Historic Garden Conservation in the Cloud: A Comparative Exploration of Strengths, Weaknesses, and Possibilities

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Abstract

This paper presents a comparative evaluation of six cloud-based platforms including ArcGIS Online, Cintoo, Flai, Pointly, Cesium ion, and Atis.cloud for historic garden conservation, applied to two contrasting case studies: the complex, large-scale Naxos Archaeological Park and the compact, formal Villa Burba in Italy. Results show that Cesium ion and Cintoo performed strongly in point cloud visualization, with Cesium ion offering responsive large-scale rendering and Cintoo supporting high-precision geometry and version control. Flai demonstrated effective AI-driven element classification, particularly in heterogeneous landscapes, while Pointly required manual refinement and showed limited adaptability to organic features. ArcGIS Online excelled in stakeholder usability and layered documentation but lacked native 3D analytics. Collaborative functions were best addressed by Cintoo and Atis.cloud. Temporal functionality, such as phase comparison or seasonal tracking, remained limited, with no platform providing fully integrated support.

The study highlights the fragmented nature of current solutions and argues for a modular, garden-oriented CDE model, integrating semantic intelligence, temporal awareness, and stakeholder-specific interfaces to support adaptive, sustainability-sensitive historic garden conservation in the cloud.

1. Introduction

Historic gardens represent a unique category of Cultural Heritage (CH), distinguished by their dual nature as both designed cultural artefacts and living, evolving ecosystems (ICOMOS and IFLA, 1982). In contrast to static architectural monuments, historic gardens are subject to continual transformation influenced by ecological processes, seasonal rhythms, and human interventions. This dynamic character renders their conservation especially complex, requiring approaches that account for temporal change and the diverse roles of stakeholders involved in their maintenance and management (Scazzosi, 2018).

Digital technologies such as photogrammetry, laser scanning, and Geographic Information System (GIS) have become central to heritage documentation practices (Letellier, 2015). However, in the context of historic gardens, these tools are predominantly used for representational purposes, generating static models or visual reconstructions (Li et al., 2025). Although effective for documentation and visualization, such applications often fail to address the operational needs of conservation, which include ongoing monitoring, adaptive maintenance, and interdisciplinary collaboration. A critical gap remains between the static nature of current digital outputs and the dynamic realities of garden heritage.

Concurrently, the emergence of cloud-based platforms, particularly within the Architecture, Engineering, and Construction (AEC) industries, has introduced new digital frameworks for collaboration and data integration (Zhao and Taib, 2022). Among these, Common Data Environments (CDEs) have gained prominence as centralized frameworks that facilitate the structured management of complex datasets across multiple stakeholders and project phases (Jaskula et al., 2024). Their potential relevance to heritage management lies in their ability to support real-time access, version control, and multi-user interaction (Crisan et al., 2024). Their suitability for historic gardens, with their semantic structures, temporal continuity, and ecological complexity, presents significant potential.

This paper aims to investigate whether existing cloud-based platforms can be effectively adapted for the conservation of historic gardens. It asks whether current digital technologies can support not only the documentation but also the collaborative, adaptive, and long-term management of living and complex heritage landscapes.

This research evaluates the extent to which existing digital tools can meet the specific requirements of garden conservation. The study employs a structured evaluation framework to assess six selected digital platforms, which are tested against two case studies representing different typologies and scales of historic gardens. The framework includes five key functional criteria: Point Cloud Integration and Visualization, AI-based Feature Recognition, Stakeholder Usability, Collaborative Workflow Support, and Temporal Change or Maintenance Cycle Adaptability.

2. Background and Related Work

2.1 Historic Gardens Survey and Conservation Needs

Historic gardens present a hybrid character that challenges conventional heritage documentation: they are both spatially intricate and temporally dynamic. While earlier garden surveys depended on Global Navigation Satellite System (GNSS), total stations, and ground-level photography (Achille et al., 2005), the integration of 3D spatial data has become a transformative development in the study and management of landscape heritage. Unmanned Aerial Vehicle (UAV) photogrammetry, for instance, enables non-invasive, high-resolution mapping of complex terrain and vegetation, offering not only geometric precision but also multispectral data useful for assessing plant health and stress (Liang et al., 2018; Sobura, 2023). Laser scanning technologies, both terrestrial static and mobile, have been employed to document built features, tree structures, and decorative elements with sub-centimetre resolution. Terrestrial Laser Scanning (TLS) offers high-density, highly accurate point cloud data ideal for capturing architectural and sculptural details, as seen in the Jianxin Courtyard (Jia et al., 2022), while Mobile Laser Scanning (MLS) provides rapid, flexible acquisition over larger areas, making it particularly suitable for complex and expansive outdoor environments, as an example of the archaeological area in Naxos (Li et al., 2024).

