The Role of Web Platforms in Balancing Sustainable Conservation and Development in Large Archaeological Site: the Naxos case study

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Abstract

Large archaeological areas or archaeological parks located within urbanized areas suffer more than other sites from anthropic pressure (urbanization and tourism), to which are added all the problems related to their conservation, safeguarding, fruition, management, maintenance, etc. Effective management strategies are essential. The use of Web Platforms in the management of 3D data is emerging as an effective solution for balancing conservation and development within large archaeological sites. This paper presents a case study of the Naxos Archaeological Park, Sicily, Italy. This case study highlights the role of advanced survey techniques, such as Mobile Mapping Systems and UAV-based photogrammetry, in generating extensive and comprehensive 3D datasets. It explores the possible contribution given by commercial web platforms for 3D data management in supporting design and development projects with reality capture data. Web platforms offer significant advantages by providing a shared environment for visualizing, interacting with, and processing large datasets. These platforms enable real-time collaboration among professionals with varying levels of expertise, fostering data sharing and reducing the need for local computing resources. This article provides a comparison methodology by testing and evaluating four commercial platforms: FlyVast, ATIS.cloud, Flai, and Cintoo, testing their functionalities and performances. It is then presented the adopted platform, Cintoo, and explained the reasons of the choice and its suitability for the project goal. Finally, it is provided an overview of the principal reasons that support the adoption of web platforms for sharing and collaboration supported by accurate 3D data, focusing on the potential cost reduction and efficiency.

1. Introduction

1.1 Background

The park and all related activities must be managed within organic planning: it is necessary to know how to program, how to produce acts of direction and coordination, and how to monitor the activities; then, it is necessary to take care of the study, conservation, enhancement, communication, and promotion of the assets contained in the park itself.

Another aspect concerns all those operations related to enjoyment and participation, which are also built by taking care of the relationships with the territory in which the park is located. As society's interest in cultural heritage (CH) grows, not only do experts intensify efforts to protect and restore these assets, but the public also increasingly seeks opportunities to access and understand them. This broadened public interest has diversified the user base for cultural heritage. Consequently, CH is assuming a significant social role in modern society.

A large archaeological site holds a dual identity: as a type of CH, it requires the protection for its historical, cultural, and aesthetic value; as a type of landscape, it should adapt to environmental changes and to the demands of contemporary societal and economical advancements. However, the conservation and development of such extensive areas inevitably require substantial investments of time, financial resources, and human capital.

The integration of digital technologies in large archaeological sites enhances management efforts by improving accessibility, visualization, and promoting sustainable practices. Starting with archaeological surveys to identify significant features and artifacts, 3D digital techniques are proving to conservation and development efforts. Compared with traditional surveying methods and static laser scanning, Mobile Mapping Systems (MMS) offer the ability to do fast surveys in large and complex areas (Fassi and Perfetti, 2019). When combined with Unmanned Aerial Vehicle (UAV) based photogrammetry, they could capture comprehensive 3D data and create an accurate 3D model of the site's features, structures, and topography. MMS, equipped with high-resolution laser scanners and cameras, collected precise point cloud data and 360-degree imagery of the ground-level features, while UAV-based photogrammetry acquired aerial imagery, providing a broader context and coverage of inaccessible areas.

These advanced survey techniques improve efficiency and reduce invasiveness in heritage areas; the cost/benefit ratio must be assessed case-by-case. MMS surveying is still expensive due to its specialized hardware and software (Di Stefano et al., 2021), but it offers the great advantage of allowing all spaces to be mapped quickly. Using different survey techniques provides for obtaining a complete and accurate 3D model, but today, one of the main challenges is how this 3D data can be accessed and used simultaneously by professionals and managers for conservation and development purposes and how different stakeholders can collaborate in an efficient, intuitive and cost-effective way.

1.2 Problem Statement

The demand for accurate 3D data from reality capture is constantly increasing as it is recognized as a powerful asset for documentation, planning, and design purposes. This fact stresses the need to address the topic of effective use of data that can be extremely heavy and difficult to be managed. A significant advancement in this direction is represented by the emerging web platforms for 3D data management (Fiorillo and Spettu, 2023), which allow users to share and access complex data and information through a Web App. The use of a web platform can be particularly useful for remote collaboration that involves professionals who may lack specific geomatics skills, have limited access to high-performance computing resources or require continuous access to up-to-date information. In this framework, web platforms are a suitable solution as they can act as a shared data environment for various data types and provide effective rendering through resource-scaling via web browser, adapting the computation requirements to the available device power.

This article explores the possibilities offered by the use of web platforms in the field of 3D data management for complex architectural and landscape scenarios, focusing on the collaboration and sharing aspects.

The topic is addressed towards a research case study involving survey and design activities in a shared environment among different groups and professionals.

Moreover, one of the research questions is how the use of commercial platforms could foster cost reduction and enhance the economical sustainability of the process of sharing and using 3D data for facility management and design purposes.

2. The Case Study Survey

Survey activities and web-based data management of the Archaeological area of Naxos Taormina (Sicily, Italy) is part of a large project developed between Politecnico di Milano, Politecnico di Milano Foundation and the Naxos Taormina Archaeological Park.

