ANCIENT MINING LANDSCAPES AND HABITATIVE SCENERIES IN THE URBAN AREA OF CENTOCELLE: GEOMATIC APPLICATIONS FOR THEIR IDENTIFICATION, MEASUREMENT, DOCUMENTATION AND MONITORING

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ABSTRACT:

This study, focused on the Archaeological Park of Centocelle, was carried out to test the functionality of different geomatic products for the identification and monitoring of complex archaeological evidences in urban areas. The method proposes a better knowledge of the archaeological context as a tool to favour a better protection, allowing the establishment of limits to urban enlargement in areas of respect. The test area is chosen because of the combined presence of hypogeal evidences related to Roman and pre-Roman exploitation of local litotypes and for the dense presence of archaeological vestiges at its surface, related to the inhabitation function of the zone in a period contemporaneous to the beginning of the quarrying activities. The methods used are the digital photogrammetry, 3D modelling, remote sensing interpretation and digital cartography. The protocol is then customized for the peculiarities of the area under study, considering both the underground structures and the ones at the surface. Archaeological features are identified by processing optical and SAR dataset to enhance the contrast of archaeological features from the background. Historical and recent DSM have been then compared to evaluate the evolutions of local topography. Concerning the study of the subterranean quarrying system in the area, a 3D model of one gallery was produced, with the aim to understand the type of ancient exploitation. A DTM of the toolmarks was then produced to understand the technological skills used for the exploitation of the local tuff and used as an indirect proof for chronological interpretation. A final trial of PSInSAR was addressed to test the method for monitoring the hypogeal levels. Several field prospections were executed, in order to first set the method properly and then validate the results.

1. INTRODUCTION

1.1 Geological and historical introduction on the case study

The archaeological Park of Centocelle is placed in a highly urbanized area of Rome whose construction has boomed in the '70s and '80s. From 1909 its importance already risen, together with the opening of the first military airport of the city. An almost continuous human occupation of this area can be then followed backward, until the pre-roman and roman period, as many different archaeological evidences, scattered in the whole area, testify. Nevertheless, it is the presence of the roman Villa Ad Duas Lauros and Villa della Piscina (Gioia, 2004), set aside a dense network of subterranean ancient quarries for the exploitation of tuff, that makes of this area a very complex case for ancient landscape interpretation. In the area of Rome the extraction of local litotypes is a millennial anthropic activity that has extremely shaped the landscape to highly artificial and altered morphology. That is why in Rome the presence of ancient underground cavities is to be found in each of its districts. The most commonly used lithic types are the pyroclastites (lava, tuff and pozzolana) from the volcanic districts of the Lazio Volcano (south-east) and the Sabatini Mountains (north-west) and the sedimentary rocks such as travertines, gravel, sand and clays.

The outcrops of pyroclastites can vary in thickness between 10 and 40 meters, exploited extensively in open cast quarries and in underground (Sciotti, 1982). The dimensions and the depth of the quarries depend on the type of rock but generally it can be stated that the tunnels are mainly located 15 meters from the ground level and are generally 3 to 5 meters high and 2 to 3 meters wide, and sometimes they are developed on several levels. In the tuff so called "*lionato*", the galleries can reach 10-15 meters per side, because of the high competence of the rock (Sciotti, 1982). Many of these quarries were probably reused in paleo-Cristian period as catacombs. In the area of Centocelle, the subterranean quarries (figure 1) are within the park borders, but also nearby Villa de Sanctis (tuff), in Via del Pigneto (pozzolana) and in Largo Perestrello and Via Tempesta, where two open cast mines are still partially identifiable. The Roman columbarium in Via Gattamelata and the catacombs of SS. Pietro and Marcellino can be also related to the reuse of ancient dismissed exploitation galleries. The archaeological subterranean levels, belonging to the ancient quarrying system, still resist in their integrity, even if their extension is only partially known and very slightly studied, to the detriment of their conservation and ingenerating, at times, issues of civil security. This enormous underground archaeological heritage of Rome, is currently little considered, causing a degradation of the areas, used also for illicit activities, that can lead to situations of risk for the citizen. A better knowledge of the importance of ancient quarries as a testimony of ancient human activity, and an inclusion of them in the context of archaeological protection projects would bring, in parallel, to a urban requalification.

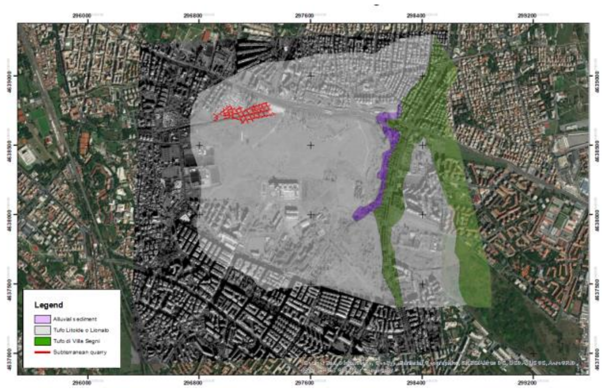

Figure 1. thematic map that shows the local litotypes in Centocelle and the representation of subterranean quarry

Contrariwise, the integrity of the archaeological vestiges at the surface, such as inhabitation settlements are, in urban areas, jeopardized by the presence of modern structures and infrastructures. The vestiges emerge in a sort of mosaic within the non-built areas, surrounded by fast roads and densely inhabited buildings (figure 2). Considering now in detail the archaeological features at the surface, Centocelle, in its 300 hectares, has a considerable density of archaeological evidence that emerge in the non-built areas of the neighbourhood (Parco di Centocelle, Parco di Villa de Sanctis and the so-called Striscia di Torre Spaccata).

