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Geomatic multiscale approach for the conservation of archeological sites: the case of Alba Fucens (L'Aquila-Italy)

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Abstract. The archaeological site of Alba Fucens (L'Aquila, Italy) (303 BC) is the largest archaeological area of the whole Apennines. Extension, location and environmental context of the site require new methods for risk mitigation and conservation. In this paper, a multiscale geomatic approach, based on remote sensing and UAV photogrammetry, is reported. The main purpose is the extraction of architectonic and weathering information, useful for a better fruition and conservation. For a multiscale approach, very high resolution satellite images (WorldView2) and UAV Photogrammetry technique have been used. The satellite image processing, performed by Normalized Difference Vegetation Index (NDVI), High-pass filter, Principal Component Analysis (PCA) and classification, allowed to detect buried or emerging structures and to estimate fire and erosion risks.

On the other hand, UAV photogrammetry technique allowed to evaluate detailed architectural information of the buried (*ima, media and summa caveae*) and excavated amphitheatre structures (arena, podium and steps). Furthermore it was also possible to systematically acquire complete and reproducible data on stone materials (limestones) and their weathering (loss of stone material, natural or anthropogenic break out, deposits, efflorescences, dark or light crusts, biological colonization, granular and crumbly disintegration, flaking and fissures).

With a multiscale and metric approach, the geomatic techniques allow to deeply investigate the monument-mapping and to create a detailed 3D models. In this way, the stone decay, the risks and their mechanisms can be evaluated, in order to plan and perform future actions and interventions for their mitigation.

Keywords: Geomatics, Alba Fucens, Conservation, NDVI, PCA, High Pass Filter, Enhancement.

1. Introduction

Restoration and conservation of monuments require a complete scientific knowledge of the work of art achievable also through objective and reproducible mapping of lithotypes and weathering; more over it is necessary taking into account past interventions, environment, stone characteristics and monument architectonic features.

Within the diagnosis, registration, documentation and evaluation of the weathering forms are long and time-consuming specific and significant activities. Monument-mapping methods must in fact guarantee complete and reproducible results contributing, essentially, to understand causes and mechanics of decay.

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The knowledge and the conservation of an archaeological site is a complex task due to its properties: the extension, environmental and outdoor location and anthropogenic factors. In addition, the choice of the better survey techniques, possibly non-invasive, is important in order not to compromise the state of the archaeological rests.

The recent advances in Geomatics offer a wide range of tools and instruments able to rapidly acquire innumerable cognitive and quantitative information useful for preparing preventive and conservative interventions for the archaeological areas, both at small and large scale.

Techniques such as Remote Sensing from multispectral satellite images are able to acquire and investigate large areas, exploiting the different way in which natural surfaces interact with electromagnetic energy from a source (solar energy) to obtain information on their characteristics. The interaction between the incident energy and the natural surface allows to detect a spectral signature in a specific range of wavelength of the electromagnetic spectrum (band) [1-3]. In archaeology, the analyses of the spectral properties, in relation to soil, geological and plant cover characteristics, improve the identification of traces and anomalies, emphasizing, often with several filters, the spectral response of satellite images. Furthermore, combining some bands, several indices can be extracted and used to analyse some characteristics, as vegetation, water and so on [4-6].

At large scale therefore, new photogrammetric methods are nowadays available to execute a complete and reproducible monument-mapping results assuring and contributing, essentially, to understanding causes and mechanics of decay. By means of the photogrammetric outputs (orthophotos) is, indeed, possible to record and to assess the type, the extent and the distribution of the used stones, to classify the decay forms and mapping the weathering in detail.

Through objective and reproducible criteria, damage analysis is performed, state of conservation and monitoring at long term damage progression, future modifications and new forms of decay are defined in order to plan conservation interventions.

In this paper, the well-known Alba Fucens wide archaeological area (30 Ha) [7-10] has been studied (figure 1).



