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Digital Workflows for the Interpretation and Presentation of Railway Heritage

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Abstract

In the domain of digital applications for museums and cultural institutions, visual and cinematic technologies provide a rich array of tools and techniques for transforming complex scientific concepts into engaging and accessible narratives for diverse, non-specialist audiences. The article illustrates a digital presentation workflow that harnesses the interpretive power of 3D reconstructive modeling and cinematic virtual reality (VR). Designed for use across various hardware and software platforms, this approach aims to improve the dissemination of knowledge and enhance public understanding of railway heritage. The discussion is grounded in a significant case study: the A.C.E. (Apparato Centrale Elettrico) cabin at Rome Termini Station, a landmark of Italian railway heritage currently being transformed into a museum. The article details the adopted workflow and the results of one of the immersive experiences developed specifically for this new exhibition space. At the heart of this experience is a permanent installation located in the former A.C.E. cabin, which reconstructs the unrealized architectural project for Termini Station envisioned by Angiolo Mazzoni (1894–1979). Within the interdisciplinary framework of the initiative, the project integrates historical research, AI-assisted modelling, and agile development practices. This combination enables the creation of compelling, historically validated narratives that enhance interpretation and foster emotional engagement with railway heritage and its broader cultural and historical context.

1. Introduction

The connection between digital representation and cultural heritage is becoming increasingly consolidated, thus supporting knowledge sharing both within the scientific community and among broader audiences (Mudge, Schroer, 2025). Since the first experiments in this field, which date back to the 1970s (Clini et al., 2022), digital representation has come to play a crucial role in supporting the interpretation and dissemination of cultural heritage (Mezzino, 2023; Tucci et al., 2023; Banfi & Azzolini, 2025).

In the context of digital applications for museums and cultural institutions, visual and cinematic technologies offer a wide range of techniques and tools to transform complex scientific concepts into engaging and accessible narratives for diverse, non-specialist audiences (Innocente et al., 2023; Silva, Teixeira, 2022; Wang et al., 2024).

Within this framework, the article presents a digital workflow using 3D modeling and cinematic VR to make railway heritage

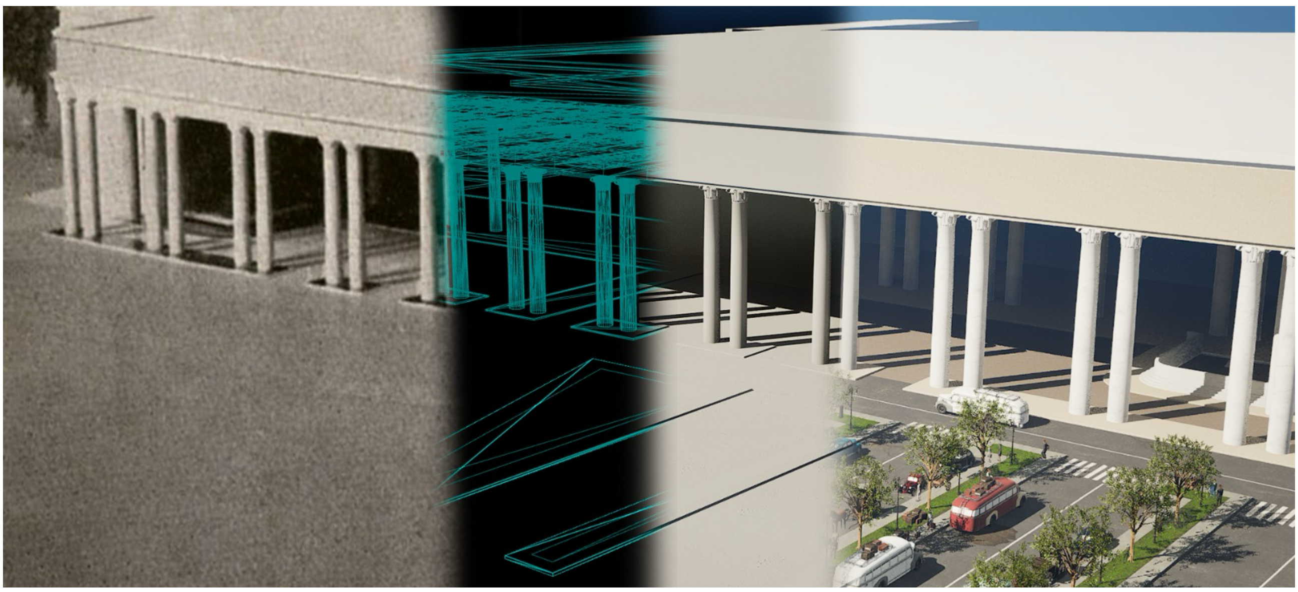

Figure 1: 3D reconstruction modelling process for the unrealised project of the Termini Railway Station façade in Rome. This digital reconstruction provided the basis for the cinematic VR experience within the ACE cabin museum. Image processing: authors.

