INTEGRATING GEOGRAPHICAL DATA WITH SURVEYS CONDUCTED WITH UAVS FOR PLANNING AREAS OF HIGH ENVIRONMENTAL VALUE

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KEY WORDS: Free geodata; UAV surveys; Photogrammetric analyses; Geo-referenced database; Natural habitats; Floristic-vegetational planning

ABSTRACT:

The setting up of a general framework for the environmental and landscape planning of a protected area requires a basic detailed survey of this area and its vegetation, accompanied by a constant monitoring of the latter, so that a specific maintenance plan can be implemented accordingly. With reference to an area of high environmental, landscape and archaeological value, such as the '*Pulo di Molfetta'* (Municipality of Molfetta – Southern Italy), some georeferenced floristic surveys have been carried out, with relative mapping and monitoring of vegetation growth. In this way, it has been possible to draw up some specific management measures for the vegetation, as well as to plan suitable interventions of ecological engineering, aimed at determining the most appropriate conditions for the recovery, use and sustainable management of this area, even for tourism purposes. These activities have been conducted through the construction of a basic model implemented in a Geographical Information System (GIS), structured on the basis of some Free and Open-Source geographic data, integrated with a geo-localized 3D survey of the geomorphology, architectural structures and the flora-vegetation habitat. The metric analyses have been conducted with commercial instruments, such as UAVs systems, GNSS and photogrammetric processing software. The obtained results have allowed the inclusion of the geo-localized 3D model in a GIS base for the knowledge of the flora-vegetation habitat, thanks to which it would be possible to provide support for the decision-making from local politicians and landscape planners.

1. INTRODUCTION

Planning technical interventions in areas of high landscape and environmental importance requires the convergence of multiple skills, which must be mutually integrated, in order to identify the most appropriate option for their management. Particularly when these areas, as it increasingly happens, find significant opportunities for tourist valorization (Statuto & Picuno, 2017), this planning activity is extremely important and requires an appropriate technical approach, which must be based on surveys - geomatic, geological, floristic, physiognomic-structural, *etc.* - of the whole area (Picuno P., 2022; Statuto et al., 2013).
The management of smart cities or particular zones, need to start from an accurate geometric survey, generating highly detailed 3D models (Adami et al., 2023). The topic of the photogrammetric survey of urban or natural areas is of great interest, both for the selected most suitable technical solutions and for the purposes and uses of the generated point cloud. The size of the surveyed area and the goals of the survey, drive the choice of the most appropriate technical tools for the survey, like the type of drone, the camera and its resolution, the quality and mode of image acquisition, the photogrammetric processing parameters, and the georeferencing approach. Although several advanced technologies have been used by surveyors and engineers for generating the structural 3D models, Unmanned Aerial Vehicle (UAV)-based photogrammetry and Terrestrial Laser Scanning (TLS) are among the most common methods used in this regard (Mohammadi et al., 2021). The resulting Unmanned Aerial System (UAS) photogrammetry point cloud can have a higher or lower density of points, according to the flight altitude and the resolution of the camera used. The recent developments in automated image processing for 3D reconstruction purposes have led to the diffusion of low-cost and open-source solutions, which can be used by everyone to produce 3D models. The level of automation is so high that many solutions are black-boxes, with poor repeatability and low reliability (Remondino et al., 2012).

In the present paper, the realization of a geolocalized3D model is described. This tool has been realized, in order to address and initiate its insertion into a Geographical Information System (GIS) base, constructed for checking the formal consistency of the cartographic and photogrammetric layers and for knowledge, and preliminary decision aid, of the floristic-vegetational habitat in an area of particular environmental, landscape and archaeological importance, the "*Pulo di Molfetta*". In this area, located in the Municipality of Molfetta (Apulia Region – Southern Italy - 41°12′N 16°36′E), the GIS that has been implemented, has been aimed to constantly enable, plan and schedule the best decisions for the management of this particular site. The construction of a georeferenced, explorable, editable and queryable database was carried out in a GIS O.S. (Open Source, QGIS) software, to facilitate rapid data interchange, into a widely used development environment.

2. MAIN BODY

2.1 Instrument selection: survey methodology

The photogrammetric analysis was carried out with low-altitude aerial photography taken by UAV with Max Take Off Weight (MTOW) < 5 Kg. The EASA (European Aviation Safety Agency) requires to fly over an area free of people overhead and, in our case, it was necessary to solve the problems regarding both the visibility, covered by tall vegetation, and the side walls of the cliffs, rich in karst phenomena of both archaeological and geological interest. The digital photo sensor used has a mechanical shutter to eliminate, during the flight path, deformation caused by electronic shutters ("rolling shutter", present on most of the cheaper sensors). The georeferenced network, preliminary to the execution of flights, was materialized on the ground, to distribute vertices on the entire area affected by the 3D model. Both photographic points (such as edges of artifacts, horizontal markings on asphalt, *etc.*) and high-contrast

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targets, of appropriate size for both flight altitude and pixel size on the ground (GSD - Ground Sampling Distance), were used.

