2025 IMEKO TC26 International Conference on
Metrology for Archaeology and Cultural Heritage
Bergamo, Italy, October 15-17, 2025

Gamified AR and supervised AI for Cultural Heritage: The Amiternum Site Experience

Federico Martusciello[1], Henry Muccini[1], Alfonso Forgione[2]

[1]*FrAmeLab, University of L'Aquila, federico.martusciello@graduate.univaq.it, henry.muccini@univaq.it*
[2]*DSU, University of L'Aquila, alfonso.forgione@univaq.it*

***Abstract* – This paper presents a mobile application prototype for the archaeological site of Amiternum, integrating Augmented Reality (AR), generative Artificial Intelligence (AI), and gamification to deliver immersive and educational experiences. Users navigate the site through a location-based treasure hunt, uncovering five historically validated Points of Interest (POIs) where 3D reconstructions are overlaid via AR. A gamification engine tracks progress, awards points, and unlocks badges, enabling a scalable model adaptable to multiple heritage contexts. A key feature is a 3D conversational assistant powered by a GPT-3.5 Turbo-based large language model (LLM), offering supervised, context-aware historical information in real time. The system relies on a modular architecture supporting personalization and extensibility. The prototype demonstrates a replicable framework for intelligent cultural heritage applications and enhances engagement through spatial computing, AI-driven storytelling, and interactive game mechanics. The study explores how immersive tools can transform archaeological interpretation, making heritage more engaging, accessible, and educational.**

I. INTRODUCTION

Archaeological heritage sites face the dual challenge of preserving physical ruins while conveying historical significance in ways that resonate with contemporary audiences. Traditional signage and static reconstructions provide some interpretive value but often fall short in representing the spatial, temporal, and cultural complexity of ancient environments-especially when only fragments remain [1, 7]. Advances in mobile technology, spatial computing, and artificial intelligence now offer powerful tools to rethink how cultural heritage is communicated in situ [3, 8, 9].

This paper introduces a mobile application prototype developed for the archaeological park of Amiternum [10], which integrates Augmented Reality (AR), gamification, and generative AI to support immersive, personalized site exploration. The application employs a treasure-hunt mechanism that encourages users to discover key Points of Interest (POIs), each accompanied by high-fidelity 3D reconstructions of structures no longer visible. A modular gamification engine governs progression and rewards, while a GPT-based AI assistant delivers on-demand, historically accurate content via conversational interaction.

Drawing on architectural patterns outlined in [8], the system is designed to be scalable, modular, and interoperable across different cultural heritage contexts. This paper presents Amiternum as a real-world case study to validate the approach and showcase its potential for broader deployment.

II. BACKGROUND AND RELATED WORKS

Recent years have witnessed growing interest in the application of immersive technologies and intelligent systems to cultural heritage (CH) interpretation. Mixed and Augmented Reality (AR) platforms have been shown to significantly enhance visitor engagement by superimposing digital reconstructions onto physical sites, thereby enabling spatial and temporal contextualization of lost or damaged heritage elements [1, 7]. However, many AR applications remain limited in narrative depth, personalization, and adaptability, often functioning as static visual overlays without interaction or contextual awareness [1, 12].

Gamification has emerged as a strategy for enhancing motivation and learning in CH settings. Studies highlight the effectiveness of game mechanics such as challenges, progression, and rewards in driving user engagement and knowledge retention [2, 4, 5]. Nonetheless, implementations often lack architectural scalability and fail to integrate real-time adaptivity or meaningful personalization.

Parallel to these developments, generative AI and large language models (LLMs) are reshaping digital heritage by enabling adaptive storytelling, conversational interfaces, and content generation tailored to user behavior and preferences [3, 9]. Despite promising individual advances in AR, gamification, and AI, comprehensive frameworks that tightly integrate all three components are still rare.

To address this gap, a reference architecture for gamified CH applications leveraging generative AI and AR was recently proposed [8]. It provides modular components including a gamification engine, AI assistant, and AR render-

ing pipeline designed to operate within a real-time, event-driven system. The Amiternum prototype extends and applies this model, demonstrating feasibility and adaptability in a real-world archaeological context.

The objective of this study is to demonstrate how the tight integration of AR, gamification, and supervised AI can foster engagement and learning in archaeological sites. To this end, three research questions guide our work:

- RQ1. *How can AR overlays support the spatial and temporal contextualization of lost or fragmented heritage?*
- RQ2. *How can a rule-based gamification engine sustain user motivation and progression during in situ exploration?*
- RQ3. *How can supervised AI assistants provide historically reliable and context-aware storytelling in real time?*

The Amiternum prototype is presented as a real-world case study designed to explore these questions and validate the feasibility of the proposed approach.