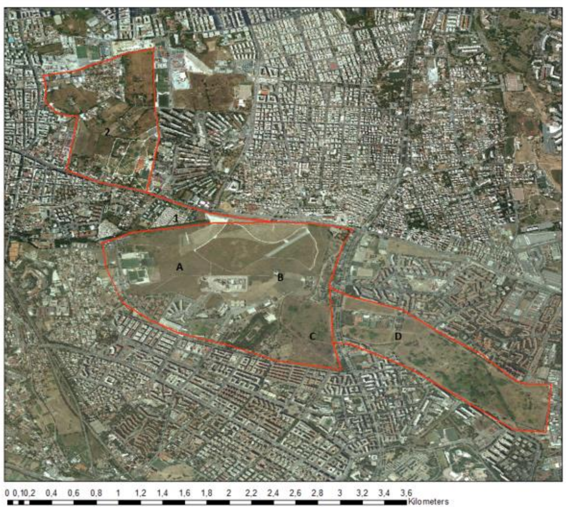

Figure 2. Map of the location of ancient quarries and settlements: A) Villa della Piscina, B) Villa Ad Duas Lauros, C) Villa delle Terme and 1) subterranean quarry (Centocelle Park); D) Villa Repubblicana (Striscia di Torrespaccata); 2) Subterranean quarry (Villa De Sanctis)

During the construction of the military airport in this area (currently not in use), various important attestations have been brought to light, testifying the human frequency of the area from the 6th cen. BC to the 6th cen. AD. The most important evidences belong to the complex of the villa Ad Duas Lauros, Villa della Piscina and Villa delle Terme but, set aside them, there are as well traces of more ancient buildings, belonging to the 7th cen. BC The traces in the Torrespaccata strip are belonging to a village of the Eneolithic Age - Ancient Bronze Age, a sepulcral area from the Republican period, two Roman villas and a medieval site (S.D.O. in charge of the preservation of the Park, P. Gioia, 2004). In both these two areas, the residual walls are in tuff, supposedly local. This peculiar concomitance of subterranean and surface archaeological features represents a very actual topic for archaeology, preservation of cultural heritage and civil engineering. The archaeological area is currently not open to visitors and covered with soil and waste heaps. The extent of the archaeological zone, to be kept under preservation policies, is only partially known, also considering the area of Torrespaccata and neighborhoods. Evidencing the archaeological extent is the first step for a wise preservation of the area, also considering the constant enlargement of urbanized zones that has to be controlled and limited to the zones that are devoid by archaeological presence. Remote sensing proves to be an non-destructive and speditive method to evaluate aerials of respect.
This zone has been consequently selected as a test area for the setting and trial of a multipurpose geomatics method, applied for both the study and documentation of the archaeological entities, both on the surface and underground level and for the monitoring of their state of preservation.

2. MATERIALS AND METHODS

This work has a methodological scope of investigating the possible uses of geomatics for the identification and the documentation of archaeological features on different scales. Landscape archaeology, intended as the discipline that is devoted to the description and interpretation of anthropogenic modifications to the territory by human activities and their impact on large scale, will be beneficiated largely by a systematic application of Earth Observation and geomatic approaches (examples of possible applications in Bitelli, 2005; Bitelli et al., 2017; Tucci, 2006).

Beside this, the case study furthermore triggered a specific interest in the understanding the interconnections of the ancient hypogeal structures with the urban environment surrounding, stimulating a preliminary attempt to approach their monitoring from remote. The implementation of the core method will be profusely explained in the following paragraph.

Before the beginning of the study, several extensive *surveys in situ*, covering the area of the Centocelle Park, the area of Villa de Sanctis and the area of the Torrespaccata strip, have been completed, for the collection of archaeological, geological and topographical information. This preliminary phase had the fundamental aim to overview the dimension and the complexity of the archaeological entities. First of all the presence of modern waste materials has to be considered, cause it compromises both the *in situ* recognition, and then the post-processing phase.

The ancient dump heaps connected to quarrying activities have been also individuated and considered as part of the archaeological landscape. Beside this, an additional issue is the presence of small landfills, caused by previous archaeological excavations, carried on in the ‘90s and the accumulation of modern waste. The vegetation coverage is contrariwise an ally especially when it is composed mainly by grass and small bushes, as their distribution is not random but covers differentially the terrain, depending on humidity and soil.

