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From Drone-Based 3D Model to a Web-Based VR Solution Supporting Cultural Heritage Accessibility

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Highlights

What are the main findings?

- The integration of close-range and UAV-based photogrammetry, mobile laser scanning (SLAM), and 360° panoramic images delivers high-resolution, multi-scale digital models of historic buildings in remote or difficult-to-access locations. This supports the precise documentation and analysis of built heritage.
- A web-based VR platform has been developed to explore the Roccapreturo Tower, facilitating the visualization of complex architectural features and promoting safe and informed planning of on-site visits.

What are the implications of the main findings?

- The designed workflow is scalable and replicable for the digital preservation, documentation, and management of cultural heritage, in order to increase its accessibility to scholars, heritage administrators, and the general public.
- The integration of multi-sensor survey data into VR applications facilitates the dissemination of heritage, promotes sustainable and safe tourism in inner areas, and supports the development of informed conservation strategies.

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Abstract

The safeguarding and enhancement of historic buildings and artifacts in Italy's inner areas are essential to protect their outstanding cultural value. However, these territories often face complex orographic and environmental conditions that make traditional surveying and documentation challenging. To address these issues, this study proposes a framework for the digitalization and virtual dissemination of architectural heritage aimed at supporting safe and sustainable tourism. The proposed approach integrates unmanned aerial vehicle (UAV) photogrammetry with laser scanning to produce three-dimensional models of historic structures. These digital models are then semantically enriched and simplified for use within a web-based virtual reality (VR) platform, enabling interactive learning experiences for increase cultural heritage accessibility. The framework is validated through the case study of the Roccapreturo Tower in Acciano (AQ), located in the inner areas of the Abruzzo region, a landscape characterized by high morphological complexity. Results demonstrate the effectiveness of drone photogrammetry in capturing detailed and accurate representations of cultural heritage assets while ensuring operational efficiency and accessibility. The resulting VR models promote heritage safeguarding and sustainable tourism, confirming the potential of UAV-based technologies in the digital transformation of cultural heritage.

Keywords: architectural heritage; drone and laser integration; virtual reality; digital platform; accessibility to cultural heritage; sustainable tourism; enhancement of inner areas

1. Introduction

The Italian inner areas [1,2], mostly consisting of small towns with populations below 5000 [3], preserve a dense concentration of architectural heritage that reflects the history, cultural, and architectural traditions of the territories. The conservation and enhancement of this heritage represent a crucial challenge for local public administrations [4,5], which are called upon to ensure the protection of assets and, at the same time, to promote the sustainable development of communities.

These challenges are increased by the vulnerability of the territory and its exposure to natural hazards [6,7], including those related to climate change [8]. The conditions of depopulation and territorial vulnerability have a direct impact on the physical preservation of built heritage, especially those in rural areas already compromised by increasing abandonment, which speeds up the degradation processes, causing, in the most severe cases, the collapse of structures. In addition to the physical loss of tangible heritage, there is the risk of a progressive loss of the cultural and identity values that characterize historic buildings and that can contribute to the revitalization of rural and marginal areas. For this reason, it is necessary to develop integrated strategies that combine risk prevention, conservation, and enhancement of cultural heritage, according to a resilience-oriented approach and sustainable development.

In this context and for the development of such strategies, the transition to digital technologies has become particularly relevant. The digitization of architectural heritage represents, indeed, a focus of both national and international research, aiming to develop innovative tools, protocols, and strategies to improve documentation, conservation and accessibility. The digitalization could facilitate the management of heritage, especially in addressing the challenges associated with the impact of climate change on built heritage.

The role of digital technologies in built heritage knowledge is investigated by several research studies. Unmanned Aerial Vehicle (UAV) systems are widely recognized as effective instruments for multi-scale, high-resolution data collection, even in sites that are difficult to reach [9,10]. The versatility of remotely piloted drones allows for a detailed survey of both extensive urban and rural contexts, and artifact and complex buildings [11–13]. Their capability to capture high-resolution data rapidly, even under critical operating conditions, has encouraged their widespread use in scientific research and building heritage management. Several studies highlight the advantages of aerial photogrammetry in improving the knowledge of the existing built environment, covering both infrastructures and historic buildings, and emphasize the usefulness of drone-based models for inspection and mapping surface decay [14–18] and planning conservation and monitoring interventions [19–24].

The use of UAV systems is increasingly complemented by other digital techniques, broadening the analytical possibilities across multiple scales and levels of detail. Among these techniques, mobile laser scanning based on Simultaneous Localization and Mapping (SLAM) algorithms and 360° panoramic photography are now widely adopted. The scientific literature discusses the effectiveness of SLAM systems for rapid data capture in heterogeneous contexts [25–28], demonstrating their discrete geometric accuracy [29–32] and their efficiency in generating datasets for assessing and documenting the current condition of infrastructure and built heritage [33].

After acquisition, the raw data are processed through dedicated algorithms to either compute 3D coordinates from laser-scans or reconstruct spatial geometry via the Structure from Motion (SfM) method. When the outputs from these distinct sources are combined, they provide a comprehensive and accurate representation, improving documentation and supporting management and enhancement of the historic built environment [34–38]. Indeed, the application of multi-sensor techniques enables reliable surveying with good accuracy across the acquired multi-scalar datasets [39–42]. The Global Navigation Satellite System (GNSS), which receives radio signals trans-mitted by satellite constellations used for global navigation, contributes to this integration process by providing ground control points, refining spatial accuracy, and facilitating dataset alignment [43–45].

Further post-processing enables the development of complex information models that incorporate historical, architectural, and diagnostic content [46–48]. These digital models adapt the concept of Level of Detail (including Level of Geometry—LoG—and Level of Information—LoI) from the parametric procedure [49], paving the way for the creation of Digital Twins [50]. Drone-based meshes can be combined with the 3D models produced through BIM or NURBS techniques, as discussed extensively in the literature [51–53]. Nevertheless, research still faces challenges in defining fully semantic 3D models and identifying efficient frameworks for optimizing and using such replicas and linking geometric and informative content within digital environments.

