

Towards an Operational Protocol for Virtual Tours in Complex Cultural Sites: The Norman Castle of Aci Castello

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Abstract – This paper proposes a structured and replicable protocol for the development of virtual tours in hybrid heritage sites, where indoor and outdoor environments co-exist and present specific challenges for documentation and interpretation. Drawing on a pilot project at the Norman Castle of Aci Castello (Sicily, Italy), the methodology integrates photospheric acquisition (Matterport Pro2), photogrammetry, and multimedia storytelling within a topographically inspired navigation model. The digital experience was further enhanced through the use of third-party software (3DVista), enabling improved interaction, media layering, and accessibility. The results demonstrate the effectiveness of a hybrid workflow in reconstructing spatial continuity, articulating historical complexity, and supporting inclusive engagement. Although user testing is ongoing, the protocol offers a transferable framework for the valorization of other large and mid-sized archaeological and architectural sites, contributing to the broader discourse on sustainable digital heritage practices.

I. INTRODUCTION

In the last decade digital technologies become increasingly central to the preservation, interpretation, and dissemination of cultural heritage [1]. Among these, virtual tours have emerged as powerful tools for enhancing accessibility, promoting public engagement, and fostering sustainable heritage management [2, 3, 4]. By enabling immersive visualization of complex historical environments, virtual tours bridge physical and geographical barriers [5]. Over the past decade, the integration of virtual tours into heritage management strategies has gained significant momentum due to their capacity to support conservation, education, accessibility, and community engagement initiatives. From a conservation standpoint, virtual visits reduce physical pressure on sensitive heritage sites by providing digital surrogates of on-site exploration [6], but at the same time they can stimulate curiosity to visit the cultural site in



Fig. 1. Panoramic view of Norman Castle of Aci Castello

person. Despite their growing adoption, virtual tours, particularly those designed for hybrid sites comprising both indoor and outdoor spaces, face notable challenges. Standardized approaches often rely on static or linear content delivery, failing to capture the interpretive depth and spatial intricacy of cultural assets [7].

This article presents a structured protocol developed during a pilot project at the Norman Castle of Aci Castello (Sicily, Italy), offering a replicable model that integrates 3D scanning, narrative design, and multimedia curation.

II. THE NORMAN CASTLE OF ACI CASTELLO: HISTORY AND CHARACTERISTICS

The Norman Castle of Aci Castello (fig. 1), situated along the Ionian coastline of eastern Sicily, exemplifies medieval military architecture skillfully integrated into the areal volcanic landscape. Constructed in the second half of the 11th century by the Normans atop pre-existing Byzantine fortifications, the castle served vital military and administrative purposes throughout successive periods of rule, including the Swabian, Angevin, and Aragonese dominations [8].

The site's strategic design is heavily influenced by the nat-

ural topography of the basaltic promontory, offering extensive sea views and natural defensive advantages [9]. This geographical context not only provided critical fortification benefits historically but also presents contemporary challenges for digital heritage documentation [8].

Today, the castle functions as a touristic site with a small museum inside, divided into three primary thematic sections: mineralogical specimens from the surrounding landscape, paleontological and fossil records, and archaeological artifacts from the area [10]. This interdisciplinary collection underscores the castle historical and scientific relevance within the broader cultural landscape of eastern Sicily.

Architectural highlights of the site include the panoramic terrace overlooking the Gulf of Catania, narrow internal staircases, remnants of medieval defensive towers, and the complex layering of construction phases visible in the masonry [8]. These features, coupled with the geological complexity of the site [9], demand a holistic and dynamic virtual interpretation strategy that captures both tangible and intangible heritage elements.

Early historiographical studies, notably those of Raccuglia [11], provide essential insights into the castle architectural evolution and urban stratigraphy. Such foundational analyses remain critical for the contextualization and accurate virtual reconstruction of the site [8].

III. THE ROLE OF VIRTUAL TOURS IN SHAPING NEW HERITAGE PRACTICES

Virtual tours have evolved from basic navigational tools into sophisticated interpretive platforms, shaped by advances in computer graphics, human-computer interaction, and museological theory [12]. These environments are increasingly valued not only for their ability to reduce physical pressure on sensitive heritage sites but also for their potential to deliver inclusive, multi-modal educational experiences [13]. They enable institutions to reach geographically or physically distant audiences, and to narrate complex historical processes through layered, user-centered storytelling strategies [12].

