Digital Innovation and Cultural Heritage Conservation: The Impact of Low-Cost Technologies in the Valorization of the Medici Villas and their Itineraries

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Abstract

The rapid evolution of digital technologies, particularly low-cost solutions, has significantly impacted cultural heritage conservation. This study presents the application of these technologies in the valorization of the Medici Villas in Tuscany, a UNESCO World Heritage site. By leveraging drones, short-range photogrammetry (SfM), and GIS integration, the project successfully developed accurate and georeferenced 3D models of the villas and surrounding landscapes. These models enhance digital preservation efforts while promoting sustainable and inclusive tourism through immersive virtual experiences and cycling routes. The project highlights the potential of integrating low-cost digital tools in cultural heritage management, offering a replicable model that aligns with contemporary sustainability goals. By making cultural heritage accessible through both physical and digital means, this initiative contributes to the preservation and promotion of Italy's rich historical assets.

1. Reference Framework

In the Italian context, characterized by a unique complexity and a multitude of features shaping the landscape and civil organization, every element of the territory assumes a cultural and symbolic significance intrinsically tied to centuries of economic and productive traditions. This aspect becomes crucial in strategies for heritage conservation and valorisation, where attention to detail—understood both as a material component and as historical memory—reveals the collective identity and civic value of the heritage itself. The Italian landscape is not merely an ensemble of natural beauties but a common good reflecting shared decisions and identities, shaped by a historical stratification that has molded the territory over centuries. From this perspective, heritage conservation goes beyond the mere preservation of physical structures: it represents an act of safeguarding a civic identity, a responsibility that should not be subordinated exclusively to economic logic. (Settis, 2019)

This contribution addresses the impact of technological development and the ensuing economic accessibility of hardware and software in the processes of documenting built heritage. The availability of drones on the market has enabled widespread use of rapid data acquisition methodologies, as exemplified by the project "Medicean Villas and Gardens: A Network of Connection Promoting Sustainable Mobility" for the enhancement of the Medicean Villas in Tuscany, designated as a UNESCO World Heritage Site in 2013. This initiative, coordinated by DAda-LAB from the Department of Civil Engineering and Architecture at the University of Pavia, in collaboration with HeRe Lab from the University of Florence, is not only aimed at acquiring knowledge-based data to launch a synergistic program for the conservation of the Villas but also seeks to promote, through dynamic and easily accessible tools, new forms of sustainable and inclusive tourism.

The research project thus has a dual objective: on one hand, the digital preservation of cultural heritage through the construction of accurate, georeferenced 3D models of architectural structures and their surrounding landscapes; on the other, the promotion of sustainable tourism by developing cycling routes and mobile applications that enrich visitors' experiences and make the Villas accessible even to those who cannot visit them physically.

Simultaneously, the use of digital documentation and immersive technologies enables the integration of traditional conservation processes with innovative tools that, when used complementarily, can amplify the accessibility and enjoyment of cultural heritage. Digitization initiatives, as in the case of the Medicean Villas in Tuscany, aim to create virtual scenarios that facilitate direct and sustainable interaction with heritage, allowing visitors to access narrative paths enriched with historical and architectural information. (Parrinello et al., 2023)

Conversely, tourism tied to cultural heritage, with particular attention to cycling tourism and the use of web apps to promote sustainable tourism, must be carefully developed to avoid degenerating into commodification. It is essential that the enjoyment of heritage does not become a process of mere spectacle, where cultural assets are reduced to consumer products devoid of authenticity. On the contrary, the valorisation of these assets should respect their historical and cultural significance, balancing accessibility and conservation to ensure an authentic and sustainable experience.

The challenge, therefore, lies in rethinking sustainable pathways, whether on-site or remote, that foster conscious and respectful tourism capable of enhancing heritage without distorting it. In this way, the synergy between tradition and digital innovation can contribute to a form of tourism that celebrates local cultural identity while safeguarding heritage for future generations. (Picchio et al., 2021)

Every trace of the past preserved through three-dimensional technologies not only keeps history alive but also projects it into a future that embraces technological progress.