2.2 Case study description

The "*Pulo di Molfetta*" is a doline extending over an area of about 3 Ha and about 35 m deep, characterized by peculiar archaeological and naturalistic features (Figure 1). This type of surface karst formations originated as a result of the collapse of the vault of underground cavities, excavated by the erosive and corrosive action of water infiltrating the limestone substrata.

Figure 1. Localization of the City of Molfetta (Apulia Region – Italy) and the "Pulo di Molfetta" area (encapsulated photo).

In the flat bottom of this doline there are vestiges of an old saltpeter factory, used in the 19th century by the Bourbons for the production of gunpowder.
This area has an extraordinary natural, archaeological and anthropological value. From a naturalistic point of view, it constitutes a treasure trove of biological diversity, due to the millennial interaction between man and a unique natural environment in terms of both microclimate and vegetation.
A geo-localized 3D survey of the geomorphology, architectural structures and floro-vegetational habitat has been performed. The surveying, georeferencing and formation of a 3D model, has referred to a planimetric extension of approximately 30,000 m^2 with an altimetric difference in height of 30-34 m.
Moreover, also mapping and monitoring of vegetation and georeferenced floristic surveys have been performed, with the aim to implement an ordinary and extraordinary maintenance plan, enabling the calculation of forest biomass as well.
The implemented methodology has also enabled a context analysis and planning of some integrated interventions, based on the investigation of the naturalistic/environmental conditions (biodiversity, ecosystems, *etc.*) of the site, also supported by the implementation of a GIS. These interventions would also include the forecast of appropriate naturalistic/ecological engineering works (Cillis et al., 2021/a), like the construction of retaining/consolidation structures (*e.g.*: dry-stone retaining walls; gabion walls; cliffs; *etc.*), and/or rockfall protection works, as well as works with a fencing/perimeter function, *e.g.*: dry-stone walls; wooden fences; *etc.* Indeed, this kind of works, may contribute to a mitigation of wetland loss, thanks to the designing and executing specific targeted technical interventions, *i.e.*, building or restoring existing constructions, able to create local micro-environment favourable for some amphibian and reptile species, restoring existing wetlands or constructing new artificial ones, *etc.* Several studies have anyway demonstrated the difficulty of replicating natural habitats when attempting to create the suitable environment for these species (Picuno P., 2017).

2.3 Data acquisition and implementation of a GIS

For the image acquisition phases related to the photogrammetric survey, two surveys were carried out, during which the areas covered by the aerial coverage were chosen.
The geo-localized 3D model has been included in a GIS for knowledge and decision support of the flora-vegetation habitat. Indeed, a GIS-based approach may enable – mostly when including both historical cartographies and remotely-sensed data, freely available online (Cillis et al., 2021/b) - the evaluation of spatial and statistical variations of the forest landscape, assessing how much, where and how the forest landscape has changed, in order to provide a methodology to support more detailed and targeted studies. Given the characteristics of the geodata and the fact that the tools are fully open-source, the techniques can be replicated and even partly improved in relation to specific needs. This GIS, would therefore also include future trans-disciplinary contributions from experts in other disciplines, *e.g.*: geologists; hydrogeologists; speleologists; geo-technicians; archaeologists; *etc.*
The survey, georeferencing and 3D model formation operations have been conducted by means of:
1) photogrammetric aerial images at low and ultra-low relative flight height, according to the orography, to obtain a 3D digital modelling with a ground resolution of at least 2 cm/pixel;
2) image coverages with nadiral and sub-horizontal shooting axes orientation for optimize the analysis of both the geomorphology and the existing vegetation;
3) creation of a framing and support network, materialized with high-contrast photographic targets, measured with RTK (Real Time Kinematics) methodologies of GNSS (Global Navigation Satellite System) satellite positioning and accuracy $\leq$ 3 cm, georeferenced in the RDN2008 Reference Coordinate System - as per the Italian regulations;
4) construction of a 3D digital model, obtained with digital photogrammetric restitution, formed by point clouds and then triangular mesh and photographic texture;
5) formation of a very-high resolution ortho-photomosaic, with GSD (Ground Sampling Distance) $\leq$ 15 mm, and of an adequate number of radial sections, with two views, each one orthogonal to the section plane;
6) georeferenced identification of the individual floristic-vegetational elements and help for the construction of a database containing the agreed attributes defined and aimed at planning the vegetation layers present;
7) provision of digital bases, of the indicated products, in the most popular formats and of hardcopy prints, having a layout as for the Municipality needs.
Following the selection and materialization of the points, a topographic campaign of absolute coordinate acquisition was carried out with a GNSS employed in RTK technology.
The differential correction of coordinates (included in RTK technology) was carried out inside the Network of Permanent GNSS stations managed by the Apulia Region. The acquisition of the points, reprojected in the Absolute Coordinate System RDN2008 UTM - Fuse 33 N, was possible for all the targets on the boundary of the imaged area, but not for others identified on the bottom of the sinkhole. In fact, in such areas there is unfortunately both poor reception of the signal from the Satellites (GPS and GLONASS series), as well as the correction signals transmitted through telephone operators (shadow of the cell phone signal). However, even with this limitation, the distribution of points was optimal and allowed for all acquisitions to contain the plano-altimetric tolerance within ± 2 cm, thus largely within the design limits and for the purposes of the survey.