Recent advances in visualization technologies have driven the increasing use of Virtual Reality (VR) for educational purposes, heritage dissemination [54–58], and tourism [59,60]. However, incorporating large-scale survey data, such as point clouds or semantic mesh models, into a VR environment remains technically demanding, as it requires high computational and network performance. To overcome these constraints, several studies have explored model optimization strategies that maintain geometric quality while reducing complexity, for example by adjusting the Levels of Detail (LoD) [61,62] and applying normal maps to preserve appearance and detail [63].

Through retopology and simplification procedures of these complex models [64,65], the number of mesh vertices can be reduced without compromising perceptual quality, producing lightweight 3D models that ensure smooth rendering and an immersive user experience [66].

Simplified and semantically enriched drone-based models, augmented with textual or visual annotations, constitute powerful tools for documenting, safeguarding, enhancing and disseminating built heritage, thereby making it more accessible to a wider audience.

This document presents a framework for the digitalization of historic buildings, according to the National Digitalization Plan for Cultural Heritage [67], and which has been addressed by the research group in different projects [68–70]. It starts with the integration of drone and laser surveying to create simplified, semantic digital models that can be used in VR to promote safe and sustainable tourism.

The document is structured as follows: Section 2 details the materials and methods used to define the framework for the digitization of built heritage. Section 3 presents the main results, with application to a case study that validated the process, making it replicable and scalable. The results obtained increase accessibility to historical heritage not only in cultural and informational perspectives but also from a physical one, as they enable the planning of on-site visits by anticipating potential risks and challenges. Finally, Section 4 discusses the results and provides concluding remarks.

2. Materials and Methods

To address the challenges associated with conserving, and enhancing the architectural heritage of inner areas, a framework for the digitization of historic buildings is proposed. This research focuses on the inner areas of the Abruzzo region, which features a highly complex orographic landscape. As a case study to validate the proposed framework, the Roccapreturo Tower (Figure 1), located in the Acciano Municipality (L'Aquila) [71], has been selected. The tower is all that remains of a medieval castle with a long history of evolution, reflecting the economic, social, and political circumstances often linked to the successive rulers over time. Its original structure was that of a castle adapted to the topography of the land, similar to many others in the L'Aquila area [72]. The remains of the medieval castle are still visible, although poorly preserved, while the pentagonal tower has remained intact thanks to restoration work over time. This structure holds significant cultural value and is located on the rocky outcrop overlooking the village of the same name, at an elevation of about 900 m asl, making it difficult to access.

Figure 1. Localization of Roccapreturo in Italy and photos of the tower.

Indeed, the area can now be reached exclusively on foot, via a path that starts from the village center and leads to the settlement in a walk of about 20 min. Although the trail is well maintained, the steep slope and morphological conditions pose a significant obstacle to public use.

The Roccapreturo tower was analyzed, thanks to an agreement with the municipal administration of Acciano, using a multidisciplinary approach that, starting from an integrated survey, led to the creation of a virtual replica of the structure accessible via a web-based platform for data visualization in VR.

The Digitalization of Architectural Heritage

The operational framework is structured in three main phases and is based on the integration of several procedures, the use of diverse tools for multi-scale representation, and the digitalization of historical/heritage artifacts (Figure 2).

The first phase involved a series of instrumental surveys combining both active and passive sensing technologies, organized according to a scalar progression (from the territorial dimension to the detailed level of a single artifact). The activities included:

