Virtual Reality and Conversational Agents for Cultural Heritage Engagement

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Abstract

Virtual Reality (VR) and AI-driven Non-Playable Characters (NPCs) are increasingly being used in education and cultural heritage to enhance engagement and interactivity. Adaptive virtual environments enable real-time digital learning [1], with studies highlighting Unreal Engine and AI-powered avatars as key to immersive educational experiences in the metaverse [2]. This project enhances the visitor experience at the Balzi Rossi Museum (Ventimiglia, Italy) through an interactive virtual guide inspired by the "Dame du Cavillon", the name given to a female skeleton from the Upper Paleolithic. The prototype was developed using freely available tools, including Generative Artificial Intelligence (GenAI) technologies, to ensure accessibility and cost-effectiveness. The guide provides historical information while enhancing the immersive and interactive experience for visitors, making cultural heritage more approachable and engaging. Key challenges include the creation of an accessible and realistic interactive guide and the effective integration of GenAI-driven dialogue systems. This paper explores the technical methodologies and user experience (UX) strategies employed to create a seamless virtual museum experience, underlining the educational potential of VR in fostering engagement with cultural heritage.

Keywords: *Virtual Reality, Conversational Agents, Cultural Heritage, Immersive Learning, User Experience*

1. Introduction

Virtual Reality (VR) has become increasingly significant in diverse fields, notably in the preservation and dissemination of cultural heritage. By enabling immersive and interactive experiences, VR allows users to engage deeply with historical sites and artifacts, overcoming traditional limitations associated with physical access [3].

The integration of Generative Artificial Intelligence (GenAI) into VR further enhances user interactions with historical content. GenAI facilitates the creation of dynamic, adaptive virtual entities, enhancing user engagement through personalized and context-aware interactions. This synergy significantly enriches educational experiences, making cultural content more accessible and interactive [4].

This paper introduces a prototype aimed at enhancing an existing VR project at the Museo Preistorico dei Balzi Rossi, located in Ventimiglia, Italy. Renowned for its Paleolithic caves, this museum offers crucial insights into prehistoric cultures. Initially launched in 2021, the museum's VR initiative provides a virtual reconstruction of the site, enabling exploration of its historical context [5]. The new prototype presented here incorporates a virtual guide inspired by the "Dame du Cavillon," an intact Homo sapiens skeleton discovered at the site in 1872 and dated approximately 24,000 years ago. The burial's rich adornments and the presence of red ochre suggest the individual's prominent role within her community. Figure 1 shows the reconstructed face of the Dame du Cavillon, preserved and exhibited in the museum.

The selection of the Dame du Cavillon as the virtual guide draws from her significant historical and symbolic value. The virtual guide aims to offer users a deeper and more interactive understanding of the prehistoric context by embodying this historically significant figure. Utilizing advanced GenAI technologies, the prototype provides a personalized and immersive experience, thereby enhancing the educational and engagement potential of the VR exhibit.

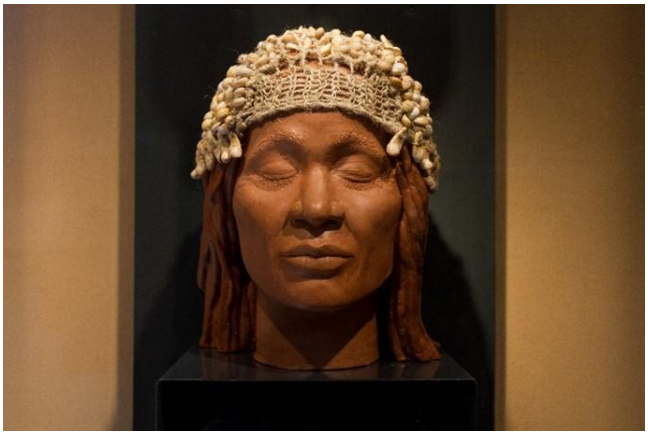

Figure 1. Reconstruction of the face of the Dame du Cavillon on display at the Prehistoric Museum of Balzi Rossi (Source: www.preistoriainitalia.it).

