ISSN 1828-5961

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UAVs and GIS models for landscape representation

The research aims to explore the representation of the landscape through methodologies and experiments that involve information systems aimed at reading and representing the landscape.
The general objective of this project is to define a methodology that integrates data acquisition with the use of unmanned aerial vehicles (UAVs), point cloud management in GIS (Geographic Information System), and the cataloguing of information and the representation of landscape components through representational maps and 3D models in GIS.
This workflow is aimed at promoting and improving the documentation, management, and enhancement processes of territorial heritage.
The research thinks about the possibilities of information systems to transfer and assign an added value in the process of knowledge of the landscape, and to be exhaustive in the aspects of Representation, through maps and three-dimensional models. The case study is a part of the Caffarella Valley in Rome, near the Vaccareccia farmhouse, inside the Appia Antica Archaeological Park.
The first phase concerns the aerial photogrammetric acquisition with a drone. The second phase involved the recognition of plant types through direct observation, collection of botanical samples, data cataloging and consultation with a botanist.
Processing in the GIS environment involved: importing the point cloud; its classification; the processing of DEM, TIN and isoipse; the construction of the three-dimensional model of the buildings of the farmhouse; the representation of vegetation systems and the assignment of information attributes; the representation of the arboreal essences with the informative attributes concerning the vegetative, botanical and metric-dimensional state.

Keywords:
UAV; SAPR; GIS; landscape representation; point cloud.

DOI: https://doi.org/10.20365/disegnarecon.29.2022.10

ISSN 1828-5961

INTRODUCTION

This research aims to explore the representation of the landscape through various methodologies and experiments. Specifically, these approaches involve information systems aimed at reading, analysing, and representing the landscape.
The general objective of this project is to define a methodology that integrates data acquisition with the use of unmanned aerial vehicles (UAVs), point cloud management in GIS (Geographic Information System), and the cataloguing of information and the representation of landscape components through representational maps and 3D models in GIS.
This workflow is aimed at promoting and improving the documentation, management, and enhancement processes of territorial heritage. This objective is explored through the case study of the Caffarella Valley in Rome[1].
In recent years, the use of UAVs for environmental monitoring and management has increased, thanks to operational flexibility and fast acquisition times in relation to the size of the areas under study. However, one drawback is their requirement of specialists for their use[2]. International research has been conducted on the utilisation of UVAs for the classification and recognition of plant species[3]. The monitoring of erosion phenomena[4] and coastal changes[5], and the identification of agricultural areas[6].
The problems inherent in the various components of the landscape require a wide range of interventions, including those designed for evaluation and control of the current state of affairs, documentation, safeguarding and protection, and the recovery, transformation, and enhancement of the landscape[7].
The process requires specialist figures belonging to different fields of knowledge. The technical, operational, and cultural tools must be able to support management, contribute to addressing interventions, and correctly convey the interventions on the landscape.
The disciplines of representation, which have always established a direct relationship with both natural and manmade contexts, can play an active, effective, and critical role within these processes[8].

Fig. 1 - Caffarella Valley in Rome, at the Vaccareccia farmhouse (photo by the author, 25 August 2021).

DOI: https://doi.org/10.20365/disegnarecon.29.2022.10

WORKFLOW

The case study chosen for the experiment is a part of the Caffarella Valley in Rome, near the Vaccareccia farmhouse, inside the Appia Antica Archaeological Park (fig. 1).
The area is characterised by a sixteenth-century farmhouse, which is still active in its agricultural production. A farm road aligned with the farmhouse structures the territorial organisation by uniting the higher areas with the valley. The Fosso dell'Almone runs transversely to this road. The vegetation is heterogeneous and depends on the presence of a ditch, volcanic soil (on the plateaus), and soil of marine origin (in the valley).
According to the methodology, the first phase of data acquisition involved the use of a UAV[9].
The data acquisition process was carried out through the following procedure: (1) markers were positioned on the ground to create the topographic base via GPS, which was aimed at scaling and georeferencing; (2) a flight plan was developed at an altitude above 25 metres; (3) aerophotogrammetric acquisition with a remotely piloted aircraft called DJI Matrice 210 V2 with Zenmuse X5S camera; shots of the frames were taken with an overlap of about 75%[10] (figg. 2-3-4).
The choice of this detection method was derived from the desire to acquire data from a large geographical region within a short time and to acquire data from inaccessible areas.
Disadvantages to the approach were the difficulties encountered in shaded areas, which, in the case in question, resulted from foliage and tree masses. This meant that it was necessary to accept a priori that not all plant elements could be observed in full.
The advantage, in addition to the expeditious acquisition, was to be able to acquire data from all the inaccessible areas, including those pertaining to the farmhouse, the areas totally occupied by vegetation and therefore not walkable, and the area inherent to the ditch at a lower altitude than the floor.
The second phase of the data acquisition process involved the recognition of plant types through direct observation, the collection of botanical samples, the cataloguing of data, and consultation with


Fig. 2 - Acquisition with DJI Matrice 210 V2 drone with Zenmuse X5S camera (photo by the author, 25 August 2021).


Fig. 3 - Overlap of frames by about 75% (graphic elaboration by the author).


Fig. 4 - Some frames taken in sequence by UAVs (August 25, 2021).

DOI: https://doi.org/10.20365/disegnarecon.29.2022.10

a botanist[11]. This phase allowed for the analysis of the plant elements and, therefore, the possibility of integrating the metric and dimensional components of the vegetation with the informative and descriptive parts in the GIS environment.
The third phase focused on the processing of the available data in a GIS environment, which consisted of importing the point cloud, evaluating and classifying the point cloud according to the individual components, constructing a 3D model of the soil, and developing a geographic information system for the plant systems of the portion examined.

POINT CLOUD EVALUATION IN GIS

The processing of the data acquired with the UAVs through Structure from Motion (SfM) made it possible to obtain the point cloud and orthophoto[12] (fig. 5).
The point cloud allows for the evaluation of metric and figurative data. It was imported into ESRI - ArcGIS Pro 2.7 through the geoprocessing operation[13] Create LAS Dataset[14] through which the data can be imported in .las format, with the spatial reference system WGS84 UTM Zone 33N[15].
In GIS, the evaluation of the altimetric data is possible through the visualisation of the points based on the elevation, which shows the cloud of points through a colour variation from blue to red.
The lower altitude in blue corresponds to the Almone ditch (+63.20 m ellipsoidal altitude = +14.75 m a.s.l.). The higher one in red corresponds to the height reached by some plant elements (+111.40 m ellipsoidal altitude = +62.85 m a.s.l.).
The visualisation of the points through the elevation allows the observer to understand the morphological trend characterised by the valley (lower) in the centre of the study area and by the portions of plateaus (higher) arranged on its sides. We can see the distribution of the linear plant masses along the Almone ditch, along the slopes, and in the plant groups on the upper parts, while the Vaccareccia farmhouse is located between the valley and the slope (fig. 6).
For the areas that were inaccessible during the inspections, the investigation of the morphological trends and the relationship between the anthro-

Fig. 5 - Orthophoto obtained from aerial photogrammetric acquisition with UAV (developed by MG Servizi di Ingegneria s.r.l, responsible for Andrea Gullotta).