more accessible. The adopted approach enhances public understanding by turning complex historical, socio-cultural, and technical content into engaging, immersive experiences.

The operative workflow has been tested on the outstanding case study of the A.C.E. cabin at Rome Termini, a key site of Italian railway heritage now being converted into a museum.

The architectural complex is owned by the FS Foundation, a branch of the Italian State Railways, which mission is to promote the railway heritage, focusing on its historical, cultural, technical, engineering and industrial significance.

Therefore, this study explores the use of digital workflows to present the history of Italian railways and support the interpretation of research conducted by the FS Foundation. This is achieved through digital visualizations and eXtended Reality (XR) experiences, with a primary focus on cinematic virtual reality (VR) development. By detailing the processes and solutions implemented for the museum environments of the A.C.E. cabin, the article highlights operational methods for applying digital visualization techniques in crafting narratives.

The article discusses the pipelines, techniques, and tools used emphasizing the potential of 3D content creation, supported by artificial intelligence (AI) and visual media, to simplify complex content while fostering an emotional connection between the narrative and its audience. To explore these aspects, the article focuses on one of the key permanent installations within the museum, located in the former A.C.E. cabin. This installation centers on the reconstruction of the unfinished project for Termini Station by architect Angiolo Mazzoni (1894-1979).

2. Methodology

The methodological contribution of this research was grounded in the development of a flexible, iterative workflow informed by agile development principles, interdisciplinary collaboration, and semantic modularity. The approach was calibrated to handle complex, layered content while ensuring high standards of historiographical fidelity and technical performance.

The content development process followed a structured sequence of design sprints, each comprising stages of research synthesis, narrative scripting, whiteboxing, asset refinement, and validation. This methodology allowed for continuous feedback loops between historical consultants, UX designers, and technical developers. Spatial affordances and interaction grammars were carefully defined to support narrative coherence and user orientation within the immersive environment. Elements such as spatial cues, narrative pacing, and multisensory feedback were designed to facilitate intuitive navigation and optimize cognitive engagement.

Particular emphasis was placed on the development and refinement of the user experience, drawing on heuristic evaluations and pilot testing to assess usability, immersion, and affective impact. These evaluations guided iterative refinements to interaction design, scenario logic, and content layering, resulting in an experience that balanced interpretative clarity with exploratory freedom. Digital assets were developed and optimized for real-time rendering in Unreal Engine, supporting high-performance deployment within physically constrained museum settings.

3. The Case Study

The selected case study highlights a significant example of Italian railway heritage: the A.C.E. (Apparato Centrale Elettrico, Italian translation for Central Electric Apparatus) cabin at Rome Termini, which is currently being transformed into a museum. The architectural complex is owned by the FS Foundation.

As a branch of the Italian State Railways, the FS Foundation's mission is to promote the railway heritage, focusing on its historical, cultural, technical, engineering and industrial significance.

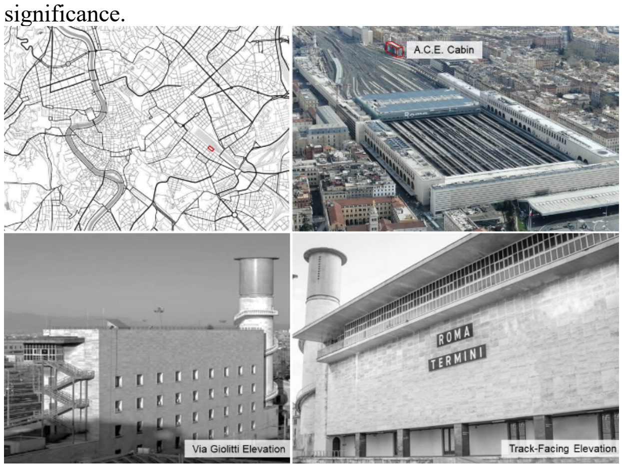

Figure 2. Localization of the ACE Cabin in Rome. Source: authors.