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Figure 3. Medium stemmed bushes covering, slopes, sink-holes and depressions filled with soil and gravel

The medium stem shrub is in fact connected, in several mining areas in the temperate zone of the world, to the coverage of steep sides of depressions, trenches and sink holes or, in other words, wells filled with gravel as a carry-over (figure 3). The bushes require terrains that drains rainwater easily, preventing water stagnation. Gravel accumulation areas (filling depressions or wells), covered by differential vegetation growing, is a type of zonation that can be used successfully for the interpretation of mining archaeology landscape.

The grass as well can draw fundamental vegetation marks that can be followed to identify the semi-buried perimeter walls of vestigial buildings. The grass growing on the wall traces in the area of Centocelle, surveyed from November to March 2017, showed always less vegetated and darker coverages on top of the wall traces, surely related to the shortage of soil (figure 4). Contrariwise, trenches refilled with soil and gravel favour a faster growth of vegetation, because of a water accumulation and a higher concentration of soil.

Figure 4. Perimeter wall traces captured in a low-tilt photo (A), enhanced with a black line in the picture (B)

A second field survey was then carried on at the end of the geomatic protocol, with the aim to verify the evidences.

2.1 Materials

The type of dataset used to implement the methodology are described in the table 1.

Dataset	type	Pixel sixe (m)
Pleiades	Panchromatic	0.5X0.5
Pleiades	Multispectral	2X2
Landsat 4-5 TM	Multispectral	30X30
Cosmo SkyMed (StripMaps)	SAR	3X3
Aerial photograms	Panchromatic	variable

Table 1. Details of the datasets used

2.2 Methods

Concerning the aim of archaeological features identification, the large amount of historical aerial photograms from topographical flights, dated back since the first period of the Centocelle Airport activity, taken from the Areonautica Militare (AM), Royal Air force (RAF), Società per Azioni Rilevamenti Aerofotogrammetrici (SARA) and other bodies since 1929, were processed with computer analysis approaches (adjustments, filtering, thresholding and vector extraction) to identify the traces of the roman villas (traces of walls, trenches, terraces and related infrastructures). The Pleiades panchromatic (0,5X0,5 m pixel) and multispectral images (2X2 m per pixel), subset on the area of interest, has been also used, after a pansharpening, for the evaluation of the IR band radiance related to vegetation indexes and the presence of differential humidity in the soil, and for the evaluation of geometrical feature. Supervised and unsupervised classifications have been then applied in order to categorize the spectral signatures in relation of type of archaeological features on the surface and the surrounding environment. Both the historical aero-photograms and the satellite images have been then processed with spatial convolution methods, with the aim of bringing out the structures of Roman villas. High Pass, Low Pass, Edge Thresholding, Edge Enhance, Edge Detect, using matrices 3X3 or 7X7, have been systematically applied to enhance the contrast of geometric features. Libraries of tools, such as the Lineament to Shape (Geomatica® from PCI Geomatics) that extracts linear features and registers the polylines on a vector layer have been satisfactorily adopted to extract automatically georeferenced polylines and polygons. This operation consists of a multiple stacking, composed by the Filter Radius (the radius of the edge detection filter), the Edge Gradient Threshold for shading settings, and the Angular Difference Threshold (minimum and maximum angles between the lines of the same feature). Several colour composites were then tried on the pansharpened Pleiades images and on Landsat 4-5 TM, to visualize the best the contrast of radiance in three channels available. For example, in 4-5-3 in Band Composite R-G_B display, the burned soils are enhanced in brown, while the tree canopy is in red, the bushes in dark green/reddish and wet areas in blueish red. For example the composite NIR-R-G in R-G-B composite channels was tried with interesting results of wet and dry terrain zonation. A supervised classification was tried on the Pleiades to classify the Land Cover, considering that, in the composite 4-5-3 in the RGB channels, dry and wet soil are distinguishable, after a definition of classification signatures on sampled areas. All these processes have been executed by using softwares as ERDAS Image® (Exhagon Geospatial), Geomatica and ARCGis® (ESRI).

SAR data have been then used for archaeological feature extraction, by interpreting backscattering anomalies due to differences in the dielectric properties, humidity, vegetation coverage, roughness and orientation of the archaeological features. The SAR data used are Cosmo SkyMed in Stripmaps HIMAGE mode (3X3 m pixel), filtered on the random multiplicative noise (speckle caused by multiple backscatter sources) with multi-looking filters (Stewart, 2017) and Gamma and Gaussian Filtering. The Intensity Processing stacking of SARScape have been followed, that is a combination of single and multiple ANLD and De Grandi Spatio-temporal Filterings. SAR time series have been also processed considering coefficient of intensity variation, related to temporal changes in the local backscatter signals. Considering the possible manipulation of phase information to execute feature extraction, interferometric products such as interferograms and coherence images have been evaluated.