This focus on detail perfectly aligns with current research trends that promote the use of accessible digital technologies to document and valorise cultural heritage, enabling a profound understanding of architectural specificities without losing sight of the broader historical context. Low-cost 3D surveying technologies allow for close and detailed examination without scale constraints, enabling the observation of even complex and large-scale structures. Portable scanning systems, open-source algorithms, and affordable 3D modeling tools provide a means to capture the complexity of a project or landscape (Doria et al., 2023), revealing aspects that would otherwise escape a more distant and generalized view. In this sense, the use of such low-cost technologies is a concrete example of how attention to detail can be achieved without losing sight of the bigger picture, facilitating the conservation and valorisation of complex architectural structures such as the Medicean Villas.

The challenges in planning and implementing infrastructural and urban projects in Italy reflect the richness and complexity of the Italian landscape, along with its deep cultural roots. These complexities do not represent insurmountable obstacles to development but rather serve as an incentive to find respectful

and innovative solutions capable of enhancing the territory's peculiarities. (Bianchi, 2019)

In this context, low-cost technological solutions offer an opportunity to overcome such difficulties. These technologies stimulate new forms of thinking and action. Their increased accessibility can play a key role not only in achieving a deeper understanding of fine details in architectural documentation but also in representing and narrating the landscape and cultural heritage.

In the project to valorise the Medicean Villas, the adoption of low-cost technologies not only facilitated the concrete aspects of research, in terms of data acquisition and subsequent digital preservation of heritage, but also ensured broader and more shared access to the Villas through the structuring of online applications dedicated to citizens. These technologies enable enriched cultural experiences even for those who cannot physically visit the sites, thus opening new avenues for sustainable and accessible tourism. (Kenderdine, 2021)
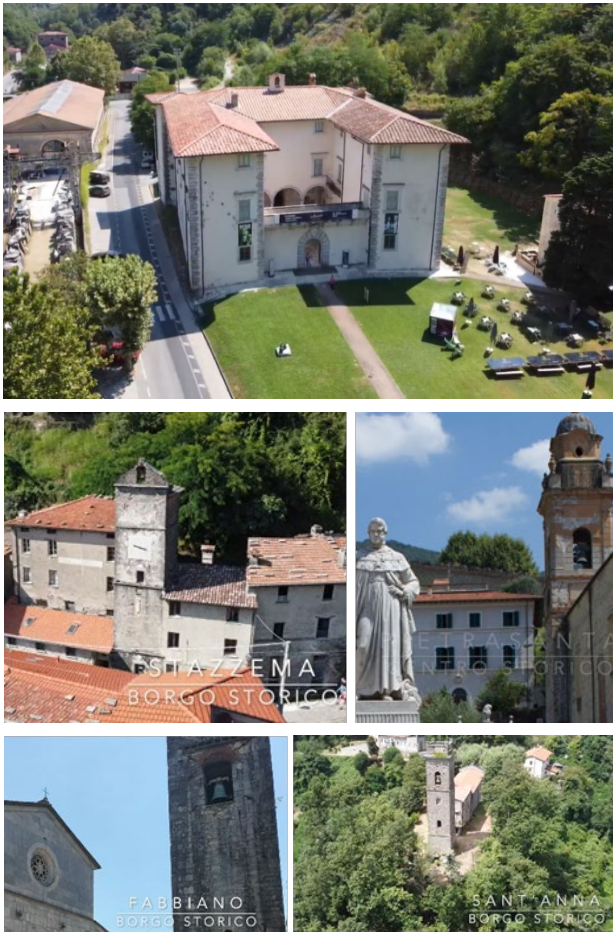

Figure 1. Spatial overview of the Villa of Seravezza, highlighting its geographical context and its relationship with the surrounding historical villages. These locations represent significant testimonies of the local cultural and historical heritage, embodying distinctive symbols of the territory's identity

Technologies that were previously available only to entities with substantial financial resources are now within reach of a broader range of organizations, enabling the collection of high-quality geographic data more quickly and efficiently. This democratization of technology has significantly improved the ability to manage the territory, allowing for more targeted interventions in environmental risk prevention and cultural heritage valorisation.

The acquisition of accurate and updated data provides more detailed knowledge of territorial conditions, helping decision-makers intervene promptly on critical issues such as landslides, floods, and soil degradation. (Parrinello et al., 2024) The use of these technologies allows for the rapid mapping of landscapes, buildings, and infrastructure, significantly reducing intervention costs and optimizing available resources. (La Placa et al., 2024)

2. Low-Cost Technologies for Digital Documentation: Advancing Sustainable Tourismdi Tecnologie Low-Cost

Numerous academic studies highlight how climate change is directly affecting cultural heritage, with particular attention to Italian UNESCO sites. Sabbioni and Bonazza, for instance, have documented how rising temperatures and humidity, combined with the pressure of mass tourism, are exacerbating the deterioration of cultural sites. This dual impact, represented by climate change and uncontrolled tourism, poses a critical challenge to the conservation of cultural heritage, as mass tourism not only threatens preservation but also degrades the environment and the quality of life for residents.