However, these efforts have largely culminated in static representations: 3D models, orthoimages, or GIS layers aimed at visual preservation rather than data-driven stewardship. Scholars have noted that garden documentation often neglects the temporal dimension, aspects including vegetation cycles, pruning histories, and seasonal management actions are seldom embedded into the digital models (Li et al., 2025; Lian et al., 2024). Moreover, such outputs are rarely designed for use by non-expert stakeholders such as Botanists, local authorities, or community conservators (Li et al., 2025), despite the inherently collaborative nature of garden care. This reveals a significant practical gap between the richness of captured data and its operational integration into long-term conservation strategies.

2.2 Digital Platforms, CDEs, and Heritage Practice

The heritage sector has witnessed increasing reliance on digital platforms to facilitate data storage, access, and multi-user collaboration. The emergence of CDEs, originating in Building Information Modeling (BIM) practice, responds to a systemic need for integrating fragmented information flows across actors, disciplines, and timeframes (Jaskula et al., 2024). These environments aim to unify various data formats (3D models, GIS layers, 2D documents, and so on) within a cloud-based project that supports version control, role-based access, and linked metadata. In architectural conservation, platforms such as Cintoo, Pointerra3D, 3DUserNet and HBIM-integrated GIS portals have begun enabling cross-disciplinary engagement (Fiorillo and Spettu, 2023; Spettu et al., 2024, 2023). However, the practical application of such integrated digital environments in landscape heritage, particularly in historic gardens, remains underexplored.

Current practices often involve the development of bespoke platforms or using Web-GIS technologies tailored to specific garden types, primarily for 3D visualization and basic data management (Cazzani et al., 2019). While such customized systems, as seen in the JBT 3D Project (Redweik et al., 2022), offer targeted functionality. They typically require dedicated web development expertise and significant financial resources, and their reusability across different garden contexts remains uncertain.

In contrast, cloud-based platforms offer a more flexible, scalable, and cost-effective alternative. These systems eliminate the need for custom-built infrastructure by providing ready-to-use environments with advanced visualization, multi-format data integration, and collaborative features accessible via the web. For instance, A large-scale archaeological area project has been used to demonstrate how platforms such as Cintoo, Flai, Atis.cloud, and Flyvast can accommodate the complexity of landscape heritage documentation and management (Li et al., 2024). This project highlights the potential of cloud platforms to support not only visualization but also AI assistance, real-time collaboration across geographically dispersed teams.

3. Gaps and Research Questions

Despite the increasing adoption of digital technologies in historic gardens, limited research has evaluated whether existing, commercially available cloud platforms can be effectively adapted to address the specific conservation requirements of this heritage. These landscapes present distinct challenges: the semantic and material complexity of garden elements, the need for accurate and scalable 3D visualization, the efficient handling of diverse spatial and temporal data, and facilitating multi-user access, use, and contribution. Crucially, it remains under-explored whether such platforms can operate as proto-CDEs for historic gardens, not fully customized systems, but flexible, extensible frameworks capable of supporting collaborative, iterative, and long-term data stewardship across disciplinary and institutional boundaries.

To address these gaps, this research investigates the following questions:

- How can point cloud data be used to test and compare their performance?
- Which features, technical and procedural, are most critical for adapting these platforms to garden-specific contexts?
- Can existing cloud-based platforms effectively support the data-driven conservation of historic gardens?

By bridging the literature on garden documentation, digital platforms, and CDE theory, this work contributes a first-of-its-kind evaluation of cloud platforms as vehicles for heritage-informed spatial collaboration in dynamic, living cultural landscapes and the growing discourse on how digital technologies can evolve from static representation toward active heritage management. It positions historic gardens not as passive objects of study, but as dynamic environments that require equally dynamic digital tools.

4. Methodology

4.1 Case Study Sites

This research employs a dual case study approach to ensure the applicability of its findings across different historic garden typologies. Two historic gardens are selected as case studies: the Naxos Archaeological Park and Villa Burba in Italy. Naxos Archaeological Park in Sicily (approximately 250,000 m^2), as a large-scale, semi-natural landscape, integrating archaeological ruins, natural topography, and vegetative growth, presents dual challenges in site conservation and development (Parco archeologico di Naxos e Taormina, 2025). On the contrary, Villa Burba in Lombardy (around 16,000 m^2), a more modern and geometrically structured garden characterized by formal design elements, active horticultural maintenance, and ongoing community use (Comune di Rho, 2025). Unlike Naxos, Villa Burba exemplifies a compact, intervention-rich site, where preservation is closely linked to seasonal cycles and routine upkeep. To support detailed evaluation, representative zones within each garden were selected as sample areas based on their distinctive spatial, ecological, and management characteristics (Figure 1).

