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UAV OBLIQUE DATA AND LASER SCANNING IN AN EXCAVATED AREA

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Abstract:

This paper discusses some enhancements concerning 3D modelling and integration of 3D data from aerial and terrestrial sensors, developed by geomatics in the field of Cultural Heritage metric documentation. For archaeological purposes, it is interesting to deal with the considerable advantages in term of sustainability (automated acquisition, quickness, precision, time and cost cutting) of new multi-sensors approaches for the data acquisition and the management phases. In particular, the UAV (Unmanned Aerial Vehicles) Photogrammetry with the joint use of nadiral and oblique cameras, can be valuably combined with the large-scale details reach by terrestrial LiDAR in vast areas or complex objects, especially in mostly vertical sized objects. Here it will be reported an experience of integrated 3D survey in an archaeological context in Piedmont region (Italy), the Hercules Fountain in the gardens of the Venaria Reale. It has witnessed several historical phases during centuries, from its construction in 16th to the disuse and dismantling in 17th, up to the 21th century in which it was lastly brought back to light. The goal of the test is the generation of a 3D continuous model of the site for documentation purposes, future consolidation and enhancement projects finalized to a public promotion. To meet these aims a terrestrial laser scanning (TLS) survey has been designed combining terrestrial and UAV photogrammetric data acquisition, to produce a high detailed 3D textured model from which infer standard 2D drawings, digital orthoimages and further 3D releases. The entire workflow and outputs were compared together to evaluate the effectiveness of each elaboration according to the survey goals.

Key words: 3D documentation, Building Archaeology, Lidar, UAVs Photogrammetry, Oblique Cameras, Savoy Architecture

1. 3D data documentation role in archaeology: integration of ground-based data and UAV nadiral and oblique cameras

New strategies with 3D multi-sensor metric survey prove that the documentation process can reach good levels of sustainability, in the direction of quality of information and in terms of time and cost. The georeferencing of spatial data is essential for interoperability during times, as a continuous part of the whole process of monitoring and Heritage preservation envolving sector-specific experts. Furthermore, the attempts of effective applications in archaeological contexts, must keep into account the importance of their spatial and temporal complexity and the choice of targeted surveys and sensors in terms of scale detail requested and of resources involved. A good numbers of research in Geomatics scenario towards these themes are approaching to improve and adapt themselves to the different sites needs (Remondino *et al.* 2011; *Lerma et al.* 2011; Balletti *et al.* 2015). In specific, for documentation purposes in the field of Building Archaeology, the high scale dense data generally reached by the combined use of TLS (active sensor) and close range photogrammetry (passive sensor) lead to a complete model rich in metric and non-metric information together with the completeness provided aerial documentation by UAV. In fact, these models allow studying not only the geometry of the surveyed object, via standars 2D and 3D representation (Boehler and Marbs 2004), but also for material analysis, pathologies and degradations, structural assessments, conservation monitoring (Patias 2013), virtual restoration and digital communication e.g. Augmented\Virtual Reality, 3D GIS and HBIM tools to manage 3D reality-based information (Landeschi *et al.* 2016). Concurrently, UAV platforms are becoming in the last years one of the most employed system for aerial mapping and 3D modeling issues. For archaeological sites, either multi-rotor or fixed wing UAVs, offer low-cost alternatives to the classical manned aerial photogrammetry, performing data acquisition with high-resolution digital camera in semi-automatic and autonomous ways. Point clouds, DSM/DTM, orthophoto, textured 3D models, 2D drawing data, etc. can be quickly produced with controlled accuracy. Usually the acquisition for architectural and archaelogical documentation are performed using the camera oriented in the nadir direction, but a big attention is now focused also on the use of oblique images (Rupnik *et al.* 2014; Xiao *et al.* 2012) and the research activities in the geomatic field are even more oriented in optimization of these algorithms.

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2. The Hercules Fountain experience

The integration of 3D metric survey techniques is presented here in a complex test site: the Hercules Fountain in Venaria Reale (Fig. 1), a UNESCO Heritage site, belonging to the residences of Savoy Royal House, located 15 km northwest of Turin (Piedmont, Italy). Nowadays the ruins of the ancient masonries uncovered 11 years ago, are involved in a second step of restoration project that needed a detailed and complete 3D metric documentation, as base for restoration, promotion and valorization projects by the Venaria Reale Royal Palace Management Consortium (client of the documentation).

