WEB PLATFORMS FOR CULTURAL HERITAGE MANAGEMENT: THE PARCO ARCHEOLOGICO DEL COLOSSEO CASE STUDY

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ABSTRACT:

This paper describes the digitization test of Fonte Giuturna (*Giuturna spring*) in the Roman Forum area, from survey to data management through the in-use monitoring system, the WebApp SyPEAH of the Parco Archeologico del Colosseo. The location of Giuturna Spring, characterized by the presence of heterogeneous archaeological remains from different ages, was surveyed in May 2022 as part of a research project that aimed to superintend the entire Cultural Heritage digitization pipeline to provide the Archaeological Park Administration the digitization guidelines as a tool to standardize future surveys and data deliveries.
Inspired by the desire to build a system of protection and conservation at the service of sustainable exploitation, SyPEAH is a web platform based on open-source modules designed to manage archaeological records with a WebGIS approach. It supports the use of several 3D data formats, including point clouds. The paper focuses on the web platform, describing the web app's main features, especially in terms of point cloud data management. Moreover, possible future development of the platform intended to implement usability for single archaeological objects is described.

1. INTRODUCTION

The recent evolution of survey techniques and instruments showed a significant improvement in terms of ease of use, time-effectiveness of the ground activities, and quality of the final data output, bringing considerable benefits for the whole Architecture, Engineering, and Construction (AEC) sector. Among the AEC disciplines, the Cultural Heritage (CH) management field can indeed benefit from this evolution in the reality capture discipline, which consents to achieve extended, detailed, and systematic documentation for the Built Heritage. The increase in terms of the amount and size of the available survey outputs stresses the urgent need for research and development on topics such as the use of data, the methods, and the systems available for the fruition of the considerable amount of digitized information produced to the present day and that will be produced in the future. Moreover, it has to be considered that the CH field is characterized by heterogeneous professional figures with different expertise and background, both technical and non-technical, stressing the need for information management systems that should be user-friendly, efficient in data sharing, and proficient in the use also on the field.

1.1 Web Platforms for Cultural Heritage Management

Web platforms for 3D data sharing nowadays represent the most promising solution to address this need (Achille et al., 2012; Fassi and Parri, 2012). The panorama of the available solutions spans from the various open-source libraries to be assembled and customized in order to build a personalized platform to the already made solutions that can provide Software Development Kit (SDK) to the users with specific needs and to all-in-one commercial platforms that provide services on a subscription basis.

A web platform for 3D data management is a service based on web and cloud computing that provides access, interaction with the geometries, and in some cases, processing tools. The services provided generally include: (i) storage space for the hosted data, (ii) a rendering module for data visualization, (iii) annotation tools for measuring and labelling. Advanced processing tools that some services provide can be: (i) point cloud alignment and scan registration (ii) segmentation and object-recognition algorithms (iii) geometry-based analysis tools.
The Architecture, Engineering & Construction (AEC) sector in general and Cultural Heritage in specific can benefit from this emerging solution for managing three-dimensional data (Acosta et al., 2022; Fassi, 2020; Fregonese et al., 2012). The advantage related to the use of web platforms can be found in the possibility to deal with large point clouds or with mesh models without using specific, high-performance hardware and dedicated software, simply through a web browser (Bruno et al., 2020; Fassi et al., 2015; Giampaola et al., 2015). Since all the data are hosted and managed by the service provider, once the initial upload phase is terminated, the final user is relieved from using a considerable amount of heavy data locally. Both advantages mentioned before can result in cost savings in hardware or software. It has to be considered that several services require a subscription which amount varies according to the selected features and the available storage.
Another significant advantage is represented by the enhanced possibility of sharing up-to-date information and data between users, with a significant reduction in terms of data duplication and version proliferation (Achille et al., 2019; Fassi et al., 2017; Spettu et al., 2021). As the access to the platform is made through a web browser and that can be made potentially from any digital device, the rendering of the viewer interface usually adapts to the computational capabilities of the device. For the aforementioned reasons, web platforms for 3D data management ease the possibility of use also by non-technical figures and occasional

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users that do not have at disposal specific hardware and software for 3D data visualization.

The advanced features listed before, now available in few cases, outline a possible future development of the web platforms in terms of full management of the reality capture data, starting from the field data processing and continuing for the whole lifecycle of the digitized data.

As a final consideration, this progressive movement of data and processes into the various emerging cloud computing services stresses the urgency of reflecting on data's property and physical location.

2. CASE STUDY: THE AREA OF FONTE GIUTURNA

This paper describes the management of graphic information, one of the six levels or activities of the multi-parameter monitoring system SyPEAH (System for the Protection and Education of Archaeological Heritage), Parco Archeologico del Colosseo in Rome, Italy (Della Giovampaola, 2022, 2021a, 2021b). This case study is part of a research project that concerned the whole pipeline of CH digitization, spanning from the survey on the field to the data fruition using SyPEAH.