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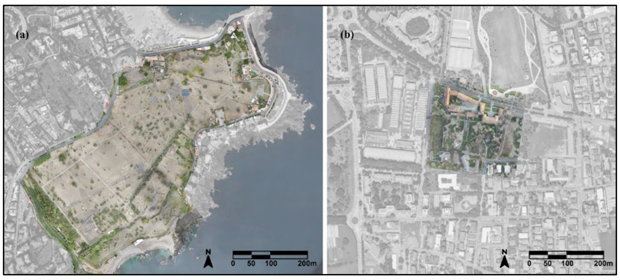

Figure 1. Overview of the two case study sites: Coloured areas show whole site areas and 3D survey coverage. Naxos Archaeological Park (a) and Villa Burba (b).

4.2 Data Acquisition and Integration

To rapidly and accurately capture the spatial characteristics of both whole sites, a combined survey approach using UAV photogrammetry and MLS was adopted. At Naxos Archaeological Park, UAV data were acquired using a DJI Phantom 4 Pro v2, resulting in orthophotos and dense point clouds derived from 4,345 images. MLS was performed with a Heron MS Twin Colour backpack system by Gexcel srl, generating colorized point clouds with a spatial resolution of approximately 2 cm based on 22 trajectories, effectively capturing under-canopy structures and archaeological remains. The integrated dataset exceeded 11.5 billion points (Li et al., 2024). For Villa Burba, the same equipment and methodology were employed. The final point cloud was generated from 606 images and three MLS trajectories, yielding over 330 million points (Perfetti et al., 2023). Unlike Naxos, the MLS data for Villa Burba lacked RGB information, offering a monochromatic dataset at the same 2 cm resolution.

The full point cloud for both case study sites was generated using local geographic references, which provided sufficient spatial context for general visualization and analysis across most platforms. To enable more advanced GIS functionalities when needed, selected sample areas were further georeferenced using the WGS 1984 UTM coordinate system, with Zone 33N applied to Naxos and Zone 32N to Villa Burba. This georeferencing step ensured compatibility with platforms that require precise spatial alignment for spatial analysis or integration with other geospatial datasets.

4.3 Platform Selection

The selection of platforms was informed by a combination of technical relevance, functional capabilities, heritage-specific applicability, and cost considerations. Six platforms were ultimately selected: ArcGIS Online (ESRI, 2025), Cintoo (Cintoo, 2025), Flai (Flai, 2025), Pointly (Pointly GmbH, 2025), Cesium ion (Cesium GS, 2025), and Atis.cloud (ATIS.cloud, 2025). These platforms reflect a diverse spectrum of digital heritage and geospatial technologies, including GIS-based environments, AI-assisted classification tools, and web-based 3D visualization systems.

ArcGIS Online was selected due to its widespread use in cultural heritage GIS workflows and its capacity for multi-user collaboration, map-based data integration, and web deployment. Cintoo offers a construction-oriented platform with advanced scan-to-BIM capabilities, enabling tests of how industrial tools might be adapted for heritage semantics. Flai, distinguished by its AI-native classification engine, was chosen for its potential to automate vegetation and surface type recognition, critical tasks in garden conservation. Pointly allows high-resolution manual annotation and semantic segmentation, offering a fine-grained control mechanism often needed in expert-based heritage interpretation. Cesium ion, built on the CesiumJS engine, is included for its ability to host, tile, and stream large-scale point clouds, and to visualize time-stamped data within a web-based 3D environment. Finally, Atis.cloud was chosen for its support of immersive point cloud exploration and user-specific interface layering, suggesting potential for role-based collaboration.

Each platform was selected not merely for its technical maturity or market presence, but for its potential adaptability to the specific demands of living heritage landscapes. The evaluation examines how these systems, originally developed for domains such as architecture, engineering, and urban planning, might be repurposed, extended, or integrated to support the collaborative, adaptive, and long-term conservation of historic gardens.

4.4 Evaluation Framework

To assess whether current cloud-based platforms can meaningfully support the conservation of historic gardens based on point cloud data, this study proposes an evaluation framework structured with five functional criteria (Figure 2). These criteria were selected based on their alignment with both the operational needs of heritage garden management and emerging capabilities within digital technologies.

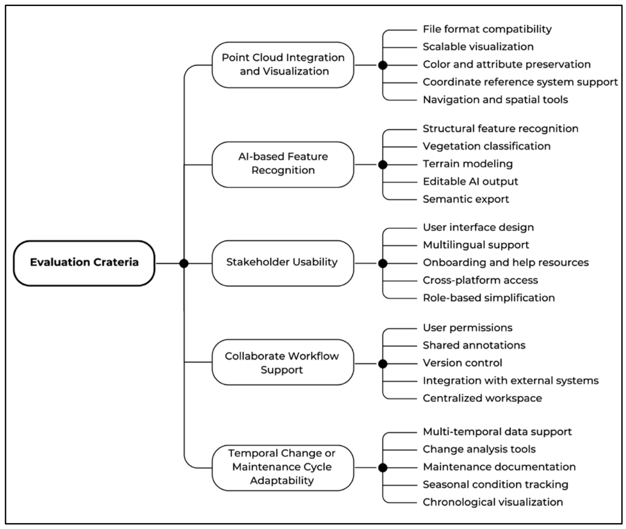

Figure 2. Evaluation framework for assessing cloud-based platforms in historic garden conservation.