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Considering also the large amount of information that the 3D dimension can also give for virtual archaeological prospection, several DSMs have been extracted from historical photograms by using digital photogrammetry (after ortho-rectification). More recent satellite images (Pleiades – resolution 0.5X0.5 m per pixel) were used for the production of an high resolution DSM. The two DSM can be compared to understand the development of the landscape, before its intense urbanization and in more recent times. A DTM has been then extracted from the Pleiades DSM, by the use of open source GIS tools (GRID Filter – DTM Filter of SAGA GIS allows an automatic separation of Bare Earth and Removed Objects layers after considering the Approx. Terrain Slope). This detailed DEM allowed the study of the topography and micro-topography, much related with the ancient quarrying landscape and the presence of semi-buried perimeter walls of ancient housing structures.

Concerning the study of the roman quarries, a 3D model of one of the main entrance galleries has been produced via digital photogrammetry. The 3D model, georeferenced and scaled, was used for the study of the type of exploitation of the local tuff. On this model was then possible to execute high precision measurements. On the walls and ceiling, the traces left by the picks are very clearly visible: after having sampled an area of about 1X1 m, with high concentration of traces, a VHR DTM of a sampled area was extracted with Photoscan (Agisoft), and the toolmarks have been enhanced using the spatial analyst of ARCGis. Classified contour lines with a step of 1 mm have been created and then filtered to remove the very high and low values, due to the wall curvature. The contour lines extracted from the DEM (less than 1 mm pass) and categorized, and symbolized in graduated colours can well represent the variation range of this surface, showing clearly the typical morphology of excavation with picks. The traces have the typical triangular or round shape, since the rock breaks into the area of impact of the chisel, but they can also appear as pseudo circular when the percussive component made by the instrument prevails on the cutting action. The study of the toolmarks types and distribution can define the type of technology used for the exploitation, allowing a chronological attribution of the quarry, the study of the gestures linked to the miner's activity and the type of tools that were used.

Finally SAR long-time series was used for a PSInSAR processing, as a trial of monitoring the cavities in Centocelle with PSInSAR. This type of technique give the best results when monitoring slow vertical movements, and it can be suitable to show sub-horizontal cracks between pillars and vaults, the gradual compression failures of the pillars and the gradual bowing of the vaults, all phenomena that can gradually develop causing instabilities on the entire asset of the galleries. A trial, using Cosmo SkyMed time series data, was done as a preliminary evaluation of this method for the area of Centocelle.

3. RESULTS

The discussion of the results will be divided by paragraphs, considering the division of the aims into: 1) feature identification using 2D data such as aerial and satellite images, 2) 3D feature identification using DSM and DTM and 3) monitoring trial using PSInSAR.

3.1 Archaeological information from aerial photograms and optical and SAR datasets

In the pre-roman and roman times, the area of Centocelle, with the Villa ad Duas Lauros and the annexes Villa della Piscina and Villa delle Terme, was originally a rural zone, later transformed in a real residential neighbourhood at the border of the city. The first documentations of archaeological presence found in the 1930 speak of very large buildings with several annexes. A study based on a systematic use of remote sensing data could allow to detect unknown coeval living spaces, in auxiliary positions to the main buildings, but also older or more recent vestiges. It is important to say that all the archaeological structures, after the archaeological excavations of 1995-2000, are currently covered and obliterated by soil and vegetation.

For this phase of the work, a series of frames was used by the aero-photogrammetric missions of various Bodies including Aeronautica Militare, RAF, SARA, ETA and SIAT, selected by the photo-index of the ICCD-EIRA Institute (Rome-Italy). On these pictures, both radiometric and geometrical improvements with ERDAS Image and feature extraction with PCI Geomatica have been tried. In the figure 5, a photogram protakenduced by SARA (1932) was processed with high pass filter, a matrix or kernel that highlights the high DN values, increasing the contrast with the surrounding ones. The visible structure shows the traces of an exedra and four rooms aligned and a further room at the base of the structure, probably with an entrance function. Subsequently, the image filtered was further elaborated with the geomatic tool LINE Lineament Extraction (figure 5, on the right tile), for the extraction of linear features from an image and records the polylines in a vector level (Sedrette & Rebai 2016).

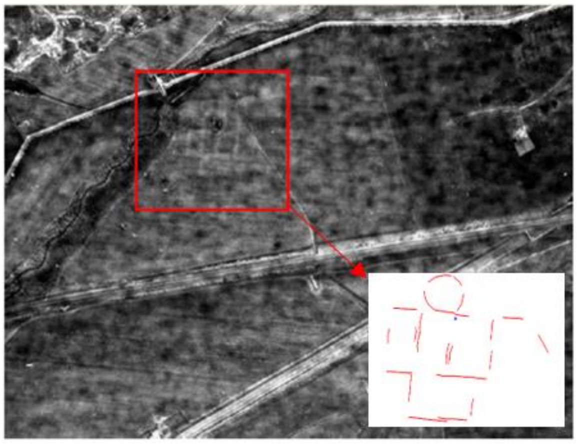

Figure 5. High Pass Filter on a historical photogram (SARA, 1932) and lineament extraction of the structure (on the right)

On the same photogram of 1953 it was also possible to better appreciate structures nearby the Villa Ad Duas Lauros, through a 3X3 Edge Enhance Filter (figure 6). An exedra and a rectangular environment are in fact visible.