2. Related Work

Artificial Intelligence (AI) has significantly evolved over recent decades, influencing diverse fields such as healthcare, education, entertainment, and cultural heritage. Among its most transformative developments are GenAI models, particularly in content creation and interactive applications [6].
Samala et al. [7] highlight GenAI's broad applicability, categorizing its roles in education, such as content generation, personalized learning, and automated assessment. Similarly, Kim et al. [8] discuss student perspectives on GenAI-assisted academic writing, emphasizing its effectiveness in idea generation and writing enhancement. These studies underscore GenAI's potential to substantially improve educational tools and methodologies.
In gaming, GenAI has been instrumental in creating immersive environments through realistic scenarios and adaptive narratives, thereby significantly enhancing user engagement [9]. AI-driven Non-Player Characters (NPCs), which traditionally relied on scripted behaviours, now benefit from deep reinforcement learning, allowing for adaptive and intelligent responses [10], [11]. Additionally, AI-driven Procedural Content Generation (PCG) algorithms dynamically create game environments, expanding content diversity and replayability [12], [13].
Natural Language Processing (NLP), another critical area within AI, has advanced rapidly, particularly through transformer-based dialogue systems and virtual assistants [14]. Modern conversational agents utilize NLP to generate realistic and context-aware interactions, significantly improving user engagement [15]. Recent research integrates NLP with sensory inputs such as voice and visual recognition, enabling more holistic interaction capabilities [16].
Virtual Reality technology has transitioned from niche applications to widespread use across education, gaming, and cultural heritage. VR's capacity to reconstruct historical sites offers novel ways for users to engage deeply with cultural artifacts and environments, surpassing traditional educational approaches [17]. Projects like virtual reconstructions of ancient cities exemplify VR's capacity for delivering engaging and informative cultural experiences [18]. Museum applications frequently utilize VR for interactive storytelling and guided tours, significantly enhancing visitor engagement and understanding [19].
Furthermore, gamification within VR contexts has proven effective in increasing user motivation and experiential learning. VR-based educational games simulate historical events and scientific phenomena, promoting active participation and deeper knowledge retention [20], [21]. Applying gamification techniques in cultural heritage VR experiences effectively attracts visitors and fosters immersive exploration [22].
The integration of AI with VR creates responsive, adaptive virtual environments that dynamically adjust narratives and character interactions based on user inputs. These developments enhance immersion, providing personalized and interactive experiences for users [23]. This intersection of AI and VR continues to open new possibilities for educational and cultural heritage applications.

3. Methodology and Materials

3.1 Challenges and Objectives

Several technical and methodological challenges were addressed in developing a virtual guide for the Museo Preistorico dei Balzi Rossi. The project's primary goal was to create a realistic, historically consistent virtual representation capable of natural language interaction, significantly enhancing user experience.

- **Creating a Realistic Virtual Guide:** A primary challenge involved accurately modelling and animating the "Dame du Cavillon," ensuring visual realism and natural, believable interactions. This required advanced 3D modelling techniques, precise facial and bodily animations, and rigorous adherence to historical authenticity.
- **Implementation with Unreal Engine** [24]**:** The existing VR environment at the museum was developed in Unreal Engine, thus necessitating continuity within this platform. Key tasks included integrating 3D assets created using Meshy 3D [25] and Blender [26] as well as configuring interactive dialogues through platforms like Inworld Studio [27] and ConvAI [28]. Leveraging Unreal Engine's capabilities was essential for delivering an immersive and cohesive VR experience.
- **Natural Language Interaction:** Enabling natural, menu-free conversations between visitors and the virtual guide was a significant challenge. Platforms such as ConvAI and Inworld Studio were evaluated and implemented to facilitate authentic and engaging interactions. Achieving conversational fluidity required meticulous dialogue configuration and responsive interaction mechanisms.
- **Knowledge Base Management:** Developing a comprehensive knowledge base about the Balzi Rossi site was essential for ensuring accurate, contextually relevant dialogue. Historical, archaeological, and cultural information was systematically incorporated to enable the guide to respond precisely to visitor inquiries.
- **Environmental Interaction:** The virtual guide was designed to actively interact with its virtual surroundings, guiding visitors toward specific points of interest. Achieving this required detailed synchronization of the guide's movements and interactions using animation rigging and programming within Unreal Engine, thus enhancing the immersive quality of the experience.