III. THE AMITERNUM PROTOTYPE

This section details the design and implementation of the Amiternum prototype, a mobile application developed to enhance visitor engagement with the archaeological site of Amiternum. The system integrates AR, a conversational AI assistant, and a gamification engine within a modular architecture. We describe the key cultural elements featured in the application, the overall system structure, the user interaction model, and the gamification strategy used to guide and reward exploration.

A. Points of Interest (POIs)

The application features five historically validated Points of Interest (POIs), selected with domain experts to balance historical relevance and spatial distribution. Each POI combines an AR reconstruction of the original structure with interpretative content provided by the AI assistant.

The five POIs were selected in collaboration with archaeologists to ensure both historical representativeness and visitor accessibility. Criteria included (i) chronological diversity, covering late antiquity to early medieval phases; (ii) architectural and liturgical significance within the urban fabric of Amiternum; and (iii) spatial distribution across the site, in order to encourage physical exploration rather than concentration in a single area.

The first Christian baptistery (6th-7th century CE) represents one of the earliest Christian baptisteries in the region, with the AR overlay reconstructing its circular font and adjoining chamber. *The Lombard cathedral* (late 6th-early 7th century CE) exemplifies Lombard ecclesiastical design, reimagined through its apsidal layout and columnar structure.

The funerary chapel: an 8th-century funerary chapel, is reconstructed with its compact volume and interior iconography. *The presbyterial enclosure* reveals liturgical zoning, with visualized marble fittings and their spatial relation to the altar. Lastly, *Building B*, a late antique structure of uncertain function (5th-6th century CE), is presented through an AR model highlighting its layout, roof, and mosaic flooring.

Where permitted, supplementary visual material such as site maps and annotated illustrations may be included to support spatial comprehension and visual engagement.

B. Overview of the System

The Amiternum prototype is built on a modular and extensible architecture that integrates three core components: Augmented Reality (AR), a GPT-based conversational AI assistant, and a rule-based gamification engine. The system adopts an event-driven, microservices-based design that ensures scalability, reusability, and adaptability across different cultural heritage contexts, following best practice outlined in modern software architecture literature [11].

At the core of the system is a mobile front-end developed in Unity, which handles user interaction, spatial navigation, AR rendering, and the 3D interface of the AI assistant. Unity communicates with backend microservices-such as the gamification engine and AI assistant-through RESTful API calls and WebSocket connections. This setup allows for real-time feedback, asynchronous data exchange, and efficient event handling during user interactions on-site.

The architecture comprises the following layers The *Presentation Layer* manages user input and output, including AR visualization and interaction with the AI avatar. The *Application Logic Layer* controls the user flow, triggering system events when POIs are discovered or learning milestones are achieved. The *Gamification Engine* operates as an external microservice, responsible for tracking user progression, assigning scores, and awarding digital badges. Its behavior can be customized via a domain-specific language (DSL), enabling cultural institutions to define their own game rules and progression models. The *AI Assistant Module* uses a GPT-based language model guided by curated, site-specific content injected through prompt engineering. It supports both voice and text interaction, delivering context-aware responses via a lightweight inference pipeline optimized for mobile.

Finally, the *Data and Communication Layer* ensures reliable interaction between the Unity client and backend services. REST APIs handle structured requests (e.g., retrieving POI content or submitting scores), while WebSockets support low-latency communication for dynamic updates and real-time feedback.

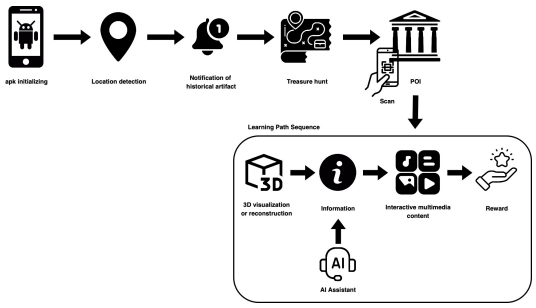

Fig. 1. The system flowchart showing the user interactions.