Figure 1. Alba Fucens environmental context and map of the archaeological site.

2. Material and method

2.1. Very high resolution satellite images processing

To investigate the great extension of Alba Fucens, World View 2 multispectral images were used. The aim of this study is to identify possible buried structures and to analyse some environmental risk related to the presence of the surrounding vegetation area (fire risks) and walkways produced by visitors, often not authorized (erosion risks). The Digital Globe WorldView-2 sensor was the first very high resolution multispectral commercial satellite [11] with a 0.5 m of geometric resolution for the panchromatic band and 2 m for the eight multispectral bands (Coastal, Blue, Green, Yellow, Red, Red edge, Near infrared, Near infrared 2 [12]. The images were pre-processed to correct the geometric distortion (ortho-rectification) with 19 Ground Control Points (GCPs) and 8 Check Points (CPs), taken by NRTK GNSS

measurements. The RMS errors of GCPs and CPs are respectively 0.75 pixel and 1.33 pixel, after the orthorectification. To improve the geometric resolution of the multispectral bands, a pansharpening process was performed [13-15]. Subsequently, the images were treated with chosen filters (high-pass filter, Principal Component Analysis (PCA), etc.) and with the Normalised Difference Vegetation Index (NDVI). The NDVI is a combination between red (RED) and near infrared (NIR) band according to the equation (1):

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

It is often used to detect and study vegetation [16] and to investigate the buried structure in archaeological sites [17].

The PCA is often used as a method of data compression. It allows to shrink redundant data into fewer bands. By means of a linear transformation of the variables, the original bands are projected in a new Cartesian system in which the new variable with the largest variance is projected on the first axis, the second to the second axis and so on. Only the bands with highest variance are taken into account, reducing the complexity [18].

The high pass filter maintains only the high frequencies of the signal, highlighting the differences in intensity between the pixels and reducing background details [19].

By the classification, pixels with similar spectral signatures are grouped into chosen classes in order to create thematic maps [19].

2.2. UAV photogrammetry

The UAV flights with aerial and oblique route were planned to obtain a complete amphitheatre “scenario”. For both routes, 40 meters of altitude were adopted obtaining about 1 cm of GSD and with 80% overlap and 60% sidelap. 60 images are acquired and they were processed with Agisoft Photoscan, that combines the photogrammetry equations with the new algorithms of the Structure For Motion and Multi-Stereo View. The data treatment allows obtaining the internal and external orientation parameter [20] to reconstruct the 3D model. During the elaboration, 5 Ground Control Points (GCPs) and 3 Check Points have been used to georeference and to evaluate the quality of the results respectively. The 3D model, the Digital Elevation Model (DEM) and Orthomosaic were obtained. The final RMSs of GCPs and CPs are respectively 0.03 and 0.05 m.

The registration and mapping of lithotypes and weathering damages of the amphitheatre were executed according to UNI NorMaL Recommendations (11182:2006) by means of the Orthomosaic with about 1 cm of resolution. Some particular decay aspects were checked by means of detailed in situ visual survey.

3. Results and discussion

3.1. World View 2 results

From the satellite images treatments, important results have been achieved.

With the NDVI analysis, the presence of several traces of buried structures could be hypothesized (figure 2).

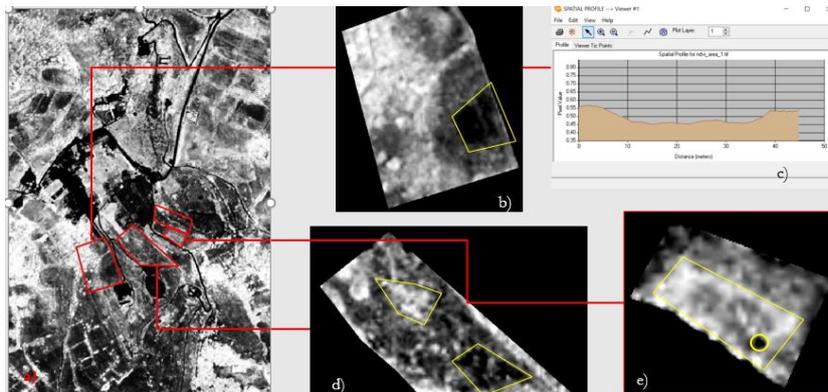


Figure 2. Archaeological traces identified with the NDVI. a) NDVI maps in gray scale; b), d) and e) traces; c) NDVI profile.