Point Cloud Integration and Visualization is included due to the increasing reliance on dense 3D spatial data, particularly from UAV photogrammetry and laser scanning. Platforms should demonstrate the capacity to render and manipulate such data efficiently, including colour fidelity, spatial accuracy, and usability across varying scales and environments.

AI-based Feature Recognition addresses the necessity for automated classification tools, particularly for distinguishing garden-specific features such as plant types, pathways, water elements, architectural elements and terrain. These capabilities are foundational for enabling semantic annotation, monitoring, and long-term interpretation.

Stakeholder Usability emphasizes the requirement for broad accessibility, encompassing intuitive interfaces, multilingual support, and clarity of interaction for diverse stakeholders,

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including non-specialist users such as government, police makers, and conservationists.

Collaborate Workflow Support evaluates whether platforms support role-based access, shared editing, version tracking, and multi-user engagement. Given that historic garden conservation often spans disciplines and institutions, collaborative functions are critical for sustainable decision-making.

Temporal Change or Maintenance Cycle Adaptability considers a platform’s ability to incorporate time-aware data, such as seasonal vegetation change, repeated surveys, or maintenance interventions. Gardens, unlike static buildings, require tools capable of recording and responding to cyclical and evolving states.

Each of the five criteria is assessed using a set of functional indicators and scored on a four-point ordinal scale:

- 0 = Not supported
- 1 = Minimally or partially supported
- 2 = Adequately supported but limited in real-world contexts
- 3 = Fully supported and usable in applied heritage workflows

This scoring system enables consistent benchmarking across platforms, revealing both functional strengths and critical gaps, and supports both detailed analysis and holistic interpretation of each platform’s suitability for historic garden conservation. The evaluation is structured around defined criteria and is based primarily on point cloud data, provided in E57 and LAS/LAZ formats for the sample areas. It also considers the platforms’ ability to integrate and manage supplementary materials such as images, orthophotos, and other 2D documentation, reflecting the diverse data landscape typical of heritage documentation projects.

5. Results

The evaluation results across the two case study areas demonstrate that platform performance varies significantly by functional domain, with each platform exhibiting distinct capabilities and limitations aligned to specific criteria.

5.1 Naxos Archaeological Park: A large-scale heritage landscape

Naxos Archaeological Park, with its expansive terrain, uneven topography, and scattered combination of ruins and vegetation, presented a demanding test for platform performance across visualization, classification, collaboration, and temporal functionality, particularly in the context of conservation and planning.

For point cloud integration and visualization, Cesium ion and Cintoo proved most effective in managing large and dense point clouds. Cesium ion’s high-performance rendering preserved topographic continuity at multiple scales, enabling intuitive spatial exploration (Figure 3, 5a). Cintoo delivered high geometric precision and integrated version control, while its interface required technical fluency (Figure 3, 2a).

About AI-driven classification, Flai stood out for its ability to segment major vegetation and structural elements using a pretrained model (Mobile Mapping FlaiNet). However, its semantic resolution was insufficient for capturing nuanced archaeological features (Figure 4, 2a). Pointly, effective on regular built geometry, underperformed with the site’s irregular and eroded forms (Figure 4, 3a). ArcGIS Online depends on external AI workflows. Its automatic classification tools are primarily designed for 2D analysis and offer limited utility for 3D point cloud interpretation. In this case, all elements except buildings were classified based on elevation alone, resulting in point clusters grouped by height regardless of their semantic meaning, an approach that compromises the integrity of feature differentiation in complex garden environments (Figure 4, 1a).

In terms of stakeholder engagement and collaborative access, ArcGIS Online offered a low-threshold, multilingual interface with integrated 2D–3D capabilities, well-suited for participatory documentation and communication among non-specialist users. Atis.cloud emphasized controlled collaboration through role-based access management, though it lacked domain-specific semantics and offered limited intuitive visualization tailored to heritage contexts. Cintoo’s “Workzone” functionality enabled data to be organized into folders and subdivided by area, facilitating role-specific access and task-based management. This structure proved to be especially useful for this big project, allowing users to interact with relevant data subsets according to their responsibilities while maintaining coherence across the entire dataset.