The case of the Norman Castle of Aci Castello exemplifies both the promise and the technical limitations of current virtual tour systems. The site’s challenging topography and architectural stratification highlight the inadequacy of linear or static visual models in capturing the full depth of its historical significance. While platforms like Matterport have made 3D scanning more accessible, their constraints, especially in outdoor environments and customizable interaction, require integrated, multi-tool workflows to achieve meaningful interpretive depth [14].

Recent international experiences, such as the “Pilgrimage to Pureland VR” project in China, demonstrate the effectiveness of combining spatial precision with immersive narrative design to enrich cultural meaning-making [15].

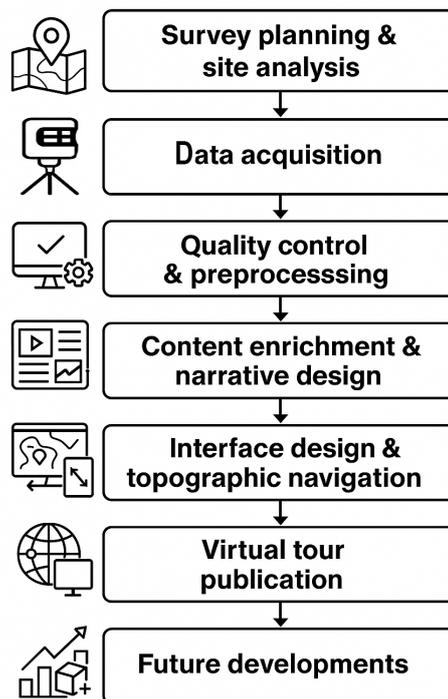


Fig. 2. Protocol summary outline

Moreover, the Seville Principles for Virtual Archaeology reinforce the importance of transparency, contextual integrity, and audience accessibility in the creation of digital heritage products [16].

This theoretical and technical framework sets the stage for the development of a site-specific protocol tailored to Aci Castello (fig. 2). The following section outlines the methodology employed to address the dual challenges of spatial complexity and interpretive fidelity through a hybrid documentation and storytelling approach.

IV. MATERIALS AND METHODS

Building on the theoretical foundations and international benchmarks previously outlined, this section presents the operational methodology implemented at the Norman Castle of Aci Castello. The protocol was designed to respond to both spatial and interpretive complexities of the site, aiming to construct a digital experience that is immersive, accessible, and academically rigorous.

A. Survey Planning and Site Analysis

The project began with a series of site surveys to map the architectural features, visitor flows, and light conditions at different times of the day. These surveys, supported by archival research and the stratigraphic insights of Raccuglia [11] and Magnano di San Lio [8], enabled the identification of Points of Interest (POIs) that would

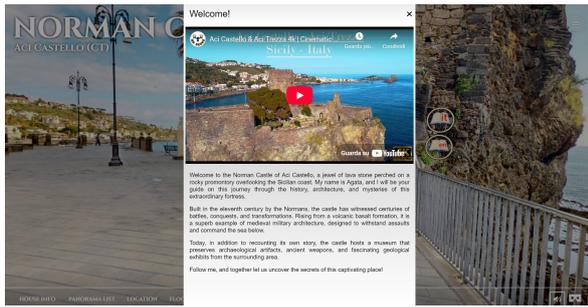


Fig. 3. Sample of POI markers (on the right) and multimedia window (at centre)

structure the tour. Each POI was associated with historical, architectural, and contextual narratives (fig. 3).

B. Data Acquisition

The acquisition campaign was conducted with a Matterport Pro2 (MC250) 3-D camera-scanner[17]. The instrument combines RGB sensors with a structured-light infrared projector, producing dense point clouds with sufficient accuracy for heritage documentation. Each 360° sweep is acquired through HDR imaging, with automatic alignment managed by the *Matterport Capture* application. With an adequate battery capacity, the system completed 228 scans during a single field session. Data were transferred via Wi-Fi to a tablet and uploaded to the cloud, where the *Cortex* engine processed the scans into WebGL tours, 4K images, scaled floor plans, and point-cloud packages (OBJ, XYZ, E57).