The PCA has been applied on the single bands and interesting results have been obtained on the band 1 (coastal band). Some traces, in the “Colle Pettorino” area, can be observed (figure 3).

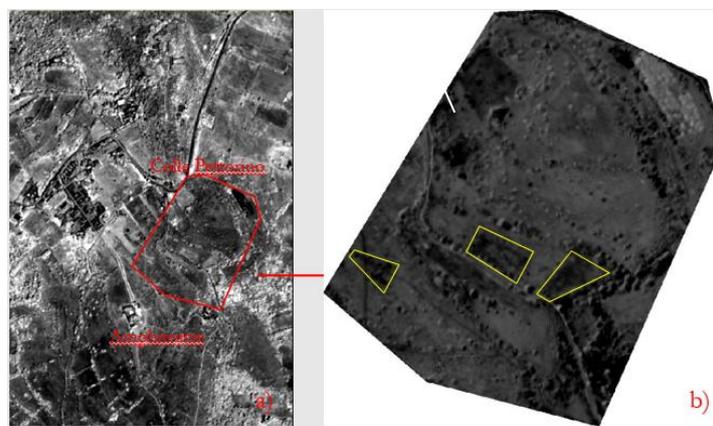


Figure 3. a) PCA applied in the site test; b) zoom on some traces highlighted by PCA.

The High Pass filter is an excellent method for identifying all the paths in the scene, and in general highlights the morphological variations of the terrain. This application is very useful to assessing and to monitoring the state of degradation of the site, in terms of soil erosion, and in the evaluation and construction of suitable walkways, from the point of view of safety and correct use (figure 4).

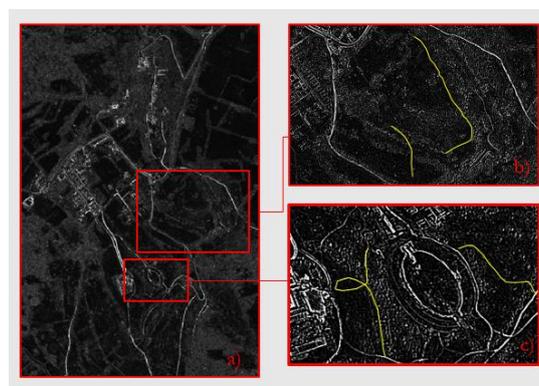


Figure 4. a) High pass filter applied in the site test; b) and c) zoom on some traces highlighted by High Pass filter.

Figure 5 shows a supervised classification into the archaeological site. The application is useful in order to generate thematic maps which, combined with NDVI, allow to distinguish between high and low vegetation. In this way, it is possible to assess the fire risks.

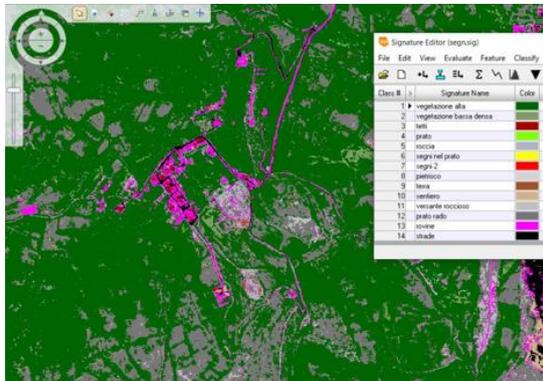


Figure 5. Classification on the VHR satellite images.