The project aims to remove architectural and cognitive barriers for visitors to the archaeological area and museum and involves different professional figures from geomatics, restoration, architectural design, and diagnostics.

The Naxos site is of considerable extension, approximately 250000 m^2 and it comprises archaeological and natural heritage areas. The site was surveyed by integrating multiple techniques, according to the different needs of documentation and accuracy for the design purposes.

The survey was carried out over one week in November 2023, with an MMS backpack Heron MS Twin Colour and UAV Phantom 4 Pro v2 drone for the whole area of the park, with higher resolution terrestrial laser scanning integrations for the archaeological areas and buildings. A topographic network covering the entire park's surface was created, from which targets (both scanners and UAVs) were measured.

The primary survey techniques for this case study include MMS (22 trajectories) and UAV photogrammetry (4,345 photos), The elaboration of the different datasets produced a complete point cloud of the park. The datasets were georeferenced using ground control points (GCPs) established within the topographical network survey and integrated through a multi-sensor data fusion process using Heron Desktop (Gexel, 2024). The result is shown in Figure 1.

The final product of the survey is an extensive point cloud containing more than 11,5 billion points with a resolution of 2cm, which is particularly challenging in terms of required space and computational resources.

This point cloud and its derived survey products, such as orthophotos and 2D vector drawings, constitute the master model, which acts as a reference for the project team's analysis and design phases.

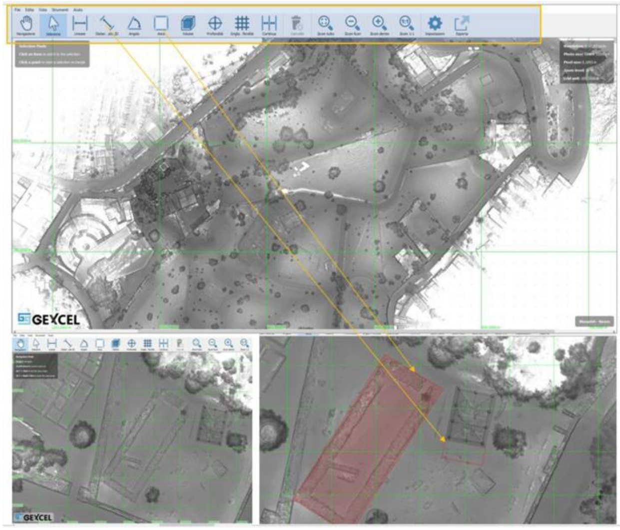

Figure 1. The map of the Naxos Archaeological Park from the MMS survey shown with the GoBlueprint tool by Gexel. Top: the whole map shown inside the software. Bottom: an example of information extraction as area and distance measurement.

3. Commercial Web Platforms for 3D Data Management

Web platforms for 3D data management are cloud-based services that are accessible in the form of a web app that offers to its users visualization, interaction, and processing tools for large 3D datasets as point clouds, meshes and BIM models (Spettu et al., 2024). Web platforms find an extensive application in fields such as the Architecture, Engineering and Construction (AEC) industry as well as archaeology landscape and architectural design. Leveraging cloud computing resources, platforms enable real-time data sharing and collaboration while reducing dependency on local computing resources and costs (Gharibvand et al., 2024), thus improving the efficiency of 3D data management. In practical applications, Web platforms often feature tools that are tailored to meet industry-specific needs related to managing 3D data across various fields.

The most interesting aspect of using web platforms for visualizing, sharing and working with 3D data is related to their ease of access and the absence of strict and performative hardware requirement. The platform is accessed through a web browser and provides the scaling of rendering resources according to the user device. Moreover, all the data are hosted within the platform and its servers, making the service accessible by anyone and from anywhere. The centralized nature of the data and their related information is crucial in determining the success of platforms, as they act as common data environment (CDE) for both geometric and non-geometric data, enabling users to work on the same version of the project, preventing data duplication and consequent mistakes and time-consuming re-works.

Moreover, the fact that users access the data instead of storing them, can result in a significant reduction of storage hardware costs.

Commercial web platforms are available mostly on a subscription basis. The cost of the subscription is generally related to the amount of available storage space, the number of allowed users and the available features and additional tools. This business model allows users to scale the platform and its cost according to their needs. On the other hand, it implies a recurrent and unavoidable cost for maintaining active the service, and the data.

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This article provides a general overview of some of the most relevant commercial web platforms with subdivision related to their main goal and feature offering.
The choice of the web platform suitable for the needs related to a specific digitization and design project should follow a detailed analysis of the available geometrical and non-geometrical data, the involved stakeholders and their roles and engagement, the design or management process that the platform is supposed to support and the available IT skills and economic resources.

