AI-Driven Avatars in Immersive 3D Environments for Education Workflow and Case Study of the Temple of Demeter, Greece

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Abstract: Generative Artificial Intelligence (AI) and Virtual Reality (VR) technologies are changing education and offer new opportunities for how people interact with environments. Technological advances over the past few decades have lowered barriers to creating virtual environments; however, there are still challenges, particularly when creating realistic virtual environments of real places. Realism is important as the fidelity of virtual environments influences user experience. In addition, methods and techniques that can facilitate ease of interacting with these environments are needed to streamline the user experience. One promising way to do this is incorporating AI-driven avatars into realistic scenes, allowing users to use natural language immersive learning experiences focused on sustainability education that incorporate realistic scenes to interact with and learn about the landscapes. To this end, we have developed workflows for design scenarios and natural interaction with AI avatars. This study created point cloud digital 3D models from photogrammetry and incorporated these into Unreal Engine 5. We then integrated generative AI avatars into the environment, enabling natural language interaction between users and an AI tutor. The integration facilitates interactive participation and enables high-precision digital reproduction of the physical environment. The novel proposed workflow is presented via a case study for a virtual study abroad experience in Naxos, Greece, using an AI-driven tutor to educate about the historical aspects of the island. This project provides the beneficial learning experience of study abroad experiences without the economic and environmental costs of sending students on field excursions. We recommend constructing immersive education experiences using real-world environments and natural AI-driven conversations and demonstrating its potential to revolutionize social interaction, historical heritage preservation, and sustainable pedagogy.

Keywords: Generative artificial intelligence, AI-driven avatars, virtual reality, heritage preservation, immersive experience

1 Introduction

Realistic virtual environments have myriad applications in a variety of disciplines including urban design and planning, virtual tourism, film and gaming, education, disaster management, and preservation and cultural heritage. However, creating virtual environments that are perceived as realistic is usually very time-consuming and expensive (KIOURT et al. 2017). Recent advances in hardware and software have accelerated the creation of and interaction with realistic environments, though there are still challenges. With the convergence of generative artificial intelligence (AI) and realistic digital 3D models of real-world locations, new types of immersive experiences can be created that will change how people interact with and learn about places. Here we demonstrate how new technologies can be applied to rapidly create realistic digital environments, virtual exploration, and AI-driven interactions. In this study, we demonstrate how to create a digital model of a real-world location using point cloud modeling and integrate that model with a video-game engine to create an immersive virtual reality environment. The immersive environment and simulated physical systems are used to replicate the virtual roaming of a historical site. A novel approach to human-database inter-

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action is applied by using conversational generative AI to support natural language interaction with an avatar allowing users to learn about the site. In the following sections, we provide background on 3D modeling techniques, generative AI, and related work.

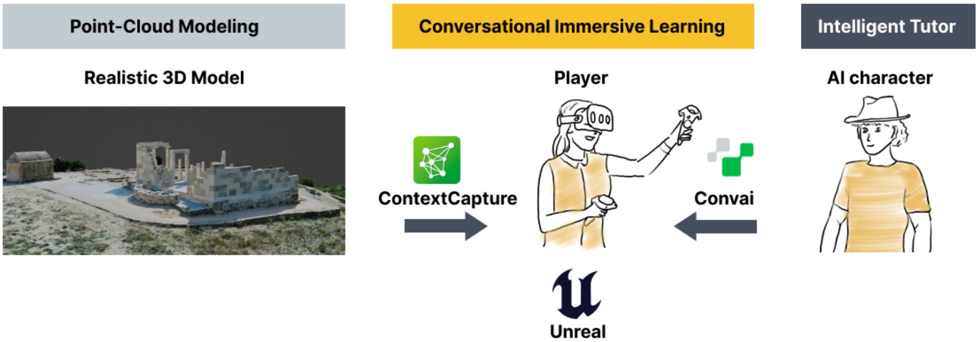

Fig. 1: The concept of the developed workflow for AI-driven immersive learning

1.1 Point-Cloud Modeling

In recent years generating 3D models of real locations has transitioned from manually creating models using CAD software to automatically generating models from photographs. Point cloud modeling uses Structure of Motion (SfM) and Multi-View Stereo (MVS) algorithms to generate dense point clouds from photographs that represent 3D objects and structures in a detailed and accurate manner (PEPE et al. 2022). The SfM methodology is a widely used method in the fields of photogrammetry and computer vision that uses overlapping images to create 3D surface models.