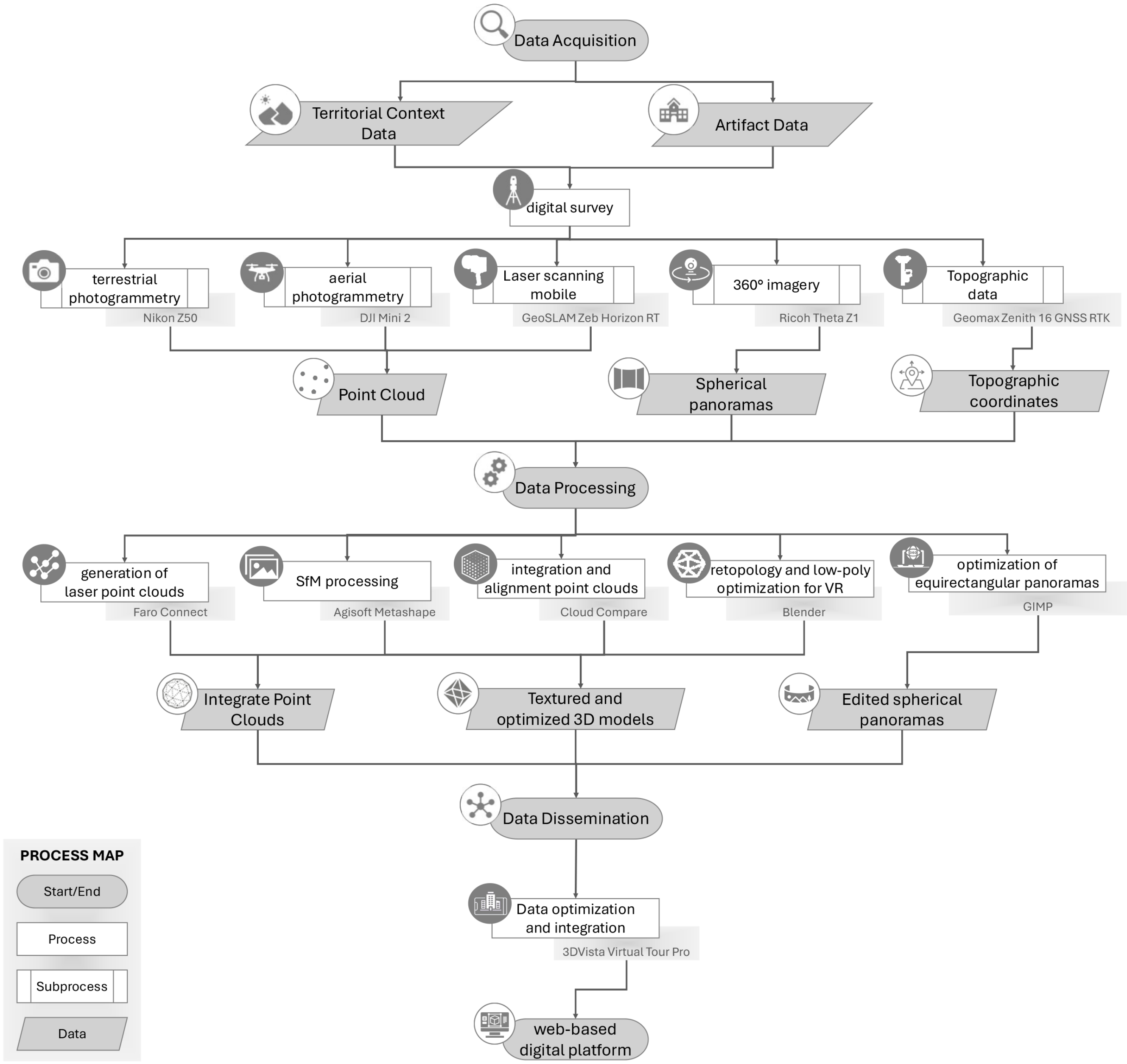

Figure 2. Workflow of the operational framework.

- UAV data collection for photogrammetric process, performed with a Mini 2 drone (DJI Sciences and Technologies Ltd., Shenzhen, China) equipped with a 12 MP 1/2.3″ RGB CMOS sensor for the test;
- terrestrial close-range photogrammetry carried out using a Z50 camera, (Nikon Corporation, Tokyo, Japan) equipped with a 21.5 MP 1.8″ CMOS sensor;
- capture of 360° panoramic imagery using a Theta Z1 camera (Ricoh Company Ltd., Tokyo, Japan) in the case described;
- acquisition of spatial data with a mobile laser scanner system, specifically, a GeoSLAM Zeb Horizon RT (FARO Technologies, Inc., Lake Mary, FL, America) using SLAM technology.

The integration of these survey techniques and datasets was achieved through the definition of a geographic coordinate reference system. This alignment was supported by collecting topographic information using GNSS technology, employing a Zenith 16

(Geomax Srl, Milan, Italy) receiver operating in RTK mode. The inclusion of these reference points enhanced the precision and interoperability of the multi-source datasets.

The second phase focused on the processing, generation and optimization of the acquired data to produce virtual replicas. The steps included the following:

- Processing of Ground Control Points (GCPs) collected via GNSS for georeferencing and topographic alignment with the global coordinate system (WGS84 was used for the test). This facilitated the integration of point clouds obtained from both laser and aerial photogrammetric surveys. Specifically, Cloud Compare software was used for this purpose.
- Creation of the laser point clouds through dedicated algorithms. For the test, the algorithms integrated in the proprietary software Faro Connect (version 2024.1.3) were used.
- Construction of photogrammetric models using SfM algorithms. Specifically, Agisoft Metashape software (version 2.2.2.21287) was used following the dataset validation process, the alignment, the generation of dense point clouds, and integration with the GNSS data for both aerial and terrestrial surveys.
- Optimization of dense point clouds, generation of mesh geometries, and creation of textured models within the Agisoft Metashape.
- Retopology and optimization of the mesh to generate low-poly models suitable for Virtual Reality (VR) environments. In this specific case, the open-source platform Blender (version 4.1) was used.
- Editing and optimization of equirectangular panoramic images captured with the 360° camera, including brightness adjustments and quality assessment.

The final phase consisted of developing a web-based digital platform accessible from both desktop and immersive VR devices. This platform integrates 3D mesh models, spherical images, and informational content, providing an interactive tool to support accessibility, tourism promotion, and the dissemination of cultural heritage. For testing purposes, the application was developed using 3DVista Virtual Tour Pro software (version 2025.1.38). This software was selected for its affordability, features, and ease of use, features that make the process replicable and scalable. The same project can handle different types of data, including 3D mesh models, images, photos, videos, and text. This versatility facilitates the integration of results, enabling them to be accessed simultaneously on different devices. In addition, the software company has demonstrated a constant effort to update the system, ensuring its reliability for implementing data over time.

Through simple and intuitive operations, the information collected in the previous steps was imported and then linked together using buttons. The software's features, primarily designed for creating virtual tours, were adapted for research purposes. The final web-based platform offers an interactive framework that allows users to navigate the 3D model and access associated information directly online.

3. Results

3.1. The Integrated Survey

To acquire integrated planovolumetric and typological-formal information and to generate a virtual replica of the artifact along with its surrounding landscape, an instrumental survey campaign was designed and carried out by integrating multiple techniques and sensor types. The adopted approach, based on the combined use of topographic methodologies, aimed to produce heterogeneous and complementary outputs at varying levels of resolution and detail.

The data acquisition followed a scalar progression, from the low-density survey of the broader area surrounding the tower to the high-resolution capture of specific structures, such as the tower itself and nearby archeological remains.

Due to the orographic complexity and limited accessibility of the site, digital drone photogrammetry played a central role, serving as the primary method for large-scale surveying of both the site and the tower. This technique enabled comprehensive mapping of the spatial context while avoiding the need for direct access to areas that were difficult to reach or posed potential safety risks.

In detail, two UAV flights were carried out using a DJI Mini 2 drone. These flights had distinct characteristics and objectives. The first one, aimed at capturing a general overview of the area surrounding the tower, achieved an average Ground Sampling Distance (GSD) of 1.11 cm/pixel and produced 516 images. The second focused on a close-range, high-resolution survey of the tower and its masonry details, achieving an average GSD of 5.56 mm/pixel and producing 470 images. In total, approximately 1000 photographs were acquired during the two survey campaigns (Figure 3).