The primary outcome of the research project is represented by the digitization guidelines, a document that systematizes best practices and requirements for digitization and data upload on SyPEAH. This document is meant to act as a reference guide for the future digitization activities promoted by the PArCo administration and to provide specific requirements for the work of the professionals involved in those activities. Guidelines also describe the data processing and upload pipeline for the sharing on the SyPEAH platform.

The site chosen as the case study is located in the south-west part of the Roman Forum, one of the Colosseum Archaeological Park areas. The surveyed area is the surroundings of the Fonte Giuturna (*Lacus Iuturnae* - Giuturna Spring), a votive architecture built on the ancient site of a water spring in the II century BCE. It was chosen because it presents heterogeneous buildings and various architectural elements. The overall extension of the surveyed area is approximately 1100 m^2 and offers indoor, outdoor and underground spaces.

2.1 The survey of Fonte Giuturna

The survey was carried out in May 2022 using a multi-sensor and multi-technique approach with a target resolution of 5mm, suitable for the 1:50 representation scale minimizing the not-surveyed areas through sensor integration.

The survey was conducted with various instruments: (i) terrestrial Laser Scanner (101 scans) (ii) terrestrial photogrammetry for both interior and exterior areas (3988 photos), (iii) UAV photogrammetry (699 photos) and (iv) topographical network survey to reference and measure ground control points.

The final output is a unified Master Model filtered at 5mm resolution obtained integrating the various point clouds resulting from the different survey techniques. The master model covers the whole area of the Spring of Giuturna.

3. THE SYPEAH WEB PLATFORM

SyPEAH is a web platform based on open-source modules, developed with the purpose of monitoring a complex and extended archaeological site such as theParco, managing data at various scales and from heterogeneous sources (Della Giovampaola, 2022, 2021a, 2021b).

The data platform can manage can vary from satellite imagery to architectonic high-resolution point clouds or information taken from monitoring sensors to data from the repository of restoration activities and condition reports. The system can generate alerts about the condition of the archaeological remains based on sensor data, signalling made by users, or predictions made by the algorithms, considering all the available data.

Among the various features and tools that the platform provides, especially at the scale of the whole Archaeological Park as it is described in (Della Giovampaola, 2022, 2021a, 2021b), this paper focuses on the aspects of the platform that concern the use of point clouds and, in general, of survey products, describing the processes of data preparation, data ingestion by the platform (upload, conversion) and information management.

SyPEAH deals with point cloud and related information using three different open-source modules: geospatial information and data inventory are managed through the Arches web framework ("Arches Project," 2022), while point clouds are converted and visualized in two different environments according to the user needs. This aspect addresses the general purpose of the SyPEAH platform, which is to manage heterogeneous data both at the global scale of the park and at the architectural one of the single archaeological objects. The central core of the platform is the management of the Archaeological Asset records (*schede dei Beni Archeologici*, as defined in Della Giovampaola (2021a, 2021b), the pivot point on which all the information and modules are related.

The Archaeological Asset records can be displayed as space-pins on their geographical position together with other information in a 3D GIS environment. In this environment, SyPEAH uses the Cesium engine (Cesium GS, 2022) to render a light version of point clouds for visualization purposes, together with other simple 3D models that can be uploaded and processed by the system. On the other hand, it is possible to access high-resolution point clouds listed as related resources from the Archaeological Asset record. High-resolution point clouds are visualized through the Potree module ("Potree," 2022) which provides annotation and editing tools such as labelling, the creaton of bounding boxes, and cross-sectioning, among others.

3.1 Structure of the platform

SyPEAH is structured into two main entities guiding user interaction with the WebApp: viewers and records. Viewers deal with 2D and 3D data, allow users to visualize and compare different information, and navigate and select information to be shown. Records are specific datasheets that summarize the available information about a database object and its relations with other records of different typologies. The central record is one of the Archaeological objects representing the centre of the maintenance activity scheduling.

3.1.1 The WebGIS viewer:

The WebGIS viewer is the main access interface to the platform, as shown in Figure 1. The WebGIS interface allows users to visualize 2D, vector and raster data as maps. It also supports 3D data as schematic models and point clouds. Point clouds are visualized through the Cesium 3D tiles writing schema (Cozzi, 2015). The GIS viewer's main aim is to provide users a working environment to gather all the data and create effective spatial representations to support the decision process of archaeological maintenance and restoration events. The module provides a basic underlayer map or satellite (e.g., OpenStreetMap (OpenStreetMap contributors, 2023), Mapbox (Mapbox, 2023)) on which can be displayed more detailed maps that can be built inside the system using vector data (as shapefiles) and raster images such as orthophotos (Figure 2) or as described in 3.1.3. The WebGIS viewer works in geographical coordinates (WGS84 - EPSG:3857), and all the input data must be georeferenced to a