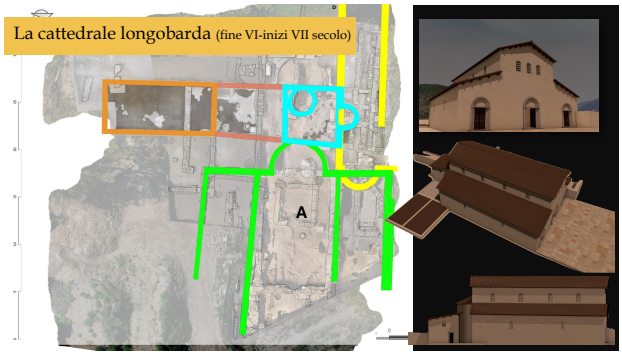

Fig. 2. An example of 3D modeling and AR placement of the one of the POIs.

C. User Experience and Interaction Flow

The mobile application developed for the archaeological site of Amiternum aims to provide an immersive, educational, and gamified experience by combining spatial exploration, historical storytelling, and user-driven interaction. The system is designed to guide visitors through a sequence of culturally significant Points of Interest (POIs) within the site, each augmented with AR visualizations and AI-assisted narration.

As shown in Fig. 1, users initiate their journey through a mobile interface that introduces the archaeological context and outlines the core challenge: to locate and interact with five hidden POIs across the site. This treasure-hunt-like mechanic encourages active exploration. As users physically approach each location, the application activates corresponding AR content, overlaying 3D reconstructions of structures that are no longer visible in their original spatial context (see Fig. 2).

Each successful interaction with a POI rewards the user with points. Accumulated points contribute to unlocking badges, and upon reaching a predefined threshold, the user completes the level designated as "Amiternum". This structure allows for the easy addition of new levels, making the system inherently scalable to other sites or thematic narratives.

D. Gamification Layer

The gamification layer is integral to the application's engagement strategy. Drawing from the reference architecture described in [8], the system employs a rule-based gamification engine capable of tracking user progression and assigning points. As shown in Fig. 3 each POI interaction is logged as a game event, which triggers the allocation of points based on time, completeness, and interaction richness (e.g., accessing historical details, rotating 3D models, or querying the AI assistant).

Users accumulate points that contribute toward the acquisition of digital badges. Once a user completes all POIs and exceeds a scoring threshold, they are awarded the "Amiternum Explorer" badge, signifying level completion. The badge system is extensible and supports the creation of thematic levels, enabling reuse of the same platform across other archaeological contexts or museum environments.

Game logic is managed by an external microservice that interfaces with the app through RESTful APIs and WebSockets, ensuring real-time feedback and synchronization. A Domain-Specific Language (DSL) facilitates the customization of rules, rewards, and progression models, allowing cultural institutions to tailor game dynamics without altering core application code.

IV. AUGMENTED REALITY EXPERIENCE

The Augmented Reality (AR) component is central to the Amiternum application's ability to recontextualize the archaeological landscape and revive structures that are no longer visible. The AR module is built with Unity and ARCore for Android. By superimposing accurate 3D reconstructions onto the physical site, AR enables visitors to visualize the original scale, volume, and architectural detail of historical buildings directly in situ.

A. AR Overlays of Lost Structures

As shown in Fig. 2, each Point of Interest (POI) is associated with a high-fidelity 3D model based on archaeological research and expert validation [10]. These reconstructions are rendered in real time over the site's terrain using device cameras and geospatial alignment techniques. The overlays aim not only to visually restore the structures but also to situate them within their historical and ritual functions, enriching the interpretive experience.

B. Spatial Tracking and Registration

The system supports both marker-based and GPS-based tracking modes. Where feasible, physical markers placed at the site improve spatial precision through visual recognition and alignment. In open areas, GPS coordinates and compass orientation ensure that digital reconstructions are placed within an acceptable positional tolerance. This hy-

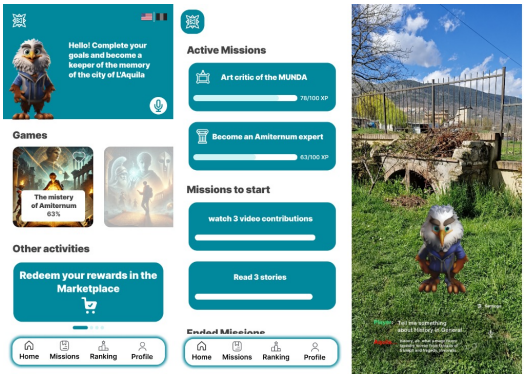

Fig. 3. The mobile app. From left to right: Home, the Gamification progress status and the 3D AI chatbot.

brid approach allows the application to function across varied environmental conditions and device capabilities, ensuring accessibility for a broad audience.