Standard consumer-grade cameras can capture images, hence rendering SfM a cost-effective tool that may be used in conjunction with other 3D technologies like terrestrial and airborne laser scanning (LIDAR). The use of unmanned aerial vehicles (UAVs) enables the acquisition of photographic datasets that possess spatial coordinates. By employing SfM and MVS algorithms, users can rapidly capture and create digital models of landscapes. Furthermore, these algorithms facilitate the categorization of features within the 3D point cloud. Using photo datasets containing spatial coordinates and overlaps proves to be highly advantageous for researchers in various disciplines such as geoinformatics, computer vision, archaeology, architectural research, human-computer interaction, algorithm evaluation for structural and multi-view stereo reconstruction in motion, point cloud processing, semantic 3D reconstruction, virtual tourism, and applications related to virtual reality and augmented reality (PEPE et al. 2022).

1.2 Generative Artificial Intelligence

AI broadly refers to the application of computers to simulate intelligent behavior with little human guidance (KONAR 2018). Generative AI, a subset of AI more generally, relies on machine learning models that have been trained using vast amounts of data (HALEEM et al. 2022). These models, known as mega-models, serve as the foundation for the functioning of generative AI systems. Researchers utilize machine learning techniques to facilitate the creation and advancement of cutting-edge digital generating applications. Generative AI uses a combination of manually crafted algorithms and machine learning to produce novel material by leveraging pre-existing databases (e. g., text, photos, images, music, etc.) (DWIVEDI et al. 2023). Generative AI techniques employ statistical models and probabilities to generate synthetic artifacts using unsupervised or partially supervised machine learning methodologies (CASTIGLIONI et al. 2021). Generative AI programs such as ChatGPT (https://chat.openai.com/) and Midjourney (https://www.midjourney.com/home) have gained significant popularity due to their ability to generate text and visuals.

The field of generative AI encompasses two primary categories: Generative Adversarial Networks (GANs) and Generative Pretrained Transformers (GPTs) (GOODFELLOW et al. 2014). The present framework of GANs consists of generator networks and discriminator networks (LI et al. 2017). Generator networks are responsible for generating and synthesizing data (KU & LEE 2023). When the discriminator network successfully identifies the material generated by the generator network, it becomes unable to differentiate between synthetic and authentic content, resulting in the synthetic content being classified as genuine (GOODFELLOW et al. 2014, RADFORD et al. 2015). Large-scale language model processing systems employ machine learning algorithms to analyze user text and pre-existing text databases, generating text that resembles human language. This facilitates seamless and natural communications between humans and computers. ChatGPT and Midjourney are developed using this underlying framework to produce text that resembles human discourse and pictures that resemble human drawings.

ChatGPT is an application for engaging in chat conversations that are generated from pre-existing language models, namely GPT 3.0 and GPT 4.0 (ABRAMSKI et al. 2023). The system possesses the ability to identify text input provided by users and generate contextually appropriate responses, resembling the comprehension of human language (BAIDOO-ANU & OWUSU ANSAH 2023). The model has garnered significant interest across multiple disciplines, encompassing education, engineering, journalism, medicine, as well as economics and finance, among other domains (AYDIN & KARAARSLAN 2023). ChatGPT possesses the capacity to offer tailored and efficient educational encounters through the provision of personalized feedback and explanations to students. Nevertheless, the functionality of ChatGPT is subject to several constraints, primarily its reliance on a solitary text-based dialogue interface (GRASSINI 2023). In the current state, the linguistic output produced by ChatGPT is similar to human language, albeit with certain limitations on the accuracy of the information provided. Research has demonstrated that ChatGPT exhibits biases and inaccuracies when it comes to spreading knowledge, posing a significant obstacle in the realm of education (BISWAS, 2023).