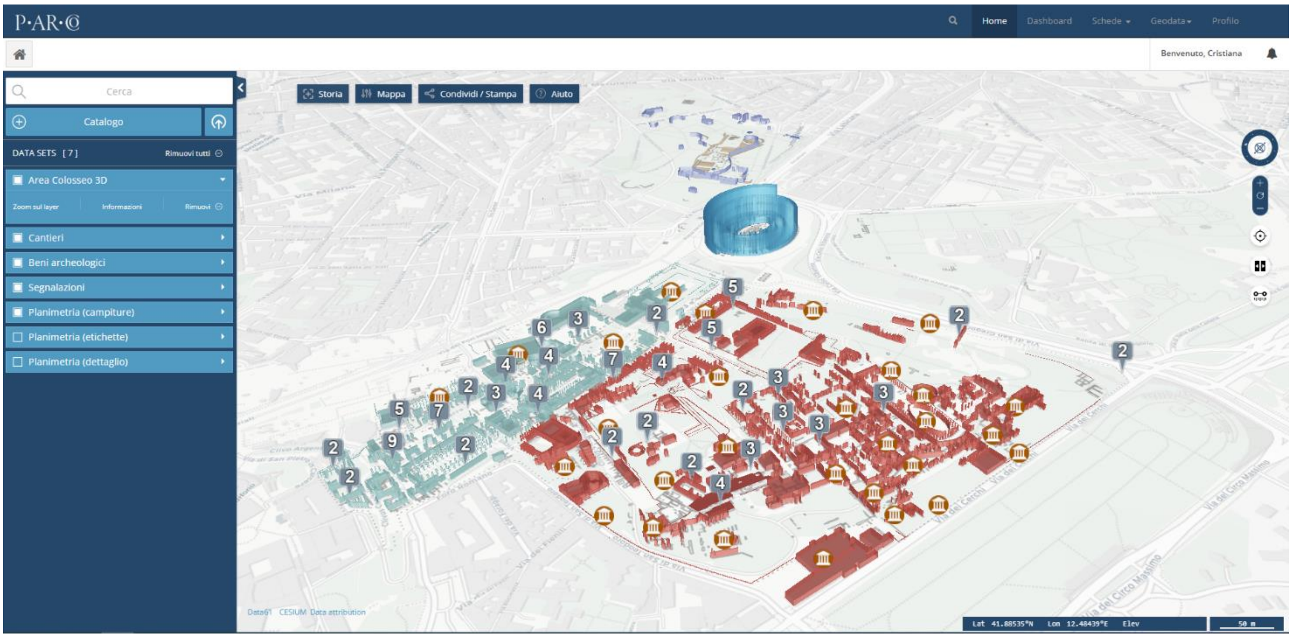

Figure 1. Overview of the WebGIS viewer, showing schematic 3D models of the objects present on the four areas of the Archaeological Park, with different colours.

known coordinate system to be visualized and point clouds (Figure 3).

3.1.2 The Potree viewer:
High-resolution point clouds are visualized in a specific environment through the point cloud record. The visualization is performed using the open-source module Potree, loaded in the 1.6 version. Potree works as a standalone viewing interface accessible through the Point Cloud record and manages also point clouds in the local coordinate system and not only in geographical or projected coordinates, as the WebGIS module. Potree can manage point clouds at various resolutions thanks to the point indexing system used by the converted cloud (Schütz, 2016; Schütz et al., 2020) and the possibility to adjust the amount of visualized points directly in the user interface. This is particularly significant when using point clouds with high resolution and large extension. The module presents various annotation tools that allow the user to take measurements of distance, area and volume, cut vertical sections, extract profiles and provides textual labelling tools (Figure 4). The Potree converter, in the version implemented into SyPEAH, supports point clouds in E57, LAS and LAZ format and can display most of its scalar fields, including the classification, that follows the scheme of Point Data Record Formats 0 to 5 as specified in ASPRS (2019).

3.1.3 The Archaeological Asset record:
The Archaeological Asset record is the pivot point on which all the information and modules are related to, and the main reference for the reporting and restoration planning activities.
The report contains all the relevant information for the planning of restoration activities. It gathers the related resources and