Florence, with over 4 million tourists in 2019 compared to a resident population of approximately 368,000, serves as a striking example of how poorly planned cultural tourism can have devastating effects on public spaces and the city's social fabric. Addressing these issues requires the implementation of integrated policies that consider both heritage conservation and overall environmental impact. Such policies must also balance economic sustainability with residents' quality of life, developing strategies that mitigate the impact of mass tourism without compromising the city's cultural identity and social cohesion. Only through mindful and sustainable tourism planning—encompassing both environmental and social dimensions—can Florence preserve its heritage for future generations (Bandarin, 2024).

The governance of the Tuscany Region thus faces the complex challenge of balancing the overcrowding of tourists in Florence with the promotion of other UNESCO sites, such as the Medicean Villas. Declared a World Heritage Site in 2013, the Medicean Villas represent an extraordinary opportunity to diversify the region's tourism offerings, redistributing tourist flows and easing the pressure on Florence.

This approach would not only help reduce the impact of mass tourism but also stimulate the local economy in less-visited areas, promoting a more sustainable and environmentally respectful tourism model. Focusing on sites like the Medicean Villas would allow for the creation of a complementary tourist circuit, enhancing Tuscany's entire heritage while maintaining a balance between conservation and economic development.

The use of technology in managing the cultural heritage of the Medicean Villas and the development of sustainable mobility through digitization represents a unique opportunity to promote sustainable tourism, improve accessibility, and preserve their cultural value for future generations, balancing tourist exploration with environmental conservation.

Digital surveying technologies, such as 3D laser scanners and drones, enable detailed mapping of the territory, identifying the most suitable areas for developing cycling routes and walking trails. With these tools, it is possible to construct accurate digital models that not only represent the landscape but also provide valuable data on terrain morphology and existing infrastructures. These data are fundamental for designing pathways that minimize environmental impact and support the conservation of natural and historical areas.

The digital transposition of the complexity and multiscalarity of a landscape like that of the Medicean Villas requires careful and in-depth reflection on the acquisition strategies to be employed. (Li et al., 2024) The Medicean Villas, scattered across the Tuscan territory, represent a unique cultural and natural system in which architectural heritage intertwines with gardens, parks, and, in some cases, hydrographic elements. For this reason, a standard documentation approach is insufficient; a flexible and multidisciplinary methodology is necessary to capture all the nuances of these complexes.

Methodological choices, which lie at the heart of any digitization project, must be guided by meticulous preliminary analysis that considers critical variables such as site accessibility, dimensions, and the potential mutability of natural elements over time. Villas such as Poggio a Caiano or Villa La Petraia, which combine extensive green areas with large-scale architectural structures, require the integration of technologies at multiple scales. On one hand, drones equipped with LiDAR sensors enable precise, large-scale mapping; on the other, to capture details of buildings and decorative elements, terrestrial 3D laser scanners are needed, capable of producing high-resolution models.

Another methodological challenge is posed by the mutable nature of landscape elements, such as gardens and agricultural land, which are subject to seasonal changes and natural cycles. In this context, multitemporal data acquisition is crucial. Only by monitoring changes over time can accurate documentation be ensured, serving not only conservation purposes but also the future management of these spaces.

The use of digital technologies is not limited to mere conservation but opens new possibilities for the sustainable enjoyment of heritage. Digitization can support the development of interactive and cycling routes, reducing tourist pressure on more congested areas, such as Florence's historic center, and promoting a more widespread and environmentally respectful form of tourism.

The digitization of the Medicean Villas is not merely an advanced form of documentation but constitutes an essential tool for sustainably enhancing cultural heritage, enabling a more conscious and inclusive enjoyment of the territory.