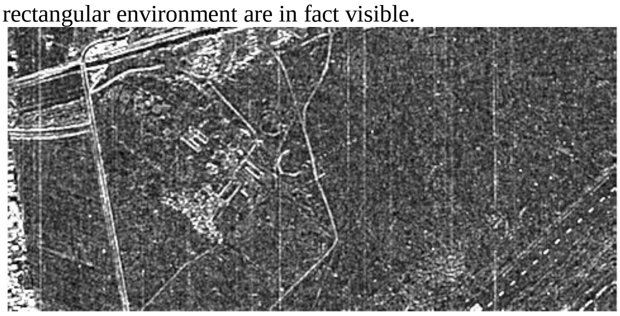

Figure 6 Edge Enhance Filter on a historical photogram (SARA 1932)

A further LINE Extraction with PCI Geomatica was applied to a photogram taken in august 1981, available from Google Earth historical images (figure 7). The summer months are perfect for this type of photointerpretation, given the absence of lush vegetation. The barren land makes visible linear trends in the area of the Villa della Piscina.

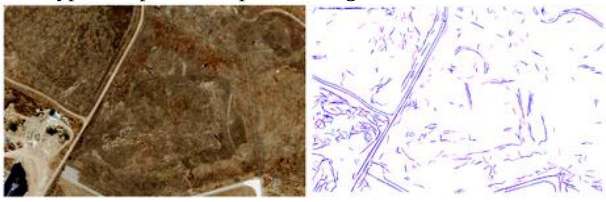

Figure 7. Aerial photograph (August 1981, Google Earth) and relative Lineament Extraction

A Pleiades multispectral image was subjected to NDVI processing (figure 8), to obtain information on the vegetation state, which indirectly could provide further information on the archaeological areas. In the NDVI, the traces of trenches in connection with the two villas are more clearly visible as white areas in the NDVI. These high NDVI values are related to the presence of vegetation in a better state of health, which was also noted during the survey. In trenches, left for example by the refilling of cavities left by wall residues, the humidity is better preserved, condition which favours the presence of more luxuriant grass. The bushes, which should, at first instance cover depressions filled with soil, seem to appear darker, perhaps due to excessive dryness of the soil.

Figure 8. NDVI on a Pleiades image (multispectral), in swipe mode visualization

The observation of multispectral images in fake colour composite is very useful for the detection of wet to dry areas. The following is the case of the Pleiades visualized in 4-5-3 in RGB channels, representing the playground of Villa de Sanctis.

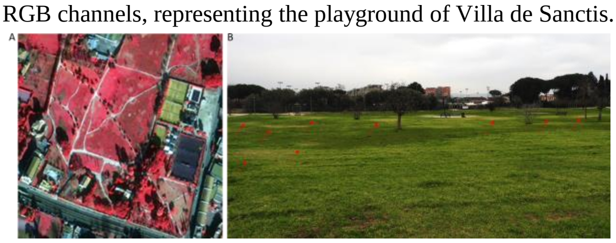

Figure 9. colour composite of the playground nearby Villa De Sanctis and, on the right frame (B), a picture of the same park taken during survey (A)

In the colour composite, several round shapes with dry soil emerged. During the field survey the same presence was detected directly (figure 9 B). These features were interpreted in connection to the presence of a subterranean quarry that develops just under the playground.

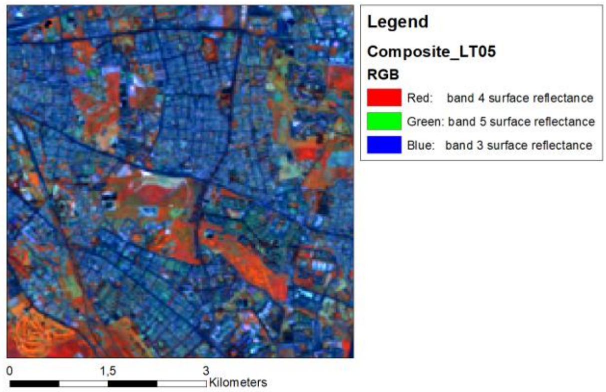

Figure 10. colour composite of a Landsat 4-5 TM

The network of cavities running under the surface level can explain hypothetically the presence of drier areas, considering possibility of water percolation in the natural cracks of the rock, that in case of voids can deprivate faster the soil of water. In the following thematic map (figure 10) it is reported the results of another fake colour composite of a Landsat 4-5 TM displayed in 4-5-3. The vegetation appear in vibrant red while soils vary in shades of different browns, urban areas are cyan, wet areas in purple and the bushes in dark green. In the image the areas of the Torrespaccata strips and Villa de Sanctis, several green areas indicates the presence of bushes surrounded by purple zone (in connection to wet soils). Both areas shows structures such as terraces, dump heaps and sink-holes that during the survey were connected to quarry structures. In the figure 11, the NIR is stretched in a single band, creating a NIR panchromatic image. From this elaboration, Villa ad Duas Lauros shows more clearly visible structures of perimeter walls and residuals of dump heaps coming from archaeological excavations.