The ACE Cabin, an integral part of Rome Termini Station, is undergoing a significant transformation into a museum space. Situated within the Mazzoni wing and bordering Via Giovanni Giolitti in the historic Esquilino district, this structure served as the railway traffic control tower for the station.

Strategically located on the southwest side of Termini's distinctive "U" shape, along Via Giolitti, the ACE Cabin is approximately 1 km distant from the main station building (Fig. 2). The cabin regulated the railway traffic of all of Rome Termini for almost 60 years.

Built between 1940 and 1942, this structure replaced the previous electrical and hydrodynamic cabins. It is a rectangular building with four floors above ground and three underground levels. The composition, skillfully designed by Mazzoni (Gay, 2006; Forti, 1978), is a prime example of balance between pure volumes, while also fulfilling its technical function of controlling the entire station. The facade is made of lithic materials: travertine and marble.

The ACE Cabin itself stands as a notable example of early 20th-century architecture, characterized by its parallelepiped form and two distinct facade treatments:

- Track-Facing Elevation: The ground floor is partially recessed, revealing six granite-clad pillars and an extended entrance hall. The third floor features a prominent cantilevered, fully glazed volume, surmounted by a substantial 5-meter projecting canopy.
- Via Giolitti Elevation: This facade presents a perfectly planar surface, seamlessly integrating with the retaining wall of Rome Termini Station.

In line with the broader architectural scheme of Termini Station, all external surfaces of the Cabin are clad in travertine slabs.

This material choice by Mazzoni underscores a preference for neutral surfaces, allowing the building's volumes to maintain their pure and essential forms, with an explicit conceptual link to classical aesthetics.

Currently, the ACE Cabin at Rome Termini Station is undergoing a significant transformation, being converted into a museum space dedicated to preserving and enhancing the

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historical memory of the Italian State Railways (FFS). This initiative is particularly noteworthy as it integrates within the rich, albeit often underexplored, historical urban fabric of the Esquilino district, an area that experienced substantial evolution from the 16th to the early 20th centuries.
The musealization project encompasses several key areas, offering visitors a comprehensive insight into the cabin's historical function and technological significance:

- The Glazed Control Tower: This section, situated on the track side, served as the operational core of the cabin, functioning as the primary railway traffic control tower.
- The "Bunker Room" Basement: This space retains the original machinery, which was designed to provide critical backup in the event of aerial bombardment affecting the main cabin above. This element offers a tangible representation of the operational resilience integrated into its original design.
- Railway Documentary Archive: A dedicated archive will house historical documents pertaining to the FFS, serving as a valuable resource for researchers and enthusiasts.

Transforming the ACE Cabin into a museum is a great opportunity to explore a pivotal chapter in Italian railway history, and to further enrich the historical and archaeological heritage of Rome's Esquilino district, where the iconic building is located.
This project focused on the Railway Documentary Archive area, visualising the results of archival research and supporting the interpretation and communication of archival resources through the combined use of 3D modelling and cinematic VR. More specifically, this article outlines the workflow and technical solutions employed for the permanent installation on the ground floor, which visualises Mazzoni's unrealised project for the Termini Station façade.
The final aim of this project within the framework of the musealization of the ACE Cabin is to present the transformation of the Termini Station and to convey the significance of railway infrastructure in relation to its cultural, historical, social, and economic contexts.

4. The Operational Workflow

The workflow adopted for this study follows a structured pipeline aimed at developing historically informed 3D content. The three main interrelated phases of the adopted pipeline included: (a) conceptualization, (b) iterative development, and (c) validation. These phases include sub-steps, with specific stages and outcomes (Fig. 3). More specifically, the conceptualization phase included four stages.
Firstly, the analysis of technical requirements, secondly, the description of the historical and cultural context, thirdly the initial reconstruction concept and preliminary source research and fourthly the exploration of possible use cases and user interaction scenarios.
In terms of outcome, the conceptualization phase enabled to develop the project hypotheses in terms of content, user experience solutions, hardware and budgeting. Finalisation of this phase included proposing the project to stakeholders, revising it, and defining the final project. Similarly, the development phase comprised four stages. The first stage focused on white-boxing the scene. The second stage involved defining the required assets. The third stage involved conducting in-depth research of historical sources and visual references. The final stage involved iterative development with continuous historical validation.
The development phase included two main outcomes: 1) the media content and 2) the virtual environment and assets that were finally generated. This phase was finalised by exporting the content. The validation phase included three verification stages: 1) the project presentation; 2) the creation of a digital twin; and 3) submission of the work to stakeholders and/or user testing.