DOI: https://doi.org/10.20365/disegnarecon.29.2022.10

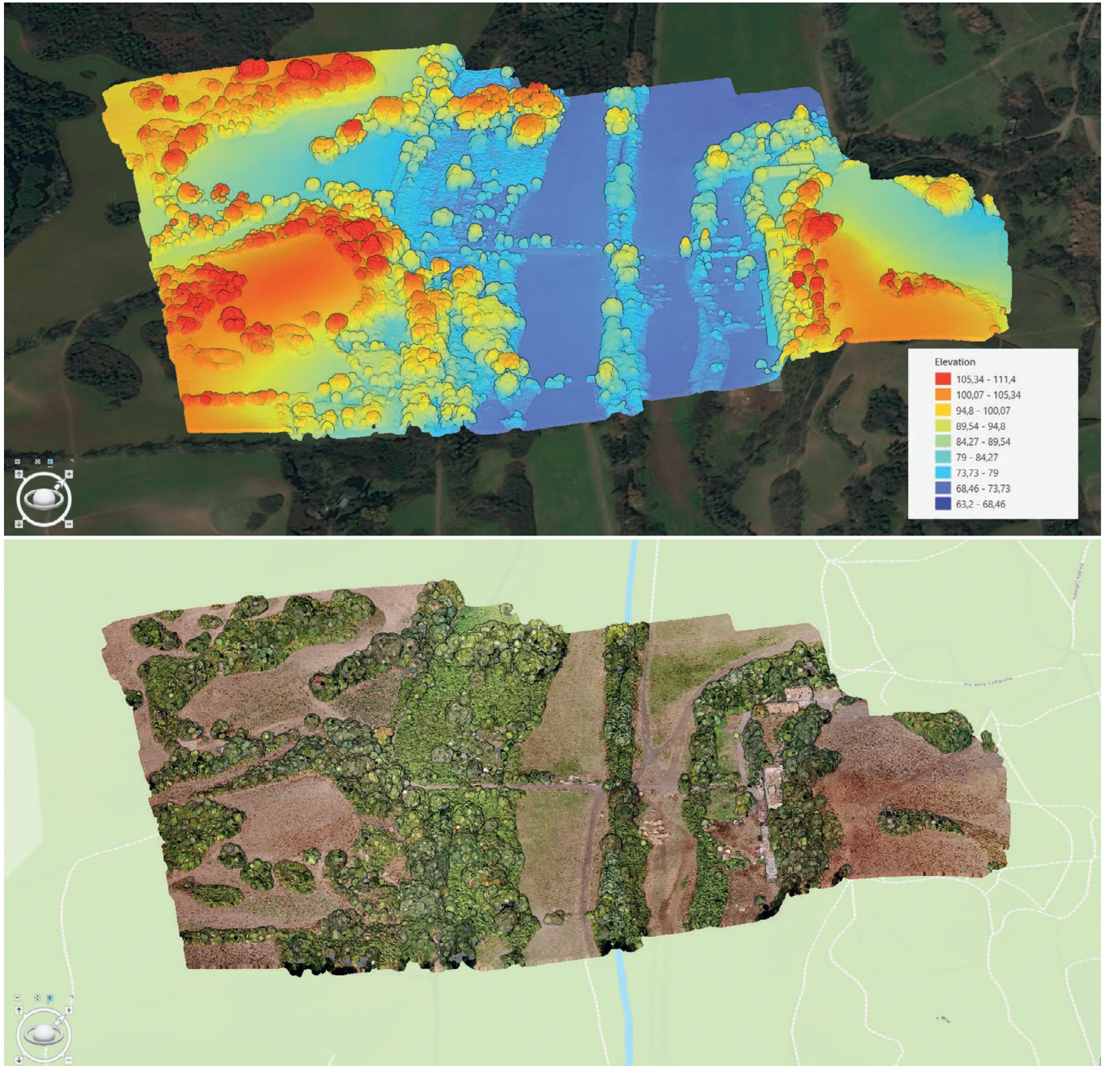

Fig. 6 - Top: Point cloud acquired with UAV, imported into GIS, georeferenced, and displayed with RGB data. In the background, the basemap consists of aerial photos presented by default within the GIS environment.
Bottom: Point cloud acquired with UAV, imported into GIS, georeferenced, and displayed with the elevation function, which expresses the elevation change through a colour gradient from blue (the lower elevation value) to red (the upper elevation value; elaboration by the author in ESRI - ArcGIS Pro 2.7).

pogenic and natural parts was performed through the analysis of the point cloud acquired with the UAV. For example, it was possible to understand the layout of the main body of the Vaccareccia farmhouse, which is located at the edge of the valley floor and close to the slope behind it, because there are plant masses arranged in rows upon it that follow the orography of the site.
This type of analysis was made possible with the surface draw method using an elevation function, which generates a visualisation with different coloured planes based on the elevation (fig. 7). Each point of the cloud, therefore, is spatially defined within the GIS through the geographic coordinates, the height, and the given RGB color.
The altitudes associated with the point cloud acquired with the UAV refer to the WGS84 ellipsoid, that is, the mathematical model of approximation of the earth's surface, since the GPS measures the geographical coordinates of the points referring to the WGS84 ellipsoid. These heights are ellipsoidal and not orthometric (i.e., above sea level), as we are used to usually reading in maps[16].
Figure 8 shows the same point with the height coordinates expressed in orthometric heights and subsequently expressed in the WGS84 reference system.

POINT CLOUD CLASSIFICATION IN GIS

After the first metric and morphological evaluation of the data, a phase consisting of the classification of the point cloud in GIS followed (fig. 9).
Classification is an important process in the management and processing of acquired data. According to the decomposition principle, starting from heterogeneous data belonging to a single set, the classification allows for the gathering of data with homogeneous characteristics into subsets.
In general, the ability to break down a whole into parts allows both the individual components and the whole formed by them to be read and understood.
It is clear that this type of processing is indispensable in the investigation of cultural heritage, be it architectural, urban, or territorial. Therefore, the experiments in this sense are useful since they

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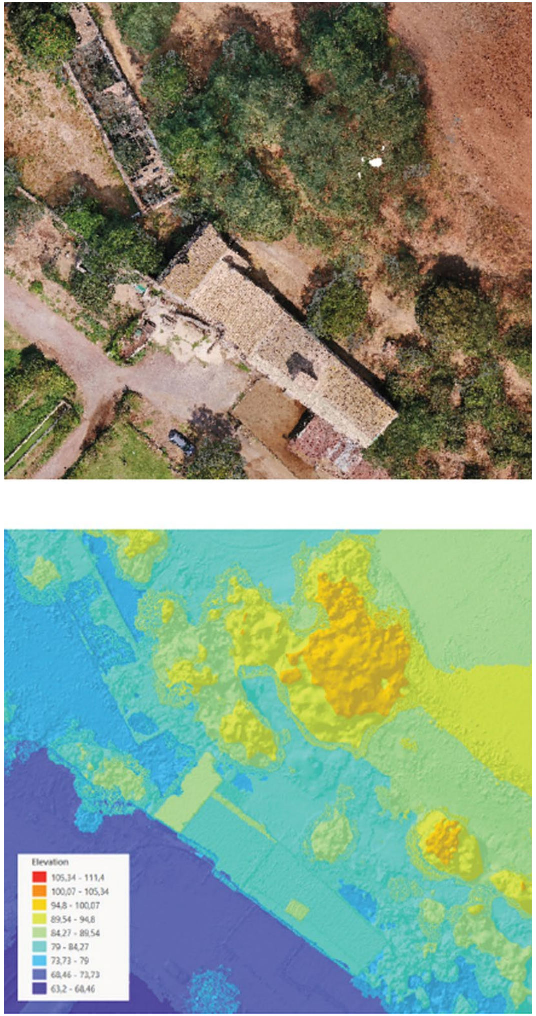