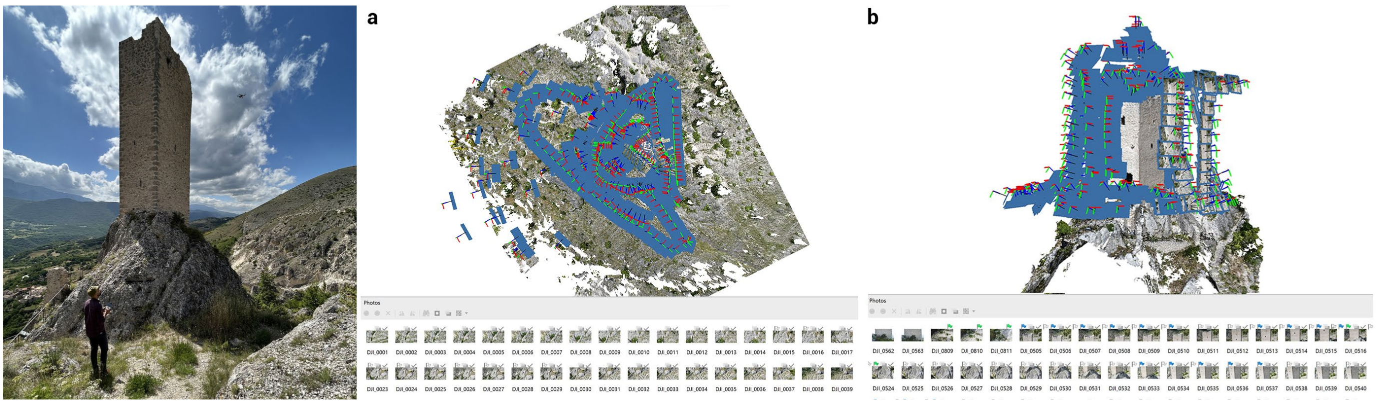

Figure 3. Drone acquisition campaign to capture photos of the area (**a**) and tower (**b**).

The survey of the interior spaces was carried out through the use of three complementary methodologies: mobile laser scanning; digital terrestrial photogrammetry; and a 360° digital camera.

The mobile laser scanning survey was performed using a SLAM-based device (GeoSLAM Zeb Horizon RT) with a range of 100 m and an accuracy of 1–3 cm. This enabled a precise and coherent three-dimensional reconstruction of the environment for geometric characterization (Figure 4) by executing a closed-loop trajectory over a period of approximately eight minutes.

The terrestrial photogrammetric campaign, carried out with a Nikon Z50 camera, resulted in the acquisition of 590 images. This ensured complete coverage of the tower's interior, as well as the combination of metric data with RGB color information (Figure 5a).

Panoramic images were acquired using a Ricoh Theta Z1 one-shot camera with a resolution of 6720 × 3360 pixels at 300 dpi. Due to the compact size of the interior spaces, one panoramic image was captured per floor, along with two additional exterior shots: one at the landing near the entrance and one at the top of the tower (Figure 5b).

A shared reference system, established through a network of topographic Ground Control Points (GCPs) collected via GNSS in RTK mode (Geomax Zenith 16 receiver with WGS84-RDN2000 datum), enabled the integration of datasets acquired with different sensors. The GCPS were strategically distributed across the survey area, selected based on stable natural features and temporarily marked with high-visibility targets (Figure 6). Each control point was documented through dedicated data sheets containing comprehensive information for their identification and localization, ensuring full traceability and enabling their reuse in future survey campaigns. These control points served as common references for georeferencing all acquired datasets, thereby guaranteeing the interoperability and scalability of the resulting models.

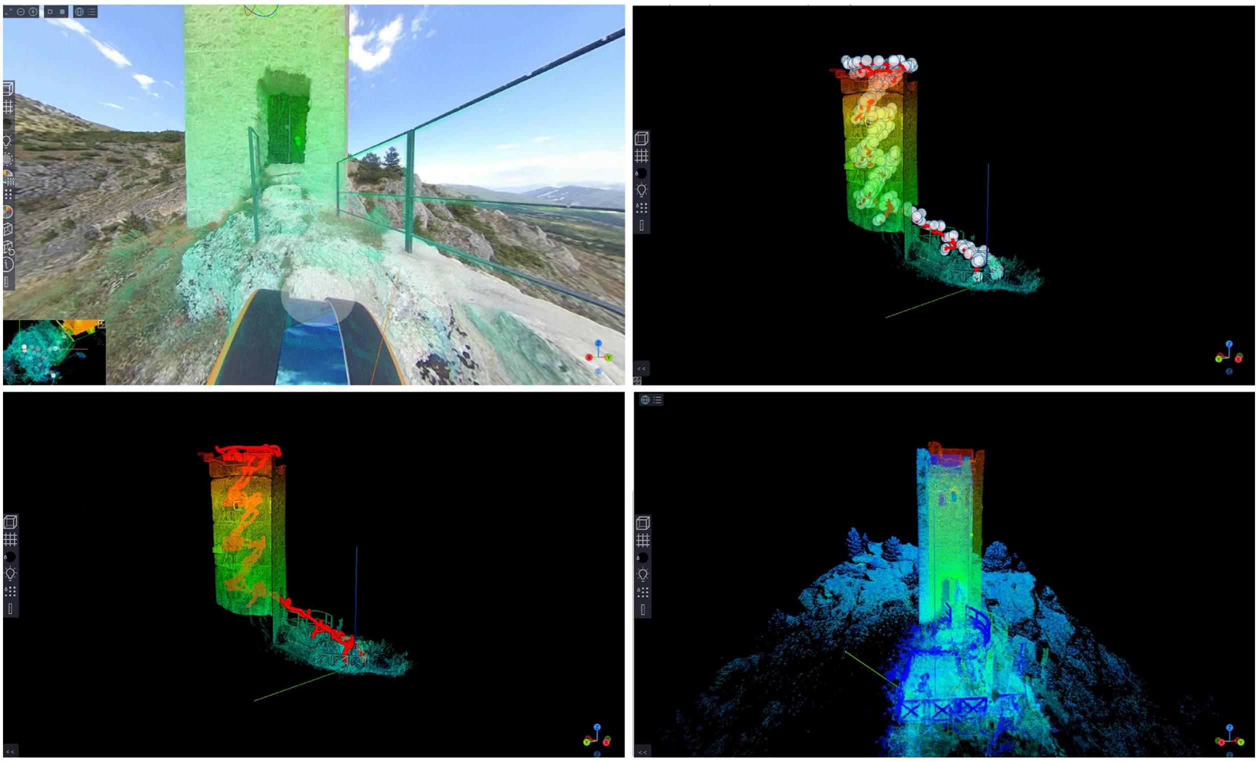

Figure 4. Survey via mobile laser scanner.