2.4 Photogrammetric process

The photogrammetric restitution stages were performed in the Metashape environment (Agisoft ver.2.0.1 and later) with modern SfM techniques, in which the simultaneous orientation of the frames, along with the associated self-calibration, are performed *en-bloc* with Bundle Block Aero-triangulation (aero-triangulation by projective stars) methodologies (Pepe et al., 2019).
The results were very good and exceeded the design target data at the end of compensation (Figure 2). The final plano-altimetric deviations of the GSDs used were less than ±7 mm as shown in the following table.

Markers	Easting (m)	Northing (m)	Altitude (m)	Accuracy (m)	Error (m)	Projection	Error (pix)
TGT_010	632172.850000	4561473.874000	41.589000	0.010000	0.001844	55	0.046
TGT_009	632144.207000	4561468.478000	41.754000	0.010000	0.002732	43	0.029
TGT_008	632110.807000	4561471.548000	41.771000	0.010000	0.006195	50	0.035
TGT_007	632079.225000	4561509.871000	38.201000	0.010000	0.010118	43	0.094
TGT_006	632230.618000	4561629.442000	35.236000	0.010000	0.006226	48	0.070
TGT_005	632230.770000	4561593.900000	35.645000	0.010000	0.008857	46	0.055
FOT_008	632075.877000	4561532.368000	37.238000	0.010000	0.025402	41	0.747
FOT_007	632073.734000	4561537.127000	37.305000	0.010000	0.026002	67	0.571
FOT_004	632204.613000	4561649.391000	35.860000	0.010000	0.007669	43	0.091
FOT_003	632154.438000	4561650.078000	36.357000	0.010000	0.002280	41	0.138
FOT_002	632085.957000	4561622.779000	38.966000	0.010000	0.006649	44	0.048
FOT_001	632068.015000	4561595.145000	37.763000	0.010000	0.009806	20	0.053
Total Error							
Control points					0.006879		0.072

Figure 2. Final plano-altimetric deviations of the GSDs used were less than ±7 mm.

Subsequent to the refinement of the guidelines, the same development environment was used to produce:
1) a dense point cloud (about 50,000,000 points) that represents a product of wide interoperability for subsequent processing also in the O.S. (Open Source) environment (Figure 3);

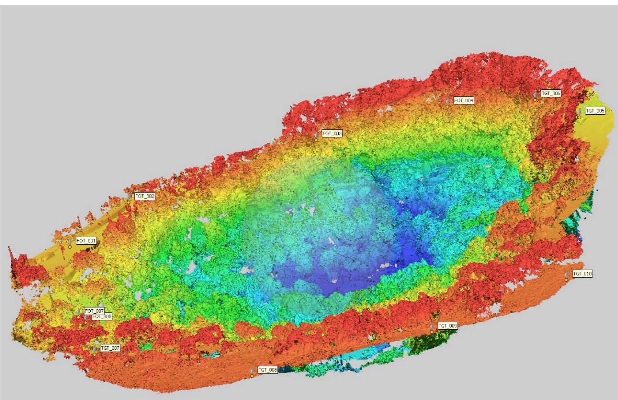

Figure 3. Representation of a dense point cloud

2) a triangular mesh formed by about 4,200,000 triangles for materializing the elementary surfaces constituting the 3D model;
3) a photo texture obtained by projecting image pixels onto the faces of triangles produced in the mesh (Figure 4);
4) an ortho-photo-plane obtained by digital projection, on a reference plane of elementary portions of the orthorectified images, with a resolution equal to 1x1 cm GSD, georeferenced in consistent way with all previous orientations, in the Reference System RDN2008. In this way, the product – *i.e.*, a georeferenced image at very high resolution - can be easily used as a base map in a GIS, where there are numerous other map layers in the respective Reference System (Figure 5 and 6).
5) the realization of 4 sections, in the vertical plane, obtained on radial orientations most significant for reading the sinkhole.