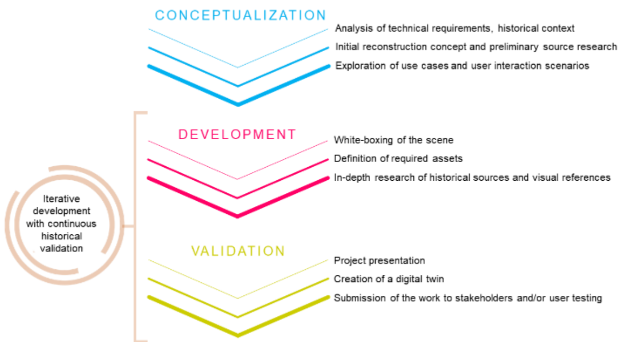

Figure 3. Diagram of the adopted operational workflow. Source: authors.

Eventually, finalisation led to project completion, on-site installation and practical testing.
This approach made it possible to achieve a balance between historical accuracy, technical implementation and user engagement.

4.1 Conceptualization

During the conceptualisation phase, a critical analysis of the site's context of use and cultural-historical significance was required.
The preliminary phase of the project involved conceptualising the type of content and how it would be delivered to the public. Various VR and XR technologies were tested. From a practical perspective, it was necessary to analyse the context of use, technical specifications, maintenance costs and operational requirements. Some examples of the evaluation include determining whether the area earmarked for the installation is suitable for immersive headset video reproduction or an interactive app.
Furthermore, from a theoretical perspective, creating media content within a historically significant environment required a thoughtful approach to ensure that the content would reflect, enhance and respect the site's heritage and cultural significance, in line with the project's communication objectives.
Regarding the spatial design, the elongated rectangular shape of the room we opted to use was leveraged to construct an immersive tunnel. This tunnel featured a projection wall depicting what Termini Station might have looked like had architect Mazzoni's original 1940s design been realized, particularly focusing on the colonnade on the Piazza dei Cinquecento side (Fig. 4). This gave rise to a second critical consideration during the conceptualisation phase. The

project's value lies in creating an engaging media representation of a hypothetical historical scenario.

Figure 4. Indoor environment selected for the permanent installation. Source: authors.

While digital technologies make this type of reconstruction possible, not all aspects and dimensions can be depicted authentically.

In line with the London Charter (2006) and the eight principles of the Sevilla Charter (2009) (Niccolucci et al., 2006; Brusaporci & Trizio, 2013), it is essential to distinguish between reconstructions based on scientific evidence (e.g. archival resources such as blueprints, technical drawings and historical photographs) and those based on the author's hypothesis.

Another key aspect was defining the communicative purpose. For example, it was necessary to determine whether the different parts of the content represented a historical, symbolic or hypothetical reconstruction. This was particularly important for the unrealised project by architect Mazzoni for Termini Station. It was also crucial to define the boundaries of the reconstruction in terms of the quality, quantity and type of sources. These parameters determine what can be faithfully reconstructed (e.g. artefacts, photographic references, architectural plans and other period materials), what can be made to look realistic (i.e. what could have been or might have been perceived based on the available sources) and what can be symbolic or interpretive (due to historical connections or the scarcity of sources). The type of reconstruction applied to each part of the project was clearly specified, especially for the latter.

Finally, the technical parameters and interfaces for visualising the content were defined, including the degree of immersion, hardware specifications and XR solution compatibility.

4.2 Development Phase

In the iterative development phase, the case study required continuous collaboration among various stakeholders. These included experts for the scientific validation of the models (primarily historians), technical developers for integrating the different aspects of digital production, and institutional stakeholders to ensure alignment with communication policies. The approach adopted reflects the 'agile' work pipeline methodologies commonly used in software houses. The working process can be considered as a 'stage-gate' model, where development phases (stages) were interspersed with moments of scientific validation (gates) from which are formulated the next steps of the development. From an operational point of view, the pipeline initially included the elaboration of a narrative plot, the selection of visual references and the production of 2D drafts. This was followed by the development of a plan-level design (using 2D blueprints of the original project by Mazzoni where available), and then the creation of a basic environment consisting of volumetric placeholders, which were gradually replaced by 3D models (a process known as whiteboxing).