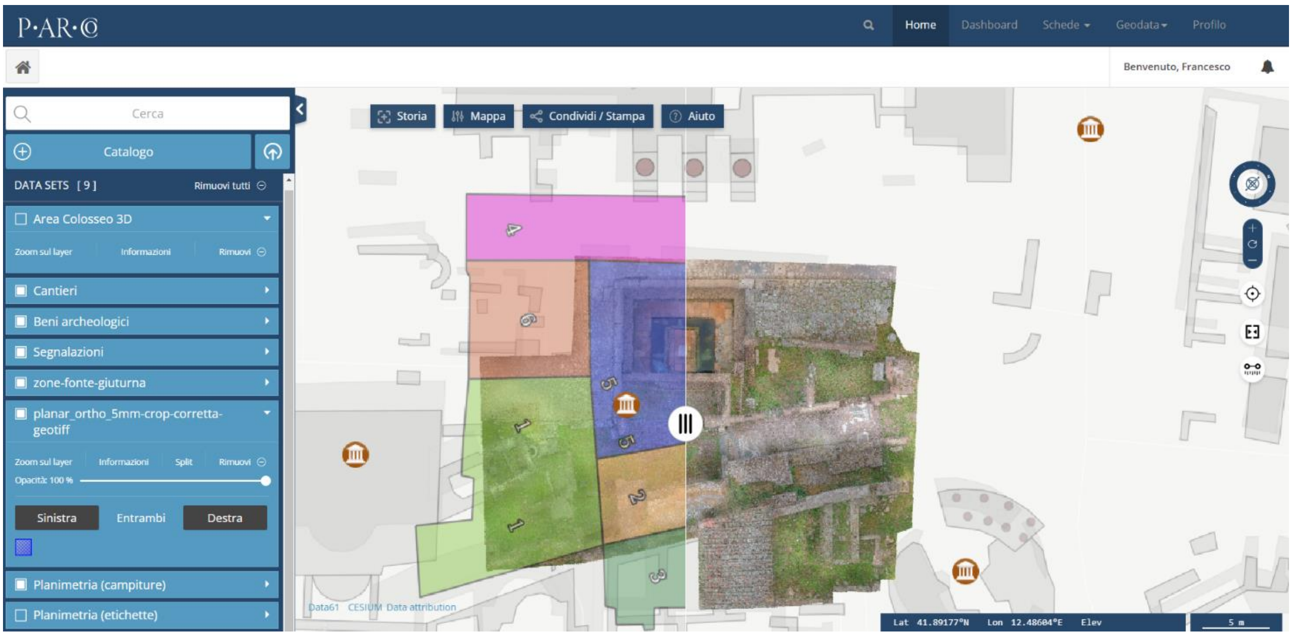

Figure 2. Split view of orthophoto and shapefile with the subdivision in survey areas.

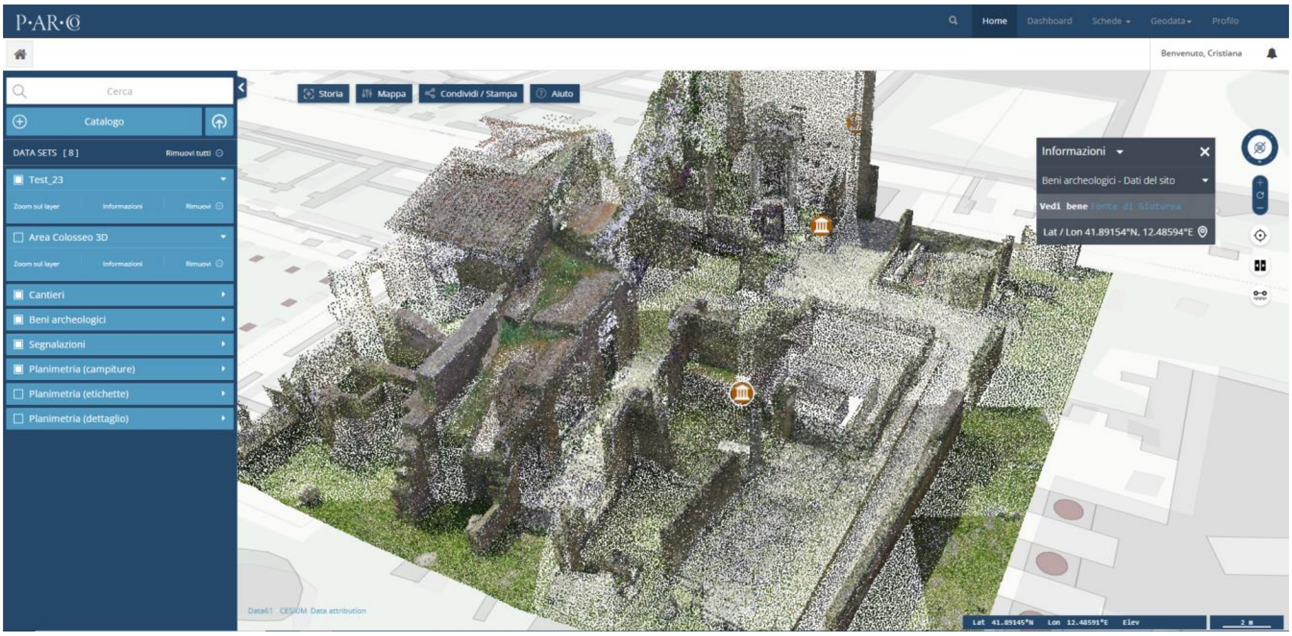

Figure 3. Rendering of the light version of the point cloud of Spring of Giuturna in Cesium format inside the WebGIS viewer. On the left is visible the dialog to access the record of archaeological objects.

objects available on the system. For related resources to an Archaeological Object is here intended another record object inside the SyPEAH database that presents as a tagged reference an Archaeological Asset and, in consequence, is listed among its related resources. Related resources can be point clouds, 3D models, or condition reports that have been redacted through time, among the various possibilities. Records are accessible via WebGIS viewer, displayed as icons in the general map, through name or attribute search and as links in the related objects' descriptions.