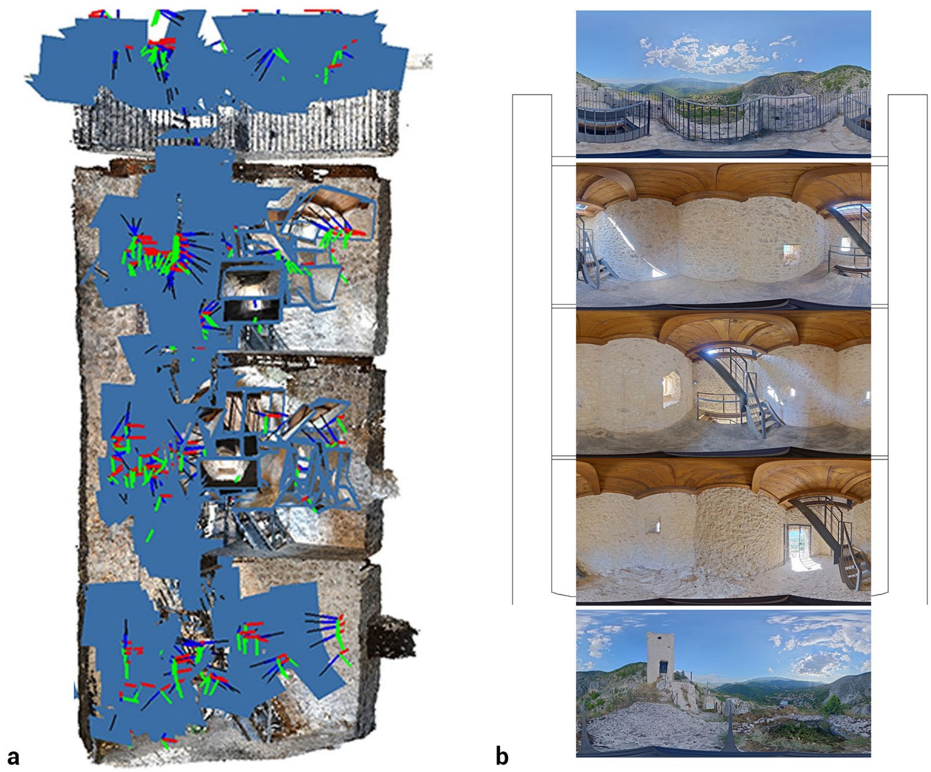

Figure 5. Survey of the tower's interior spaces: terrestrial photogrammetry (**a**), equirectangular photos (**b**).

Figure 6. Positioning and measurement of Ground Control Points (GCP).

3.2. Digital Models: Processing and Optimization

The first operational step in creating the digital models involved analyzing the GNSS data to define a common reference system, which served as the basis for processing the SLAM and photogrammetric data acquired in the field. The coordinates for each GCP were exported and evaluated for accuracy considering mean square deviations (Table 1).

Table 1. Coordinates of control points in the WGS84-RDN2000 datum with mean square deviation values in the plane and in elevation.

Point ID	Latitude	Longitude	Ellipsoidal Height	RMS Horizontal	RMS Vertical
100	42°11′49.6764″	13°42′07.8816″	916.949 m	0.010 m	0.010 m
101	42°11′49.8608″	E 13°42′07.7991″	915.798 m	0.008 m	0.014 m
102	42°11′50.1148″	E 13°42′07.6791″	915.952 m	0.008 m	0.012 m
103	42°11′49.8480″	E 13°42′07.0382″	916.987 m	0.070 m	0.013 m
104	42°11′49.7653″	E 13°42′07.1181″	917.877 m	0.008 m	0.016 m
105	42°11′49.8692″	E 13°42′07.0056″	916.976 m	0.008 m	0.017 m
200	42°11′49.8338″	E 13°42′07.0267″	916.991 m	0.008 m	0.019 m
201	42°11′49.7770″	E 13°42′07.1823″	917.963 m	0.026 m	0.041 m
202	42°11′49.7104″	E 13°42′07.0941″	916.604 m	0.023 m	0.040 m
203	42°11′49.8502″	E 13°42′07.0732″	917.019 m	0.080 m	0.020 m
204	42°11′49.8576″	E 13°42′07.1075″	917.067 m	0.070 m	0.018 m
205	42°11′49.6227″	E 13°42′07.3365″	914.600 m	0.080 m	0.020 m
206	42°11′49.9311″	E 13°42′07.7741″	915.617 m	0.080 m	0.021 m
207	42°11′49.6860″	E 13°42′07.8458″	916.795 m	0.010 m	0.023 m

Processing of the raw data obtained from the mobile laser scanner resulted in the generation of a point cloud of approximately 62 million points (Figure 7), later georeferenced by assigning coordinates to GCPs to ensure consistent alignment with other datasets acquired within a single reference system.