2 Related Work

2.1 VR in Education

Significant advancements have been observed in the integration of VR technology in the education domain in the past five years. One study conducted by RADIANTI et al. (RADIANTI et al. 2020) showed that immersive VR facilitated improved comprehension and educational achievements. However, the primary focus of the research was on scenarios that occur within the classroom setting. This highlights the need for more extensive and practical applications of VR in real-world environments. In this context a study undertaken by WALMSLEY et al. (WALMSLEY et al. 2020) investigated the creation and effectiveness of a 360 virtual reality instructional tool, yielding noteworthy outcomes. While promising, the study relied on 360-image-based VR environments which are static and less interactive than 3D model-based VR. HASKINS et al. (HASKINS et al. 2020) conducted a study where they demonstrated that the use of VR 3D environments increased student engagement. Nevertheless, the study conducted by the researchers failed to place significant emphasis on the advancement and use of authentic virtual worlds that accurately replicate real-world settings. Furthermore, ROUMANA et al. (ROUMANA et al. 2022) proposed an innovative approach to cultural heritage education by integrating VR technology with realistic environmental models to enhance cultural immersion. While promising, the research did not delve into the specific benefits of integrating AI tools with 3D environments, which is a promising new area for teaching and learning.

2.2 AI in Education

The integration of generative AI in the domain of education has emerged as a potential avenue for revolutionizing teaching and learning. Promising developments are in the creation of generative models that can augment student learning and increase engagement. In a recent paper, DWIVEDI et al. (DWIVEDI et al. 2023) highlight the efficacy of generative AI in facilitating individualized learning trajectories. JEON et al. (Jeon et al. 2023) employed generative techniques to create educational chatbots designed for language acquisition. This innovative approach facilitated a conversational learning trajectory. Further, the use integrating AI with simulated characters for education allows for the provision of adaptive content tailored to the specific needs of learners. These AI characters can take on many roles such as playing coaches, program creators, and teachers. To this end, CHHEANG et al. (CHHEANG et al. 2023) developed an intelligent tutor for anatomy education within a VR setting. However, their study did not include a dedicated database tailored to anatomy education, and the intelligent tutor was shown to be ineffective in delivering appropriate instructional content. Furthermore, the integration of the intelligent instructor with the actual environment was not accomplished, and the intelligent entity was unable to identify the things present in the environment. This highlights the substantial scope for further innovation in this field. Nevertheless, a significant deficiency in current AI education programs is the absence of a comprehensive examination of the dynamic interplay between AI characters and individuals engaged in the learning process. The current scope of AI applications is confined to structured learning models, while the potential of natural language processing applications remains largely untapped. The use of generative AI in education has a significant impact. Our research involves the integration of AI into VR and its combination with real-world 3D models. This integration aims to provide learners with an immersive and interactive educational experience that offers precise data information.

3 Methods

3.1 Case Study Selection

The global mass tourism industry has been expanding rapidly over the past 15 years and is associated with negative environmental impacts (AFRIN et al. 2013, LEKA et al. 2022). These impacts are evident in our case study site, Naxos Island, Greece which is undergoing gradual erosion and loss due to the combined impact of natural processes and human activities (EVELPIDOU et al. 2021), posing a significant threat to the preservation and education of the islands' biodiversity and cultural heritage.

The process of digitizing architectural and cultural sites holds inherent significance within the realm of heritage preservation. Simultaneously, the digital preservation of historical sites serves to enhance their accessibility, facilitating broader engagement from a diverse audience using online platforms. The accessibility of historical and cultural resources has a positive influence on the preservation of history and culture, as well as the advancement of sustainable development concepts. The majority of digital engagements with these websites are confined to passive endeavors, wherein users are restricted to clicking through and retrieving information. Regrettably, digital platforms frequently fall short of delivering engaging guided tours and interactive experiences to their visitors. To overcome these challenges this study aimed to explore the use of realistic virtual environments and AI-driven avatars for increasing engagement with cultural heritage sites.