3. Enhancing the Medicean Villas: From Documentation to Interactive Engagement di Tecnologie Low-Cost

The project for the enhancement of the Medicean Villas, promoted by the Tuscany Region as a pilot experimental test to counteract the phenomenon of unmindful tourism, has enabled the use of a set of advanced digital technologies to document and promote these historical assets, making a heritage otherwise difficult to access available to the public. An integrated surveying methodology was adopted, utilizing terrestrial laser scanners, drones equipped with photogrammetric sensors, and 360° cameras (Insta 360 X3, Insta 360 Pro 2). This combination of tools allowed the creation of an extensive and detailed digital database, accurately representing the architecture of the villas and their surrounding areas. The selection of technologies was guided by specific objectives, each contributing to different aspects of site documentation and accessibility. (Remondino et al., 2024)

The use of terrestrial laser scanners provided highly detailed surveys necessary to document every surface, decoration, and structure with millimetric precision, useful both for conservation and the creation of digital content for the public. The collected data was integrated into open-source software, making the large volume of information accessible and manageable, ideal for restoration and conservation projects. While this tool is not low-cost, it was deemed strategic due to the level of detail it achieves,

providing a reference model for potential future interventions. (Li et al., 2024)

Drones equipped with photogrammetric sensors were employed to capture an aerial overview, integrating architectural details with a comprehensive vision of the surrounding landscape. This approach proved invaluable for documenting gardens, parks, and adjacent areas, offering a holistic representation that connects the architecture to its natural context. Moreover, the use of drones enabled the generation of 3D terrain models, creating a "Digital Terrain Model" (DTM) that serves as a robust foundation for future landscape and conservation analyses.

Architectural documentation was further enriched through ground-level photography with reflex cameras and 360° cameras, capturing complex details such as interior decorations, statues, and frescoes. These details, visible in the final models, make the database an effective tool for analysis and valorization activities related to the Medicean Villas. The 360° cameras, in particular, were used to create immersive content that allows users to virtually explore the spaces, interacting with the site as if they were physically present.

Parallel to this, the project will develop mobile applications integrating augmented reality (AR). Such applications represent a significant innovation for cultural tourism, as they enable visitors to access historical and architectural information directly on their mobile devices. Using AR, it is possible to view historical reconstructions, consult interactive maps, and gain contextual insights into specific architectural details. This makes the visitor experience richer and more engaging, blending the physical and digital worlds in an approach that promotes sustainable and respectful tourism. (Fu, 2024)

A fundamental aspect of the digitization project for the Medicean Villas is ensuring accessible and sustainable use. Through the adoption of digital technologies, it is possible to extend access to cultural heritage to a broader audience, including those unable to physically visit the site. The images and 3D models collected were also designed to support virtual tours, enabling immersive exploration of the spaces. This solution is particularly beneficial in alleviating physical pressure on the more fragile sites, limiting the impact of mass tourism and contributing to the long-term preservation of the heritage. (Picchio, 2024)

The database created for the Medicean Villas, in addition to being a resource for scholars and restorers, can be utilized in educational and tourism contexts. Through the developed applications, users can interact with the digital models, engage in narrative and personalized tours, and access historical information that enriches their cultural experience. This approach not only increases interest and awareness about heritage but also represents a valuable resource for the development of inclusive cultural tourism. The integration of diverse technologies posed challenges related to data compatibility and management. However, the adoption of an open-source system facilitated the processing and sharing of information, reducing overall costs and promoting replicability of the model in other areas of historical interest. One of the future objectives will be to enhance database accessibility, making it usable not only by professionals but also by the public through user-friendly interfaces. To this end, it will be crucial to continue investing in technological updates that support interaction and inclusivity.

As part of the Digital Decade initiative, Europe aims to empower businesses and citizens with a sustainable, human-centered, and more prosperous digital future by 2030 (European Commission source).

4. Metodology

The documentation activities carried out within the project focus on high-precision digital surveying, optimization of point clouds,

and detailed modeling of the terrain, buildings, and architectural and landscape structures of the Medicean Villas and Gardens. The study area, including the Palazzo Mediceo in Seravezza and other historically significant complexes, represents an ideal case for experimenting with multiscale surveying and documentation techniques due to the complexity and variety of its architectural and landscape components.

The processing conducted has enabled the development of an innovative application capable of integrating all the collected information into an interactive digital system for accessing the villas. This application, accessible both on-site and remotely, allows users to explore 3D models and access detailed informational content related to the history, architecture, and landscape context of the Medicean Villas, significantly enhancing the cultural and touristic experience.

The methodology adopted is structured into three main phases, described below.