3.1 Visualization and Interaction Platforms

All the web platforms primarily support real-time viewing and browsing of 3D data, and most of them provide interaction and markup tools such as annotation, measurement, and labelling that facilitate detailed analysis and collaboration.
Sketchfab (Sketchfab Inc, 2024) is a platform that features enhanced rendering abilities, visualization and shading filters, and model presentation tools, through an easy and user-friendly interface. It supports virtual reality (VR) rendering, and the uploaded models can be shared and sold in a dedicated digital store. The overall features of Sketchfab make it suitable for educational purposes, and product and object design.
Euclideon udCloud (Euclideon, 2024) and Cesium (Cesium GS, 2024) are oriented towards the visualization, interaction and streaming of massive 3D datasets through the web and features also a desktop application. The use of udCloud is particularly effective in the case of extended datasets of territorial scale that have to be visualized both at geographical scale and at the detailed building scale.
FlyVast (Geovast 3D, 2024) is a platform that provides advanced visualization and annotation tools, as well as some experimental segmentation and object recognition algorithms for point clouds. The annotation and sharing tools provided, such as cropping, labelling and sectioning are particularly effective for applications at the architectural scale.

3.2 Asset Management Platforms

Beyond the basic or advanced visualization and annotation tools described previously, some platforms are designed to provide a suitable work environment for a collaborative management task of built assets, e.g. programmed maintenance and issue identification. These processes are supported using accurate 3D data from reality capture together with the annotation and task assignment tools that are provided by platforms. These platforms usually support point clouds, meshes and IFC models as diffused 3D support in the AEC sector.
BloomExplorer (Bloom Technologies, 2024) supports both structured and unstructured point clouds as well as CAD and IFC models. The supported geometries are visualized in the same workspace and can be checked for interferences, clashes, and floor levelling and flatness. The platform supports various annotation and marking tools and a demolition-reconstruction utility. Its main goal is to provide support to the design and validation phase in the AEC sector.
Cintoo (Cintoo, 2024a) provides a wide support for structured point clouds but also supports MMS and unstructured point clouds displayed in the same environment. The main goal of the platform is to provide a single and shared environment for all the supported geometrical and non-geometrical data, including not only 3D geometries but also 2D vector drawings and generic documents and pictures.
Pointivo (Pointivo Inc, 2024) is a platform dedicated to the inspection of assets and facilities, especially in the telecommunication and energy sector, mainly from data coming from UAVs. The company that develops Pointivo also provides the UAV capture, inspection and the data processing services, with the idea of giving to the client a turn-key digital twin of the captured asset. The platform also features AI-based data analytics for business decision support.
ATIS.cloud (ATIS.cloud, 2024) supports both unstructured and structured clouds as well as meshes and other 3D model formats. The platform has various annotation and representation tools that make it very versatile and helpful in various use scenarios.

3.3 AI-driven Platforms

In this category are described the platforms that provide AI-based tools applied to the geometrical data, as their main feature offer. The primary features concern the object recognition and classification of 3D assets, mainly on geospatial point cloud data.
Pointly (Pointly GmbH, 2024) is a platform with overall basic features in terms of visualization and annotation tools, which is focused on the processing and classification of the uploaded data. It provides standard classification workflows and models available for geospatial data as highways, urban areas and railways.
Flai (Flai, 2024) offers a powerful set of embedded processing algorithms (e.g. classification, filtering, vectorization...) for various use-case scenarios based on geospatial data. The processing of the input data is managed through a visual programming interface that allows users to combine different processors and to obtain the desired workflow. The platform also features useful visualization and annotation tools, and a manual classification feature that allows users to modify or manually intervene on the processing results.

4. Methodology

As an extensive archaeological site, the case study requires a proficient way to share large, high-resolution, and complex datasets with a heterogeneous group of users, each with varying expertise in reality capture.
Implementing a suitable web platform in the design and management process offers a solution to support and enhance subsequent management and design processes by leveraging 3D data as an asset for informed decision-making.
A comparative methodology for selecting a web platform suitable for 3D data management is proposed to identify the most appropriate platform for the Naxos project, balancing the different needs and role of the involved stakeholders. Four platforms, briefly introduced previously, were tested, each with different main functionalities and performance: FlyVast, ATIS.cloud, Flai, and Cintoo. This methodology part is structured into two stages: testing and evaluation. Each stage is guided by criteria tailored to the project's unique demands in management and area development, particularly for the efficient handling, storage, and interaction with high-quality 3D data.
In the testing stage, requirements specific to the Naxos project were defined to guide the selection process.
These requirements focus on the technical and operational needs of the working group with high-resolution 3D data, mainly starting from point clouds (visualization, taking measurements, adding annotation, creating a repository, etc.). The platforms were tested for their performance in hosting complex 3D models, focusing on real-time, high-quality rendering capabilities that ensure accuracy and detail in the representation of archaeological and natural features. Another crucial requirement was the support for unstructured point cloud (PC) data from multiple sources, including MMS and UAVs, which are frequently used for data capture in CH contexts. Additionally, platforms were tested for their interaction and annotation tools, allowing users to add notes

or tags within the 3D environment, an essential feature for collaborative research and documentation.
Finally, requirements included a centralized file repository for storing and accessing related documents and multi-user capabilities to support collaboration among a team of researchers, conservators, and other stakeholders.
The evaluation stage then applied criteria to assess the platform's affordability and practical use. The first criterion was process efficiency, where platforms were evaluated on their capacity to save time and consequently, reduce the costs that are associated with data processing and management tasks. This included assessing the speed of data uploads, downloads, and interactions, which are critical for maintaining a streamlined workflow in large-scale cultural heritage projects. Real operational costs, including subscription fees, were also factored in to ensure project budget compatibility. Hardware savings constituted another evaluation criterion, where platforms that minimized hardware demands and allowed for remote or cloud-based processing were favoured. Lastly, storage savings were considered, particularly the platform's ability to optimize storage use without sacrificing data quality or accessibility, a significant factor given the extensive storage needs of 3D cultural data.