3.2 Virtual Environment

This study used a consumer-grade UAV (DJI mini 3 pro) to capture 243 aerial oblique photos of the site at angles ranging from 30 degrees to 45 degrees which were subsequently used to create a 3D model. The images were processed in ContextCapture (now iTwin Capture Modeler, https://www.bentley.com/software/itwin-capture-modeler/.) to generate an intricate mesh composed of textured triangles, using the spatial coordinates derived from the pictures. The software then goes through a process of image matching, 3D reconstruction, and seamless texture mapping, to create an authentic 3D textured model. The modeling process is an unsupervised process, and in this modeling, we have a total of 243 control points, which are provided by 243 UAV aerial photos with camera angles. The 3D model was exported as an OBJ file and enhanced using Blender to rectify damaged meshes and eliminate any flaws or impurities present in the model.

After error correction, the model was exported as an FBX file and imported into Unreal Engine 5 (https://www.unrealengine.com/). Unreal Engine was used due to its high level of realism and superior simulated physics when compared to other game engines. Unreal Engine also has a variety of VR templates and feature called Blueprint that enable users to implement VR gameplay mechanics without the need to code. These presets encompass guided tours, object manipulation, rotation, and many functionalities. These functionalities permit individuals to freely explore and engage with virtual models, while the incorporation of realistic lighting effects and physical systems enhances the level of immersion experienced by users.

3.3 AI-Driven Avatars for Conversational Immersive Learning

To facilitate users interacting with AI-driven avatars we used ConvAI (https://convai.com/) ConvAI provides AI-driven avatars to augment virtual experiences by facilitating human engagement with AI in video games and virtual worlds. The process uses character modeling and animation from video games to the creation of realistic avatars.

ConvAI provides an enhanced level of contact between humans and virtual avatars using various technological components such as Natural Language Processing (NLP), speech recognition, speech-to-text conversion, ChatGPT, and customizable databases. ConvAI provides the functionality to create custom avatars and update the avatar knowledge using a custom text-based database development. ConvAI also supports avatars created using Ready Player Me (https://readyplayer.me/) which use personal photographs to construct virtual personas. The system offers both virtual characters and rudimentary animation functionalities and uses OVRLipSync technology to improve the authenticity of an avatar's verbal communication by generating lifelike lip movements that correspond with the character's speech.

To support seamless and authentic interactions between people and AI avatars ConvAI uses advanced speech recognition technology that converts spoken language into text. This allows users to engage in interactions through voice-based input. The recognized text content is transmitted to ChatGPT, where ConvAI converts it into synthetic voice output. Simultaneously, ConvAI allows users to customize avatars by including distinct backgrounds and specialized knowledge sets. Considering ChatGPT's propensity for generating inaccurate material, users have the option to establish a connection between the language model and their database. By doing so, they can contextualize the persona and enhance the correctness of the generated content.

In our project, ChatGPT was augmented with the background of an ecology professor involved in fieldwork for our case study site, along with historical details about the Temple of Demeter. We designed 10 questions based on the knowledge base, encompassing topics such as history, significance, architectural style, and building materials (Table 1). In addition, various labels were assigned to objects within the virtual environment, facilitating interaction between the avatar and such objects.

Table 1: Ten Questions for students to learn about the Temple of Demeter

Q1	When was the Temple of Demeter at Sangri built, and what materials were used in its construction?
Q2	What is the primary significance of the Temple of Demeter at Sangri?
Q3	Who was responsible for commissioning the construction of the Temple of Demeter?
Q4	Which deity was the Temple of Demeter dedicated to?
Q5	What unusual feature did the columns of the Temple of Demeter have?
Q6	What purpose did the two doors in the entrance area of the temple serve?
Q7	How was the roof of the Temple of Demeter constructed?
Q8	Which god was intended to be worshiped in the temple alongside Demeter?
Q9	What did the outer layer of the temple's walls consist of, and how were they linked?
Q10	Who conducted the investigations and excavations of the Temple of Demeter at Sangri?