The absence of physical targets, the all-in-one architecture and the high acquisition throughput make the Pro2 particularly suitable for rapid production of 360° virtual tours, albeit with limitations in maximum range and susceptibility to direct sunlight. In the specific case of the Norman Castle, the virtual itinerary was planned to lead the viewer from the square at the foot of the hill, up the narrow stepped path to the monument, and finally through all exterior and interior spaces of the castle.

C. Quality Control & Preprocessing

Several challenges, common to practitioners striving for a consistent, high-quality virtual tour, were encountered during acquisition. Variable outdoor illumination demanded multiple passes at different times of day and the activation of HDR to attenuate deep shadows and highlight clipping [20, 18]. Complex surface materials, ranging from highly porous lava stone to reflective metal or glass, introduced noise and mis-registration in the point cloud; these issues were mitigated through denser scan spacing and post-acquisition filtering [19]. In open-air scenes, the limited range and reduced depth accuracy of the Matterport Pro2 infrared sensor required a tighter scan grid and



Fig. 4. Result of the acquisition of stairways



Fig. 5. Result of the acquisition of first floor

constant weather monitoring to avoid excessive direct sunlight [17]. Finally, tourist traffic and concurrent events imposed strict logistical constraints: micro-time-slots and movable barriers were deployed to preserve tour continuity and to minimize artifacts produced by moving subjects [20].

D. Virtual Tour Construction

The challenges encountered during the scanning campaign prevented the generation of a single, fully integrated model. Consequently, data had to be acquired as discrete photospheres, yielding seven independent aerial datasets. Robust alignment was achieved only for the stairway (fig. 4) leading to the castle (31 scans) and its first floor (103 scans) (fig. 5), except for the museum's subterranean exhibition areas (23 scans) that could not be aligned. The upper level proved to be the most problematic zone, ultimately necessitating photosphere by photosphere acquisition.

To address these issues, scan frames generated with Matterport Pro2 were exported individually and reassembled using third-party software, *3DVista Pro*, allowing greater flexibility in the virtual environment and improved navigation for open spaces. This software offers greater flexibility than the Matterport ecosystem in terms of media layering, outdoor navigation, and interactive storytelling. Here, each POI was enriched with:

- Audio narrations and textual descriptions;
- Historical and architectural drawings;
- Embedded 3D models and external links to academic resources.

Table 1. Aci Castello Scans Areas

Area	Connected Scans	Isolated Scans
Public Square	-	7
Entrance and Stairway	31	1
First Level+Bizantine Chapel	103	-
Museum Rooms	23	-
Second Level/Panoramic Terrace	-	48
Main Tower	5	1
Third Level	-	9

A topographically inspired navigation interface was implemented to mimic the visitor experience, while also allowing for non-linear exploration.

V. RESULTS

The operational protocol produced a multi-layered virtual tour that faithfully conveys the spatial and historical complexity of the Norman Castle of Aci Castello. The combination of Matterport scans for interior spaces and 3DVista-based enhancements for exterior segments generated a continuous digital itinerary linking the public square, the stepped ramp, and all accessible museum areas. Each Point of Interest (POI) is furnished with harmonized multimedia annotations (audio, text, archival images, 3D reconstructions) that articulate architectural phases and geological context (fig. 6). The topographic navigation interface permits both linear (guided) progression and free exploration, thereby balancing narrative control with user autonomy. Modular content architecture further enables rapid localisation (multilingual layers) and thematic re-configuration for diverse audiences-school groups, heritage professionals, and general visitors. Preliminary internal reviews confirmed the technical stability of the tour and the semantic consistency of the interpretive assets, establishing a robust baseline for subsequent user evaluation.

VI. LIMITATIONS

During the experimental phase, several limitations emerged, primarily related to the use of the Matterport Pro2 system in the hybrid context of the Norman Castle of Aci Castello. The coexistence of indoor and outdoor spaces posed particular challenges, as the device is highly sensitive to direct sunlight and requires stable lighting conditions. At certain strategic acquisition points, where repositioning the scanner was not feasible, the sharp contrast between light and shadow produced a noticeable “flare” effect, manifesting as bright halos and loss of detail in over-exposed areas.