5. Test of Naxos 3D survey Data in Web Platforms

5.1 FlyVast

FlyVast supports unstructured point clouds of large dimensions coming from any source, in the most common file formats (e.g. E57, TXT, LAS/LAZ). It also supports coloured meshes. The uploaded geometrical data can be visualized in the same space together as they can be turned on and off from a menu (Figure 2, top). The visualization and rendering performance are consistently reliable, stable, and work smoothly also with big datasets. Users can adjust manually for each cloud various rendering options, as the number of visualized points, their size and other rendering options.
Interaction with the geometrical data can be done through several measuring tools (distance, area, angle) and the use of hot spot labels. This tool enables users to add an annotation to a specific interesting point of the cloud or mesh with text, images and web links. With the same tool users can mark specific interesting points with labels visible in the 3D visualization interface and in the label list.
The platform allows users to use adjustable bounding boxes, which can highlight a portion of the point cloud or temporarily isolate or hide its content. Moreover, the box's content can be downloaded in LAS format, a feature that can be particularly useful for delivering the point cloud to users who have to use it for specific tasks to be performed locally (e.g., vectorization, and CAD drawing) but want to work on portions of it, avoiding the need to store and manage the full dataset.
One of the notable features of FlyVast is the section tool (Figure 2, middle), which allows users to draw a section line and obtain a slice of the point cloud with adjustable depth. This tool is also available with the section plane coordinate input, for a more accurate result. Once the section line is established, the platform displays the result in form as slice of points. Inside the section tool interface, users are possible to take measures, add annotations as labels and draw polylines for vectorization purposes. It is also possible to download both the sliced cloud in LAS format and the vectorization in DXF format, an interesting feature for interoperability and sharing purposes.
The most advanced feature available on FlyVast is the unsupervised segmentation of point clouds performed during the data upload. The processing algorithm identifies regions geometrically homogeneous regions and groups them as

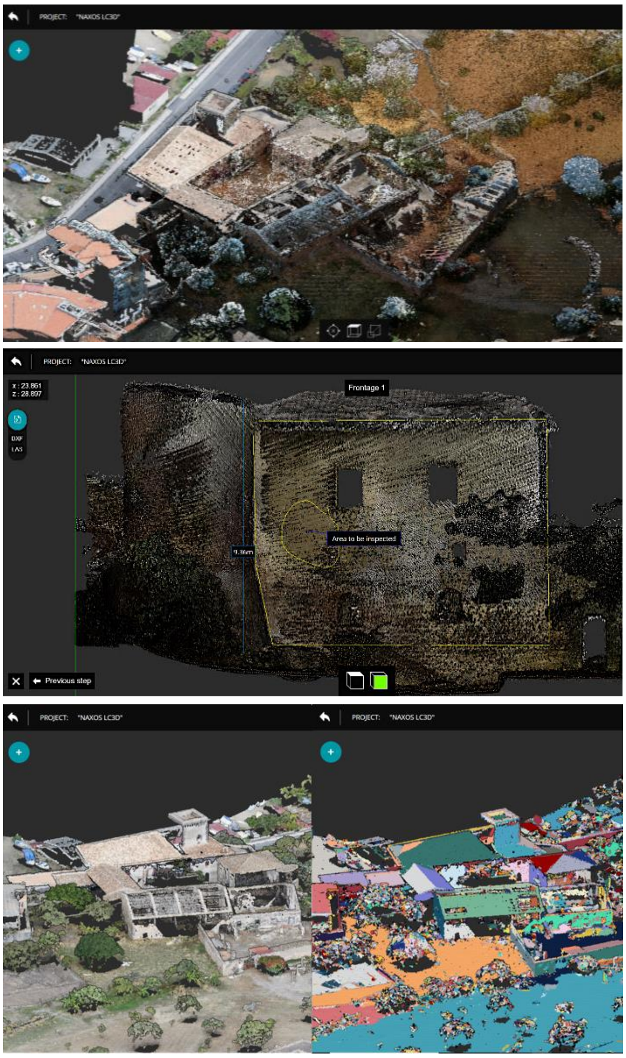

Figure 2. An overview of the FlyVast platform. Top: a portion of the UAV and MMS point cloud of the Castle area in Naxos Archaeological Park. Middle: an example of the use of the section tool with vectorization, measurement and annotations. Bottom: the UAV point cloud of the Castle area and the product of the automatic segmentation algorithm.

segments (Poux et al., 2022), as shown in Figure 2, bottom. The feature is still in the beta phase and under development and can be significantly challenged by complex and heterogeneous datasets, but it appears as particularly promising for the future developments.
FlyVast, at the present time of development, does not feature a document repository to be used as CDE. This aspect can be partially addressed by using the labelling tool in combination with web links to an external data repository, "attaching" the documents to specific hot spots on the point cloud, but the centralized document repository inside the platform is not available.
On the FlyVast platform, data sharing can be done in two ways. The first is the collaboration between registered users on the project, which allows to work, manage, upload and interact with the data using all the tools. The second way is through the use of deliverables, which are specific views of the project data that can be shared with any non-registered user through a link. The end user of the deliverable can see all the markups on the point cloud made by the project team and take measurements. The deliverable tool is also available for the sections.