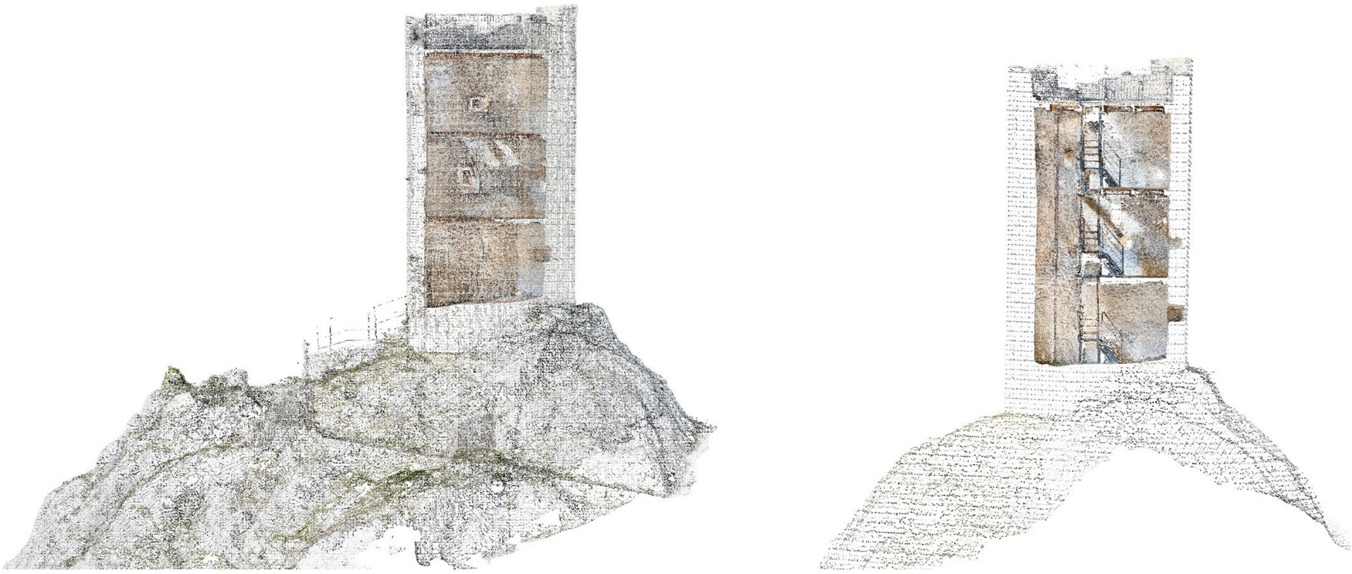

Figure 7. SLAM laser cloud points.

In parallel, photogrammetric processing of the datasets acquired through UAV and ground-based cameras was initiated (Table 2). The initial phase involved a critical assessment of the photographic dataset's quality using dedicated algorithms integrated in Agisoft Metashape software. This step allowed for the identification and removal of images that did not meet the required quality standards for processing. Subsequently, the photogrammetric workflow proceeded through two main stages: the alignment of images and the generation of the sparse point cloud, followed by the densification of the cloud and the creation of textured mesh models for three-dimensional restitution.

Table 2. Data summary of the photogrammetry process.

Survey Technique	Equipment	Type of Data	Processed Output	Software
Aerial Photogrammetry (UAV)	DJI Mini 2 (12 MP CMOS sensor)	720 photos	RGB dense point cloud: ~111 million points Mesh: ~37 million faces	Agisoft Metashape (version 2.2.2.21287) Cloud Compare (version 2.12.4) Blender (version 4.1)
Terrestrial Photogrammetry	Nikon Z50 (21.5 MP CMOS sensor)	590 indoor and outdoor photos	RGB dense point cloud: ~233 million points Mesh: ~73 million faces	Agisoft Metashape (version 2.2.2.21287) Cloud Compare (version 2.12.4) Blender (version 4.1)

The two computations, carried out using high-accuracy parameters, produced two distinct point clouds. These were subsequently analyzed and decimated using the confidence filtering tool integrated into the photogrammetric software, yielding the following results:

- a RGB dense cloud consisting of approximately 111 million points, derived from the UAV survey of the surrounding area (Figure 8a);
- a high-resolution dense cloud of about 233 million points, resulting from the integration of UAV and terrestrial datasets, providing a comprehensive representation of both the exterior and interior of the tower (Figure 8b).

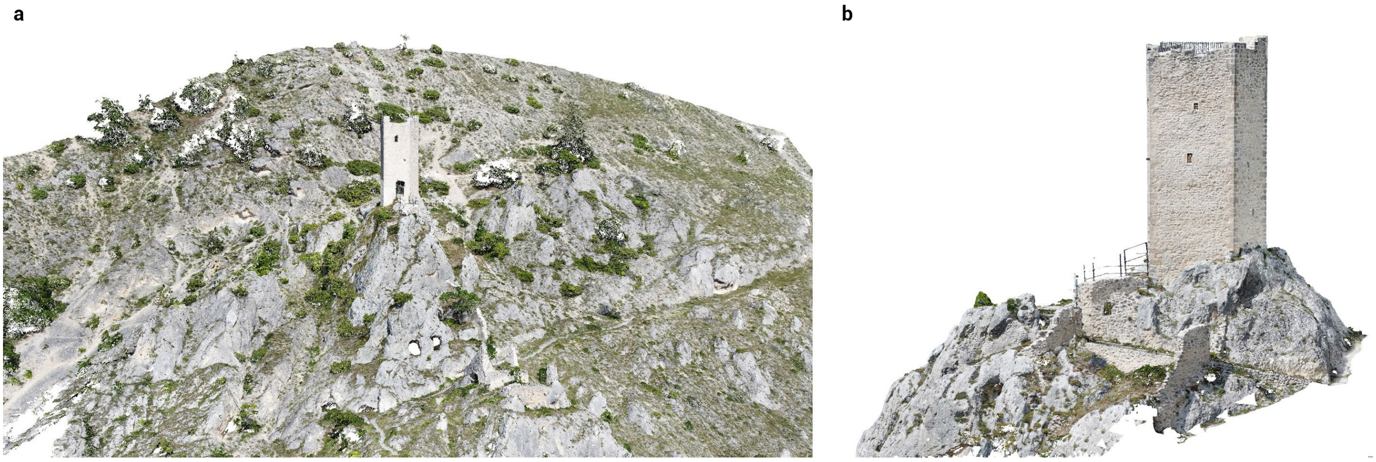

Figure 8. Detail survey: (**a**) drone cloud; (**b**) integrated terrestrial and drone cloud.

From these optimized point clouds, the textured three-dimensional mesh models were generated, specifically:

- a mesh model of the entire area, consisting of about 37 million faces (Figure 9a);
- a detailed mesh model of the tower, consisting of approximately 73 million faces (Figure 9b).