Figure 4. Image of the obtained photo texture.

Figure 5. Orthophoto (GSD = 1 cm) produced as an overlay to Apulia orthophoto (GSD (50x50 cm) year 2006.

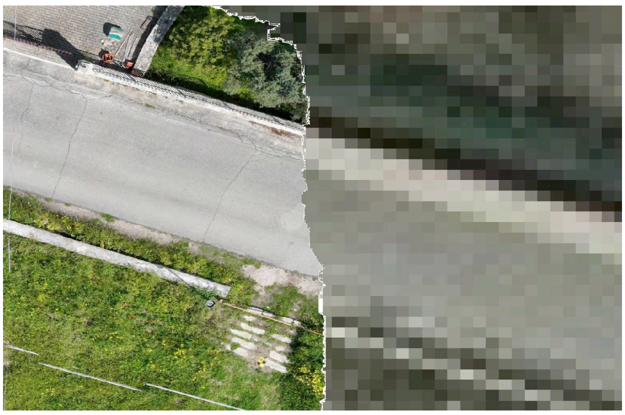

Figure 6. Overlay of Orthophoto (GSD = 1 cm) produced on the Apulia orthophoto (GSD (50x50 cm) year 2006 - detail.

2.5 Results and Discussions

In order to address and initiate the insertion of the geolocated 3D model, an initial GIS base was constructed for checking the formal consistency of the cartographic and photogrammetric layers and for knowledge, and preliminary decision aid, of the floristic-vegetational habitat. The construction of a georeferenced, explorable, editable database, that can be queried by its user, was carried out in a O.S. (Open Source, QGIS) GIS, to facilitate rapid data interchange, within a widely used development environment.
The first frame acquisition campaign consisted of a (high) cross-swipe flight and nadiral axes (for photographic shadow

optimization) consisting of about 1050 images. In addition, a series of flights were performed at lower absolute altitudes, aimed at very-high resolution coverage of the lower area and some stripes with pseudo-horizontal camera axes, for multiple coverage of cliff faces. The total number of frames was thus 1050 (nadiral) and about 400 with variously tilted axes, for a grand total of 1447 calibrated digital images.
Based on the geolocated 3D model, some Immersive Virtual Tours (IVR) of the geomorphology, the structures architecture and floristic-vegetational habitat (Figure 7), were performed as well:
1. No. 12 terrestrial shots: (19/04/2023) with 360° camera RICOH THETA Z1 for spherical images 6720x3360 pix used on dedicated stand, positioning of station points with GNSS Leica G14 connected in RTK to the Permanent Stations Network of the Apulia Region;
2. No. 180 aerial shots: (17/5/2023) flights with non-photogrammetric purposes but aimed at producing 360° "spherical" photos taken from no.7 points aerial shots taken by the same technique with a scheduled specific.
In this way, the aircraft maintains, at the chosen altitude, its coordinates acquired by the GPS/GLONASS System, by taking n.25 shots distributed over a solid angle of 360°. Figure 7 is the initial page of a Digital Virtual Route (DVR) that allows, with on-line and/or Wlan network interrogation, an access to the visibility of about 20 spherical images, both terrestrial and aerial, useful in the observation of vegetation details, not visible from the ortho-photo-projection.

Figure 7. Digital Virtual Route (VR)

CONCLUSIONS

The photogrammetric survey of the area of high environmental, landscape and archaeological value "*Pulo di Molfetta*" has enabled the construction of a basic model implemented in a Geographical Information System, which has revealed very useful to study this particular area. The photos taken on-site were exploited through a photogrammetric process, to generate an orthophoto of the area with a pixel size of 1 cm.
The presented approach is suitable for the generation of high resolution orthophoto and highly detailed point cloud, to be used for further environmental studies, which will enable policy makers to implement the right and proper planning and management strategies for this area. It would contribute to plan also appropriate actions mitigating anthropic interventions, so incorporating into the rural landscape suitable elements able to protect natural components, enabling the development of a more sustainable tourism as well.

FUNDING INFORMATION

This work has been financed by the Municipality of Molfetta, in the framework of the agreement it has signed with the SAFE School of the University of Basilicata.

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