At Naxos, temporal adaptability was essential for monitoring seasonal dynamics, reconstruction phases, and long-term landscape change, but remained underdeveloped across platforms. While Cintoo enabled version-based comparisons and ArcGIS Online allowed for historical layering, no platform offered fully integrated tools for multi-temporal visualization or time-aware annotation essential to dynamic conservation.

5.2 Villa Burba: A formal historic garden within an urban context

In contrast to Naxos, Villa Burba presented a compact, geometrically ordered site characterized by axial pathways, regular built forms, and formally composed vegetation. This spatial clarity highlighted the necessity for platforms optimized for usability, fine-scale annotation, and layered documentation.

Visualization performance was uniformly stable due to the lower data volume. ArcGIS Online proved particularly effective, enabling integration of historical maps, vector layers, and stakeholder commentary within a familiar GIS environment (Figure 3, 1b). Cesium ion preserved visual integrity but lacked tools for site-specific markup or annotation (Figure 3, 5b). Cintoo (Figure 3, 2b) and Atis.cloud (Figure, 6b) supported collaborative review, though both retained technically oriented interfaces that limited accessibility for non-specialists.

In AI-based classification, Flai delivered the most accurate results, successfully identifying structural and vegetative elements even at a fine scale (Figure 4, 2b). Its pretrained model (Mobile Mapping FlaiNet) adapted well to the site’s geometric clarity, outperforming. While Pointly offered potential through rule customization (Figure 4, 3b), it required significant manual refinement to achieve usable results. ArcGIS Online, lacking in-platform classification tools, continued to rely on external AI workflows, the same as the Naxos case study (Figure 4, 1b).

Stakeholder usability was strongest in ArcGIS Online, especially for municipal staff and local users, due to its intuitive interface and 2D–3D hybrid workflows. Atis.cloud and Cintoo facilitated more structured, role-based collaboration environments.

Temporal adaptability remained limited across all platforms. While static documentation was feasible, and both ArcGIS Online, Cintoo, and Cesium ion supported layered representations or time-stamped data of historical states, tools for capturing cyclical or seasonal changes, such as vegetation dynamics or maintenance routines, were largely absent.

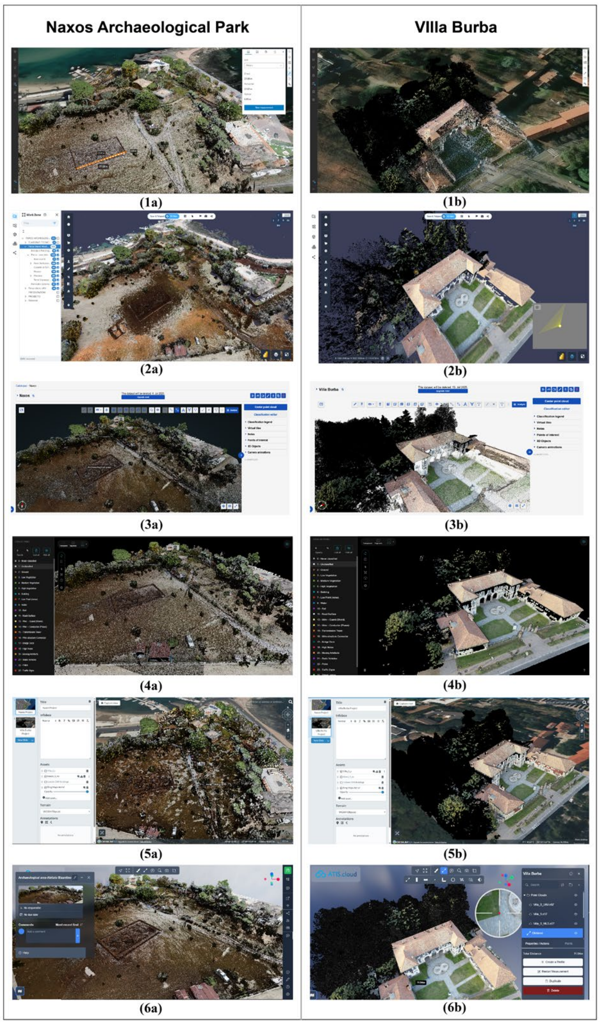

Figure 3. Sample point cloud visualization in selected platforms for historic garden applications. ArcGIS Online (1a, 1b), Cintoo (2a, 2b), Flai (3a, 3b), Pointly (4a, 4b), Cesium ion (5a, 5b), Atis.cloud (6a, 6b).

5.3 Cross-Platform Comparison

Platform performance varied not by technical capacity alone, but by how well each system aligned with the spatial, functional, and temporal logic of historic gardens. Figure 5 presents the evaluation results across five criteria, using a scoring system to highlight each platform's strengths and limitations concerning the distinct conservation challenges posed by these contrasting sites.