Figure 11. NIR in B/W mode, detail of Villa Ad Duas Lauros

A last colour composite is here reported, coming from a field nearby the Torrespaccata Strip. A circular shape arises, but the nature of this shape can be attribute to ancient structures but as well as modern ones, necessitating of a direct verification (figure 12).

Figure 12. false colour composite on a cultivated field of Torrespaccata

Finally, as a last trial, a supervised classification is proposed as a way to classify spectral response patterns (Cavalieri & al.

2009). A supervised classification was then attempted on the pansharpened Pleiades image (figure 13). A first phase of assignment of spectral signatures to specific classes allows the following execution of a next automatic classification. In this way it is possible to collect all the features that can be related to archaeological presence. The classes collected in this case are wet areas, the dry areas and the presence of shrubs with medium stems, wall traces and fields. A first fake colour composite (4-5-3) was used to collect the spectral signatures of forestry (red), bushes (dark red to green) and wet areas (bluish red). Then, after having fed the system with this classification, the tool searches automatically areas with radiances similar to the classes collected during the training phase. The supervised classification allowed visualizing an order in the recurrence of spectral signatures, which follow geometric patterns. A final trial for feature identification was done by the use of Cosmo SkyMed SAR Amplitude data. The anomalies in the backscattered signal can in fact give significant information related to the soil moisture, type of vegetation (dimension of leaves and texture), terrain roughness, steepness of slopes, semi-buried structures. First of all the images have been cleared through the application of several filters such as the Gamma and Gaussian filters (for single SLC). Multi-looking speckle filters, De Grandi Spatio-Temporal Filter and Anisotropic Non Linear Diffusion multi-temporal filter have been applied on a coregistered dataset (16 images from February to December 2015). Multi-temporal features, non-identifiable from a single SAR data, are then visible when considering a time series, as in picture 14. The features that appear in the Feature Extraction image are two semi-square structures, a possible clue of semi-buried walls (fig.15) that needs to be verified on the site.

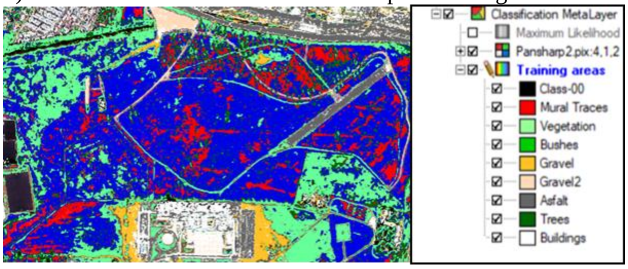

Figure 13. supervised classification of the Pleiades Pansharpened image

Figure 14. Feature extraction on SAR time-series

In picture 15, the multi-temporal feature extraction in fake colours show another polygonal shape, non visible in the previous image.

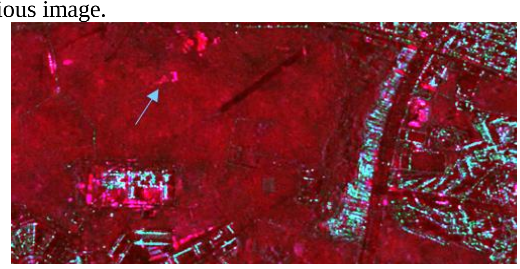

Figure 15. Feature extraction on SAR time-series

A last consideration was attempted by the use of the SAR phase band. In figure 16 a coherence image in RGB, extracted from the processing of a master image (July 2015) and a slave image (December 2015) is reported showing clearer polygonal shapes in the area of the Villa ad Duas Lauros. This result can be interpreted by considering that on the semiburied structures less vegetation is usually growing, determining an higher coherence of signals captured at different seasons.

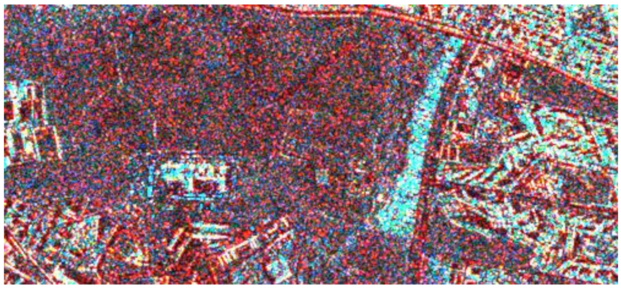

Figure 16. RGB Coherence between two SAR images (August-November 2015)

These are few examples of possible image-processing for archaeological virtual prospections, that proved to be useful in the detection of known and unknown archaeological structures in the field.

Following, the 3rd dimension information will be used to grab additional insight on the case study.