3.2. UAV photogrammetry results

The 3D model and DEM of the amphitheatre (figure 6) show that the different orders of caveae (ima, media and summa) are clearly visible and detectable only on the right side of the north oriented Porta Triumphalis. The reconstruction of the whole structure with the definition of the architectonic elements and their dimensions is reported in figure 7.

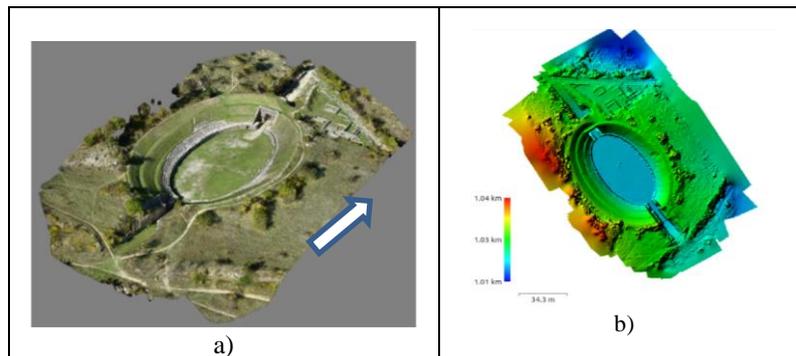


Figure 6. a) 3D model and b) Digital Elevation Model of the Alba Fucens amphitheatre (arrow point to North).

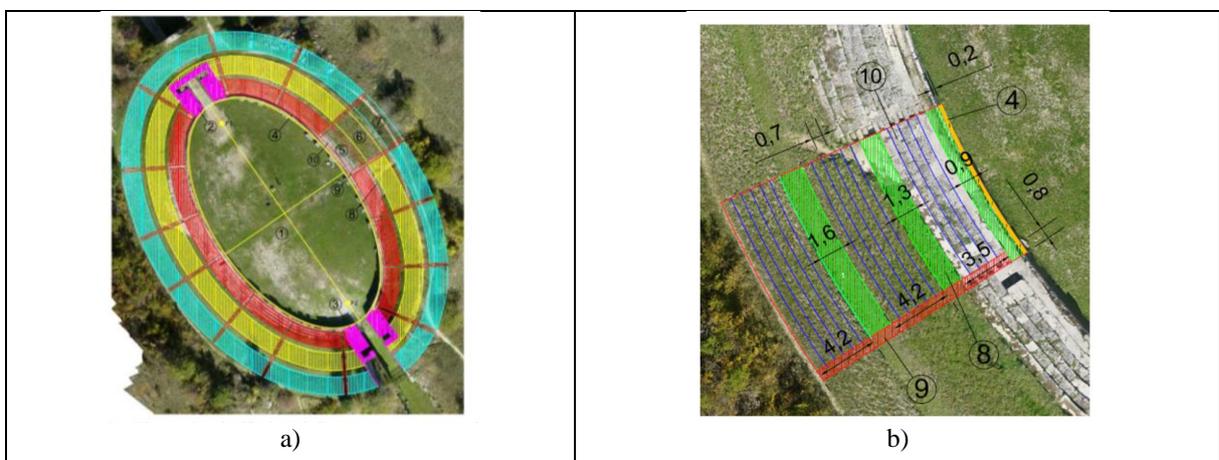


Figure 7. a) Reconstruction of the architectural elements of the Alba Fucens amphitheatre: 1) Arena; 2) Porta Triumphalis; 3) Porta Libitensis; 4) Podium; 5) Ima cavea; 6) Media cavea; 7) Summa cavea;

8) circular corridors; 9) stairs; 10) steps. The arena surface is 1680 square meters with major and minor axis (reported in yellow), respectively, of 62 and 34,1 meters. F1 and F2 focuses of the ellipse; b) Detail of possible dimension of the steps and the circular corridors of the three order of caveae. 6000 persons is the estimated maximum capacity.