Cesium ion and Cintoo exemplified this functional divergence. Cesium ion excelled in rendering large, topographically complex landscapes with high responsiveness, making it particularly effective for expansive sites like Naxos. Cintoo, by contrast, supported precise, review-oriented workflows through version control, point-level accuracy, and structured data management. Notably, Cintoo also included integrated tools for cultural annotation and interpretive layering, features essential for heritage documentation and planning. However, both platforms still lacked broader semantic enrichment and temporal modelling capacities, which constrained their use for adaptive conservation in dynamic garden environments.

In terms of AI-based feature recognition, Flai demonstrated the strongest overall performance, adapting consistently across both case studies. However, its pretrained models were too generic to capture the nuanced materiality and layered semantics of historic gardens, such as decorative elements, mixed vegetation groups, or traces of past interventions. Pointly, although narrower in its classification scope, revealed potential when paired with manual refinement, suggesting a viable hybrid model that integrates automated detection with expert interpretation. Nevertheless, both platforms exhibited limited support for stakeholder collaboration: neither provided role-specific interfaces, nor shared environments conducive to participatory verification or interdisciplinary input, features essential for data-driven workflows. This reflects a broader misalignment between current AI-driven classification tools and the collaborative, interpretive nature of garden conservation.

ArcGIS Online proved to be effective in stakeholder usability, providing a low-threshold, multilingual interface with seamless hybrid 2D–3D workflows that facilitated participatory management and communication. However, its analytical depth, particularly in 3D classification and semantic enrichment, remained limited, restricting its value for more advanced interpretive or diagnostic tasks in GIS environments. In contrast, Cintoo and Atis.cloud supported more structured collaboration through role-based access and version control, yet their interfaces were primarily oriented toward technically proficient users. This design bias limited their effectiveness for interdisciplinary heritage teams, which require interfaces that can accommodate diverse knowledge systems and interpretive practices.

As mentioned before, temporal adaptability across platforms remained partial and fragmented. ArcGIS and Cintoo allowed the layering or versioning of static data to present time-changing; none could provide a fully integrated framework for representing the rhythms of garden life to track seasonal change, cyclical maintenance, or long-term evolution, which are functions fundamental to the conservation of living landscapes.

6. Discussion

This study has shown that while current cloud-based platforms offer significant capabilities in point cloud visualization, AI classification, and collaborative access, they remain fundamentally limited in addressing the full complexity of historic garden conservation. These limitations stem not from technological immaturity but from a deeper structural misalignment between how these platforms model heritage and how gardens function as heritage.

A number of systems, particularly those influenced by BIM, do incorporate life-cycle thinking. Platforms such as Cintoo offer features including version control, maintenance tracking, role-based access, and support for staged interventions. These functionalities position Cintoo as a viable option for addressing some of the evolving documentation and management needs of historic gardens. However, their temporal logic is typically linear and event-based, shaped by assumptions relevant to built heritage: discrete interventions, clearly bounded objects, and project-oriented change. By contrast, historical gardens are cyclical, continuous, and driven by ecological growth. They evolve through seasonal patterns, slow decay, ongoing care, and episodic interventions, none of which are adequately captured by current temporal data structures.

Similarly, while AI-based classification platforms like Flai show promise in segmenting vegetation and basic spatial features, their application remains constrained by visual regularity and general-purpose training. They are not sensitive to the semantic complexity of garden elements, where meaning may reside in informal arrangements, culturally encoded forms, or signs of age and decay. The symbolic, historic, and ecological dimensions of gardens remain invisible to these systems.

Collaborative functions, though technically enabled in platforms like Atis.cloud, ArcGIS Online or Cintoo, also reveal implicit biases about expertise and decision-making. Interfaces tend to treat all users as equal actors within a single workflow, without recognizing the diverse knowledge practices involved in garden conservation. Policy makers. Botanists, planners, and communities engage with gardens in different ways, often operating across temporal and disciplinary boundaries. Platforms currently lack role-sensitive perspectives and interface differentiation required to support truly integrated collaboration. What emerges from these findings is not a list of feature gaps, but a pattern of mismatch. While the evaluated platforms are functionally usable for historic garden conservation, current platforms conceptualize heritage as static, discrete, and visually legible. Gardens, by contrast, are living, layered systems, formed through time, shaped by care, and interpreted across cultures. These conceptual differences lead to recurring failures in how platforms handle temporality, meaning, and participation.

Importantly, this is not a matter of simply extending existing tools. It is a question of rethinking how digital environments understand and support heritage that is temporal, processual, and plural. Without this realignment, platforms will continue to offer functional utility in isolated domains while failing to support conservation in their full ecological and cultural dimensions. Therefore, the findings point not toward rejection of existing technologies, but toward the necessity of redefining their framework, a transition from heritage as dataset to heritage as care system, from static representation to ongoing mediation.