3.2 Tools and Technologies

The development of the virtual guide involved integrating multiple advanced technological tools to ensure high-quality visuals and interactive capabilities.

Unreal Engine [24] is a real-time 3D creation platform initially developed for game design, now extensively used in diverse fields such as VR, film, and architecture. It provides sophisticated rendering, animation, physics simulation, and visual scripting tools, facilitating detailed and interactive virtual environments. Unreal Engine 4 was selected for this project to ensure compatibility with the museum's existing VR infrastructure.

MetaHuman Creator [29], developed by Epic Games, was utilized to create highly realistic digital characters. Leveraging real human scans, MetaHuman generates fully rigged characters with detailed facial expressions, realistic hair, and clothing. It significantly streamlined character animation, improving visual fidelity within Unreal Engine.

Meshy 3D [25], an AI-driven modelling platform, was employed to generate detailed 3D models from images. By automating complex modelling processes through machine learning, it enabled high-resolution mesh creation, crucial for accurate visual representations.

Blender [26], Blender is an open-source 3D graphics software widely used for modelling, rigging, animation, and rendering. In this project, Blender was instrumental in refining meshes created by Meshy 3D, optimizing proportions, and ensuring compatibility with Unreal Engine and MetaHuman.

Two prominent conversational platforms, ConvAI and Inworld Studio [27], [28], were evaluated to enable dynamic, natural-language interactions between users and the virtual guide.

- **ConvAI** integrates sophisticated conversational capabilities into virtual characters, leveraging technologies such as NVIDIA’s Avatar Cloud Engine (ACE) to facilitate real-time facial animations, voice-to-text, and text-to-voice functionalities. ConvAI’s "Knowledge Bank" feature supports the accuracy of responses by integrating verified external knowledge bases, thus reducing conversational inaccuracies.
- **Inworld Studio** offers extensive customization for AI-driven characters, focusing on creating nuanced personas with clearly defined goals, motivations, and contextual dialogue responses.

Its "Knowledge Filters" functionality provides different levels of information control, ensuring coherence in character interactions and adherence to narrative contexts.

Both platforms facilitate comprehensive dialogue integration and support interactive capabilities extending beyond simple conversational exchanges, enabling characters to respond dynamically to user commands and environmental interactions within Unreal Engine.

4. Prototype Development

The development of the "Dame du Cavillon" virtual guide followed a structured approach, combining theoretical research and practical application of advanced tools. The development process involved the integration of Unreal Engine, MetaHuman, ConvAI, and Inworld Studio to ensure an engaging interactive experience.

The initial phase involved:

- **Defining Objectives:** Clearly specifying immersive, interactive, and culturally accurate representation goals.
- **Technology Selection:** Identifying suitable tools for 3D modeling (MetaHuman), virtual environment creation (Unreal Engine), and dialogue interaction (ConvAI and Inworld Studio).

Subsequent phases included:

- **Character Creation with MetaHuman:** Using MetaHuman Creator to model the "Dame du Cavillon," ensuring historical authenticity in appearance, as can be seen from Figure 2.
- **Animation and Retargeting:** Animations were developed using external sources (Mixamo), then retargeted to MetaHuman within Unreal Engine.
- **Dialogue Integration:** ConvAI and Inworld Studio were implemented separately, each offering unique approaches to creating natural-language interactions. A comparative analysis of these platforms was conducted to assess their effectiveness.