3.1.4 The Point Cloud record:

The point cloud record is the database object that defines point clouds into the system and allows users to access them and refer to the Archaeological Object record. From the point cloud record is possible to access the Potree viewer for 3D data consultation and access the list of alerts, described by a specific record and localized on the point cloud by a point mark (Della Giovampaola, 2021a). The record describes the underlying 3D Layer, that represents the point cloud (or, in general, the three-dimensional object) in the system database. This record is created during the upload phase. It refers to the data converted in the various formats during the upload, according to the specified input parameters, as shown in Figure 5.

3.2 Data upload

3.2.1 Point clouds:

Creating the 3D Layer record will enable users to upload various types of 3D data, e.g., point clouds, mesh models, and IFC models. For the point clouds, the supported formats are E57 (E57.04 3D Imaging System File Format Committee, 2023), LAS

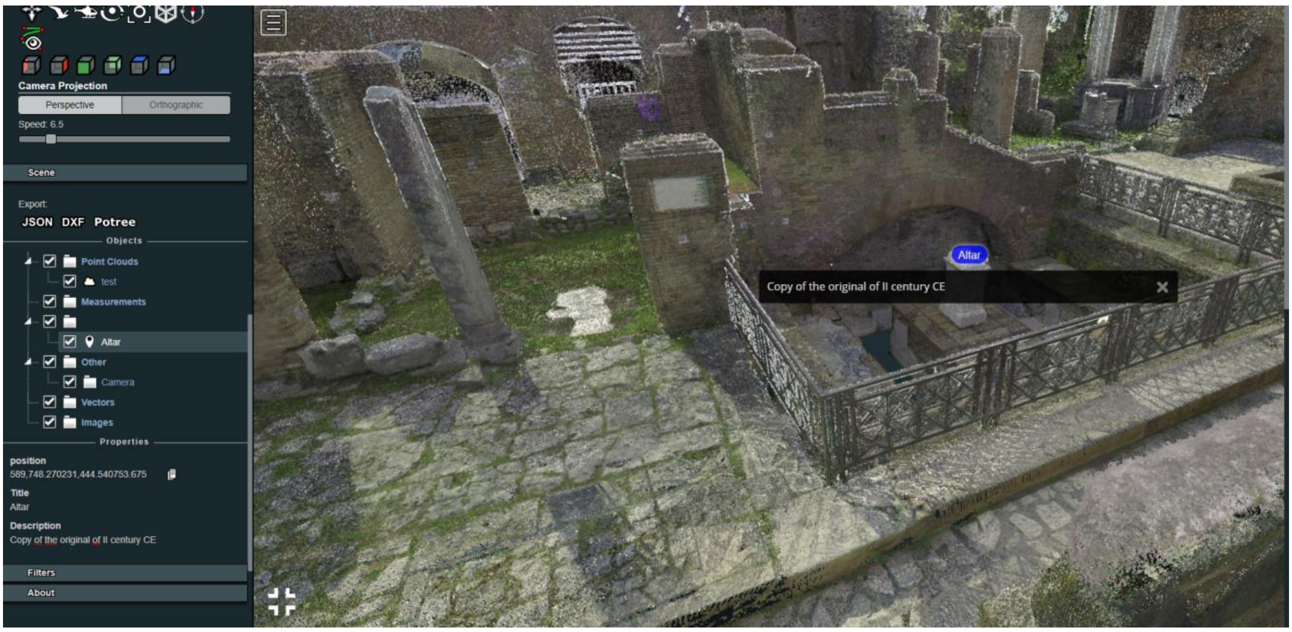

Figure 4. A detailed view of the point cloud of the surveyed area inside the Potree viewer with an example of annotation through labelling. The point cloud represents the full Archaeological Asset of Fonte Giuturna, accessed through its Record

(ASPRS, 2019), and LAZ. In this phase, it is possible to provide the converter inside SyPEAH with the coordinate system to which the point cloud is referred, specifying an EPSG code (Klokan Technologies GmbH, 2022) or a PROJ code (PROJ contributors, 2022). If the geospatial coordinate system code isset, the uploaded point cloud is converted in the Potree format and Cesium tiling; if not specified, the converter assumes that the coordinates are in a local system and the conversion is performed only for Potree, as shown in Figure 5. If the point cloud is uploaded in the E57 format, the converter processes it only for Potree, which does not support geospatial conversion. Once the upload of the point cloud is successfully completed, the data in the converted formats are available in SyPEAH as a 3D Layer that can be referred to and visualized through the Point Cloud Record.