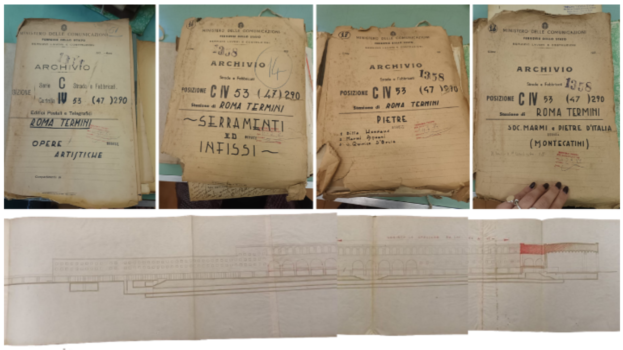

Figure 5. Archival documents used to retrieve the information for the 3D digital reconstruction of A. Mazzoni's unrealised project. Source: Fondazione FS Archive.

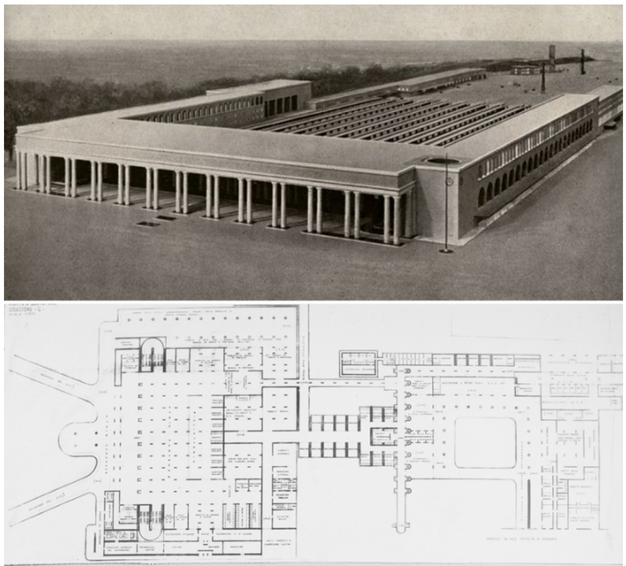

Figure 6. Axonometric view and floorplan of the uncompleted project for the Termini railway station in Rome by architect Angiolo Mazzoni (1894-1979). Source: MART Museum Archive.

Figure 7. Drawings and historical images of part of the unfinished project for the main façade of Termini Station by A. Mazzoni. Source: MART Museum Archive.

Archival sources have played a pivotal role in the 3D reconstructive modelling process. Visual and textual information was mainly derived from two archives: the FS archive in Rome and the MART archive in Rovereto (Fig. 5).

Visual information retrieved from archival research included technical drawings (floor plans, elevations, cross sections, axonometric and perspective views) at different scales, detailing decorative elements, as well as historical photographs (Figg. 6-7).

Then, additional information was derived from desk and bibliographical research. The 3D assets were created using solid modelling software such as 3ds Max and Blender, and then textured using Adobe Substance Painter. The 3D development of the surrounding architecture has been facilitated by the presence of various extant buildings, such as the 'Palazzo delle Poste' and the 'Mura Serviane'. These structures provided invaluable visual references, ensuring a high degree of fidelity in the digital reconstructions.

However, Piazza dei Cinquecento has historically been an important node in the Roman transport network, undergoing numerous modifications to accommodate evolving mobility needs. Notably, the areas designated for bus and carriage stops have been reconstructed several times over the years.

Figure 8. Final scene with secondary assets were developed to enrich the virtual environment, including architectural details. Software employed; Unreal Engine. Source: authors

Therefore, extensive historical research was undertaken to accurately depict these transformations and enable precise reconstructions that scientifically convey the site's dynamic history. A pertinent example of this approach is the Terme di Diocleziano. Following the initial modelling, photorealistic techniques were employed to enhance the accuracy of its representation, incorporating high-resolution photographs to reconstruct surface materials and textures. This methodology produced a more authentic portrayal of the building's appearance, bridging the gap between digital models and historical reality.