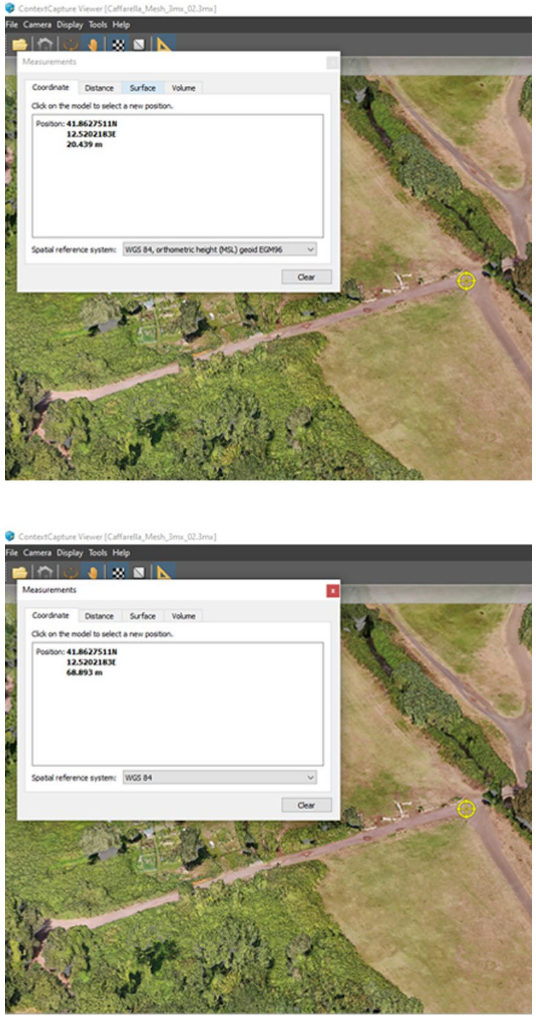

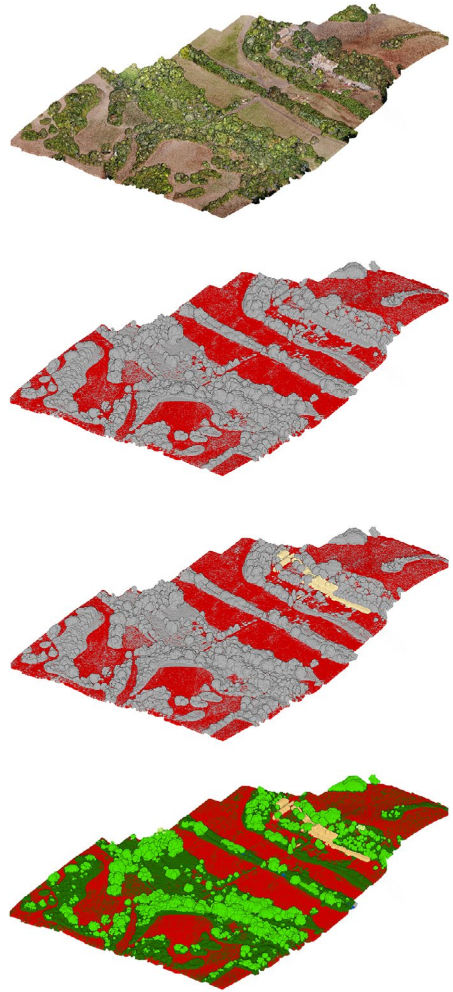

Fig. 7 - Top: Point cloud acquired with the UAV and imported into GIS, georeferenced, and displayed with RGB data.
Bottom: Point cloud imported into GIS, georeferenced, and displayed with the surface draw method using the elevation function, which generates a visualisation with different coloured planes based on the elevation (elaboration by the author in ESRI - ArcGIS Pro 2.7).

Fig 8 - Top: a point expressed in the WGS84 reference system has an altitude of +68.893 m.
Bottom: the same point expressed with orthometric altitude has the value +20.439 m a.s.l. (elaboration by the author).

Fig. 9 - Classification of the point cloud in GIS (from top to bottom): Point cloud with unclassified RGB data; soil classification; building classification; and classification of plant elements (elaboration by the author in ESRI - ArcGIS Pro 2.7).

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simplify and speed up the knowledge process. The classification is a preparatory step in the generation of three-dimensional models and two-dimensional drawings and facilitates the attribution of information to the overall system.
The first classified component, which was catalogued within a specific subset, was that of the soil.
The second classified component was that relating to buildings, which was processed manually by selecting the corresponding points belonging to the Vaccareccia farmhouse, and then assigning them to the class to which the buildings belong.
The third classified component was vegetation, which was obtained through the geoprocessing operation Classify LAS by Height, which allows for the points based on their height from the ground surface to be grouped and assigned to low, medium, and high vegetation categories.
This operation made it possible to better understand the distribution of tree masses and the trends of individual elements and plant groups, as well as to effectively distinguish between trees and shrubs. This aspect was preparatory to the subsequent phase of assigning the attributes (i.e., the descriptive information), but also to the construction of the model.
An additional phase of checking the automatic classification process was carried out, in which the errors in the assignment of points were checked and corrected.
The classification of the points, performed in both manual and automatic ways, provided a valid and useful means of visualising and filtering the point cloud, starting with the cognitive process of identifying the single components and then determining the reciprocal relationships.
The membership classes were obtained from the American Society for Photogrammetry and Remote Sensing (ASPRS), which defines the specifications for the classification of data with numerical codes associated with each separate component (fig. 10).