4.1 Expedited Data Acquisition with UAV.

The selected case study, focusing on the Palazzo Mediceo in Seravezza and its historical-landscape context, was divided into specific map sections to enable detailed data acquisition using UAV technologies. This approach allowed for the careful planning of survey paths, utilizing drones such as the DJI Phantom RTK to perform high-resolution imaging with close-range Structure from Motion (SfM) photogrammetry techniques. The DJI Phantom RTK, commonly employed in urban contexts and complex historical landscapes, enabled the generation of a high-quality 3D point cloud, effectively documenting both the architectural features of the Palazzo and the morphology of the surrounding landscape.

To optimize the photogrammetric survey of the Palazzo and its surrounding gardens, a high-overlap and multi-angle photogrammetry approach was employed. These methods were planned to ensure maximum accuracy in the captured details and data consistency while minimizing the need for physical ground targets. The techniques used are based on Italian academic research, which highlights how increasing overlap and utilizing different angles can significantly enhance the quality of photogrammetric data.

To obtain an accurate and detailed model of the site, flights were planned with horizontal and vertical overlaps exceeding standard values. Specifically, an overlap of 80% along the flight path and 70% between adjacent flight strips was implemented. This strategy compensated for the absence of physical ground targets and ensured high consistency among the data from each subsection of the site.

High image overlap, as indicated in the literature, provides several technical advantages. It facilitates the creation of common points among the images, a critical element for improving the alignment of frames and reducing errors in mosaic creation and 3D reconstruction processes. Additionally, such high overlap helps mitigate perspective variations and provides redundant information, thereby increasing the overall accuracy of the photogrammetric data.

In addition to high overlap, multi-angle surveys were conducted for each subsection of the Palazzo and its gardens. This approach involved capturing images from various angles: close-range (to document specific details), nadir (vertical views), and oblique (side views). Oblique images were particularly useful for documenting the facades and vertical elements of the Palazzo, while nadir images ensured comprehensive coverage of horizontal surfaces. This method enabled the collection of a redundant dataset from multiple angles, enhancing the quality of the overall 3D model.

Figure 2. 3D Visualization and Photogrammetric Analysis for the Valorisation of the Medici Villas and Their Context

During the post-production phase, these multiple angles minimized distortions caused by vegetation, particularly relevant in the gardens, ensuring an accurate representation of both open spaces and architectural structures. In summary, the integration of high overlap and multi-angle acquisition produced a detailed and accurate model of the site, maximizing data consistency and accuracy. These advanced photogrammetric survey methods represent a consolidated best practice, achieving high-quality results without the use of physical ground targets, as confirmed by reference literature.

The division of the survey area into specific subsections was determined by the drone's technical capabilities and the optimal flight altitude, maintaining a Ground Sample Distance (GSD) of 1 cm/pixel, as suggested by studies emphasizing the importance of resolution in historical architectural surveying applications (Russo et al., 2018). To avoid interference from trees and aerial infrastructure, the flight altitude was maintained between 35 and 40 meters, adhering to best practices for surveying complex sites. (Dominici et al., 2017)

Based on battery autonomy and imaging coverage, the area was divided into subsections with a minimum overlap of 10%, ensuring continuity and integrity of the collected data. The importance of overlap has been confirmed by research on UAV surveying methods for creating detailed and continuous models. (Fiorillo et al., 2023)

Survey operations were completed in approximately 2.3 hours, excluding battery recharging breaks, with each subsection documented through approximately 350 images. Subsequently, the subsections were precisely combined through an accurate alignment process to minimize errors between adjacent sections, maintaining a maximum error margin of 0.08 meters, as applied in other studies on Italian historical monuments. (Banfi & Mandelli, 2021)

To capture significant architectural details of historical value, the UAV survey was complemented by ground-level photography using a Canon EOS 2000D. This integration resulted in a rich digital model supporting both conservation documentation and the interactive valorisation of the site.

This surveying and documentation methodology enabled the creation of a detailed digital model of the Palazzo Mediceo, producing an interactive visual database that serves as a reference for the digitization and monitoring of other architecturally and historically valuable assets.

4.2 Discretization and 3D Modeling Process for the Palazzo Mediceo of Seravezza and Its Cultural Context.

To digitally document and enhance historical sites, specifically the Palazzo Mediceo in Seravezza, the Mausoleum of Sant'Anna, the Medicean Tower, and the Romanesque Church of Seravezza, a discretization and 3D modeling process was adopted. This method divides complex datasets into modular units that are easily manageable and representative of the different architectural and landscape components. Each site was analyzed in terms of surfaces, lines, and key points: surfaces identify the main architectural structures, lines trace the profiles of connecting elements, and points highlight specific details and artifacts, such as decorations and architectural reliefs.