In some cases, artificial intelligence was explored to generate 3D models in order to assess its limitations and potential to optimise certain processes. Subsequently, a series of secondary assets were developed to enrich the virtual environment. These included architectural details such as manhole covers, street signs and street lamps, as well as functional elements such as suitcases carried by characters and carriages and cars driven by them. These elements were integrated into the game engine, specifically Unreal Engine (Fig. 8).

Various assets were also produced, including realistic animated characters. This required research into period clothing and its 3D reproduction. The clothing was designed using software such as Marvelous Designer. The 3D mesh was optimised, rigged, and skin-weighted for use with realistic characters in the game engine (see Fig. 9).

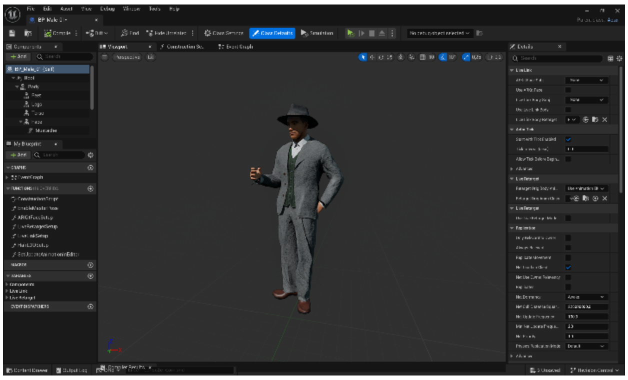

Figure 9. A 3D reproduction of a realistic animated character modelled in clothing consistent with the historical period of the Mazzoni project. Software employed; Unreal Engine. Source: authors.

Numerous historically accurate outfits have been produced to create a sense of naturalism and realism.

The final steps involved scene optimisation, final assembly, lighting design, exporting, sound design and post-production.

4.3 Validation

The final phase involved validation, a process that mirrors the iterative verification conducted throughout the project.

While iterative verification focused on ensuring the technical and scientific accuracy of the reconstructed elements, validation aimed at assessing the rendering quality and immersiveness of the final product (Fig. 10).

Specifically, validation was carried out through the use of digital twins to test final enjoyment, emotional and cognitive impact, through engagement metrics and qualitative feedback.

This process also helped identify actions for cross-media optimization, such as introducing pre or post-visit services, adding video captions, or designing supplementary elements to the reconstruction, like smartphone apps.

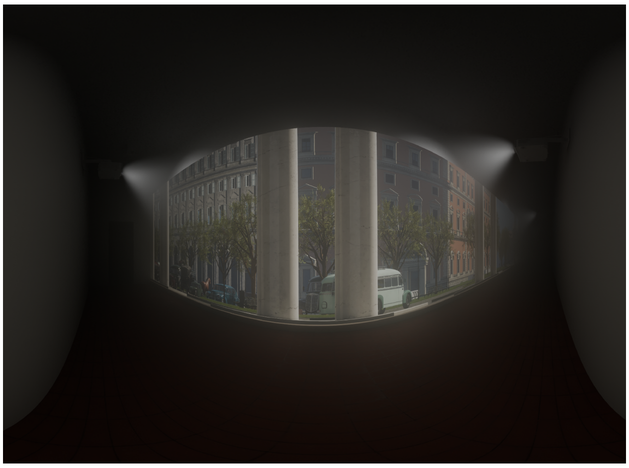

Figure 10. Assessment of the rendering quality and immersiveness of the final product carried out by digital twins to test final enjoyment, emotional and cognitive impact. Source: authors.

Figure 11. Designed solution for one of the cinematic installations developed for the museum environment of the A.C.E. cabin. Image processing: authors.

5. The Project Outcomes

A major outcome of the project was the implementation of a cohesive immersive narrative framework that integrates historically accurate reconstructions with interpretative speculation, resulting in a sophisticated, multi-sensory visitor experience.

Extensive historical research has been translated into a structured interpretative grammar embedded within a spatially articulated CVR environment.

Photorealistic architectural models were combined with animated period characters and contextual environmental assets to reconstruct the urban fabric of 1940s Rome with a high degree of historical fidelity. This realism was underpinned by a rigorous use of primary sources, including architectural plans, cartographic evidence, and iconographic material. Secondary assets—such as furnishings, signage, vehicles, and everyday objects—were developed through a combination of procedural modeling and AI-assisted techniques, enabling scalable production while maintaining historical plausibility.