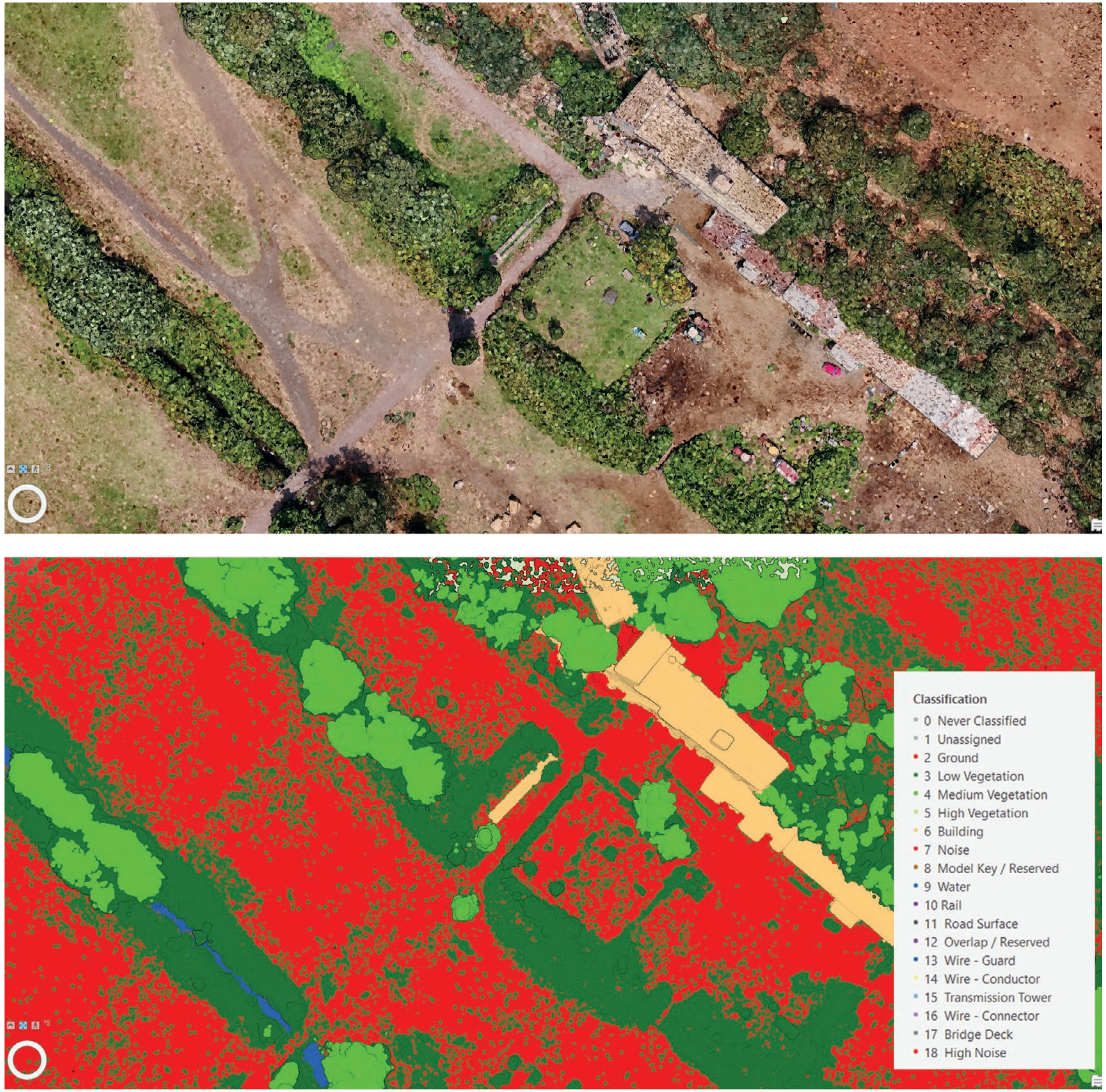

Fig. 10 - Top: Classification of the point cloud in GIS, with the respective codes assigned according to the ASPRS specifications. Examples: 2 = soil; 6 = buildings; 3 = low vegetation; 4 = medium vegetation; 9 = water. Bottom: Comparison with the same portion displayed with the RGB data (elaboration by the author in ESRI – ArcGIS Pro 2.7).

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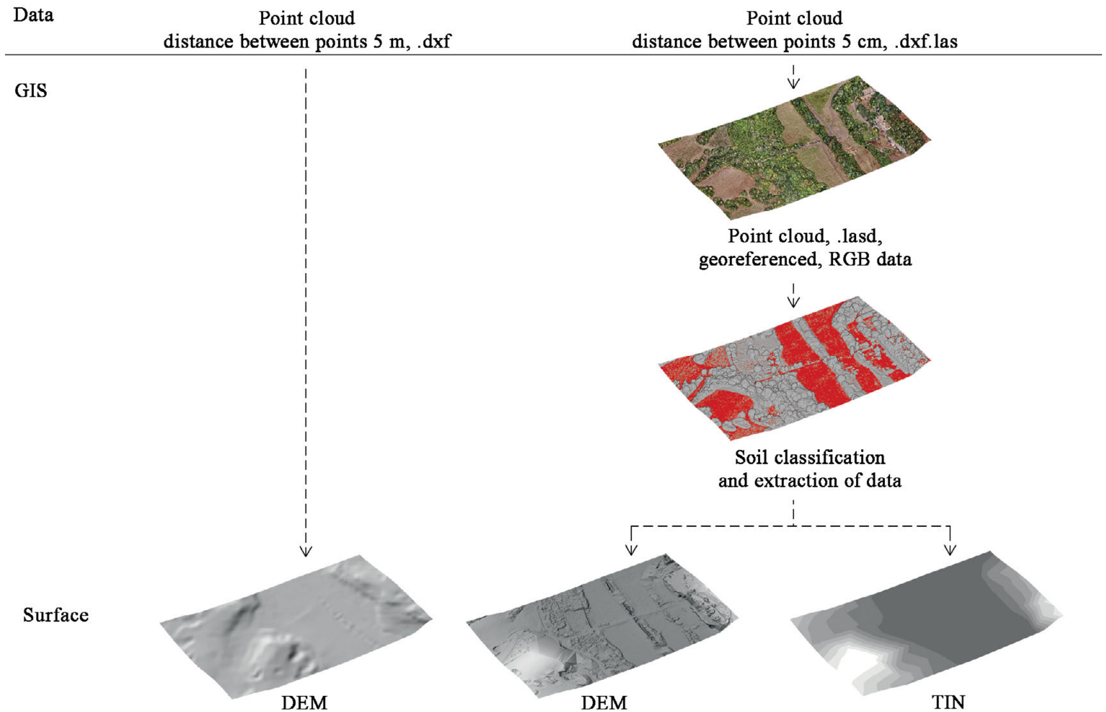
ISSN 1828-5961

GROUND SURFACES

In GIS, it is possible to develop a digital elevation model (DEM) and a triangular irregular network (TIN) to represent the morphology of the terrain.
The DEM is "a representation of the topographical surface of the bare soil (bare earth) of the Earth, excluding trees, buildings, and any other surface objects"[17]. Its format is a raster grid (i.e., a grid of square cells), each of which expresses the elevation value of the surface[18].
In contrast, a TIN, with the format of a vector, is an elevation surface formed by a set of points that make up the vertices of irregular triangles.
In the case in question, two types of source data were available to be processed: the first was the point cloud with a pitch of 5 centimetre obtained from the UAV, and the second was the point cloud with a pitch of 5 metres, represented in the CTR and available on the Lazio Region open data site[19]. Both datasets were processed to obtain an overview of the types of products in relation to the types of source data.
Initially, the 5 centimetre pitch point cloud in .las format obtained from the UAV was processed. This cloud was a numerical point model that contained the points of all the elements present in the area, including the soil as well as the anthropogenic and plant elements; consequently, it has the disadvantage of showing shaded areas concerning portions not acquired.
This cloud is called the a digital surface model (DSM), which is equipped with all the elements found on the earth's surface, including buildings and vegetation. In GIS, the model is georeferenced, so each point is associated with the geographical coordinates of latitude, longitude, elevation, and RGB value.
With the classification operation, the geometric data relating to the soil were extrapolated from the point cloud to generate an autonomous layer consisting only of the points belonging to the soil[20]. This operation was necessary to build the TIN surface of the terrain, consisting of irregularly arranged points and triangles[21].
The TIN is a three-dimensional surface in vector format; however, it contains a simplification of the orographic trend of the terrain, due to the decima-