Figure 1: A view of the *Reggia di Venaria Reale*

Amedeo di Castellamonte (the royal architect of the Savoy family) projected the Reggia di Venaria in the second half of the XVII century, to be a hunting residence for the Royal Family, and the Fontana d'Ercole, richly decorated and covered with mosaics of shells and stones, located in the lower gardens between 1669 and 1672 (Cornaglia 1994). The Hercules fountain was subjected to a series of restorations and was finally dismantled in the 1751. The works for the restoration started only in the 1999 and, after years of efforts, the original magnificence of Reggia di Venaria was returned to the public; today, with 573.337 visitors in the last year, is one of the most visited historical sites in Italy. In the summer of 2005, the Fontana d'Ercole was brought to light during some work of excavation in the gardens, was restored and is now part of the tours of the Reggia (Cornaglia 1994). The structure of the masonries in the Hercules Fountain is quite complex and irregular; the Northern part of the structure, recently excavated, is exposed at the ground level and constrained by many trees, while the Southern area is still underground. Furthermore, the Eastern and the Western parts of the fountain differ in the terrain elevation and in the upstanding structures height. Finally, all masonries present a deep status of alteration and generally a bad conservation, since the architectural coating is almost totally lost.

In the site, an integrated multisensor 3D survey was conducted: the UAV photogrammetric acquisitions integrate the terrestrial one, via close-range photogrammetry and LiDAR survey. A complete oblique acquisition by UAV was performed with the aim to understand the real potentiality of the oblique cameras for large-scale documentation purpose. The collection of data have been carried out in several steps. The measurement of the topographic network by using static GPS/GNSS of 7 vertices. A group of Ground Control Points (GCPs) were placed on the masonries using paper targets, and then measured with a Total Station, for the photogrammetric process and scans registration. The LiDAR scans performed by Focus3D Cam2 by Faro were planned to cover all the area n°82 acquisitions at 360°; n°79 registered scans; 20*105 points/scans; Resolution MPti 1pt/6mm at 10m). The terrestrial photogrammetric recording, using a Nikon D800E reflex digital camera (457images, 24mm lens, 36 Mpx CMOS sensor, image size 7360 x 4912 pixel, pixel 4.89 μm) using an overlapping >80%, complete the terrestrial documentation. The fieldwork was finally completed by three photogrammetric flights on the area, based on nadiral and oblique acquisitions to produce a detailed DSM of the fountain with a high-scale detail especially in the vertical dimension. They were perfrmed using a Hexakopter by Mikrokopter (Fig. 2) with a ground sample distance of 0.51cm. In the employed configuration the multi-rotor platform is equipped with a commercial off-the-shelf (COTS) Sony Alpha 5100 digital camera (24.3 MPx CMOS sensor, 6000*4000 max resolution, pixel 3.92 μm, equipped with a 20mm lens).

Figure 2: The multi-rotor system and the ground control station

Thanks to the Lidar precision in the very high scale, after the point clouds registrations, many orthoimages have been extracted (Using Pointcab software). Starting from this data, an accurate interpretation and drawing using CAD software (Figs. 3 y 4) have been performed. Furthermore, the terrestrial images collected on the field were processed as well, by photogrammetric approach based on Structure from motion (SfM) using Agisoft PhotoScan software. The results from the photogrammetric process on an area of 154sqm are: (GSD) 1.23 mm/px. (RMS) on 14 GCPs: 14mm. Final point cloud, 100millions of points, contains around 9608.06pt/m2. Final digital surface: 1.6 million of triangles. Finally, the workflow has included the processing of the aerial acquisitions: camera orientation, images georefereincing using GCPs, point cloud densification, mesh calculation and texturization, with the software Pix4D for the generation of the final DSM and orthoimage (Fig. 3 y 5). The results from the photogrammetric process on an area of 10.700sqm are: (GSD) 0.51cm. (RMS) on 29 GCPs: 0.4 cm. (RMS) on 12 CPs: 0.5 cm. Final point cloud, 71 ml of points. Final mesh, 10 ml of triangles.