3.2.2 Geodata:

The module dedicated to uploading geospatial data supports planar orthophotos in the GeoTIFF format and shapefiles for vector geometry. The vector layer’s appearance is managed by uploading a style information file in SLD format, which can be exported from standard GIS software. SyPEAH reads the coordinate system in which the data is referenced during the upload phase, and the geospatial layers are immediately available in the WebGIS module. The system also provides tools to create pre-defined maps to be used in the WebGIS module, with different layers and styles.

4. GIS AND HBIM [FS1]INTEGRATION APPROACH

4.1 The Technical Register of the Monument

Implementing the information management framework defined as the Technical Register of the Monument is a fundamental goal in the practice of the PArCo. The register is an activity of systematizing all the knowledge available and useful for the maintenance, management, and restoration of Archaeological Assets. This knowledge is also available as digitised data in the form of textual information, images, orthoimages, point clouds, 3D models, etc., concerning heterogeneous assets in terms of dimension, composition, building technique, material, and conservation state.
The primary purpose of the Technical Register of the Monument is to provide to the PArCo managers, archaeologists and restorers a complete, flexible and effective tool to plan and implement the restoration and maintenance intervention relying on qualitative data such as description and information records about the archaeological heritage and its condition, and on quantitative data that can be extracted from three-dimensional geometry both as derived representation (e.g., orthophoto, vectorial drawing) and as measures taken on the geometry. Combining qualitative and quantitative data is fundamental to precisely and consciously estimating the intervention costs and identifying possible problems and delay factors.
The Technical Register of the Monument is a framework able to provide, at the same time, an archive method for information management and operational support for daily activities on complex archaeological heritage sites.

4.2 The integrated approach

Implementing the Technical Register framework requires that the adopted information management system (e.g., a web platform) provides the needed granularity in terms of the level of detail of the data (De Nitto, 2022).
As described in the previous paragraphs, the SyPEAH platform is mainly oriented to GIS-like management and the park-wide

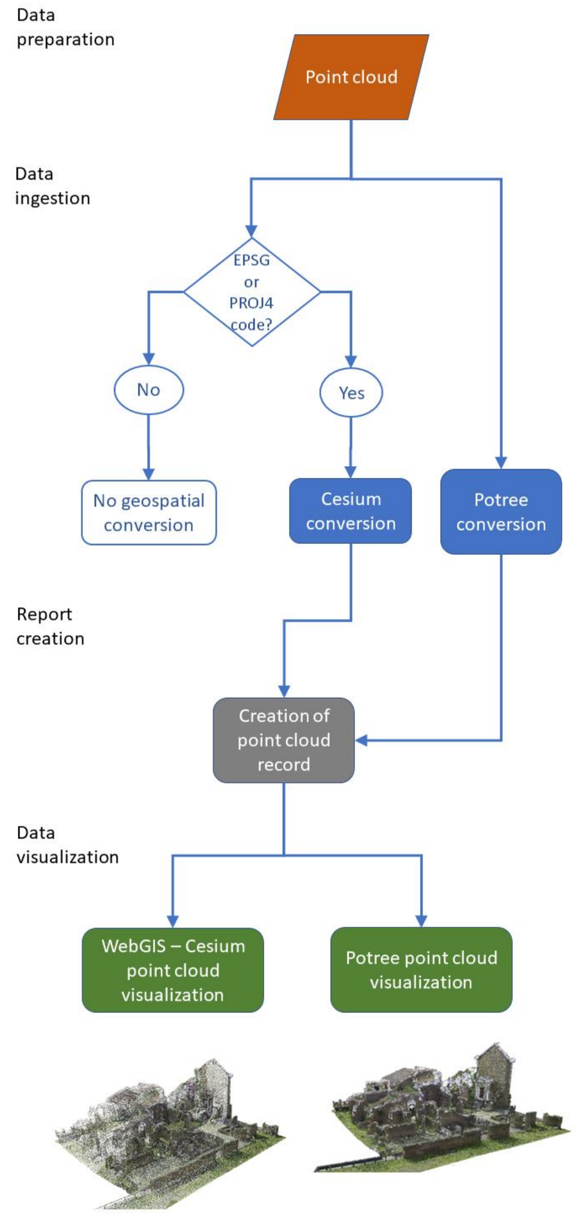

Figure 5. Schematic representation of the upload-conversion pipeline on the SyPEAH platform.