The platform is accessible by subscription, with an entry-level module with 100GB of space and up to 5 collaborators for about 1700€, billed annually. The partner subscription, with the access to more features and beta tools costs about 3000€. The platform allows to add, according to the needs, more space and more collaborators.

5.2 ATIS.cloud

ATIS.cloud primarily serves 3D data, supporting unstructured point clouds from mobile scans, terrestrial scans and UAVs and managing the most common file formats such as E57, LAS/LAZ, and RCP. It also supports 3D models in mesh format like OBJ and parametric ones as the IFC. The platform has a powerful visualization model and provides users with manual customization options, such as modifying the size and density of the rendered points. Considering its rendering capabilities, ATIS is suitable for handling large and articulated datasets, as they are listed hierarchically in the menu based on their source and relationships (Figure 3, top), and the user can choose which clouds or models to show or hide.

The platform features several powerful annotation tools that enable users to add measurements (e.g. distances, areas, angles), comments and tags within the 3D environment. More specifically, the annotation tool is of particular interest as it allows users to highlight specific points, attach files to the annotation and assign tags to users for task assignation. This latest feature is particularly relevant in the built and landscape environment management and can be used to identify areas requiring further inspection or preservation (Figure 3, bottom). The annotations in this format are compliant with the BIM Collaboration Format (BCF), which is an interesting feature in terms of interoperability and sharing.

ATIS also provides some advanced tools for data representation, as the one dedicated to the deviation analysis between point clouds and 3D models or the orthophoto creator.

The platform's collaboration tools allow users to work on shared projects with an internal organization in teams.

It is supported also a collaborative mode in which team members are present at the same time in the 3D environment, simulating a virtual on-site visit. ATIS supports both sharing with restricted access, among the working team and the public sharing of project views and contents.

Additionally, the platform provides a plugin for streaming the uploaded point clouds to some of the most diffused BIM software, as Revit (Autodesk, 2024) and Allplan (Nemetschek Group, 2024), which is particularly useful in the design process, when these software are used inside the established workflow.

This platform provides a file repository system that includes all the non-geometrical data uploaded within the platform's tools, such as panoramic 360° images and the files attached to the annotations, as well as files uploaded by users. On one hand, the file repository tool has a simple structure, and it is not possible to implement any file structure aside from the type of data filtering. On the other hand, this feature is not common among web platforms for 3D data management, and it can be particularly useful for multi-user collaboration. The system can be used to store documents related to the project such as reports and drawings. The document repository in ATIS cannot be defined as a CDE that can support a project organization in centralizing the data, but it represents a further step towards the use of web platforms for complete management of design projects supported by reality-capture 3D data.

In this sense, ATIS represents a product oriented towards management, as it also supports the versioning of projects and the possibility of structuring the working team into roles through customizable permission settings. ATIS.cloud provides two different subscription access options, according to needs and possibilities. The freemium subscription is free of charge and offers limited features and data retained in the platform for a limited period.

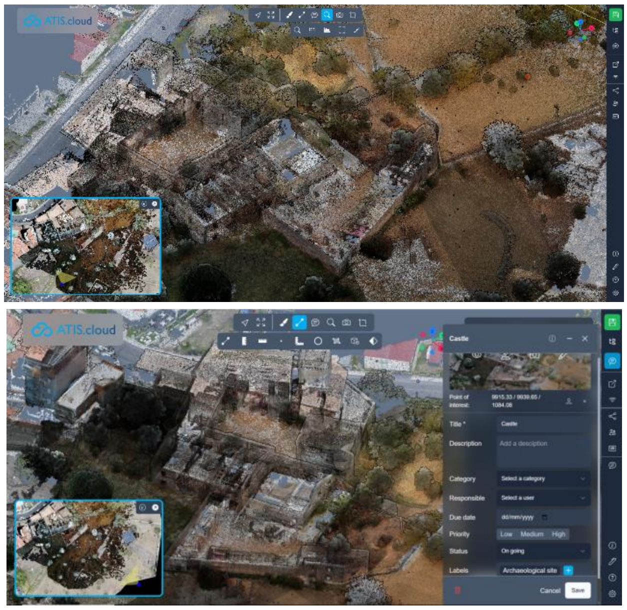

Figure 3. An overview of the ATIS.cloud platform. Top: the UAV and MMS point clouds of the Castle area displayed together. Bottom: an example of annotation with task and priority attribution.