Figure 3: (left) The orthoimage from the UAV acquisition and (right) detail of top view of the vectorialized laser point cloud

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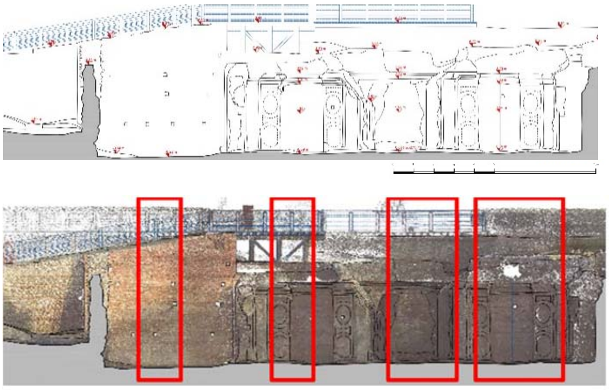

Figure 4: The digitalization of section G-G' from LiDAR data and the 4 samples for analysis: (a) masonry wall; (b) pilaster with niches, mixed stones-bricks walls; (c) central apse part, mixed stones-bricks walls; (d) lateral apse and walls ridges.

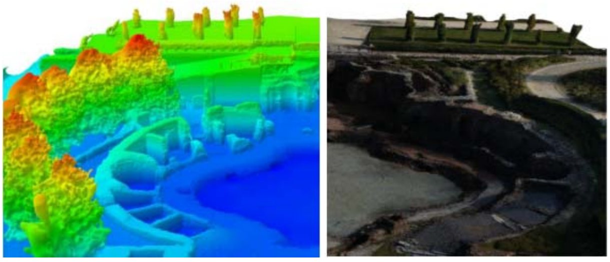

Figure 5: Images of the DSM in colors range by elevation (left) and the RGB textured one (right).

Since the aims of the 3D survey were the definition of the whole volume and the determination of the main geometries of the fountain, a comparison between different results and employed techniques is needed. Firstly, for the production of the plan it was necessary to integrate the terrestrial LiDAR data and the orthoimages from the aerial ones. The laser point cloud defined in a hight detailed way all the masonries features in order to cover different levels of the entire fountain area, both in the caves and in the bassin. The coverage of the TLS was generally very good and wide but lacked in details in the higher portions of the masonries. Otherwise, the data from UAV, despite the intrinsic different scale, allowed filling deficiencies of the terrestrial point cloud and generating a complete 3D model of the site. In Table1 some comparison data on one (Fig. 6) of the samples tested for a global evaluation on the 3 different sensors.

3. Conclusions

In case these complex objects or sites, the integration of multisensors data can be pinpointed, according to acheived results, as the best solution for a multiscale 3D documentation. Infact, the level of detail offered by the three approaches applied on the case study, if distinctly evaluated, are indeed different, and then their scale is diverse in terms of quality of image, richness of information, time and resources consumption (human, software, hardware). Thus, their selection depends mostly by the characteristics of the sites and the available time for the fieldwork. Neverthless the use of TLS has to be combined anyway with cameras acquisition for high quality texturing of the model. Then time processing and human involvement in close-range acquisitions can be defined as very competitive factors thanks to the more and more automated algorithms of digital photogrammetry now available. It is importan to underline that all these technology improvements in digital photogrammetry softwares are largely affected by computer hardware configuration. The geometrical definition provided from the UAV photogrammetry process is radically different in terms of scale, but this technique complete necessarily the terrestrial survey and reach a good definition of DSM, thanks to the combinated nadiral and oblique cameras, now increasingly use in research applications.

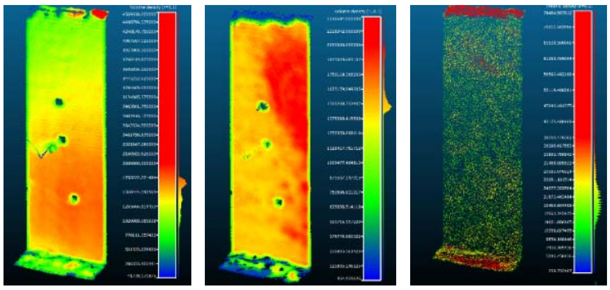

Figure 6: Example of Density analysis on Sample (a): point clouds (left) from LiDAR, n°pt 2.617.678, Density 186.995 pt/m2; (centre) close-range phot., n°pt 2.734.377, Density 205.860 pt/m2; (right) UAV n°pt 44.823, Density 3.489 pt/m2.

Table 1: Results from comparison between points clouds. Close-range and UAV photogrammetry were matched to LiDAR by "cloud/cloud distance" tool in Cloud Compare software.

Absolute distances (m)		*Lidar - close-r*	*Lidar - UAV*
Sample (a)	mean	0.012	0.016
	st. dev.	0.007	0.013
Sample (b)	mean	0.009	0.017
	st. dev.	0.011	0.021
Sample (c)	mean	0.004	0.021
	st. dev.	0.003	0.030
Sample (b)	mean	--	0.014
	st. dev.	--	0.015

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