Features, differences, similarities	- DEM - Raster - 2,5 d - Distance between points 5 m - Absence of shaded areas - Fast processing	- DEM - Raster - 2,5 d - Distance between points 5 cm - Presence of shaded areas, since it derives from a DSM (acquired points of all the elements found on the ground, such as buildings or trees) - Fast processing	- TIN - Vector - 3 d - Distance between points 5 cm - Presence of shaded areas, since it derives from a DSM (acquired points of all the elements found on the ground, such as buildings or trees) - More time-consuming processing than DEM - Simplification of the topography caused by the decimation in the elaboration phase of the TIN

Fig. 11 - Differences and similarities between the surface construction methods in GIS (elaboration by the author in ESRI - ArcGIS Pro 2.7)

DOI: https://doi.org/10.20365/disegnarecon.29.2022.10

tion of points during the processing of the TIN that is necessary for the computational calculation of the software. The TIN also has grey areas as a consequence of being a product generated from data that already had them. These were closed automatically during the processing process.
From the classification and filtering of the data of the point cloud belonging to the ground, it was also possible to build the DEM in raster format[22]. Compared to the TIN, the DEM had a better definition; however, it had closed grey areas during the processing phase.
The second experiment involved the construction of the DEM, starting from the point cloud at a 5 metre pitch based on the Regional Technical Map available on the Lazio Region open data site. This DEM had no grey areas, unlike the previous one, since it was derived from data that did not include this disadvantagee[23]. However, it had a lower resolution, since the source data were based on a step of 5 metres (fig. 11).
In GIS, the use of TIN models is less widespread than the use of raster models, since they are more complex to construct operationally; furthermore, their processing may be less efficient than the processing of raster data.
Nevertheless, although DEM and TIN return the latitude, longitude, and elevation values for each point, the use of TINs should allow for better visualisation and management of the three-dimensional space and profitable management of the mutual relationship of the three-dimensional elements.
Finally, the soil surface was discretised through the extraction of isoipses from the point cloud in CAD and subsequently imported into GIS in such a way as to have the component of the vector polyline complete the various products (DEM and TIN) identifying the earth's surface (fig. 12).

PLANT SYSTEMS GIS

Knowledge of plant elements inevitably made use of the contribution of botanical science, therefore interdisciplinarity was a basic factor for the recognition and study of botanical species aimed at the correct cataloging of data.

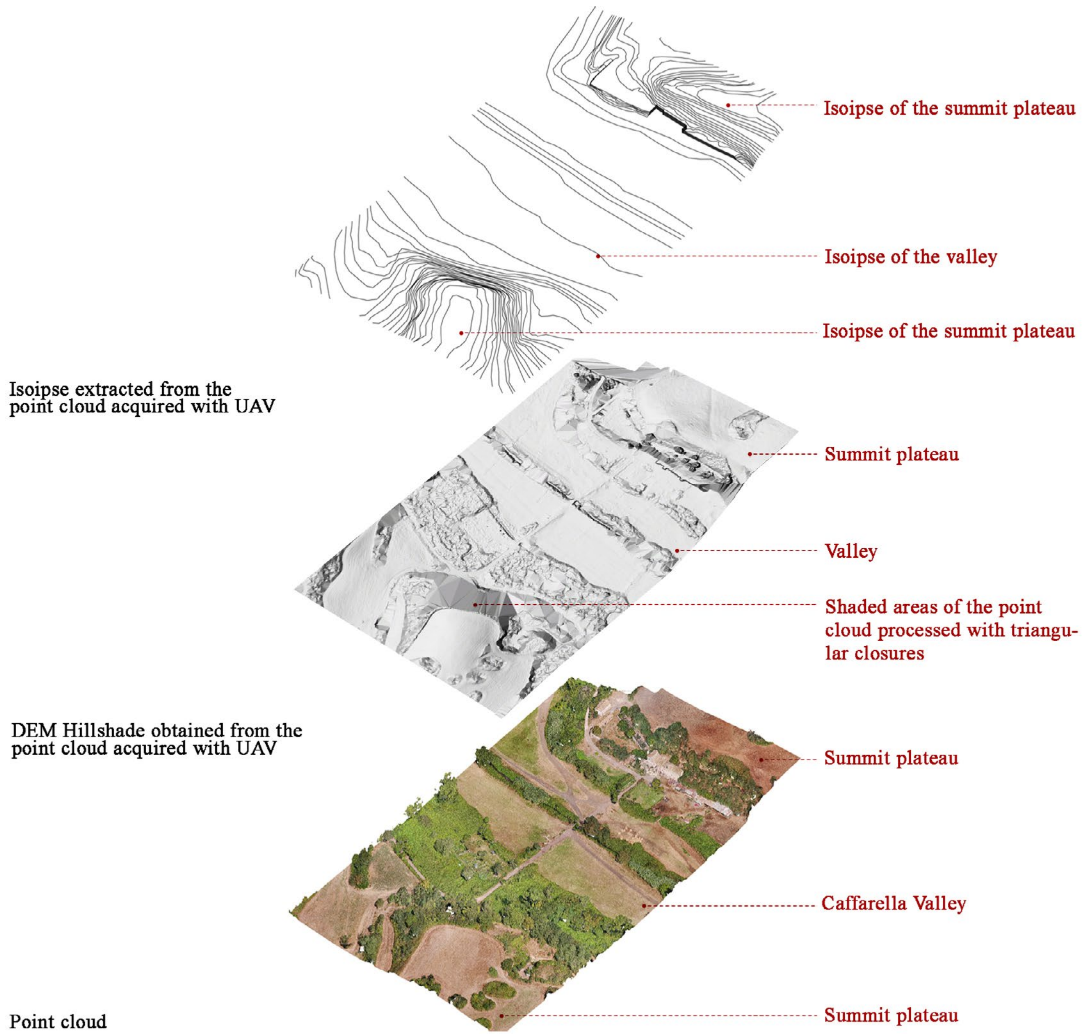


Fig. 12 - Point cloud, DEM Hillshade, and isoipse (elaboration by the author in Autodesk Autocad and ESRI - ArcGIS Pro 2.7)

DOI: https://doi.org/10.20365/disegnarecon.29.2022.10

The trees were the main object of this survey, since they correspond to the most recurring component, which contributes to defining the spatial organizational structure in a pre-eminent way.
The portion under examination comprises various areas; in fact, there are easily accessible areas characterized by single elements, by elements arranged in groups, or by elements arranged linearly. There are also areas that are not easily accessible or that are even inaccessible, since they are entirely occupied by plant elements. In this case, the use of UAV systems was useful and advantageous, as it made it possible to return the planimetric trend of the foliage and derive the height values of the plant elements.
The objective in this phase of the research was the analysis of plant systems, meaning not only the identification of shrubs and trees in the area but also their creation of a system, that is, a connection of elements in an organic and unitary. Therefore, the relationships between plant masses and their environmental contexts were examined.
The available data in the point cloud were useful for identifying the shape of the foliage and therefore for analysing the foliage's disposition. This can be point shaped if the element is arranged in isolation, linear if the element is arranged in a line, or areal if the element constitutes a group with others. The point cloud's elevation function, in addition to the orthophoto derived from it, made it possible to return the formation of plant elements (fig. 13).
Figure 14 shows the plan of the investigated area, obtained from GIS through the processed data. It was a prerequisite for the creation of the plant component's informative attributes. The attributes have been catalogued by assigning the *predominant species*, *disposition*, *classification*, *field*, and *soil*.
The *predominant species* describes the most abundant species in an element through its scientific name and vulgar name.
The *disposition* identifies the element's conformation, whether point, linear, or areal.
The *classification* indicates whether the element is arboreal or shrubby.
The *field* describes the physical landscape on which the element is located: the ditch, the valley floor, or the slope.