It is possible to create only one project with a limit of 512GB, which can be shared with an unlimited number of users. The platform provides most of the features and the data downloads are charged on a per-GB basis. The regular subscription is articulated in three different plans (standard, advanced and enterprise) with increasing available tools, storage space and minimum user accounts. For example, the entry-level Standard plan provides four users and 200GB of storage for 860€ annually, the entry level Advanced provides ten users and 5TB of storage for 2400€ annually. Extra storage can be purchased as needed and it has to be noticed that the amount of data uploaded and downloaded included in the plan is limited and can be billed separately. On one hand, the subscription model allows users to scale the fees according to their limit, on the other hand, the data transfer limit can become an issue and increase costs, as the details of the subscription should be carefully considered according to the needs.

5.3 Flai

Flai is a platform that supports unstructured point cloud data from any source and multiple formats, for processing purposes, such as classification, object recognition and vectorization.

The platform offers the common measurement tools (e.g. distance, area, angle) and basic annotation features that allow users to add text labels to the point cloud, in form of comment thread. Flai supports a useful cropping tool that works with various types of selection (e.g. rectangle, buffer from line, polygonal), allowing users to isolate specific portions of the point cloud, with options to download the selected data in LAS format for local use (e.g., CAD vectorization). Furthermore, users can create cross-sections of the point cloud, enabling precise slicing and measurement capabilities. These sections can be exported for further analysis or sharing.

The most advanced feature and main purpose of Flai is its AI-powered point cloud classification, which identifies and groups

the geometrically homogeneous regions with the goal of annotating the point cloud through classification, identifying objects such as the ground, trees, buildings etc.
The automated classification process significantly enhances the efficiency of working with large point cloud datasets by reducing manual processing efforts, when the algorithm can efficiently recognize the objects. The feature applies deep learning and computer vision algorithms to detect and classify different structures within the cloud based on their geometric properties (Figure 4, top). The processing algorithms are accessible from a visual programming interface that enables users to establish their workflow and manage inputs, processing, and expected outputs (Figure 4, bottom).
Flai also provides a manual reclassification tool accessible from the 3D visualizer for error correction or cases where unsupervised segmentation cannot effectively recognize the objects.
Moreover, there is also a tool for the training of the classification algorithms with custom datasets for advanced users.
On the data sharing side, registered users can collaborate on projects, while “deliverables” can be generated as specific views of the project data, which can be shared with non-registered users using a link, including annotated sections and measurements.
The platform, similar to ATIS.cloud, offers a free entry-level access option to the platform that, with a limited storage of 25GB and a 30-day expiration of the dataset, charges users for processing only at the time of download, allowing users to test and explore the tools offered and design workflows according to the needs. For a more continuous and structured use, the platform also offers the usual subscription models divided in steps (starter, growth, professional enterprise), with increasing storage space and full access to the features. The cost ranges from the 240€/year of the starter plan that include 25GB to the 3000€/year for the professional plan, with 1TB of storage. The processed clouds are charged only when the dataset is downloaded: this allows users to test several different workflows and classifiers, in order to find the desired result.
This platform is advantageous for users who work with extensive point cloud data that need to be classified or processed to extract useful information, but do not want to develop or acquire the specific expertise and technologies (e.g. algorithms, hardware) to achieve this result. This approach is widely supported by Flai as it covers both occasional uses with the pay-per-download mode and the more structured uses with algorithm customization.

5.4 Cintoo

Cintoo is a platform that works mostly with structured point clouds, as the ones from static TLS, and from MMS, but it is progressively introducing support for unstructured point clouds, such as those from UAVs. The input file format includes both exchange formats like E57 and LAS/LAZ, as well as proprietary formats such as ReCap RCP. It also supports various other 3D data formats, allowing for a flexible project workflow within the platform. The platform supports 3D model formats like IFC as well as mesh formats such as OBJ, STL, and PLY. Except for the point cloud data, it handles 360° images, and other different documents such as PDF, TXT, CVS.
One of distinctive features of Cintoo is the Work Zones, which allow users to organize scans, models, and other project data into specific and easily accessible zones that function as folders. Each Work Zone can contain related documents, such as scans, models, or drawings, and users can freely create zones for areas of interest within their projects, according to their needs. Cintoo provides high-performance rendering for both point clouds and 3D mesh models, maintaining usability even with large datasets (Figure 5, top). The visualization capabilities are enhanced by TurboMesh

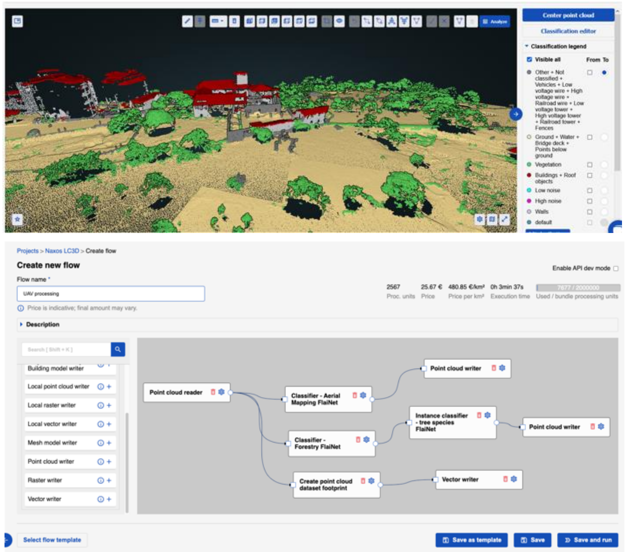

Figure 4. An overview of the Flai platform. Top: an overview of the UAV point cloud classified using the Areal Mapping FlaiNet classifier. Bottom: the visual programming interface configured to run an articulated classification workflow with different output and processing from the same point cloud input.

