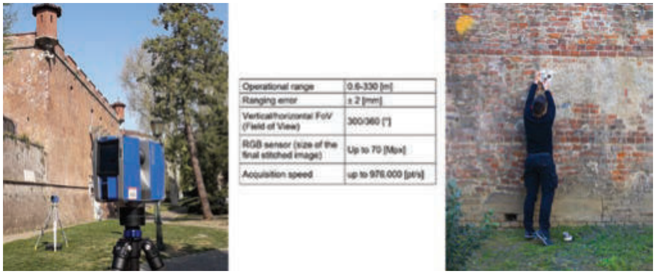


Figure 5. Employed acquisition schema: nadir in red, circular oblique in green and vertical in blue (above on the left), the drone during the manual fly (above right). Sample image of the nadir flight (below left) and oblique (below right).



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).

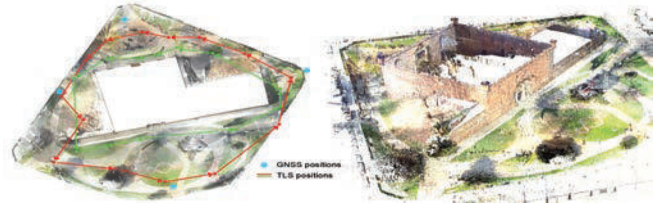


Figure 7. Main paths followed by the TLS acquisitions (left), a 3D view of the complete laser point cloud (right).

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.

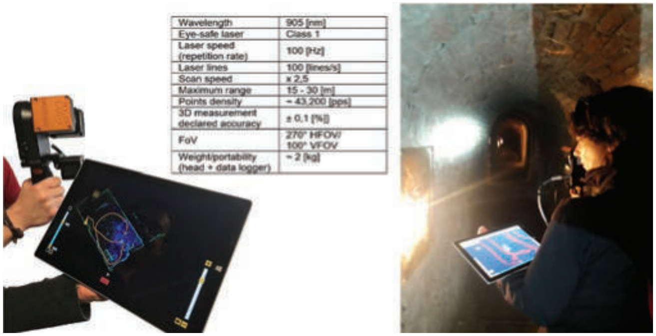
In the case of the Mastio due to the well-known limitation related to the actual UAV regulation a very light platform has been used and as a consequence for improving the quality of the terrestrial data, a complete laser scanner survey has been performed as well.

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).

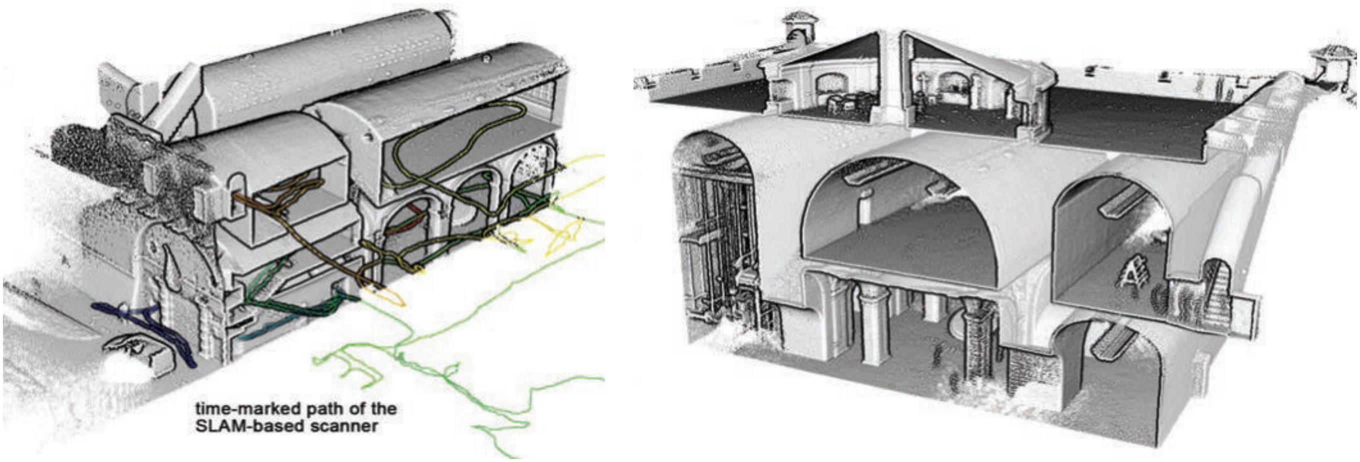


Figure 9. Visualization of the ZEB point clouds with (left, longitudinal section) and without (right, transverse section) trajectory.