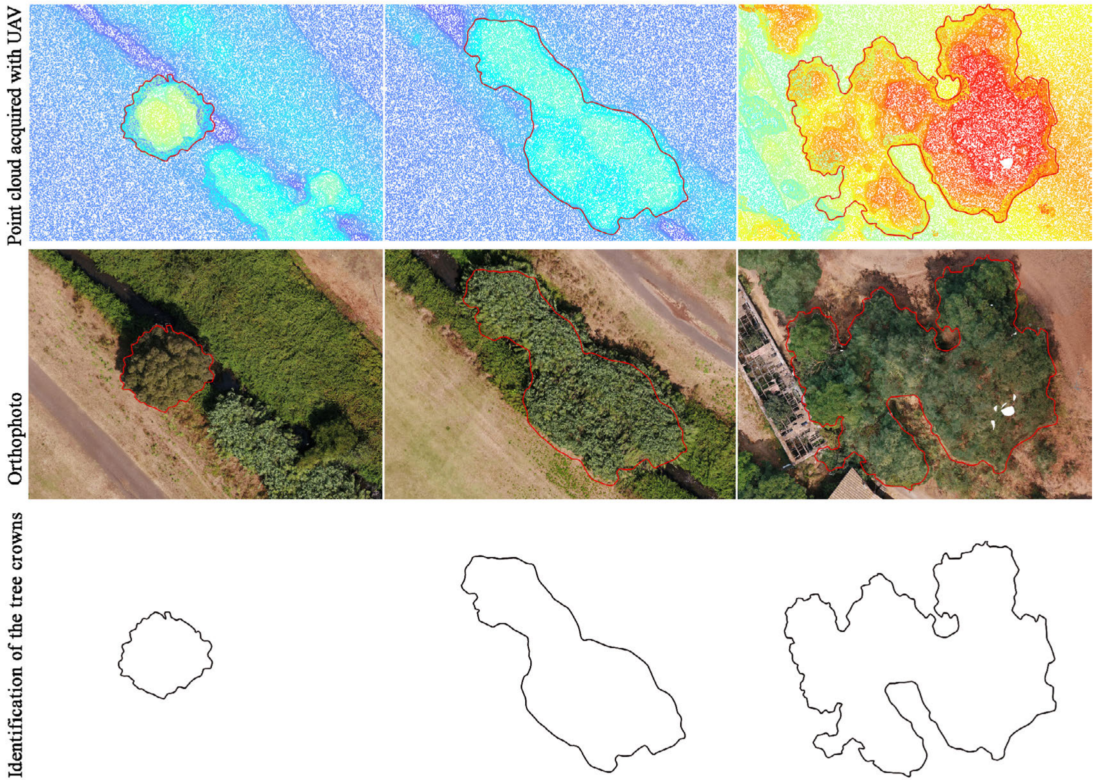


Fig. 13 - Identification of the crowns of the elements with punctual, linear and areal formation on the basis of the orthophoto derived from the point cloud and on the basis of the point cloud displayed using the elevation function (elaboration by the author in ESRI - ArcGIS Pro 2.7).

Soil indicates whether the earth is alluvial or volcanic in constitution.
The GIS demonstrates the different information in a single environment: the plant systems catalogued according to the prevailing species, the map or three-dimensional scene of the area, the integral attributes, and the specific details for each individual element (fig. 15).
The information system as a whole works on the basis of multiple descriptive and graphic data. It makes use of a variety of information that is displayed simultaneously for use and querying. The data entered for the management and processing of this information are derived from different disciplines and are intended for analysis and knowledge of a predominantly natural environment, which has a strong historical value[24].
The analysis of environmental characteristics allows for the assignment of information attributes[25]. The analysis of plant systems includes approaches and parameters from botany as well as approaches, methodologies, and criteria from

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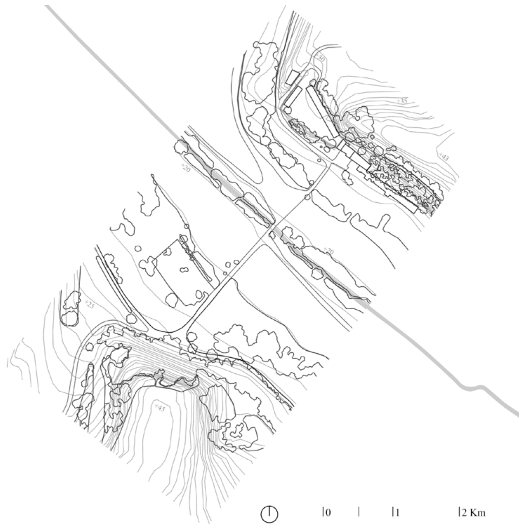

Fig. 14 - Plan of the portion of the Caffarella Valley examined with the identification of the tree and shrub masses (elaboration by the author in ESRI - ArcGIS Pro 2.7).

architectural studies (such as the propensity to investigate space).
The plant systems consist of riparian vegetation along the ditch area (which assumes a general linear conformation parallel to it), an arboreal and shrubby component on the valley floor, and woods on the slope.
Subsequently, it was possible to query the GIS according to the different parameters inserted into the attributes. The query of the prevailing species returns different maps depending on the query[26] (fig. 16).
The term geographic information system has multiple connotations, including database, searchable system, and information viewer[27]. In fact, it is a database, since it contains the set of descriptive and informative attributes entered and functions as a cataloguing and documentation service[28].
It is also searchable, and it is possible to request to show one type of information with respect to others. The query is usable through representa-