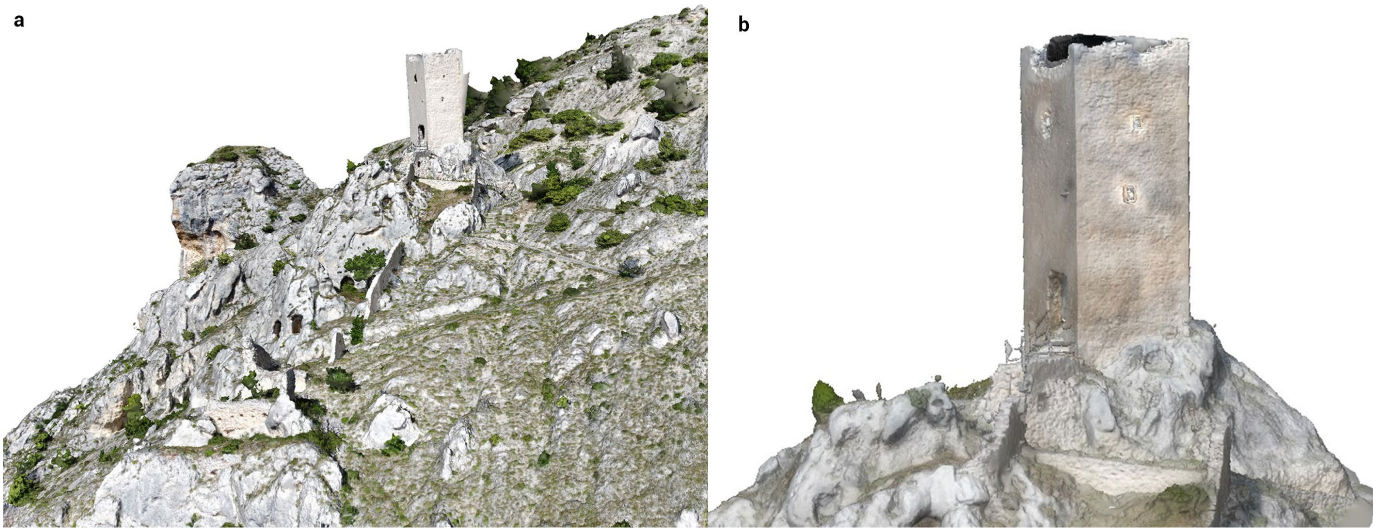

Figure 9. Mesh models: (**a**) landscape area; (**b**) tower detail.

The mesh models were optimized using Blender software through cleaning, simplification and merging operations to ensure topological and chromatic uniformity and enable their subsequent smooth integration into the web-based application.

Specifically, the general area model, including the tower in its spatial context (Figure 10a), underwent a retopology process, which returned an optimized mesh composed of approximately 1,380,000 faces, and integrated with solid modeling to define the terrain cross-section (Figure 10b). The tower detail model was also optimized, resulting in a final mesh consisting of approximately 900,000 faces yet maintaining the geometric quality required for close-up visualization.

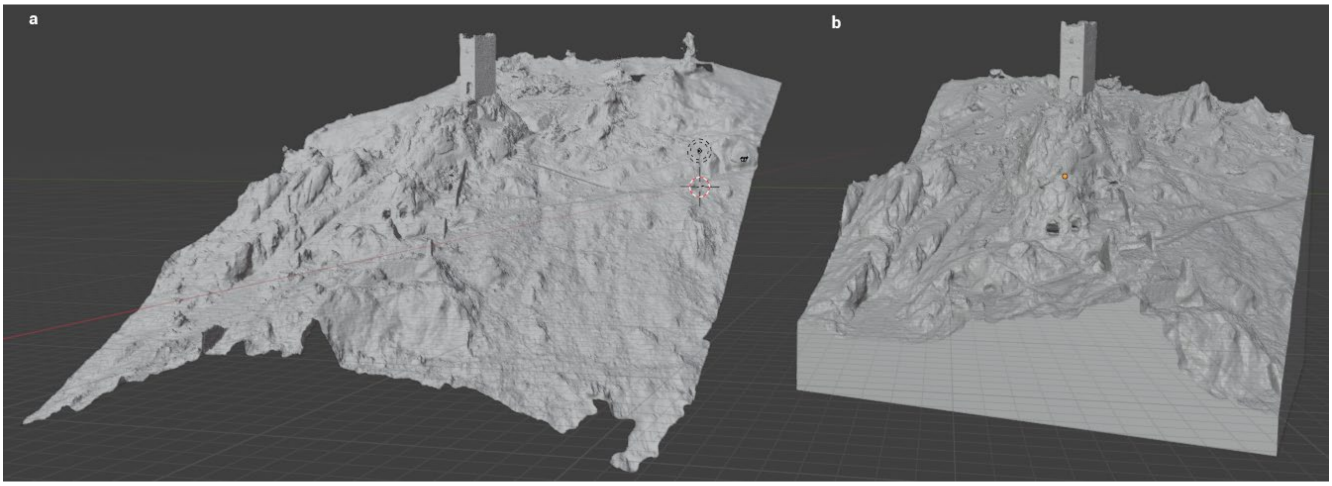

Figure 10. Photogrammetric mesh model of the tower in its landscape context (**a**) and simplified mesh model with cross-sectional view of the terrain via solid modeling (**b**).

Despite the significant reduction in the number of polygons, a high-resolution texture was maintained. It was improved by generating images in 8K resolution, accompanied by corresponding normal maps, to increase the perception of the three-dimensionality and depth of the elements.

3.3. VR Web-Based App for Virtual Replica Use

Recognizing the potential of simultaneously using diverse datasets to support the safeguarding and enhancement of the historic built environment, a web-based application was developed to visualize the virtual replica of the medieval Roccapreturo Tower and its surrounding landscape. The platform aims to increase accessibility to cultural heritage through immersive virtual tours and planning of on-site visits (Figure 11).

Figure 11. Web-based platform homepage for the virtual replica fruition.

To achieve this goal, digital models generated at varying Levels of Detail (LoDs) were integrated using the proprietary 3DVista software, the functionalities of which were adapted to enable navigation and provide information related to tourist routes. To ensure a realistic and immersive virtual experience, a low-poly model with high-resolution textures was adopted, balancing visual quality and performance. This approach guarantees smooth and dynamic usability within the web-based application, as models with lower LoDs can be accessed easily across a wide range of mobile and desktop devices without requiring high hardware specifications or excessive network resources.

The web app proposed, usable remotely in both immersive and desktop modes, was designed to be updatable and implementable over time. To reach a broad and heterogeneous audience, the platform was developed according to the principles of edutainment, which combines education and entertainment [73,74]. Its interactive mode integrates a virtual replica with informational content that has been simplified and tailored to the needs of a wide community, and presented in an engaging and creative manner to enhance accessibility and stimulate cultural curiosity.

The main purpose of the VR web app is to facilitate the learning process about and appreciate the tower and its surrounding context, increasing accessibility to the heritage site. Within the virtual environment, visitors can use interactive controls to explore the 3D digital models from a bird's eye perspective and switch to a first-person view by activating the Virtual Tour created from 360° images (Figure 12).