3.2 Archaeological information form DSMs and DTMs

Considering the artificiality of the topography and micro-topography ingenerated by the presence of archaeological vestiges, a first attempt of DEM extraction was elaborated via digital photogrammetry, executed on a couple of photograms coming from a topographical flight of Aeronautica Militare (1953).

These pictures have been chosen as they show the asset of Centocelle before the extensive urbanization. The extracted DEM band, reporting the elevations, are visualized in comparison with the image after ortho-rectification and mosaicking. This compared visualization allowed to understand the morphology of areas that, from the historical photograms, where showing peculiar shadings. The DEM was also visualized in the stretched mode on the DEM band, showing structures that could have been related to superficial exploitation of the local litotypes, among the traces left by the bombing of II World War. Modern buildings currently cover the area, so these details are appreciable only using historical photograms.

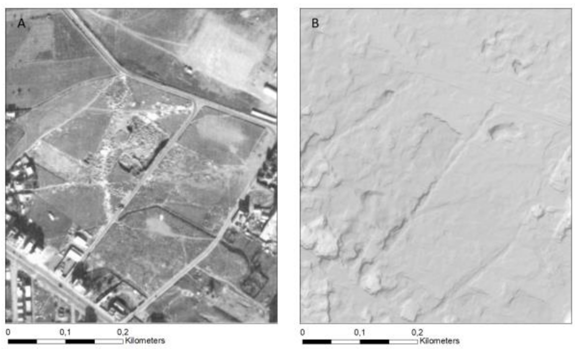

Figure 17. A) ortho-rectified photogram, B) DEM of the same zone, visualized in hill-shaded stretched band

The stereo-couples panchromatic images, acquired in 2017, have been then used for the extraction in digital photogrammetry of a HR DEM (pixel 0.5X0.5 m). The following elaboration of the DTM, necessary to have a clearer image of the area devoid by buildings, is executed with the tool Grid Filter-DTM Filter of SAGA GIS (SourceForge), that allowed, through an unsupervised classification, the automatic separation of Bare Earth Layer and Removed Objects Layer. The Bare Earth layer is a raster that contain several voids left by building removal. With the aim to make an interpolation, the raster has to be first converted to a point cloud (shapefile), interpolated on the attribute elevation, and then rasterized again. In picture 18, the DTM, visualized in hill-shade, give information for the understanding of depressions, earthworks, terraces, interpreted as possible clues of ancient use of the area.

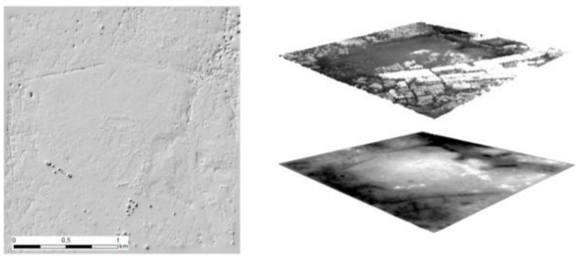

Figure 18. DEM of the Archaeological park of Centocelle (left) and DTM extraction from the DSM (right)

At this point the discourse skips to the application of digital photogrammetry for the documentation of the quarries. During one of the inspections, more than 320 photos were taken (partially overlapping) of a quarry tunnel entrance. These photos were used to generate the 3D model of the gallery (fig.19).

Figure 19. 3D model of the entrance area of a tuff quarry in Centocelle

The model generated with Photoscan was then scaled and georeferenced by measuring the relative position of control points with a precision distance-meter and measuring the absolute position with a GPS. This model was used for the study of the type of exploitation of the local tuff, to support interpretation of chronology. The big dimensions of the gallery, 3X3 meters, is quite big in comparison with the normal shape of pre-roman or medieval galleries that attest to about 1,20 X 0,8 meters and the typical roman galleries of mines that are about 2x 1,20 m. First of all, this peculiarity shows that the function of the gallery was not mining of minerals but massive extraction of the tuff. The 3 x 3 dimension testify that this entity is not belonging to "normal" structure but more correctly a subterranean quarry. These dimensions are classified as typical of Roman subterranean quarries, considering also the squared shape of the entrance. Given the clear visibility of the traces left by the pickaxe tips on the ceiling and on the walls of the entry area, and in order to study their development on the walls and ceiling and give a clearer view of them, an HR-DEM was extracted from an area with high concentration of toolmarks (figure 20). The DEM shows the typical deep circular and semi-triangular pits followed by longitudinal scratch marks. The DEM model imported into ArcScene is shown in fig. 20 B.

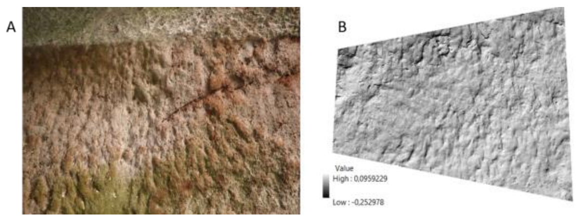

Figure 20. A detail picture of tool marks, B) DTM of a zone of the wall

The tool marks appear as partially crossing, which means that the miners cleaned the wall during exploitation so that the rock could break more regularly and the final product was a block, standardized in shape, easier for storing and transportation.