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).

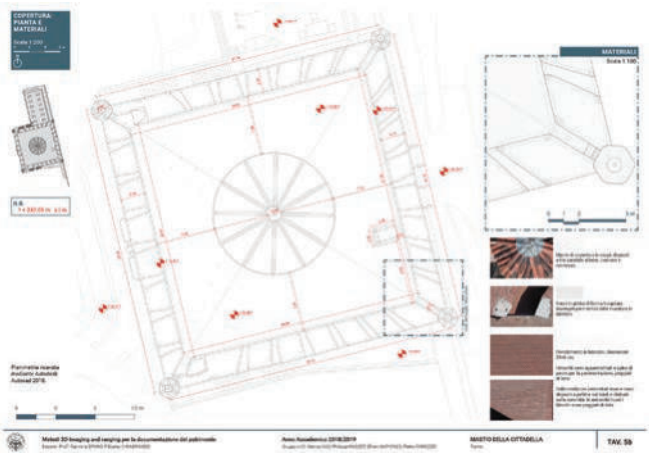


Figure 12. Plan of the Mastio with a study on the materials of the structure using UAV images (Group 1: M. Agù, P.Rosset, E. Sapienza, P. Tarozzo).

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).

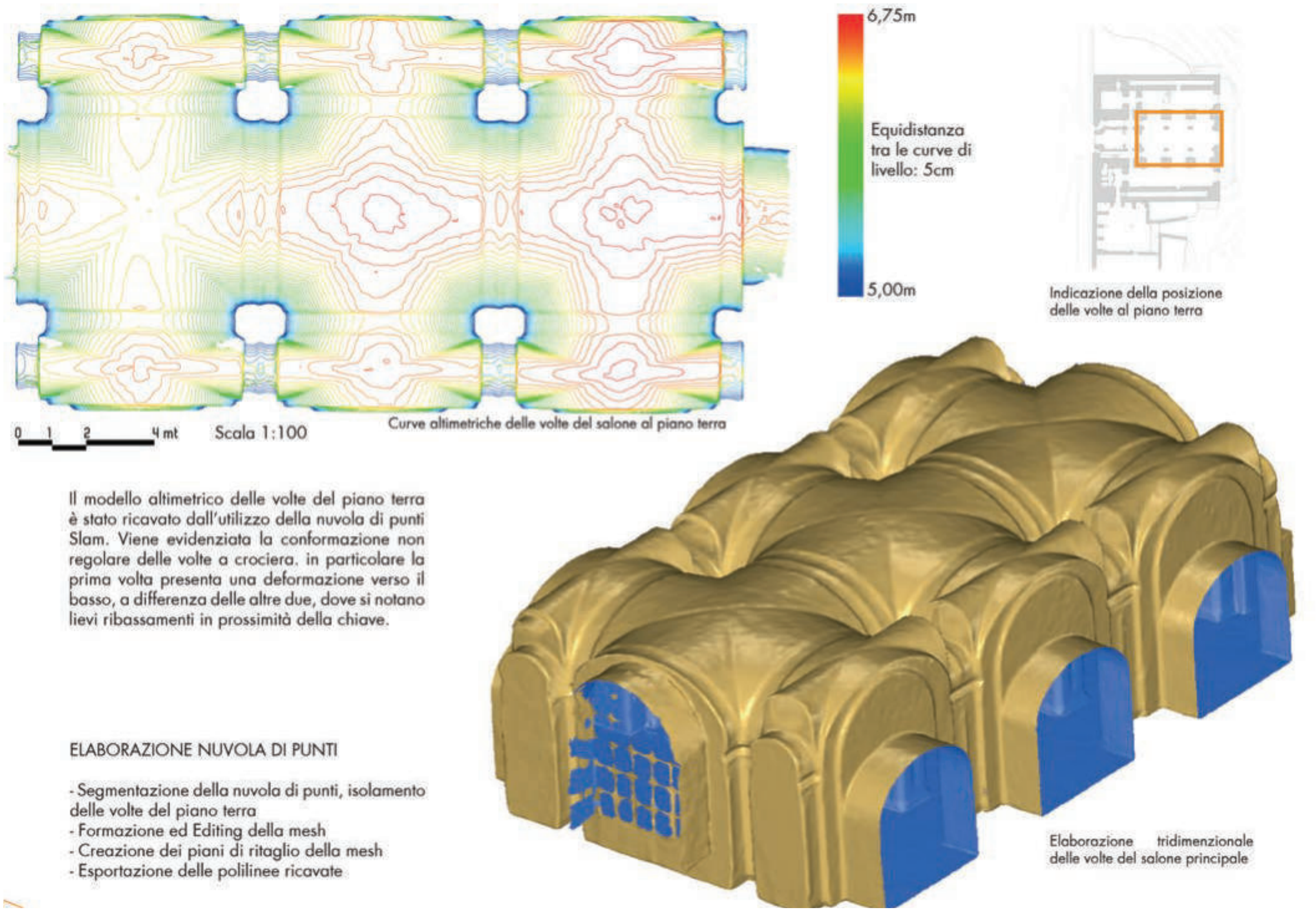


Figure 13. Main façade 2D drawing and achieved orthophoto from LiDAR data (above), photogrammetric orthophoto (centre), study on the deformation of the first floor vault (Group 2: A. Alaimo, A. Bertero, C. Bovet).

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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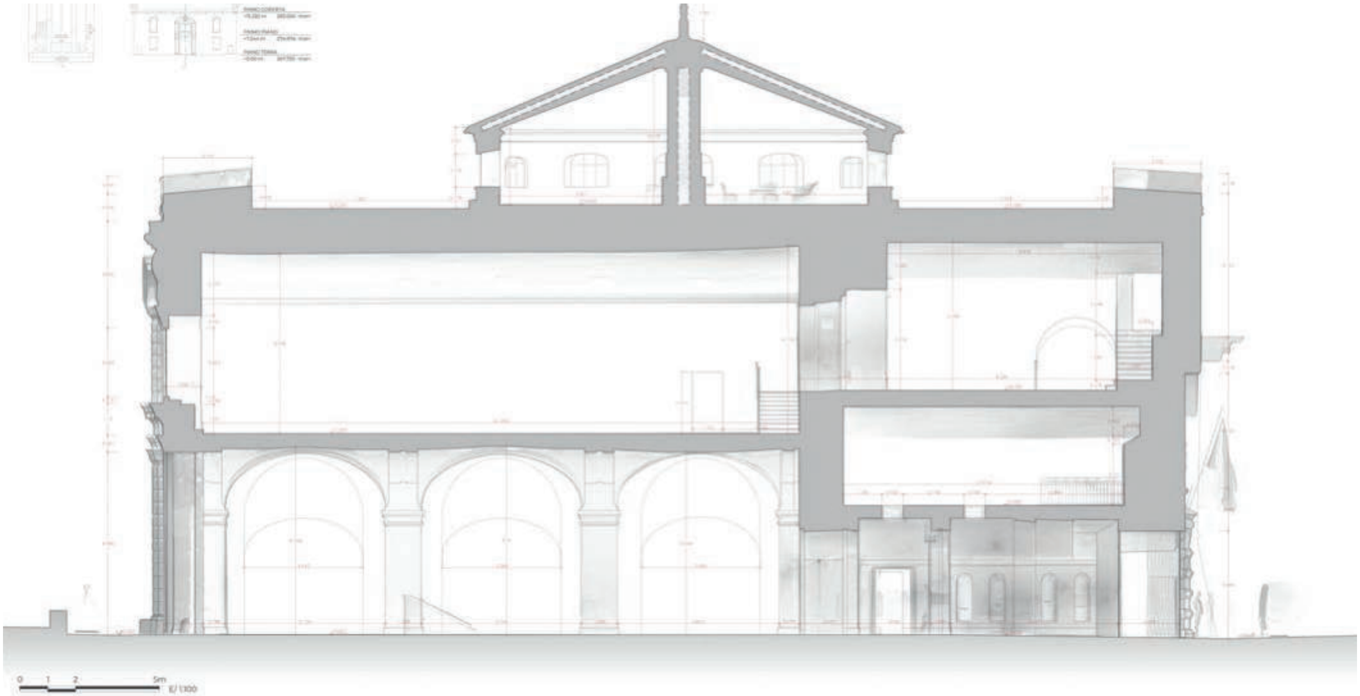

Figure 14. Longitudinal section (Group 5: P. Compte, M. Giancarli, L. Pérez De Ciriza A. Mudarra).

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