The use of differentiated Levels of Detail (LoD) enabled the creation of multiscale models that combine the constructive accuracy of architectural details with an overarching view of the historical landscape. In some cases, to emphasize the integrity of the historical context, minor elements were schematized, while structural components and significant details were reproduced with extreme precision. The final product is a composite three-dimensional model that integrates the distinctive features of each site with its surrounding landscape, making the historical stratification and cultural significance of each element visible.

The survey was conducted using aerial photogrammetry with drones to acquire high-resolution data on the terrain and buildings, followed by the extraction of a Digital Terrain Model (DTM). This step, documented as effective for historical sites (Yunfei et al., 2008; Vallet & Papelard, 2015), included filtering out above-ground points (vegetation, trees, modern infrastructure), ensuring a reliable and clean terrain model. For greater detail in architectural structures, such as the facade of the Romanesque Church and the decorations of the Medicean Tower, Structure from Motion (SfM) techniques with ground-level photography were employed. This approach allowed the reconstruction of each building with high precision, capturing even the finest details.

The standardization of modular elements facilitates the reuse of main components across different models and enables quick and consistent updates over time, making the process sustainable for future expansions or modifications. By utilizing open-source software such as Cloud Compare, costs were contained, ensuring that the methodology can be replicated for other areas of historical significance.

Figure 3. Point Cloud Generated from Laser Scanner Data Processing for the Valorisation of the Medici Villas and Their Context

Figure 4. Point Cloud Generated from Laser Scanner Survey of the Interiors of the Medici Palace in Seravezza: Room for the Exhibition of the Medici's Ancient Jars"

The final model not only faithfully represents each site but also serves as a versatile resource applicable to both conservation management and cultural dissemination, with potential uses in virtual tours and interactive valorisation projects.

The precision of the DTM and the quality of the 3D models now allow for a detailed interpretation of Seravezza's historical context. For example, the survey of pathways between the Palazzo Mediceo and the Medicean Tower highlights ancient routes of communication and topographical relationships with the surrounding settlements, offering new interpretative perspectives for scholars and visitors alike.

This model thus represents a tangible and sustainable tool for the valorization of local heritage, supporting both conservation activities and accessibility for a wide audience, in line with the principles of digital accessibility and inclusivity.

Figure 5. 360° Surveys Conducted by Researchers for the Virtualization of Routes Leading to the Main Cultural Sites in Alta Versilia and the Medici Palace of Seravezza"

4.3 Digital Technologies and Cultural Accessibility: Challenges and Solutions for Inclusive Heritage Engagement.

Accessibility and digital interaction with cultural heritage represent a fundamental frontier for the conservation and enjoyment of cultural resources. One of the primary innovations in this field is the discretization of integrated documentation information—a process that subdivides and organizes complex data into modular and accessible units adaptable to the needs of a wide variety of users, including those with disabilities. This digital approach enables personalized and incremental experiences, enhancing public understanding and engagement.

Digital applications integrating Augmented Reality (AR), Virtual Reality (VR), and Artificial Intelligence (AI) are revolutionizing the experience of cultural heritage, offering immersive and accessible opportunities for individuals with diverse abilities.

However, it is equally essential to acknowledge the practical and technological limitations of these approaches, a critical aspect for comprehensive scientific evaluation.

AR and VR technologies allow barrier-free experiences, enabling users to virtually explore museums and historical sites from any location and at any time, thus expanding accessibility for individuals with mobility challenges or those geographically distant. Studies such as those (Yanti et al. 2023) demonstrate that these technologies create immersive environments that facilitate a deeper understanding compared to traditional documentation methods.

Interfaces designed with a focus on user experience (UX) and accessibility, as recommended (Jantan et al. 2023), support an inclusive approach by offering customizable navigation tools and immediate feedback, thereby improving usability even for users with visual or motor impairments. The integration of AI further enhances personalization by adapting content to user preferences and facilitating multilingual translations, making cultural content accessible to an international audience.

Despite these advantages, AR and VR technologies face economic constraints, as they require dedicated devices, such as headsets, which can be expensive and not universally accessible, limiting the inclusivity of immersive experiences. Additionally, reliance on specific devices presents challenges: while many contents can be accessed via smartphones, high-quality experiences often require VR headsets, which not everyone owns. This creates difficulties for cultural institutions with limited resources.