Figure 2 depicts a flowchart illustrating how an AI avatar engages in interactions with a user.

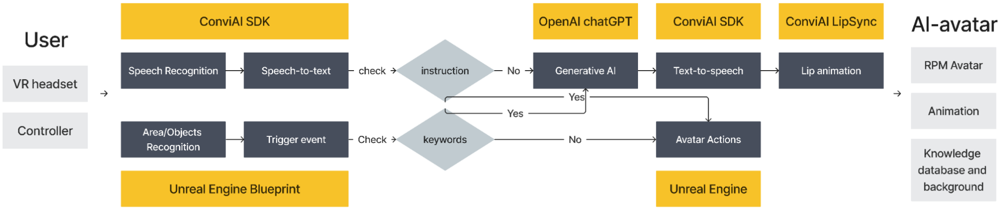

Fig. 2: Information architecture of VR environment with generative AI virtual avatar

4 Results and Discussion

4.1 Practical Applications of Artificial Avatars in Virtual Reality

Realistic 3D models, incorporating accurate materials and simulated lighting effects, serve as the foundational elements for digital exploration. Meanwhile, widely available Meta Oculus headset devices offer the necessary hardware support to enhance user immersion. These advancements have enabled the integration of AI avatars into virtual reality, allowing for conversational scene interactions that enhance user immersion.

Fig. 3: The digital model (Left) and photo (Right) of the Temple of Demeter, Naxos Island, Greece

This project involved the development of a user interaction framework within a VR environment. The participants were provided with a Meta Oculus controller to navigate and engage with the virtual scene. The fundamental operations encompass navigating within the environment, rotating one's perspective, engaging in dialogue with the AI avatar, manipulating objects within the area, posing inquiries using the inquiry control panel, requesting the AI avatar to accompany, and engaging in further forms of interaction.

The practical implementation entails the integration of genuine historical heritage site into a virtual environment, wherein the textures, terrain, and proportions are faithfully replicated to mirror their real-world counterparts. Furthermore, the AI-powered avatars are provided with narrative frameworks that are intricately constructed from the ecologist's personal life story and the historical narrative linked to the respective location. This synthesis offers users an exceptional experience by immersing them in a virtual environment and facilitating a meaningful and evidence-based dialogue with the created AI database. The present workflow, characterized by its inventive nature, has given rise to a diverse range of practical applications, all of which have the potential to bring about significant transformations. The primary use of this technology lies in the domain of immersive learning experiences. In the realm of education, students are bestowed with the ability to not only passively observe their surroundings, but also engage in active involvement, hence leading to the acquisition of knowledge through experiential learning. The integration of an interactive environment with AI-driven interactions enhances the learning paradigm by transforming the venue into an engaged pedagogical collaborator. This approach has a broader scope and appeals to various fields of study. The applications of this technology are extensive, as it enables the generation of computer models that accurately represent the physical environment.

(a) (b) (c)

Fig. 4: (a) Talk with AI virtual avatar; (b) Use teleport to navigate; (c) Question board for studying (see table 1)

The method used is a rapid and resource-efficient approach that offers several advantages. Firstly, it significantly decreases the time required for the modeling process. Additionally, it effectively maintains the authenticity of the materials and textures used in the model. Furthermore, it ensures the safeguarding of geographic and topographic data. This approach also presents limitations: it necessitates the utilization of a requiring high-performance computing systems to handle the processing and generation of photos and models, and intricate details, particularly those pertaining to plant components, may be challenging to capture.