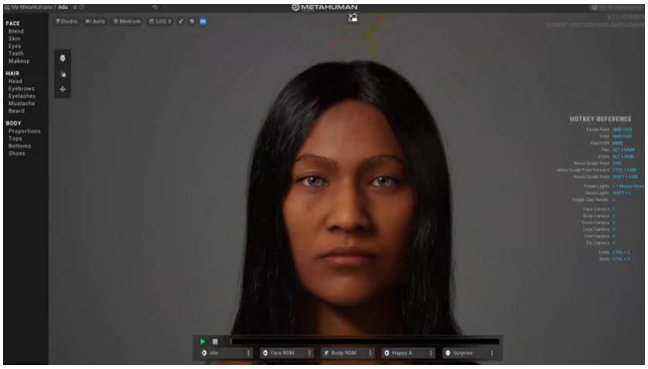

Figure 2. Avatar of the Dame du Cavillon created using MetaHuman Creator.

4.1 Retargeting for MetaHuman

Retargeting involved adapting external animations from Mixamo to the MetaHuman character using Unreal Engine's Inverse Kinematics (IK) system. The workflow included:

- **IK Rig Setup:** Creating an IK Rig for MetaHuman, defining articulation chains, and adding an IK solver to manage realistic movements.
- **Animation Import:** Animations from Mixamo were imported into Unreal Engine and mapped onto the MetaHuman IK rig.
- **Testing and Refinement:** Rigorous testing ensured fluidity, naturalness, and correct animation mapping. Adjustments were implemented to optimize vertex weights and bone rotations, significantly improving the overall animation quality.

Specifically, the IK Rig was structured according to MetaHuman's skeleton hierarchy, setting IK targets for precise limb movements. Mixamo animations were imported as FBX files and served as source animations for the retargeting process. Retargeting assets were created to map animation data effectively onto the MetaHuman model, addressing discrepancies in bone scaling and rotations. Iterative adjustments ensured the animations were visually accurate, realistic, and compatible with the MetaHuman character. Figure 3 shows an example of this operation, specifically to make the MetaHuman sit.

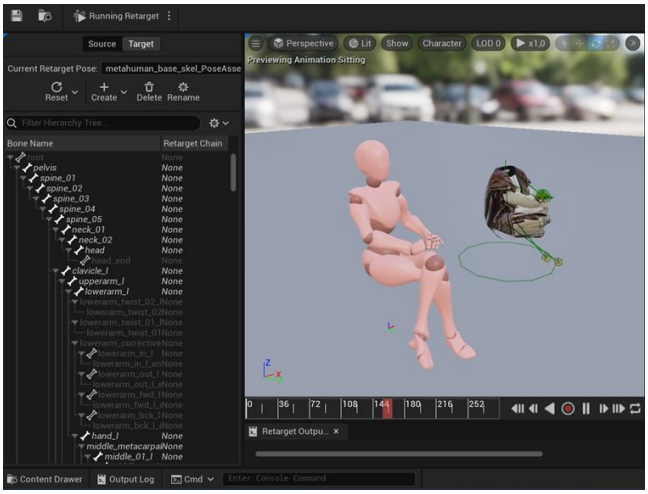

Figure 3. MetaHuman rigged with Mixamo animations using inverse kinematics (IK).

4.2 ConvAI and Inworld Studio for Dialogue

Once the MetaHuman character was finalized, our focus shifted to integrating two dialogue engines, ConvAI and Inworld Studio, so that the “Dame du Cavillon” could converse naturally without straying beyond her Paleolithic knowledge.

In ConvAI, we first defined the persona in the ConvAI Playground by supplying a concise back-story that described her role as a guide at Balzi Rossi, alongside metadata for formality and response length. We then configured ConvAI’s Knowledge Bank by uploading a curated corpus of archaeological reports and publications specific to the Balzi Rossi site. To avoid “hallucinations” or anachronistic references (as demonstrated by Chelli et al. [30]), we disabled any unbounded web-search or general-purpose language model calls, forcing ConvAI to draw responses solely from this curated knowledge base. In practice, when a user asks a question outside the curated topics, ConvAI returns a polite fallback such as “I am not familiar with that subject” rather than speculating .