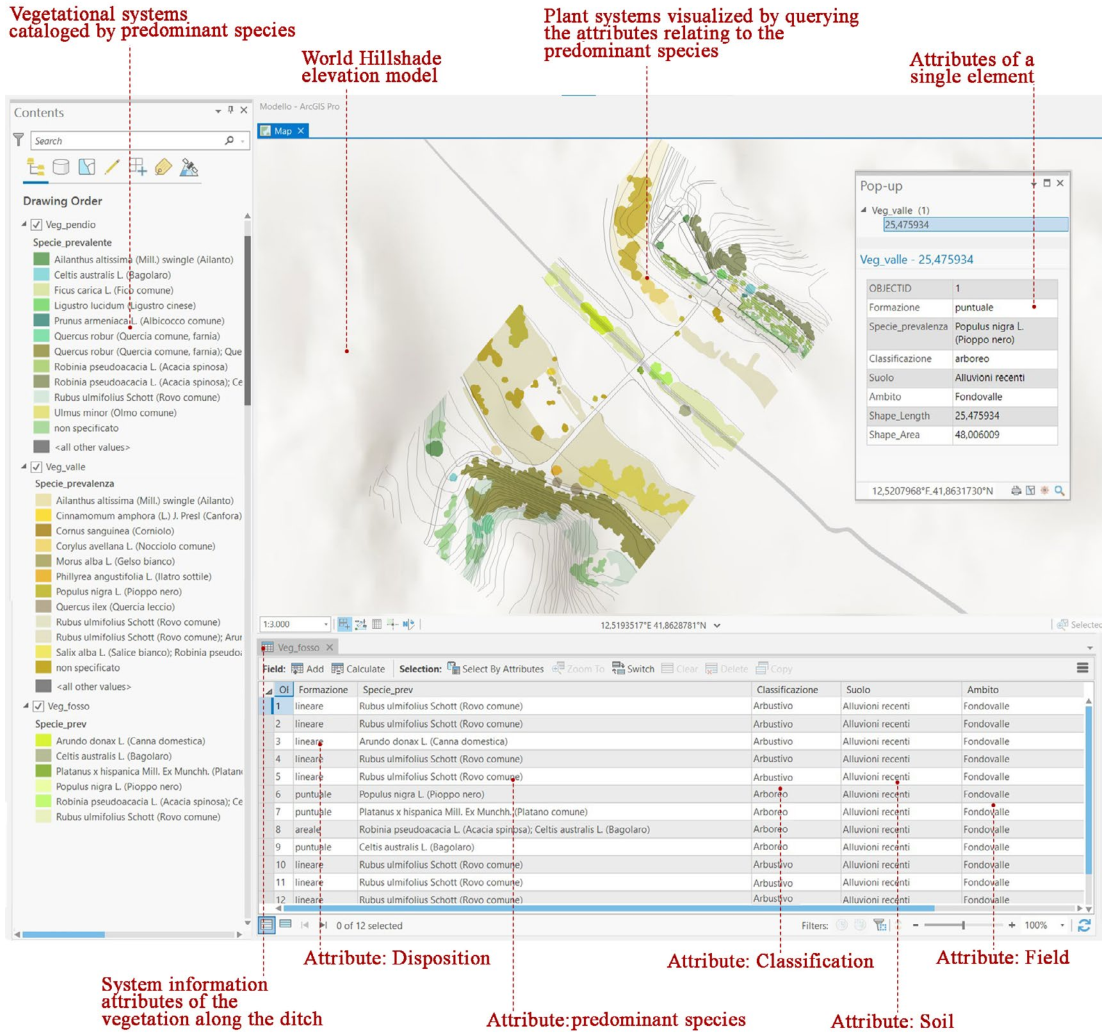

Fig. 15 - The information system on vegetation ensembles in ESRI - Arc-GIS Pro 2.7: cataloging by systems, attributes of each system, map displayed by querying the attributes (elaboration by the author in ESRI - ArcGIS Pro 2.7).

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Fig. 16 - Representation and visualisation of vegetational systems through the query of the GIS according to the attribute of the *predominant species* (elaboration by the author in ESRI - ArcGIS Pro 2.7).

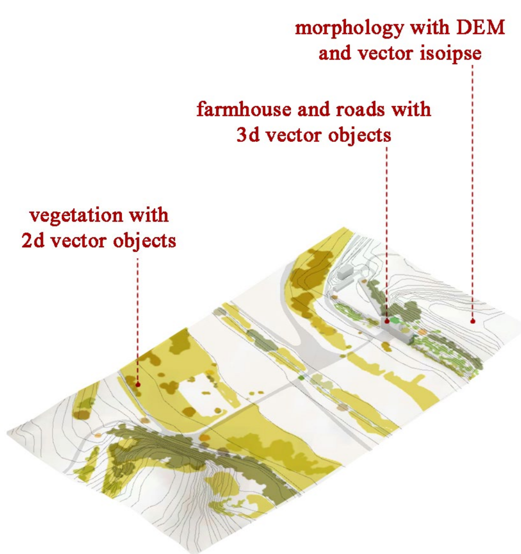

Fig. 17 - GIS hybrid model: morphology with DEM and vector isoipse; farmhouse and roads with 3d vector objects; vegetation with 2d vector objects (elaboration by the author in ESRI - ArcGIS Pro 2.7).

tion, which becomes an explanation of the information. In this regard, it is possible to query the GIS regarding the attributes of training, scope and classification. From these queries taken individually and interrelated, it is possible to understand the functioning of plant systems by returning a series of analyzes.
Furthermore, the botanical mapping superimposed on the terrain model made it possible to understand and represent the relationship between the plant component and the topography.
Figure 17 shows the GIS hybrid model with anthropogenic and natural components: the morphological part obtained with DEM World Hillshade and vector isoipse; the farmhouse built with 3D objects and the paths built with 3D vector polylines; the vegetation created with 2D polylines.
It highlights the mutual relationships between the components that characterize the historical anthropic landscape of a portion of the Caffarella Valley belonging to the Appia Antica Archaeological Park.
Subsequently, an in-depth analysis was carried out on a small area concerning the analytical study of a single plant architecture with the aim of investigating the potential for three-dimensional representation of tree elements in GIS.
Another purpose of this analysis was to assign the information particular to the individual in the system, including data dimensions, stationary data, morphological data, and defects that reveal the vegetative state[29]. The crowns are identified by the point cloud derived from UAV and georeferenced in GIS. Each plant element was identified with a point vector[30].
Subsequently, the information system of plant architectures was designed from the assignment of the information attributes associated with each punctual vector element that determines the individual tree.

General data relating to botanical aspects were included[31] (genus, species, family, division, class of gardener), as well as dimensional data (total height, trunk diameter, crown diameter) and stationary data concerning the site (dwelling, soil, disposition). Data relating to the morphological characteristics (posture, exoticism, plant, age) and information relating to the plant element's defects (collar, stem, branches, crown) have also been added[32].
There is a geometric-graphic aspect, with two-dimensional and three-dimensional elements, which in the case of plant architectures has punctual vectors, or three-dimensional elements with simple geometry or three-dimensional elements with realistic geometry. Then there is the information aspect, in which the value of the database is revealed in its meaning as a container capable of managing, organizing and accommodating a considerable and varied number of data, which can be consulted with agility.

CONCLUSIONS

Technological innovation involving all sectors of knowledge has made it possible in recent years to coordinate the typical complexity of open spaces and landscapes. This process of renewal and transformation involves both data acquisition methods and their management.
In the enhancement of cultural heritage, understood as the set of built assets and environmental contexts, all those processes of acquisition, management, and representation that support the phases of documentation, knowledge, and recognition of open spaces of the landscape and the territory are to be favoured and encouraged. Tools and methodologies are needed that are able to synthesise the spatial organisational structure and plant systems in a language that is configured as a model of reality, with the aim of promoting site analysis and interpretation.
If the Piano Nazionale di Ripresa e Resilienza (PNRR) has among its objectives the digitisation, innovation, and safety of the Public Administration (Mission 1 - Component 1), as well as the protection of the territory and its water resources (Mission 2