The irregular morphology of the site, with its narrow

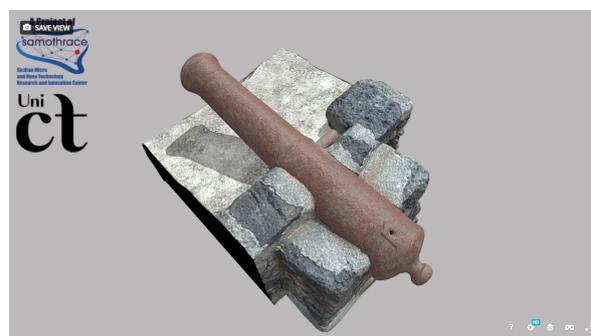


Fig. 6. Sample of 3D model generated by photogrammetric technique

staircases and uneven surfaces, further restricted the scanner’s field of view, generating gaps and occasional misalignments. As summarized in Table 1, this complexity hindered the production of a fully linear tour as initially envisioned during the planning phase, forcing ad hoc adaptations in the acquisition strategy. A major technical limitation also emerged in open-air areas: since the Matterport Pro2 operates within a low-range system, it struggled to detect sufficient stitching points between consecutive photospheres, in some cases even falling below the average effective distance of five meters.

VII. DISCUSSION

The results of the implementation phase, as outlined in the previous section, demonstrate the feasibility and effectiveness of a hybrid, multi-platform protocol for the creation of virtual tours in complex heritage sites. The integration of different tools - namely Matterport Pro2 for indoor documentation and 3DVista for content enrichment and customization - allowed the project team to overcome the respective limitations of each platform and produce a more holistic digital representation.

This approach confirms that successful virtual heritage experiences require more than high-fidelity spatial scan-

ning. Narrative design, interpretive coherence, and adaptive user engagement strategies are equally essential. As highlighted by different studies [21], [22] the ability of virtual tours to foster cognitive and emotional connections depends on the seamless integration of historical data, visual storytelling, and intuitive navigation.

The Norman Castle of Aci Castello provided an ideal testbed due to its hybrid architectural nature and historical stratification. The success of the pilot supports the idea that virtual tours can act as interpretive layers capable of enhancing access to both tangible and intangible heritage dimensions. Moreover, the flexibility of the workflow adopted, combining structured data acquisition with modular content architecture, offers a replicable model for other mid-sized historical and archaeological sites.

Finally, this phase also revealed the need for further testing and user analysis. As no formal usability testing was conducted, future development will include structured evaluation with different user groups (students, tourists, heritage professionals) using metrics such as usability, engagement and learning outcomes. This will ensure the virtual tour remains effective for diverse audiences and contexts. This will allow for refinement of the interface and content delivery mechanisms, ensuring that the virtual experience remains effective across educational, museological, and public outreach settings.

VIII. CONCLUSION

This study set out to develop a replicable and scalable protocol for the creation of virtual tours in complex historical and archaeological contexts, with the Norman Castle of Aci Castello serving as the pilot case. Drawing on the motivations presented in the introduction - namely, the need for accessible, narratively rich, and scientifically accurate heritage experiences - the project combined interdisciplinary tools and practices to address both technical and interpretive challenges. The discussion confirmed that virtual tours, when developed through a hybrid and modular framework, can effectively convey both the tangible and intangible values of cultural heritage sites. The integration of high-resolution spatial scanning, multimedia content, and topographic storytelling within a user-centered digital environment represents a step forward in the sustainable valorization of vulnerable sites.

Although formal user testing is still forthcoming, the initial results highlight the viability of the proposed approach and underscore the importance of iterative development. The protocol not only meets current technological capabilities but is also adaptable to future enhancements such as augmented reality and analytics-based feedback.

In conclusion, this pilot experience illustrates how digital tools, when critically applied, can extend the interpretive reach of heritage institutions and enhance public engagement. Moreover, the protocol emphasizes its poten-

tial social and cultural impact by fostering inclusive access, supporting educational practices, and strengthening community connections. Future developments will include structured validation with users and the extension of the model to museums and urban contexts, broadening its application for tourism and cultural education. The model proposed here offers a foundation for further research and application in diverse heritage scenarios, with the ultimate goal of fostering inclusive, meaningful, and enduring connections between people and places.

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