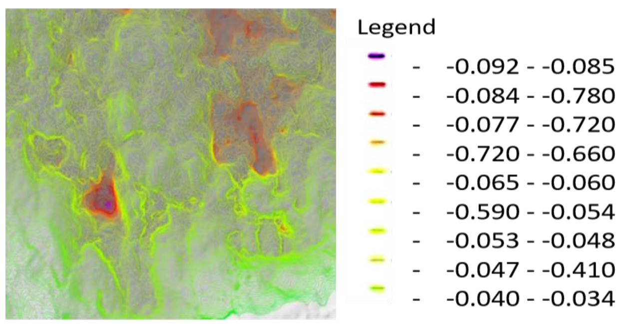

Figure 21. DTM of the wall sample – visualized in contour lines

From the DEM, the contour lines (figure 21) were then extracted with the Surface - Contour tool of the Spatial analyst (ARCGIS). Given the very small variation range of this surface, the classification has a pitch of 1 mm. The lines of altitudes too high or too low, due to the curvature of the wall, typical morphology of excavation with pickaxes, have been eliminated. The traces have the typical triangular or round shape since the rock fractures in the impact area of the tip, but also pseudo-circular because in relation to how the shot vibrates, the percussive component can prevail over the cut action made by the instrument. This brief example has the purpose of evaluating methods for rendering images that are easy to understand and of high information content, useful for example to accompany publications or technical reports of excavation and archaeological recognition.

3.3 PSInSAR

A final consideration, which is kept at the preliminary trial level, is made at this point on the possibility of monitoring ground displacements due to the structural instability of cavities.

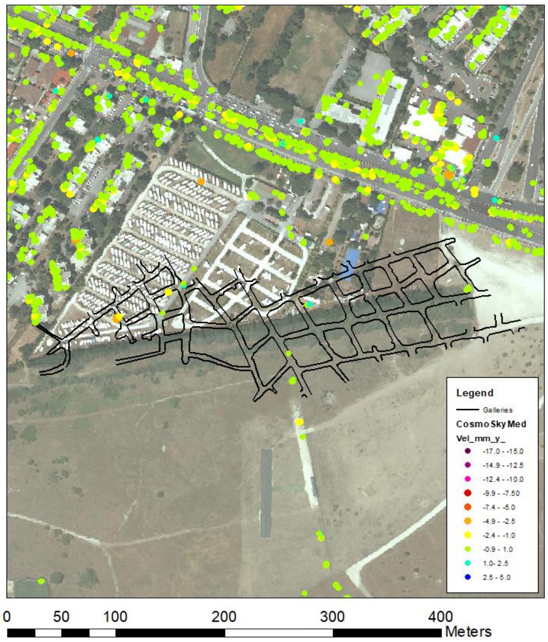

Figure 22. PS shapefile from SAR Cosmo SkyMed dataset (2010-2015) zoomed on the area of the galleries in Centocelle Park (vectorization of the planimetry (Mecchia & Piro, 2000).

For this purpose, Permanent Scatterers are extracted from Cosmo SkyMed time series covering the period between 2010-2015 (fig.22). PSInSAR method is extensively used for the monitoring of slow, linear displacement of buildings, infrastructures and geological entities (D'Aranno et al., 2015; Marsella et al., 2015; Scutti et al., 2013). The use of the method for the monitoring of ancient mines and quarries is currently under experimentation. A classification of symbology of the point shapefile on the attribute Velocity (mm/year) allow the visualization of the behaviour of the PS. A planimetry of the galleries which develop under the park was vectorised starting from the map reported in Mecchia & Piro, 2000, after its georeferencing. The response of the PS in the area of the galleries is affected by the presence of dense vegetation that prevents the extraction of a significantly coherent dataset. More extensive application of this method is proposed for a further development of the topic, considering also cavities in different types of rocks in the urban area and involving also more specific examinations.

4. CONCLUSION

The case study of the archaeological park of Centocelle presented, in its complexity, many hints for different geomatics applications. The proposed method was suitable to answer to the proposed archaeological questions on the aspects of archaeological feature identification, allowing to recognize new structures and to visualize the already excavated Villa ad Duas Lauros and Villa della Piscina, currently covered by soil and waste. The DEM and DTM models extracted from historical and recent datasets allowed to evaluate topographic features related to the exploitation of the local litotype. The 3D model allowed understanding the toolmark dispositions and assigning to them a function. The monitoring method gave preliminary results that must be further verified by considering in situ measurements and testing trials also on other areas of Rome, studying the responses also considering the litotypes in which the galleries develop and the surrounding conditions. The method is proposed as a speditive tool to monitor the archaeological presence in cities, in order to limit urban growth in these areas and to submit them to the attention of the competent bodies in terms of conservation and valorisation.

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