Narrative design was structured to support differentiated modes of engagement, allowing for varying degrees of visitor agency and interpretive depth. The experience supported both passive and active engagement, thereby accommodating a broad spectrum of learning styles and preferences. The result is a narrative system that aligns with contemporary best practices in immersive heritage interpretation, offering both educational value and affective resonance (Fig. 11).

6. Replicability and Scalability of the Adopted Approach

The workflow developed through this project was conceived as a modular and interoperable system, designed to facilitate adaptation across a range of heritage contexts beyond the railway sector. Its architectural logic—organized into decoupled layers for narrative structure, visual assets, interaction models, and spatial configuration—supports both vertical scalability (in terms of content depth and resolution) and horizontal scalability (in terms of adaptability to different sites or typologies).

A parametrized asset library and reusable spatial modules were developed to support efficient re-contextualization and cost-effective deployment. The use of open-standard file formats, metadata-based asset management, and cross-platform scripting environments ensures long-term sustainability and compatibility with diverse technological infrastructures, including VR headsets, projection systems, and interactive displays.

The framework also lends itself to integration with institutional archives and cultural heritage databases, enhancing its potential for reuse in research, education, and public engagement.

Furthermore, the modular narrative model is capable of incorporating divergent historical narratives, multi-temporal stratification, and even contested memories, making it an effective tool for curating complex or sensitive cultural heritage content. As such, the system provides a robust foundation for sustainable communication strategies across the broader domain of digital cultural heritage.

7. Conclusions and Future Scenarios

The research aimed to define, test and propose an effective workflow for representing and visualising cultural heritage associated with the railway.

The process involved different scientific fields, knowledge and skills that worked together to achieve the project's objectives.

Specifically, 3D modelling, thanks to an iterative method, was a true collaborative research tool, aimed at obtaining a final product that was as complete, realistic and above all scientifically correct as possible.

Then, the development of the cinematic VR application enabled the scientific work to be disseminated in an immersive way. The focus on photorealism ensured that users were fully immersed in the virtual environment, arousing an emotional involvement capable of stimulating curiosity and supporting knowledge acquisition.

The project and the resulting installation activated several areas of research. The first of these concerned the introduction of new interactions and multimedia content to better describe the reconstruction process of the station's unbuilt façade.

Secondly, the possibilities of integrating 3D modelling also supported by artificial intelligence (AI) and visual media were tested to simplify complex content while fostering an emotional connection between the narrative and its audience.

Within the interdisciplinary framework of this project, particular attention was given to designing and implementing digital storytelling strategies to enhance the intelligibility and affective resonance of railway heritage. One of the key challenges involved translating complex historical, architectural, and infrastructural data into compelling and accessible multimodal narratives capable of engaging diverse audiences, particularly those without specialist knowledge.

To address this, a layered interpretive model was adopted, leveraging the affordances of cinematic virtual reality (CVR), spatial dramaturgy, and ambient storytelling. This model enabled the transformation of archival material and technical schematics into experiential narratives that fostered both intellectual understanding and emotional engagement. By blending data-driven reconstruction with sensorial immersion, visitors could access the semantic richness of the A.C.E. cabin site through a structured narrative experience that unfolded across descriptive, symbolic, and affective registers.

The design privileged the visitor's embodied presence within a reconstructed historical environment, cultivating an experience rooted in situated cognition and perceptual immediacy. This strategy sought to overcome the epistemological gap between scientific content and public perception, creating a fluid continuum between historical authenticity and experiential accessibility.

In terms of future scenarios, a crucial aspect is the development of a user experience study to gain a thorough understanding of how visitors relate to these technologies. This will help to improve the interfaces and interactions, as well as shedding light on the effect of these technologies on cognitive processes.

Authorship

Despite methodology and results are shared by the authors, Davide Mezzino wrote: Abstract, 1. Introduction, 4. The operational workflow, 4.1 Conceptualization, 4.2 Development phase, 6. Replicability and scalability of the adopted approach, 7. Conclusions and future scenarios; Sabato Gargiulo wrote: 3. The case study; Adele Magnelli wrote: 2. Methodology, 4.3 Validation; Alessandro Cavallaro wrote: 5. The Project outcomes.

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