The different profiles and the heights of the two sides of the amphitheatre, pointed out by the DEM (figure 8), can be justified with an unfinished construction and/or the collapses over centuries.

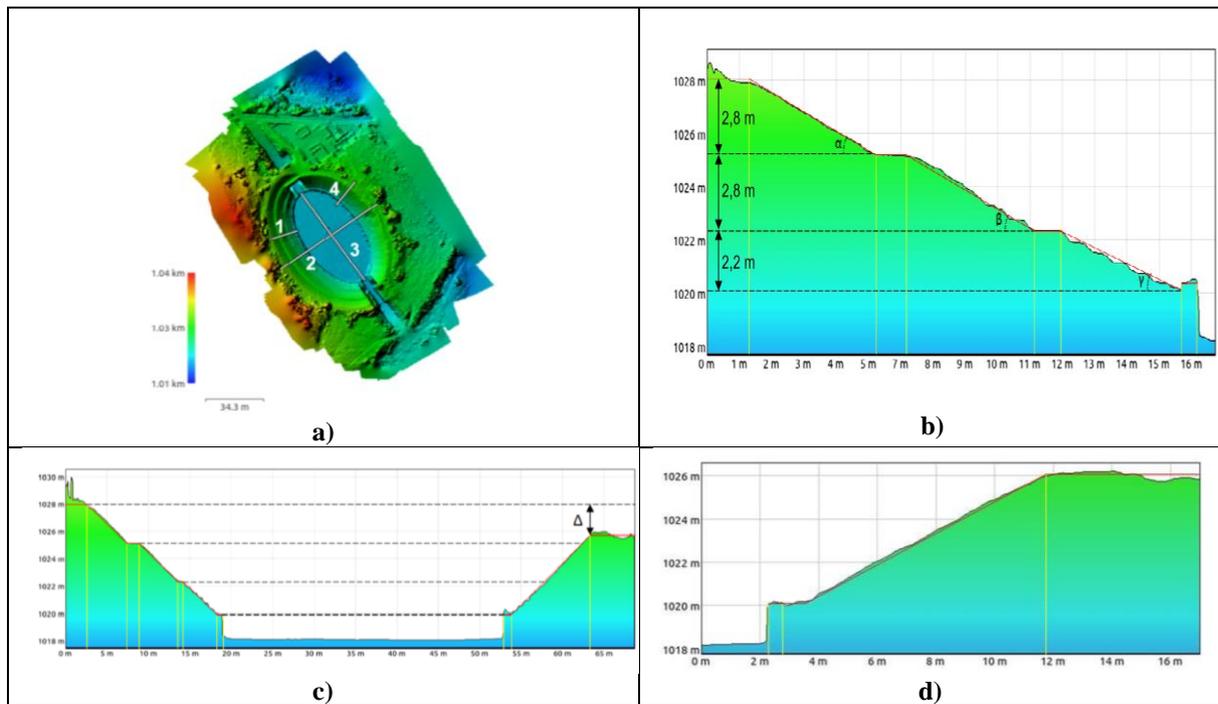


Figure 8. a) DEM profiles of the amphitheater. b) Profile 1: slopes of the right side of the summa, media and ima caveae realized, respectively, with angles of 34 (α), 34 (β) and 32 (γ) degrees; c) It is clearly observable a difference of height of 2.2 meters within the left and the right side; d) Profile 4: absence of the summa cavea of the left side. Along the x-axis the distances (m) and along the y-axis the altitude (m).

Table 1. Weathering of the litypes constituting the amphitheater of Alba Fucens.