C. Interactive Exploration

The AR module supports direct interaction with the 3D reconstructions. Users can rotate, scale, and reposition the models through standard touch gestures, enabling close examination of architectural features. Additional contextual overlays such as annotations, guided audio, and historical timelines can be toggled to support layered learning. When combined with the AI conversational assistant, users can also query specific elements of the reconstruction, prompting explanations or historical anecdotes contextualized to the structure in view.

This multimodal interaction model transforms passive observation into active exploration, promoting spatial reasoning, sustained engagement, and deeper historical understanding. The AR experience is optimized for mobile devices but can be extended to head-mounted displays (HMDs) or smart glasses for hands-free operation in future deployments.

V. 3D AI CHATBOT ASSISTANT

To support personalized learning and contextualized storytelling, the Amiternum application integrates a 3D AI-powered conversational assistant (see Fig 3). This component enhances the visitor experience by enabling real-time access to historically validated information through natural language interaction, both in textual and vocal modalities.

A. AI Model Tailored for Amiternum

The assistant is powered by a GPT Turbo 3.5-based large language model (LLM), trained on a curated corpus of site-specific materials that includes excavation reports, historical records, scholarly publications, and expert narratives. GPT-3.5 was selected for its optimal tradeoff between linguistic performance, computational efficiency, and latency, which makes it particularly suited for mobile, real-time cultural heritage experiences. This domain-specific adaptation ensures a high level of factual accuracy, thematic coherence, and contextual relevance to the Amiternum site. The model is deployed through an optimized inference pipeline that enables low-latency responses, both on mobile devices and via cloud-edge processing, ensuring seamless real-time interaction.

Interaction is conversational and context-aware, with responses constrained to brief, factual answers through controlled tokenization. Importantly, all generated content is supervised and validated by domain experts to ensure historical accuracy and to prevent speculative or embellished interpretations.

B. Real-Time Historical Querying

Users can activate the AI assistant at any POI and during the visit to ask open-ended questions or request specific historical context, such as construction techniques, religious symbolism, or societal roles of the structures in view. The assistant interprets queries contextually, drawing from both spatial positioning and session history to deliver relevant answers. It also supports proactive storytelling by offering prompts or interpretive pathways based on user interest and behavior.

C. Multimodal Interface: Voice and Text

The assistant operates through a multimodal interface that combines both voice and text interaction. Voice input is processed using Whisper for speech-to-text (STT) conversion, while responses are delivered through OpenAI's text-to-speech (TTS) engine. To achieve realistic facial animation of the 3D avatar, a phoneme-to-viseme mapping system-based on the Rhubarb lip-sync tool-synchronizes spoken audio with mouth movements. Voice interaction is particularly valuable for hands-free engagement during site exploration, while text input supports silent or more detailed querying. Responses are synthesized using natural prosody and emotion-aware TTS models to enhance immersion and comprehension.

D. Expert Supervision and Content Validation

To ensure the historical reliability of AI-generated responses, all prompt-injected data is curated in collaboration with archaeologists and historians. A human-in-the-loop validation process governs dataset construction, response review, and iterative refinement of the assistant's behavior. Additionally, curated content is periodically reviewed and updated by domain experts, with user interaction data informing iterative refinements. This process ensures traceability and continuous improvement of the assistant's responses over time.

By integrating conversational AI into a spatial and gamified experience, the Amiternum prototype transforms the visitor from a passive observer into an active, inquisitive participant in historical discovery. The assistant also supports inclusive access to cultural knowledge, fostering broader educational reach and long-term engagement.

VI. EVALUATION AND FUTURE WORK

The Amiternum prototype is currently in the pre-deployment phase, with structured user evaluations planned to assess in situ technical performance, engagement, usability, and educational outcomes. These evaluations will follow a mixed-methods approach, combining on-site observation, post-visit questionnaires, and interaction analytics to measure user satisfaction, cognitive retention, and interface intuitiveness.

The first pilot study, scheduled for summer 2025, will involve participants from diverse age groups and backgrounds to validate the application's accessibility and educational impact. Key performance indicators will include time spent at POIs, frequency and nature of AI assistant interactions, quiz completion rates, and users' ability to recall or contextualize historical content after the experience.

While the assistant delivers contextualized content, it does not currently implement true Retrieval-Augmented Generation (RAG). Instead, it operates on a static, expert-curated dataset. Future iterations will integrate a vectorized retrieval layer and dialog-based refinement to enable dynamic, personalized responses through user interaction.