To overcome these limitations, a pragmatic approach that integrates accessible technologies and alternative tools can be adopted. Solutions such as AR applications for smartphones, 360° videos viewable across multiple platforms, QR codes for interactive content, and cost-effective headsets like Google Cardboard offer engaging and personalized digital experiences at lower costs, thereby broadening access to cultural heritage.

From a technical standpoint, these applications demand advanced expertise and continuous updates, a challenging aspect for smaller cultural institutions that often lack the resources to maintain such systems over the long term. Furthermore, the need for a stable internet connection poses an additional barrier, particularly in remote areas, restricting access to real-time content and high-quality experiences.

Digital applications for cultural heritage thus present extraordinary opportunities to make historical and artistic content more accessible and engaging. However, the effectiveness of these solutions depends on careful planning that thoroughly considers costs and access barriers. A balanced strategy should integrate affordable and accessible technological solutions, ensuring that content is available on common devices to strike a balance between innovation and inclusivity.

An application can facilitate the democratization of knowledge by overcoming physical and logistical barriers, allowing autonomous and continuous access even from a distance. However, the effectiveness of an app depends on the quality of its interface and the cultural adaptation of the information it presents: an unintuitive interface or inaccessible content may alienate users rather than engage them.

4.4 Case Study: The Ville Medicee App.

The design of the Ville Medicee app follows a methodological approach aimed at optimizing accessibility and cultural interaction, aligned with advanced UX/UI design practices. Recent studies (Jantan et al., 2023) highlight the importance of interfaces accessible to users with visual impairments, leveraging intuitive navigation features and personalized feedback. During the app's development, the team adopted the Design Thinking approach, which, according to (Hiererra et al. 2022), has proven particularly effective in cultural applications. Structured into phases of empathy, ideation, prototyping, and testing, Design Thinking enabled the team to address the needs of target users, validating the design through the System Usability Scale (SUS), which achieved high acceptability scores.

The integration of AR and VR elements in the design draws from (Yanti et al. 2023), who emphasize the potential of these technologies to enhance the digital experience of cultural heritage. Specifically, the app facilitates virtual exploration of environments, demonstrating improvements in user satisfaction and accessibility. In accordance with Kapoor's (2021) guidelines, an inclusive design approach was implemented to ensure content accessibility, applying accessibility standards and conducting tests from the early stages of development. This approach, as demonstrated by Kapoor's research, incorporates the needs of users with disabilities into the design, maximizing the usability and inclusivity of the digital experience.

Figure 6. Procedures and Workflow for the Development of the App for Cultural Sites Enhancement

5. The Synergy Between Digitization and Cycling Tourism: Toward a Sustainable and Immersive Cultural Heritage Experience

The integration of digital surveying of cultural heritage with cycling tourism represents a significant innovation in the enhancement of built heritage, fostering sustainable and deeply immersive travel experiences. Through initiatives such as the National Plan for the Digitization of Cultural Heritage, Italy is creating a digital infrastructure that enables the preservation and sharing of detailed information about cultural assets, easily accessible via mobile applications and interactive platforms. These digital resources allow cycling tourists to access historical and architectural data about the places they visit during their journeys, often enriched by technologies such as augmented reality.

In regions like Tuscany, for example, cycling routes intersect with cultural itineraries that, thanks to digital guides and interactive maps, offer a journey enriched with historical narratives and real-time architectural insights. Renowned academics, such as Professor Maurizio Forte of Duke University,

are driving innovation in this field by developing advanced methodologies for digital surveying and applying their research to improve the accessibility and understanding of cultural heritage. In this way, the synergy between cycling tourism and digitization fosters greater awareness of local heritage, encouraging travelers to rediscover the territory in a more informed and environmentally respectful way.

The integration of digital technology with cycling tourism can be seen as a new modality of "revealing" heritage. Digital technology, rather than distancing us from the reality of historical sites, becomes a tool to bring us closer to the essence of what we visit, enabling a deeper understanding of heritage (Heidegger, 1976). Contemporary schools of thought increasingly conceive of technology as a means to reveal the world. This invites us to consider digital surveying as a technique that, when used with respect and mindfulness, can enhance the authenticity of cultural sites.