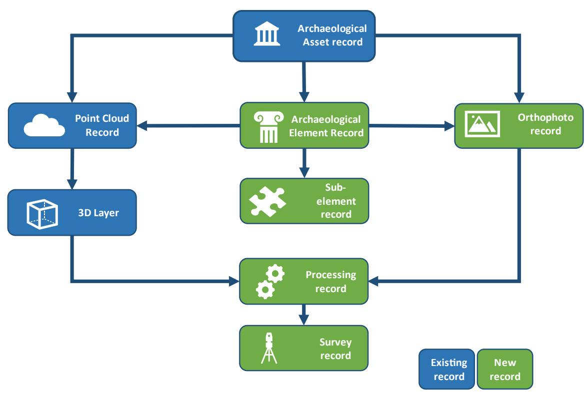

Figure 6. Representation of the relations between the different object records in the further development proposal of the SyPEAH platform

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scale. However, it supports visualization and annotation of point clouds at an architectural scale by implementing the Potree module.

Considering the significant dimensions of the Archaeological Park and the nature and diversity of the objects present, an informative platform dedicated to the management of the PArCo can benefit from a multi-scale approach and be adaptable to the dimension of the specific use case. This scenario is, at the present time, is now implemented and designed as a SyPEAH improvement.

This further evolution focuses on a more advanced use of the point clouds through Potree and on designing and implementing database entities specific to the architectural scale. Introducing new records improves the ability of the SyPEAH users to access data and information on a more granular basis, characterizing the single archaeological element and its components.

The multi-scale approach is believed to be particularly effective if applied to a case study that presents the need for a general overview and coordination for the whole park and, at the same time, the need to make decisions about interventions that focus on specific Archaeological Assets. The introduction of new database entities, which correspond to a logical and semantic subdivision of the archaeological area and more in detail, to a segmentation of the 3D data, answers the need to distinguish and characterize the different objects for precise documentation of the archaeological objects.

4.3 The Structure of the Data

4.3.1 Archaeological data:

The Master Model in the form of a point cloud produced by the test survey of the Giuturna Spring area has been manually segmented into elements according to the data structure inspired by the needs of the Technical Register of the Monument.

This semantic structure divides the Archaeological Asset into Archaeological Elements, defined as the minimum object the restoration interventions consider. The element can be identified as isolated archaeological remains or as part of a bigger structure, e.g., an architectural element.

The nature of this subdivision is mainly inspired by the needs of the restoration practice, although based on architectural logic. For this reason, a further possible subdivision into sub-elements has been provided to reach a detailed description of all the Archaeological Elements. Sub-Elements are defined as homogeneous components of architectural objects in terms of material and building techniques.

4.3.2 3D and 2D representations:

Reality-based representations are a fundamental tool to assess the condition and the geometrical characteristics of Archaeological objects, both as 3D models or point clouds and as technical drawings or orthophotos. Each representation constitutes a specific database entity that describes the condition of the heritage objects at the moment of the data capture. For this reason, its description within the framework of the Technical Register has to represent its main technical features (e.g., file format, coordinate reference system, resolution) and consider the information about acquisition and processing to assess its final quality.

4.3.3 Survey and processing data:

The information related to the data acquisition and processing phases is valuable to keep a record of the quality and resolution of the 3D and 2D representations of the Archaeological objects. For this reason, a framework to describe the characteristics of the reality capture process has been designed and systematized into the paradata tables inserted into the final database structure as specific entities that establish a semantic relation with the representation they produced.

4.4 Database Entities implementation

In order to apply the Data Structured that has been designed for the development of the SyPEAH platform, each of the mentioned semantic elements is implemented as a specific database entity in the form of a record, with the same logic as the ones already present into SyPEAH system, as described previously in paragraphs 3.1.3 and in 3.1.4.