In Inworld Studio, we implemented a parallel workflow. After importing the same archaeological corpus, we applied Inworld’s Knowledge Filters to enforce strict information boundaries. These filters allow us to set maximum and minimum detail levels, ensuring that broad questions yield concise overviews while specific inquiries produce deeper explanations, all drawn exclusively from the approved dataset. Any attempt by the model to reference events or technologies beyond Upper Paleolithic context is automatically suppressed, thereby preventing the avatar from discussing concepts a person from 24,000 years ago would not know .

Voice and language support were configured next. We selected a speech synthesis profile with a calm, authoritative timbre appropriate for a Paleolithic guide. Automatic language fallback was enabled so that, based on the museum kiosk’s settings, the avatar seamlessly switches among Italian, English and French without manual intervention .

Integration into Unreal Engine followed a two-track yet analogous process. For ConvAI, we installed the official plugin from the Unreal Marketplace, entered our API credentials and added a ConvAI Component to the MetaHuman blueprint. A built-in lip-sync module reads phoneme timing data from ConvAI’s speech API, driving the MetaHuman’s facial blend shapes in real time. For Inworld Studio, we compiled the C++ plugin, imported it into our UE project and attached an Inworld AI Controller to the same blueprint. This controller streams dialogue text and phoneme timing to UE’s animation graph, triggering synchronized head gestures and facial expressions .

To facilitate a controlled comparison, we developed two nearly identical prototypes, one powered by ConvAI and the other by Inworld Studio, both using the same MetaHuman asset. This parallel approach allows us to measure response latency, information accuracy (via user scoring against the curated knowledge sets) and the frequency of out-of-scope fallback messages. Qualitative user tests will further assess engagement and perceived authenticity, as each engine’s style and handling of historical context can produce different experiences.

By restricting each system to a locked knowledge base and employing feature-specific filters or banks, we ensure that the virtual guide remains historically faithful and avoids generative errors commonly

known as hallucinations. This method establishes a robust foundation for subsequent quantitative and qualitative evaluations of conversational AI in cultural heritage settings.

5. Testing and Evaluation

The testing and evaluation phase of both “Dame du Cavillon” prototypes was essential to verify that the virtual guide delivered an immersive, interactive and historically faithful experience. We structured this phase around two key areas, animation testing and dialogue testing, each designed to assess and refine specific aspects of the system before wider deployment.

5.1 Animation Testing

Animation testing aimed to confirm that the MetaHuman’s gestures, facial expressions and body movements appeared smooth, natural and well synchronized with speech. We reused a set of pre-existing Mixamo animations, applying them to the MetaHuman asset and observing performance across a range of motions, from gestural pointing to conversational head tilts. Given that the MetaHuman character was designed to interact dynamically within a virtual environment, it was essential to ensure that her animations were both realistic and well-synchronized with her dialogues. Particular care was taken to ensure that the 3D mesh did not stretch, collapse or exhibit clipping artifacts during playback, and that lip movements aligned precisely with audio cues generated by both ConvAI and Inworld Studio. Whenever we detected distortion or timing mismatches, we adjusted animation curves and blend-shape weights in Unreal Engine until the motion appeared seamless.

5.2 Dialogue Testing

Dialogue testing focused on quantifying and qualifying the interactions produced by ConvAI and Inworld Studio, ensuring that the “Dame du Cavillon” delivered historically accurate information with acceptable performance. Our evaluation combined objective metrics, response latency, information accuracy and fallback frequency, with structured internal tests and real-world simulation scenarios.
First, we conducted ten scripted sessions per prototype (twenty in total), each comprising a mix of knowledge-based questions (e.g., “Who are you?”, “What tools did you use?”) and out-of-scope queries (e.g., “Can I use Google Maps to reach the museum?”).
During each session, we logged:

- **Response latency**, measured from user query submission to the onset of the avatar’s speech. Both ConvAI and Inworld Studio averaged between 1 000 ms and 2 000 ms, perceptibly introducing a short pause as the models “thought.” Latency varied inversely with network quality: under high-bandwidth conditions, simple queries from the curated knowledge base received near-instantaneous replies (< 500 ms), whereas more complex or generative prompts incurred the full 1–2 s delay.
- **Information accuracy**, scored on a five-point Likert scale by comparing each response to the curated archaeological corpus. Across all twenty sessions, every knowledge-domain reply received a score of 4 or 5, indicating consistent factual correctness and adherence to the source material.
- **Fallback frequency**, calculated as the ratio of safe-fallback messages (“I am not familiar with that subject”) to total queries. Both systems correctly defaulted on most out-of-scope prompts, yielding a fallback rate of approximately 90 %. In a minority of cases (e.g., the Google Maps question), the guide attempted an informed guess but immediately shifted to a credible fallback when prompted further, claiming to have “heard of maps from previous travelers.”