Natural break out (Wedge work of roots, seismic actions, freeze-thawing)
Anthropogenic break out (Freeze-thawing of restoration mortars and bricks, detachment of plasters, corrosion of welded mesh)
Humidity (Descendent rainwater seepage from the <i>ima cavea</i>)
Efflorescences (White poorly adhesive deposits of salt aggregates)
Biological colonization (Microbiological: lichens (<i>Genera Aspicilia, Caloplaca, Lecanora</i>), algae (<i>Class Chlorophytae</i>) weeds and higher plants.
Disintegration (Granular (stone powder), crumbling and splintering)
Fissures (Single or systems of fissures dependent from loadings and deformation)
Flaking (Single or multiple)
Crusts (Precipitation process of calcium carbonate (White)) (Atmosphere and microbiological deposition (Dark))
Erosion (Rainwater run-off on the surfaces)

The main current weathering forms of the limestones (mainly intrabiomicrites or calcareous breccia), summarized in table 1 are shown in figure 9. The humidity of the podium areas is significant because of the rainwater seepage coming from the buried upper *caveae* (2500 square meters 84%).

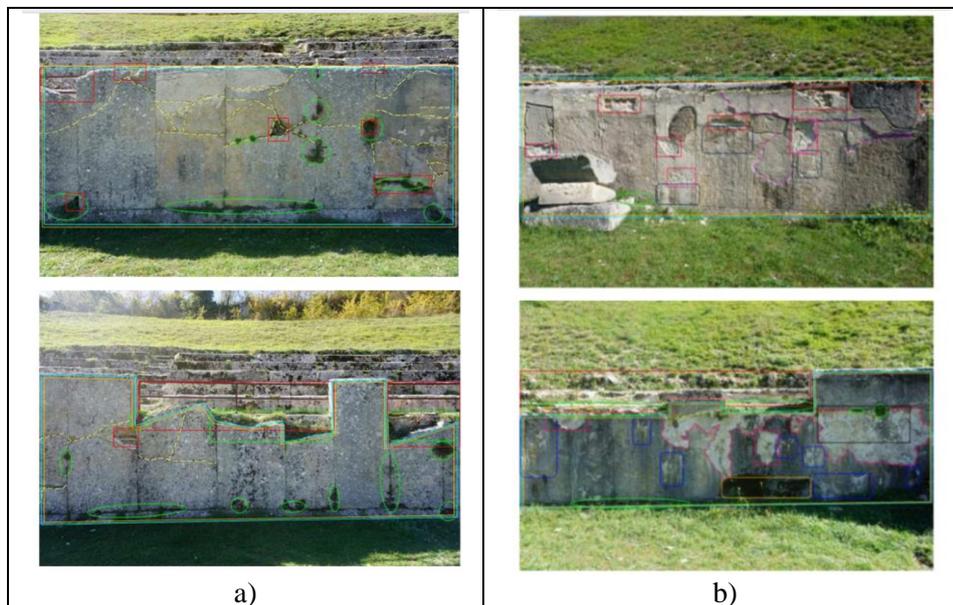


Figure 9. Weathering forms a) of the right and b) left side of the amphitheatre: break out (red), biological crusts (cyan), weeds and plants (green), fissures (dotted yellow); white crusts (blue), disintegration (pink), detachment (violet), anthropogenic break out (black)

4. Conclusions

In this paper, a multiscale geomatic approach was applied to the knowledge and the conservation of a wide archaeological site. Alba Fucens area was taken into account and it was studied by means of VHR satellite image (World View 2) and UAV photogrammetry. About the satellite image, NDVI, PCA, High Pass filter and classification technique were performed to highlight the main features of the image. In particular, several buried structures was hypothesized by NDVI and PCA, while morphological variations of the terrain and the walkpaths were extracted by the High Pass filter. Finally, the NDVI and classification method permitted to classify the high and low vegetation.

The 3D model and DEM obtained by the UAV photogrammetry allowed to survey in detail the amphitheatre structure in order to analyse architectonic elements with their dimensions. By the orthophotos, weathering forms and decay was defined.

The small and large scale study is a powerful tool to reduce the risks linked to the identified elements in order to programme suitable intervention plans for the territory management and the promotion of cultural heritage.

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