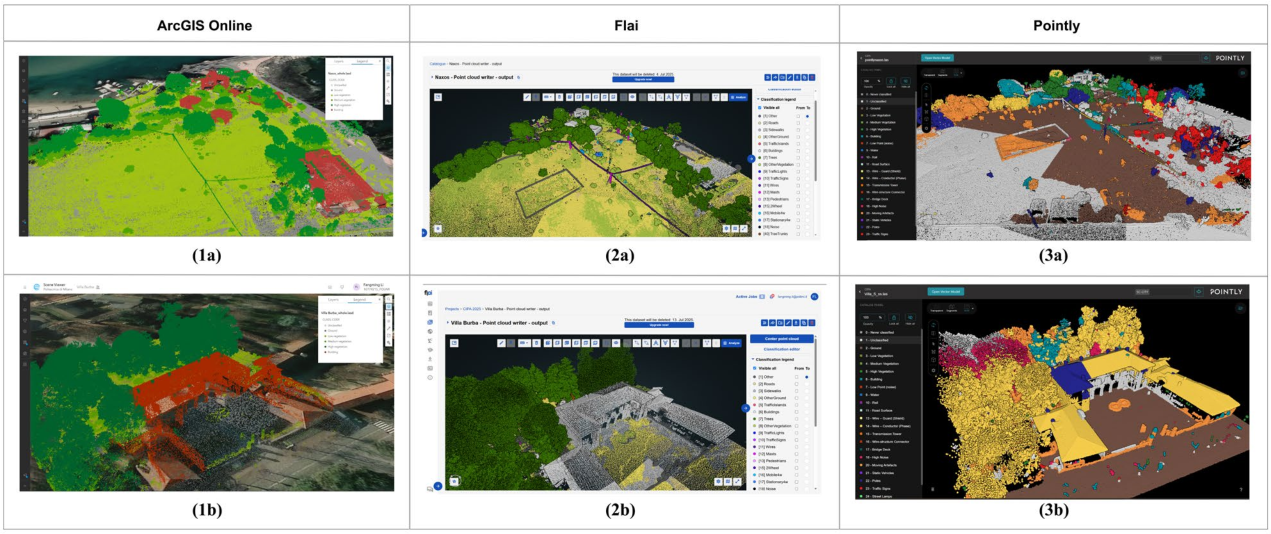

Figure 4. AI-based classification of sample point cloud data from Naxos Archaeological Park (top) and Villa Burba (bottom) using ArcGIS Online, Flai, and Pointly.

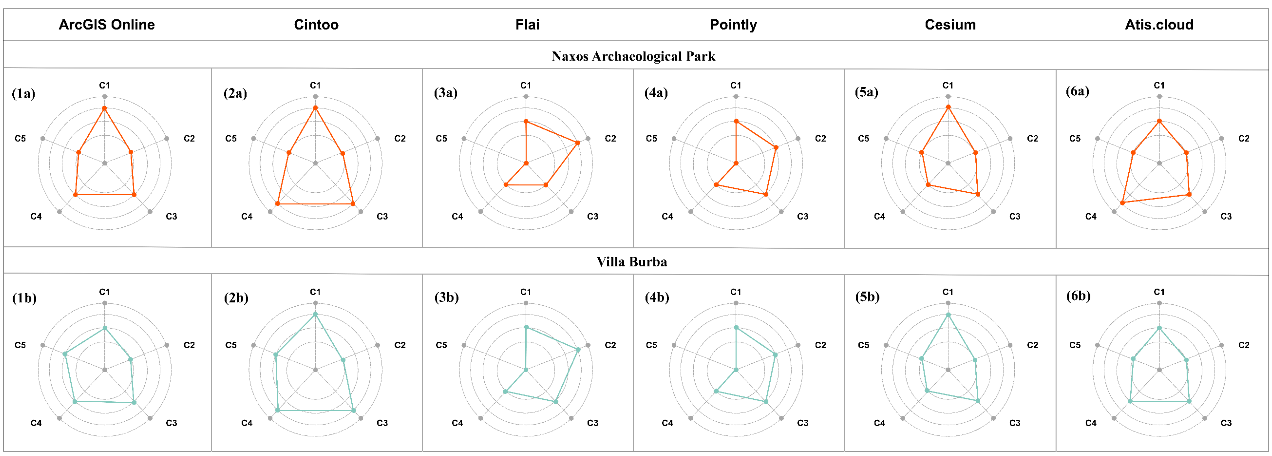

Figure 5. Evaluation of selected platforms based on five criteria for the conservation of Naxos Archaeological Park and Vill Burba. C1: Point Cloud Integration and Visualization; C2: AI-based Feature Recognition; C3: Stakeholder Usability; C4: Collaborate Workflow Support; C5: Temporal Change or Maintenance Cycle Adaptability.