From another perspective, experience is always tied to corporeality and sensory perception. Cycling tourism, enriched by digital technologies, represents a complete phenomenological experience (Merleau-Ponty, 2014). Pedaling through the landscape while interacting with cultural heritage via digital tools providing real-time information allows for a fusion of sensory perception and intellectual knowledge. This type of experience combines the physical dimension of travel with a deeper understanding—not only visual but also historical and symbolic—of the places visited.

A further aspect worthy of reflection concerns the simulacrum and the perception of hyperreality, whereby augmented reality and digital applications might risk detaching users from the "real reality" of the places. However, a conscious approach to digitization could counterbalance this risk, promoting the use of technologies that enhance rather than replace the cultural essence of the sites visited. Addressing this critical reflection involves ensuring that the experience remains authentic, avoiding its reduction to mere digital representation, and remembering that places possess their own presence, an aura that must be respected (Baudrillard, 1981).

Finally, an ethical and responsible approach offers an additional dimension, highlighting the value of digital cycling tourism as a sustainable practice that reduces the environmental impact of mass tourism. With ethical responsibility toward future generations, the use of digital technologies in service of cycling tourism not only enhances cultural heritage but also encourages environmentally respectful travel practices, setting limits on the intensive exploitation of cultural assets (Hans Jonas, 2009).

6. Conclusions

The digital approach adopted for the enhancement of the Medicean Villas exemplifies an emerging paradigm in cultural heritage management, where technology is not merely a technical support but becomes an integral part of the process of interpretation and access to heritage. The use of tools such as laser scanners, photogrammetric drones, and augmented reality represents a "revolution in surveying" that, unlike traditional methods, not only documents architecture but translates it into accessible and interactive formats. In this way, historical heritage is no longer confined to a specialized audience but becomes available to a broad and diverse public, creating a new dimension of inclusivity in heritage management.

The Medicean Villas project demonstrates how digital technologies can serve as a "bridge" between past and future, combining the need to preserve the details and original structure of cultural assets with the opportunity to offer immersive and accessible experiences. As art historian and theorist Erwin Panofsky observed, every interpretation of historical heritage is inevitably mediated by contemporary contexts. In this sense, the use of digital technologies does not betray historical authenticity but rather reinterprets it to make cultural heritage relevant to current and future generations.

A crucial element of the project is the use of 3D technologies and mobile applications, allowing visitors to virtually explore architectural details, decorations, and historical environments in real time. This interactive dimension represents a significant step toward a participatory model of heritage engagement, where visitors are no longer passive spectators but active explorers. This approach aligns with a broader theoretical framework, drawing on John Dewey's theories of aesthetic experience and Maurice Merleau-Ponty's concept of phenomenological engagement. Both suggest that a truly transformative experience requires the active and sensory involvement of the visitor, who, thanks to digital technologies, can engage in direct dialogue with cultural heritage.

The choice of low-cost digital technologies is another innovative and significant aspect of the project. The economic accessibility of tools such as drones and digital photogrammetry not only democratizes heritage management but also enables broader and more sustainable implementation. In a context where resources for heritage conservation are often limited, the adoption of efficient digital technologies provides a concrete response to the challenges of economic and environmental sustainability. This approach aligns with UNESCO's guidelines for heritage management that is both economically sustainable and respectful of local communities, contributing to less invasive and more environmentally friendly cultural tourism.

The project represents a replicable model on both national and international scales, demonstrating that digitization can be a strategic resource for heritage conservation. Such initiatives could be adapted to other contexts, addressing the needs of accessibility and protection of cultural heritage in areas with limited resources for restoration and maintenance. Furthermore, the success of the Medicean Villas project could contribute to a paradigm shift in cultural heritage management policies, encouraging collaboration between public and private institutions, research centers, and local communities.

The digitization of the Medicean Villas showcases how digital technologies can transform the experience of cultural heritage, creating an approach that is simultaneously educational, sustainable, and inclusive. The project embodies a balance between conservation and innovation, demonstrating that historical heritage is not merely a legacy to be preserved but an opportunity to generate new forms of knowledge and cultural participation. The creation of accessible three-dimensional models and the use of AR applications effectively bring heritage "to life," fostering dynamic engagement that respects the past while looking to the future.

The digitization of the Medicean Villas stands as an example of synergy between innovation and sustainability, demonstrating how digital technologies can make cultural assets accessible in a respectful and inclusive way. Beyond digitally preserving heritage, the project facilitates the dissemination of knowledge and promotes a more mindful and conscious form of cultural tourism, aligned with contemporary needs for sustainability and territorial enhancement.

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