Figure 12. View of the web app for exploring 3D models and the Virtual Tour.

The virtual replicas allow users to understand the morphological characteristics of the site and obtain valuable information for planning an on-site, informed, and safe visit, further improving accessibility to the heritage. The bird's-eye view and the first person one, in fact, convey the complexity of the terrain highlighting steep areas, slopes, and difficult-to-access zones, which supports visitors to plan a customized on-site experience suited to their individual abilities (Figure 13).

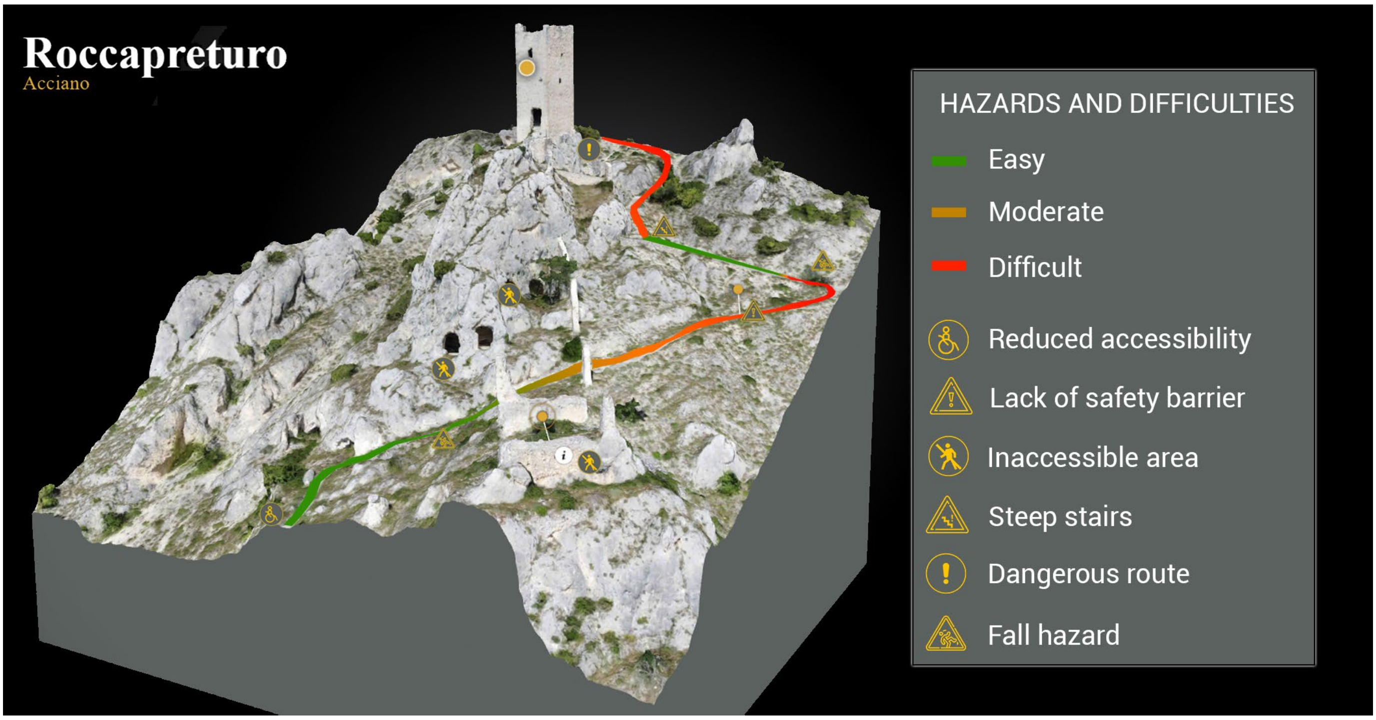

Figure 13. Planning of the on-site-visit route in the digital application: information and warnings about route complexity.

This technological solution enhances accessibility to cultural heritage by breaking down physical and cultural barriers, enhancing heritage dissemination and diversifying the tourism offer in the inner area. The web-app allows a wide audience to explore the reconstructed spaces, enter the tower, which is not always physically accessible, and admire the view from its top, offering an immersive, interactive and personalized experience (Figure 14).

Figure 14. Section for the dissemination and promotion of the Roccapreturo Tower with an immersive virtual visit.

4. Discussion and Conclusions

The results demonstrate the potential and effectiveness of models generated through drone-based aerial photogrammetry, as well as those derived from the integration of multiple surveying techniques, in generating accurate and operational virtual replicas that are accessible through web-based platforms. The application of the proposed framework to the case study of the Roccapreturo tower, chosen for its relevant cultural significance and morphological complexity, allowed the validation of the methodological approach.

The platform, conceived for a broad and heterogeneous audience—encompassing citizens, local schoolchildren, tourists, and tour guides involved in visit planning—has been implemented and validated from technical and functional perspectives, although it has not yet undergone field testing. It is, however, ready for integration into the municipality's official website, where it is expected to enhance both the attractiveness and safety of the site by enabling informed and structured planning of visitor access routes.

The designed web-based platform has been optimized for remote accessibility through low-poly models with high-resolution textures, reducing processing times and enabling efficient information sharing in the VR environment. This optimization ensures smooth interaction and provides users with access to data on possible routes to plan safe and informed visits.

Virtual access to historical content presented in an engaging and accessible format makes the platform an effective tool for promoting sustainable cultural tourism, even in difficult-to-access areas. Users can explore the interior of the tower, which often cannot be physically visited, and enjoy the panoramic view from the top, living an immersive, inclusive, and highly personalized experience.

In addition to these strengths, the results highlight potential areas where the framework can be further refined. In this regard, future developments will focus on the implementation of the current system into an application more geared toward the management, maintenance, and monitoring of built heritage. The goal is to evolve towards the definition of a Historic/Heritage Digital Twin (HDT) capable of supporting long-term preservation and sustainable decision-making processes. The key features of the selected software facilitate connections to external systems via specific URLs. This circumstance positions the proposed platform as a functional prototype for developing a HDT connecting technical data, such as that derived from monitoring campaigns or previous maintenance actions. These characteristics enhance the system's scalability towards practical implementation, support its replicability, and contribute to process optimization.

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