DOI: https://doi.org/10.20365/disegnarecon.29.2022.10

ISSN 1828-5961

- Component 4), in our time and our country, we must prioritise issues involving the landscape and the territory together with their management, documentation, and enhancement by public bodies[33].
The results of the research presented here are related to these themes; in fact, this particular project led to the definition of a geographic information system of the Caffarella Valley aimed at representing the area through a mapping of the components, particularly the vegetation, to conduct investigations aimed at documentation and the advancement of knowledge.
The information system works on the basis of multiple data of a metric, dimensional, descriptive, and graphic nature. Its use and interrogation show that various types of information can be viewed at the same time. The searchable information and the models that can be consulted within it are made possible thanks to a methodological process based on data acquisition from the UAV aerial photogrammetric method, as well as the management and processing of metric-dimensional and descriptive data.
Two innovative outcomes have emerged, which include the possibility of having a coherent workflow between data acquired with a UAV and data processed in GIS, and the possibility of three-dimensional modelling.
The use of an information system allows for the systematisation of information in support of the development of knowledge[34]. The system is able to prepare an integrated set of geometric-dimensional and formal-iconic data that represent both the built architecture and the components of the landscape.
This has allowed us to obtain cognitive models that include spatial aspects that are geometrically and dimensionally defined, including a descriptive apparatus, a database for archiving, and a geographical location on the earth's surface. Therefore, the functioning of this information system "allows to return in an integrated way all the available databases prepared for continuous updates"[35].

NOTE

[1] The research presented here is part of a doctoral dissertation on landscape representation involving contemporary information systems, which was completed in 2022 at the Department of History, Drawing and Restoration of Architecture of Sapienza University of Rome. PhD: Sara Colaceci. Tutors: Emanuela Chiavoni, Maria Grazia Cianci.

[2] Miraki, Sohrabi e Esmailzadeh 2022, pp. 921-926.

[3] Guerra-Hernández *et al.* 2017, pp. 1-19. Gini *et al.* 2018, pp. 1-18. Baena *et al.* 2017, pp. 1-21.

[4] Bazzoffi 2015, pp. 1-18.

[5] Pagán *et al.* 2019, pp. 1034–1045.

[6] Wang *et al.* 2022, pp. 1-12.

[7] Bianconi e Filippucci 2018, pp. 15-22. Chiavoni e Tacchi 2019, pp. 397-408. Cianci 2008a. Cianci 2008b.

[8] Gregotti 1991, pp. 2-4. Salerno 2019, pp. 23-32.

[9] This process was developed through the consultancy with MG Servizi di Ingegneria s.r.l., responsible for Andrea Gullotta, who dealt with the administrative procedure regarding the request for authorization to the National Civil Aviation Authority (ENAC), the flight of the aircraft and the elaboration of the Structure from Motion (SfM).

[10] Technical data: Remotely piloted aircraft: DJI Matrice 210 V2. Camera: Zenmuse X5S. Sensor: CMOS 4/3", 17.30 x 13 mm. Resolution: 20.8 MP. Image pixels: 5280 × 3956 px. Flight altitude: 25 meters. Number of shots: 1400. Frame overlay: approx. 75%. Total time of the acquisition phase: 3 hours. Area of the acquired portion: about 300 x 500 meters, about 15 hectares. GSD: 2cm / pixel.

[11] Consultation was with the botanist Giovanni Buccomino.

[12] Point Cloud Processing Software: Bentley ContextCapture. Number of points: 173 million.

[13] Geoprocessing is a set of tools for processing geographic data, performing, spatial analysis, and managing GIS data in an automated way.

[14] Create LAS Dataset generates a standalone file that references the point cloud. "The LAS dataset is a standalone file that resides in a folder and references the data in the .las format". (https://pro.arcgis.com/en/pro-app/latest/help/data/las-dataset/create-a-las-datasets.htm). Last consultation on 12 October 2021.

[15] WGS84 (World Geodetic System 1984) is the datum that defines the ellipsoid that approximates the surface of the Earth. If we hypothesize its surface at the average sea level, we obtain a physical model called Geoid, which is neither an ellipsoid nor a spheroid. The Geoid has a complex mathematical formulation and therefore approximates the surface of the Earth to an ellipsoid. The WGS84 datum is the most well known form and is used by current GPS. Biallo 2005, pp. 68–69.
Among the different projections, we cite the Universal Transverse of Mercator (UTM), which is the universal transverse projection of Mercator, a projection of the Earth's surface on a plane (32N and 33N spindle).

[16] The altitude indicated in the maps is the orthometric altitude (i.e. the one that indicates the value above sea level), therefore referring to the surface of the Geoid. The GPS, in contrast, measures the coordinates of latitude, longitude, and altitude by referring to the surface of the ellipsoid WGS84, which expresses the ellipsoidal altitude. The Geoid and ellipsoid almost never coincide. In Italy, the difference between the Geoid and the ellipsoid is 40–50 metres.

[17] (https://www.usgs.gov/faqs/what-a-digital-elevation-model-dem?qt-news_science_products=0#qt-news_science_products). Last consultation on August 17, 2021.

[18] Shingare, Kale 2013, p. 2413. Bartłomiej 2017, p. 84.

[19] (http://dati.lazio.it/catalog/dataset/carta-tecnica-regionale-2002-2003-5k-roma). Last consultation on February 27, 2020.

[20] To generate an independent layer with only the ground points, the geoprocessing operation Make las dataset layer was initiated, which allowed for the points belonging to a specific class from the point cloud to be extrapolated in .las format.

[21] To build the TIN surface, the Las dataset to TIN geoprocessing operation was started, which generated an irregular surface made up of triangles starting from a set of points in .las format.

[22] To build the DEM, the Las dataset to raster geoprocessing operation was initiated, which generated a raster using the elevation values of the points in .las format.

[23] To build the DEM, the Point to raster geoprocessing operation was started, which generated a raster from a set of points in .dxf format.

[24] Calzolari 1999.

[25] De Carlo e Paris 2015, pp 547-554. Pierdominici 2016, pp.133-142

[26] Accettella *et al.* 1997, pp. 1-125. Buccomino, Stanisci 2000, pp. 1-15. Calzolari 1984, pp. 165-175. Simbolotti 1984, pp. 209-222.

[27] Bocconcino 2015, pp. 217-232. Novello e Bocconcino 2019, pp. 33-44. Ippoliti 2010, pp. 9-20. Bertocci, Bua, Parrinello e Picchio 2014, pp. 1-20. Parrinello 2012a, pp. 1-6. Parrinello 2012b, pp. 386-396.

[28] Burrough e McDonnel 1986, pp. 189-203.

[29] This topic is explored in Colaceci 2022, pp. 132-145.

[30] There are: *Ligustrum lucidum*, *Prunus sp*, *Celtis australis*, *Robinia pseudoacacia*.

[31] For the botanical classification see the Acta Plantarum website (https://www.actaplantarum.org/). Last consultation on 30 November 2021.

[32] A method for evaluating the stability of the tree is the Visual Tree Assessment (VTA), performed with the protocol of the Italian Society of Arboriculture. It is conducted with a visual approach and with specific equipment where necessary. (https://www.isaitalia.org/images/stories/documenti/Indispensabili/protocollo_vta.pdf). Last consultation on 01 December 2021.

[33] (https://italiadomani.gov.it/it/home.html). Last consultation on 25 August 2022.

[34] Bruno, Bianchi, Zerbi e Roncella 2015, pp. 189-203.

[35] De Carlo 2016, p. 26.

DOI: https://doi.org/10.20365/disegnarecon.29.2022.10

ISSN 1828-5961

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