(Tapia, 2024), which processes a mesh from point cloud data during the upload for data compressing and solid visualization of the point cloud. Users can manually control visualization parameters, including point density and size. The platform enables users to switch between viewing modes, making it possible to visualize multiple layers simultaneously and to toggle them as needed for specific tasks. The platform supports the navigation through 360° images acquired by the instruments or with the creation of virtual points of view during the data upload (Figure 5, middle).
Cintoo includes tools for measuring distance, area, and angles within 3D models. The annotation feature allows users to add detailed descriptions, images, and hyperlinks to specific points in the cloud or mesh, providing context for others reviewing the data.
These annotations, organized in a searchable label list, enable effective communication among team members or clients by linking insights directly to model areas. Moreover, the annotation tool can be used for delivering information to specific users (private notes) and issue reporting, including a severity field and users assigned to the task.
Cintoo provides integration with VR, through the Cintoo Metaverse, which offers an immersive experience to explore and assess 3D environments in detail. This feature is mainly developed for industrial and facility management using Unreal Engine and Unity (Cintoo, 2024b). The VR feature can be particularly useful in supporting realistic site visualization and help with tasks such as construction inspection, urban planning, and design validation. With the VR feature, the platform allows users to better interpret spatial relationships and conditions in a virtual walkthrough, enhancing collaboration and decision-making, especially for remote teams.
It also presents a document repository as a central hub for managing and sharing project-related files. Users can store documents, blueprints, images, and other relevant assets for the project management and archive purposes. Permissions and access levels can be customized for each user to collaborate with internal teams and external partners while protecting sensitive data through restricted access (Figure 5, bottom).

The platform's real-time editing and sharing features further facilitate collaboration, allowing users to work on shared projects without duplicating files. The subscription model of Cintoo is different from the ones described before. It is based on the number of scans (namely, a single scan for structured point clouds or virtual vantage points for MMS and unstructured clouds) instead of storage space. Moreover, the subscription is articulated in modules according to the type of activities expected. The available modules are "collaboration, sharing and distribution", which serves as base module and enables users to upload and share data; "BIM and CAD" that adds the possibility to upload BIM and CAD files also from other cloud services and perform cloud-to-model deviation analysis; "asset tagging and display", that improves the annotation and tagging tools and also adds some AI features. For the aforementioned reasons, it is difficult to define a cost for the platform as it is strongly dependent on modules and the number of scans bought with the plan. This solution is particularly scalable because the number of scans and modules can be modified as necessary, according to the type of project. The base module includes an unlimited number of users and projects independently from the number of scans, which is a feature particularly interesting for the collaboration and sharing of data and projects.

5.5 Evaluation

According to its business model, offered technology, and target users, each platform offers features that aim to enhance the design and management process efficiency and improve data accessibility. FlyVast provides powerful rendering abilities and annotation and representation tools that are very useful and can be fully exploited in the AEC sector. Moreover, its in-progress unsupervised segmentation algorithms appear to be potentially useful in enhancing workflows with advanced annotation features.

ATIS.cloud combines powerful annotation and representation tools with the possibility, although very simple, to share non-geometrical data and to assign tasks to users, appearing as a well-balanced solution that can be used in various cases.

Flai stands out for its AI-powered automation, especially in the unsupervised classification of geospatial point cloud data, which can indeed simplify complex tasks and anticipate workflow requirements. The use of classified point cloud has the potential to significantly enhance the workflows based on reality capture data, but at the present time, it is not a familiar experience for most of the users, and in this sense Flai is suitable for advanced and experienced users and firms.

Cintoo appears to be an optimal choice for projects that require 3D visualization of extended datasets from various sources and acquisition devices. The provided tools are advanced and can foster annotation and collaboration on complex datasets. The possibility of structuring the document repository as a CDE is particularly useful for managing complex design and management workflows. The real operational costs of each platform are difficult to predict as the actual subscription costs may vary with the amount of storage space, number of users tools and models that are included. All these aspects, within the same firm or group of users, might vary from project to project. This variability also represents the main advantage of the use of web platforms if compared to the traditional workflow based on licensed on-premises software and local storage, as it can be scaled according to specific needs or with the expansion or contraction of the business. An example of this scalability is represented by the pay-per-download business model of Flai, which on one hand, relieves users from the cost of performative hardware for processing, on the other hand, charges only for the download of the dataset after obtaining the desired results.