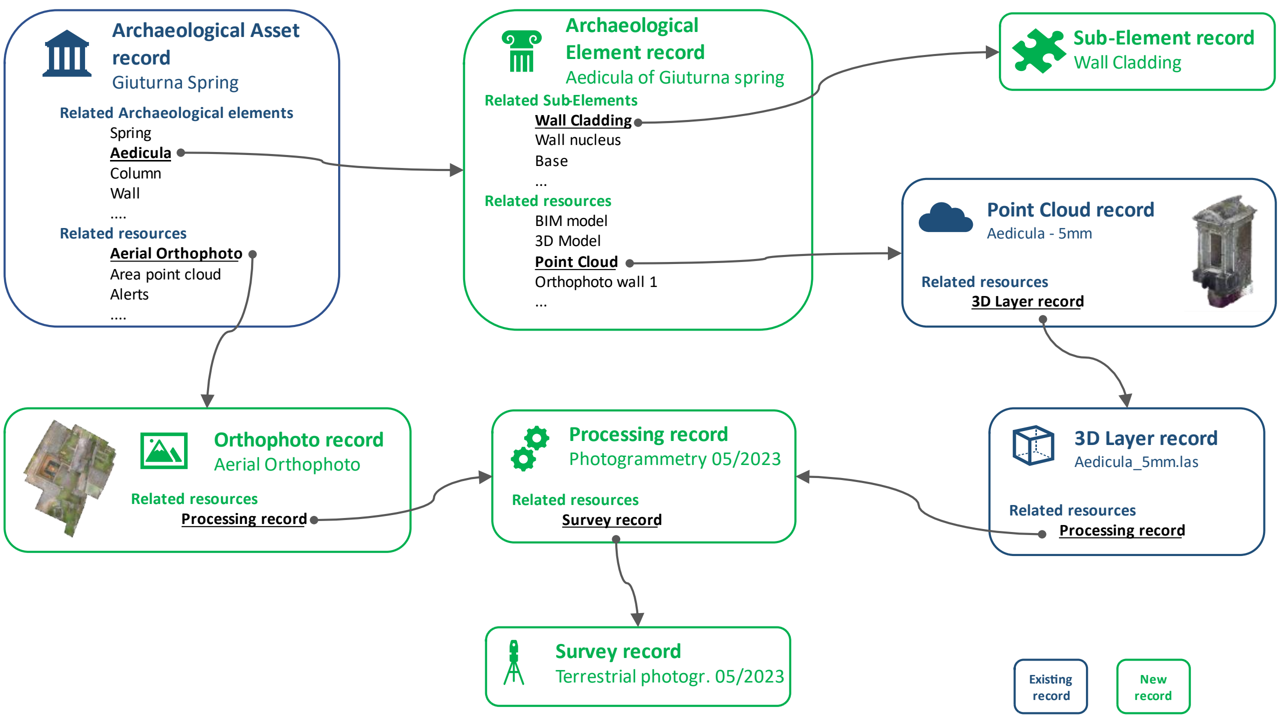

Figure 8. Diagram that shows more in detail the existing and proposed database records and the relations between them.

Each new record is designed according to its role in the framework of the Technical Register of the Monument, with informative fields and relations between records that are consequently determined. An overview of the structure and links between records is represented in Figure 6 and Figure 7.

4.4.1 Archaeological Element and sub-element record:

As described in 3.1.3, the central node in SyPEAH is represented by the Archaeological Asset record, which gathers all the information available on the considered object. This record is meant to describe the present conservation state of the element and list all the related resources useful for its condition assessment and description, such as high-resolution point clouds, horizontal and vertical orthophotos, technical drawings, and historical documents.
The Archaeological Element record keeps some of the main features of the Archaeological Asset record that are demonstrated to be effective and integrated with features specific to objects at the architectural scale.
The sub-element record follows the same logic but is applied to the even smaller scale of architectural components. This record aims to describe the composition of the Archaeological Element in terms of material and building techniques. It is designed as a text information record about physical characteristics and degradation phenomena.

4.4.2 Orthophoto record:

According to its main geospatial aim, SyPEAH supports only planar georeferenced orthophotos, as described in 3.2.2. Orthophotos at the architectural scale describe representative views of archaeological elements with a resolution that has to be adequate for geometrical description, chromatic characterization, and condition assessment. For this reason, was believed to be essential to implement the 2D representations of elements by creating an additional database record devoted to host orthophotos and providing all the related information, such as dimension, scale, and resolution. Survey and processing paradata, with their dedicated records, will be displayed as related resources to provide information about the representation’s date, quality, and responsible figures.

4.4.3 Survey and processing paradata:

The creation of a record dedicated to the survey and processing paradata (Denard, 2009) addresses the need to keep log of all the actions and processes that lead to a specific survey product (e.g., point cloud, orthophoto, mesh, etc.) to assess its quality and be accessed through time. For this reason, a record for hosting the paradata for the different typologies of survey and elaborate had been designed, using it as a reference to the schema proposed by Maravelakis et al. (2013). The arranged records include terrestrial close-range photogrammetric surveys, UAV aerial surveys, photogrammetric processing, and survey and processing of terrestrial laser scanning surveys. The survey and processing paradata records will be referenced as correlated resources inside the updated version of the point cloud record (see 3.1.4) and in the ones dedicated to orthophotos and other representations.

4.4.4 Navigation through the point cloud:

SyPEAH manages the navigation through the different Architectural Object records on the database using queries or symbols in the WebGIS visualization module. The increase in the number of available records on the platform described before stresses the need to have a proficient navigation system that has to be also intuitive and fast in use. Aside from the usual database query for names or attributes and the possibility of navigating through the relations between resources, point-cloud-based navigation is implemented. From the point cloud of the Archaeological Asset, inside the Potree viewer, it is possible to navigate through the records using localized icons on the specific objects, redirecting to the sublayer records.

5. CONCLUSIONS

The previously described research experience underlines the fact that management tools in Cultural Heritage should evolve according to technological improvements, on-field feedback, and increasing specialization of the involved operators.
Web platforms represent a promising and constantly implementing possibility for managers, archaeologists, and restorers and provide a suitable environment for collaboration and data sharing between different professional figures.
The evolution of informative systems from now on is a key feature for their constant use and to ensure a systematic, comprehensive, and detailed use and archive of all typologies of data related to Cultural Heritage.

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