7. Toward Garden-Oriented CDEs

Building on the preceding discussion, it is necessary to reconceptualize digital infrastructures for historic gardens, not simply as repositories of heritage data, but as interpretive environments capable of mediating the dynamic, multi-temporal, and interdisciplinary nature of gardens.

The notion of CDE offers a structured approach to data centralization, collaboration, and lifecycle management. However, this framework, predicated on the built environment, tends to assume a linear progression from design to demolition, with relatively stable elements and standardized professional roles. Historic gardens, by contrast, unfold through cycles of growth, decay, and renewal. Their identities are shaped not only by spatial arrangement but by ecological rhythms, cultural reinterpretation, and continuous care. Adapting the CDE model to this context requires a fundamental shift in orientation: from object-centric information control to process-oriented, heritage-sensitive mediation, which implies a move toward a garden-oriented CDE.

In a garden-oriented CDE, time should not be treated as just another layer of metadata; it should be central to the system’s structure. Seasonal rhythms, ecological change, and periodic interventions are not background conditions. They are integral to what makes a historic garden valuable. Therefore, a truly responsive digital environment should be able to record both continuity and change, enabling not only retrospective analysis but also forward-looking planning. This requires a data environment where temporality is built into the core, through versioned datasets, dynamic visual timelines, and the integration of sensor data, to create a living, evolving narrative of the garden’s condition and care over time.

Equally essential is the advancement of semantic intelligence within digital environments. Current classification tools, often constrained to geometric or spectral parameters, fail to capture the cultural, functional, and symbolic significance of garden features. A robust garden-oriented CDE should facilitate the integration of domain-specific ontologies, taxonomies that reflect not only visual or spatial attributes, but also design intentions, botanical characteristics, conservation status, and historical meanings. Achieving these demands requires interdisciplinary collaboration, where heritage experts, ecologists, and data scientists collectively shape the semantic frameworks that present the system’s interpretive capacity.

In addition, the interface between users and data in a garden-oriented CDE should be fundamentally reimagined. Unlike conventional CDEs in construction or engineering, which typically serve a relatively homogeneous group of technical professionals, historic gardens engage a wide and diverse community: landscape architects, arborists, planners, scholars, and volunteers. A single, uniform interface cannot meet such varied informational and functional needs. Instead, the system needs to enable differentiated perspectives, offering role-specific access, visualization modes, and interaction pathways tailored to the expertise and objectives of each user group. In this context, the CDE is not merely a neutral tool but an adaptive, participatory environment, one that structures engagement while remaining sensitive to disciplinary plurality and interpretive diversity.

Importantly, the development of a garden-oriented CDE does not necessitate building an entirely new system from the ground up. Existing platforms already demonstrate distinct modular strengths: Cintoo enables high-fidelity visualization, Flai contributes AI-driven segmentation, and ArcGIS Online facilitates accessible mapping and stakeholder engagement. The critical task may not be created, but integration, aligning these capabilities through interoperable frameworks, open standards, and heritage-specific data logic. A modular, composable architecture, rather than a monolithic solution, offers the adaptability required to support evolving conservation methodologies while remaining responsive to the unique spatial, temporal, and semantic demands of individual sites.

The future of garden conservation in the cloud is not about copying existing BIM or GIS systems. Instead, it is about rethinking what digital tools can be when they are shaped by the values and practices of heritage care. A garden-oriented CDE should be more than a data archive or a visualization dashboard. It should act as a shared environment for understanding, a kind of digital framework where the changes of time, the rhythms of nature, and the responsibilities of human stewardship come together to support historic garden conservation.

8. Conclusion

This study has explored that while cloud-based platforms offer useful capabilities, such as 3D visualization, AI-supported classification, and collaborative tools, they remain limited in addressing the specific needs of historic garden conservation. Key challenges persist in representing semantic detail, capturing temporal change, and supporting diverse user roles, especially for non-experts. These gaps reflect a broader misfit between the current cloud environment and the complex, evolving nature of garden heritage.

At the same time, these limitations point to new possibilities. Historic gardens are not static monuments but living cultural landscapes, shaped by seasonal rhythms, ecological processes, and human care. Supporting their conservation requires digital systems that are more than data storage and access. They should help users understand change, manage complexity, and support informed decisions.

To meet these needs, a garden-oriented CDE is suggested to go beyond existing models. it should be capable of handling rich semantic content, tracking change over time, and offering flexible access for different users, from professionals to non-experts. Rather than simply applying existing BIM or GIS tools, it would build digital environments grounded in the values and practices of historic garden conservation. In this way, historic gardens even landscape heritage could guide, not just follow, the next generation of digital innovation.

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