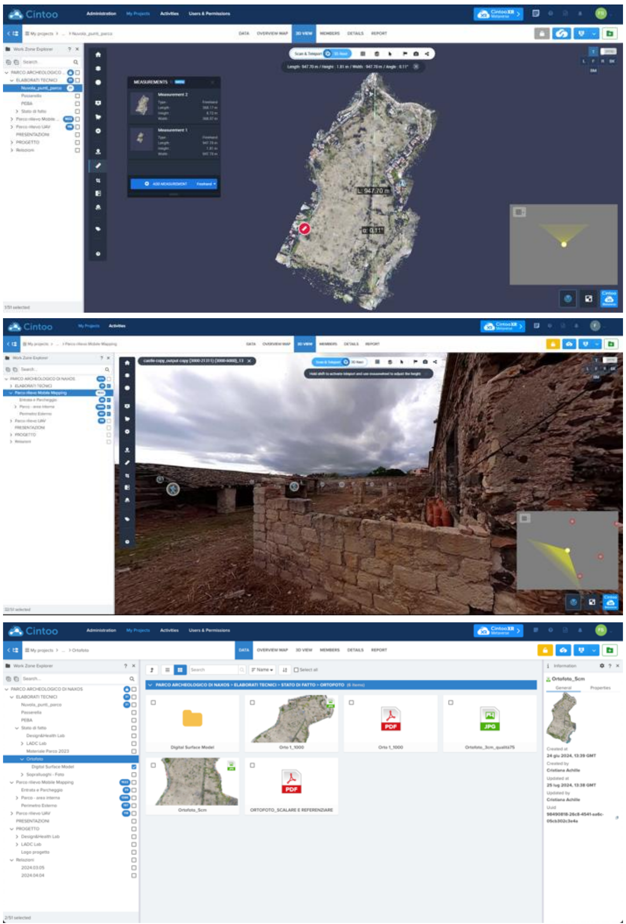

Figure 5. An overview of the Cintoo platform. Top: the full point cloud of the Archaeological Park from UAV survey. Middle: a 360° image from the MMS trajectory, accessible from the 3D view. Bottom: a folder of the document repository available on the platform, showing some of the products of the survey as the final orthophoto of the archaeological park.

6. Discussion

For the Naxos Project, Cintoo was the adopted platform, as it was evaluated as the one with the most balanced features for the project's goals. The rendering capabilities and 3D visualization are suitable for a large-scale and high-resolution dataset as the one of the Archaeological Park in Naxos.

A major requirement for the Naxos Project is a reliable, centralized data repository that allows efficient access to all data types to guarantee a collaborative design. In this aspect, Cintoo was the most complete and promising among the examined platforms. This repository functions as a shared CDE, enabling users to access, upload and download relevant data in a user-friendly environment and without requiring specialized technical skills. The ability to manage all the data involved in a project remotely, promotes a collaborative framework and can foster secondary time and cost savings, as all the stakeholders work on the same version of the data with updated information.

Issues like security and resiliency of the data of cloud computing and web platforms sector should be further investigated by dedicated studies. The Naxos Park Management established as institution the mode of data accessing according to its policy and supported by the tools of the platform, was able to attribute specific the access and editing privileges to users based on their role in the project team, with a case-by-case evaluation.

The use of cloud computing-based solutions for handling extended 3D datasets allows users to minimize local hardware requirements. The computing load is taken by dedicated servers, which can allocate resources more efficiently, and scalable computing infrastructures can adapt to computational demands. This approach can decrease the project physical infrastructure costs and align with a more sustainable model for digital heritage management.

The reduction in storage cost is related to the fact that different project teams working on-premises with large datasets need to have their copy of the data locally on hard drives able to support intense read-write cycles. Working on a shared dataset accessible online also relieves users from this cost.

The use of CDEs is able to bring another kind of saving, which is related to the increased efficiency of the process and to the fact that working on constantly updated data significantly reduces errors and version proliferation, that lead to miscommunication and work repetition by different teams. As previously explored, access to web platforms is generally related to a subscription the cost of which may significantly vary according to the required features, storage and allowed users.

This cost should be confronted to the one of the on-premises software or data sharing services that have to be provided for a comparable workflow. In this case, the final cost is not easily predictable and varies from project to project. This aspect highlights as the scalability of the subscription fees can be a resource for cost-saving.

The increasing demand for high-accuracy 3D data for documentation, planning, and design highlights the need for tools that can efficiently handle large datasets. The growing interest in web platforms for 3D data management exemplifies this trend, offering a centralized, accessible, and resource-efficient tool that supports interdisciplinary requirements.

7. Conclusions

The use of the Cintoo platform was important in providing a reliable and structured asset to deliver, access and interact with a large 3D dataset that would have been difficult to share. The platform also allowed the project participants to interact and share data and expertise in the same environment, with a significant increase in the efficiency among the experts participating to the project. The use of web platforms enhances remote collaboration and can foster digital inclusion and participation, as the data are immediately accessible to potentially anyone and from anywhere. This aspect is related both to project participants and generic users, as the data are already held online and can be easily shared in view-only mode for other purposes, like communication, fruition and valorisation.

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