Beyond these quantitative measures, we assessed the flow of interaction and user satisfaction qualitatively. The controlled sessions revealed that even when a brief latency occurred, the conversational turn-taking felt natural thanks to appropriate lip-sync and gesture timing. Testers reported no jarring interruptions or incoherent transitions, and the avatar’s concise, on-topic replies maintained engagement throughout each ten-question script.
Feedback from these tests informed adjustments to plugin configurations and knowledge-filter settings, resulting in a virtual guide that consistently delivers prompt, accurate information within a believable Paleolithic persona. This foundation paves the way for larger-scale user trials and performance benchmarking in cultural heritage applications.

6. Future Work and Enhancements

Future work will focus on expanding and refining the evaluation of the ConvAI-based prototype to assess its performance within the complete virtual environment. While the initial goal was to conduct a comparative evaluation between ConvAI and Inworld Studio, this is no longer feasible due to Inworld Studio's recent shift to a custom pricing model. As of writing, their free version is no longer available, and new accounts require direct contact with their sales team to access personalized packages. This change has made continued use of Inworld Studio impractical for academic prototyping and constrained testing options.

Consequently, the next phase of the project will concentrate exclusively on the integration and testing of ConvAI within the fully realized virtual museum experience. This environment includes not only the virtual guide but also the previously developed 3D reconstruction of the Balzi Rossi caves. This integration phase will be critical for identifying practical challenges that emerge from real-time deployment, including issues related to frame rate stability, system responsiveness, and synchronization between user inputs and avatar reactions.
Ongoing work involves assessing how ConvAI handles contextual dialogue once embedded in the complete VR scene and how effectively the avatar can respond to user interactions across different locations and actions. Particular attention will be given to evaluating conversational coherence, the responsiveness of the avatar to physical navigation requests (e.g., "Can you show me the burial chamber?"), and overall user immersion.
Once the integrated prototype has reached a stable state, broader user testing will be conducted. This will include a diverse group of participants and will gather both qualitative and quantitative feedback to assess usability, engagement, and perceived authenticity.
Ultimately, these developments aim to ensure that the final version of the guide offers a historically faithful, technically robust, and engaging experience for visitors, both within the museum setting and in remote educational contexts.

7. Conclusion

The development of the virtual guide prototype for the Museo Preistorico dei Balzi Rossi has demonstrated the potential of combining VR and AI-driven conversational agents to enhance engagement in cultural heritage experiences. By leveraging tools such as Unreal Engine, MetaHuman, and ConvAI, the project achieved high standards in modeling, animation, and dialogue integration, resulting in a historically consistent and immersive virtual guide.
Nonetheless, several limitations emerged throughout the development process. The evaluation phase was limited in scope due to a small participant pool and the recent unavailability of Inworld Studio's free-tier version, which restricted the planned comparative testing. Technical challenges also persist, including the need for stable internet connectivity to support conversational features and the potential performance bottlenecks associated with real-time integration in complex VR environments.
Future work will address these issues. These efforts aim to refine both the linguistic capabilities and interactive responsiveness of the guide, ensuring a seamless experience for visitors.
Beyond the immediate context, this research lays the groundwork for broader applications of AI-powered virtual guides. The methods and findings may inform future implementations in museums, educational platforms, and other sectors where immersive storytelling and contextual interaction are valuable. By addressing current technical and methodological challenges, the project contributes to the evolving dialogue on how AI and VR can be harnessed to promote engagement, accessibility, and deeper understanding in cultural contexts.

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