Future developments aim to incorporate a vector-based retrieval layer to support more dynamic, personalized interaction. This will enable the assistant to not only provide grounded responses based on vectorized content representations, but also to refine its answers through dialog: posing clarifying questions to users in order to tailor information delivery. Such bidirectional interaction will move the system toward a more adaptive, reasoning-enabled architecture capable of nuanced educational storytelling.

Planned enhancements also include improved AR tracking capabilities through SLAM (Simultaneous Localization and Mapping) to increase spatial precision in complex environments. It is also important to note that the AR experience is influenced by hardware and environmental constraints, such as device camera quality, GPS accuracy, lighting conditions, and visual occlusions, which can affect the spatial precision and overall usability of the system during on-site exploration.

Additional planned enhancements include multilingual support (initially Italian and English), and the introduction of persistent user profiles to track learning progress, cross-site achievements, and deliver personalized content.

In the long term, the platform is envisioned to support collaborative features (e.g., group quests), integration with external cultural heritage datasets, and broader deployment across archaeological parks, open-air museums, and exhibition environments, thereby extending its educational and cultural impact.

VII. CONCLUSION

This work presents a novel prototype that enhances archaeological site exploration through the integrated use of Extended Reality, gamification, and generative AI. Applied to the ancient site of Amiternum, the application enables visitors to interactively discover historically validated POIs through spatially anchored 3D reconstructions, intelligent narration, and game-based challenges.

Built on a modular reference architecture, the system supports scalability and adaptability across diverse heritage environments. The conversational AI assistant enriches contextual understanding, while the gamification layer sustains engagement through structured progression and rewards.

By combining AI, AR, and gamification, the Amiternum prototype offers a replicable model for revitalizing archaeological storytelling. It bridges physical remains and intangible heritage, making history more engaging, accessible, and personally meaningful for diverse audiences.

REFERENCES

[1] Bekele, M. K., Pierdicca, R., Frontoni, E., Malinverni, E. S., Gain, J. (2018). A survey of augmented, virtual, and mixed reality for cultural heritage. *Journal on Computing and Cultural Heritage (JOCCH)*, 11(2), 1-36.

[2] Cetin, Ozgul, and Fethiye Erbay. "Gamification practices in museums." *Journal of Tourismology 7.2* (2021): 265-276.

[3] Casillo, Mario, et al. "The role of AI in improving interaction with cultural heritage: An overview." *Handbook of Research on AI and ML for Intelligent Machines and Systems* (2024): 107-136.

[4] Erbasi, Zeynep, Busra Tural, and Ilknur Coskuner. "The role and potential of artificial intelligence and gamification in education: The example of vakif participation bank." *Orclever Proceedings of Research and Development 3.1* (2023): 243-254.

[5] Khan, Imran, et al. "Role of gamification in cultural heritage dissemination: A systematic review." *Proceedings of Sixth International Congress on Information and Communication Technology: ICICT 2021*, London, Volume 1. Singapore: Springer Singapore, 2021.

[6] Marques, Celio Goncalo, Joao Paulo Pedro, and Ines Araujo. "A systematic literature review of gamification in/for cultural heritage: leveling up, going beyond." *Heritage 6.8* (2023): 5935-5951.

[7] Panou, Chris, et al. "An architecture for mobile out-

doors augmented reality for cultural heritage." *ISPRS International Journal of Geo-Information 7.12* (2018): 463.

[8] Martusciello, Federico, Henry Muccini, and Antonio Bucchiarone. "A Reference Architecture for Gamified Cultural Heritage Applications Leveraging Generative AI and Augmented Reality." arXiv preprint arXiv:2506.04090 (2025).

[9] Trichopoulos, Georgios. "Large language models for cultural heritage." *Proceedings of the 2nd International Conference of the ACM Greek SIGCHI Chapter*. 2023.

[10] Brusaporci, Stefano, et al. "The "Amiternum Project" on Archaeological Site Valorisation." *Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage*. Cham: Springer International Publishing, 2023. 105-116.

[11] Dragoni, Nicola, et al. "Microservices: yesterday, today, and tomorrow." *Present and ulterior software engineering*(2017): 195-216

[12] Casillo, Mario, et al. "A multilevel graph approach for IoT-based complex scenario management through situation awareness and semantic approaches." *Journal of Reliable Intelligent Environments 10.4* (2024): 395-411.