After updating the database with the supplemental information responses provided by the AI avatar were evaluated for accuracy. The responses (Appendix 3) were factually accurate. and the language used by the avatar proved to be natural sounding. The synchronization observed in this context demonstrated a very engaging form of character interaction that effectively replicated the educational experience encountered during the field trip. Furthermore, this engagement extends beyond simple dialogue and influences the surrounding environment. Various labels are assigned to objects within the virtual area, facilitating interaction between the avatar and such objects. When a user engages with a designated destination, the virtual representation of the user, known as the avatar, spontaneously offers interpretive insights that augment the educational encounter.

Through the interaction of the intelligent virtual avatar with its knowledge content, background information, modeling of the 3D environment, material matching, light and shadow rendering, and physical system simulation, our research successfully integrated the generative AI avatar with the real-world 3D scene. The digital medium offers the potential to accurately replicate real-world landscapes and structures, thereby facilitating advancements in architectural and urban planning, virtual tourism, and historic preservation. The significance of applications within the realm of environmental protection cannot be overstated. The utilization of technology facilitates the opportunity for individuals to engage in immersive environmental awareness tours, allowing for virtual excursions and investigation of ecologically sensitive locations. The utilization of immersive interactions with the AI avatar aligns seamlessly with this objective, as it fulfills a dual role as an informative guide and a platform for engaging in discussions about sustainability. Furthermore, the proposed workflow enhances its transformative influence on the advancement of smart city development through the establishment of a digital twin. By employing geographic precision and advanced modeling techniques, the creation of digital replicas enables informed urban planning and decision-making processes.

4.2 Limitation

Our digital temple of Demeter model is generated using a consumer-grade drone, DJI Mini 3 pro with 4K footage at 75% quality, so there is a lack of accuracy and detail in the model, which affects the user's experience. Additionally, the scope of interaction options with our AI avatar is constrained. We have implemented only voice command interaction and question panels as means for users to engage with the system. Furthermore, user's interactions with the virtual environment are restricted to roaming and object grabbing, without the AI avatar having the capability to access information within environment objects or facilitate more diverse interaction modalities. For the current research, we need to design experiments to validate the combination of generative AI avatars and point cloud modeling in terms of user immersion and immersive learning experience.

4.3 Future Work

In the realm of digital replication and 3D modeling, our future endeavors encompass a comprehensive exploration of advanced techniques. Beyond the utilization of point cloud modeling, we aim to integrate algorithm-based neural rendering approaches, exemplified by Nvidia's Neurolangelo. These neural surface-based 3D reconstruction methods excel not only in preserving model geometry but also in faithfully representing material properties. Concurrently, Nvidia is actively harnessing AI-assisted point cloud modeling to iteratively refine models, progressively bridging the gap between virtual and real-world fidelity. In addition to using AI-enabled point-cloud modeling techniques, modeling using neural radiation fields (NeRF) is also our future direction of inquiry. These modeling techniques serve as vital underpinnings for elevating the realism of VR scenarios, facilitating swifter and more efficient digital world development for developers.

Our forthcoming research agenda necessitates the systematic evaluation of diverse modeling techniques to complement and enhance the existing modeling workflow deployed in our current research. This evaluation will extend to a multifaceted approach, encompassing visual, auditory, and emotional recognition, eye tracking, and body posture analysis of AI avatars. These aspects hold significant promise for augmenting the user's experience within virtual environments, aligning with user-centered interaction design principles. Moreover, our research will entail training AI avatars to recognize virtual objects and designing interaction behaviors tailored to user movements and object interactions within the virtual environment.

To validate the effectiveness of the design strategies, we will embark on a series of designed experiments, with a particular focus on assessing their impact on user immersion and immersive learning experiences. We envision that the workflow currently under investigation possesses broad applicability across various domains, and we invite fellow researchers to explore and validate its effectiveness within their respective areas of expertise.

5 Conclusion

In this paper, we present a workflow for VR immersive learning experience using point-cloud modeling and AI-driven avatars. By combining point-cloud modeling, generative AI, and VR technologies, our work not only achieves the digital modeling of architectural heritage site but also provides digital tours and immersive learning experiences for the Temple of Demeter at Sangri, Greece.

The integration of generative AI, digital 3D models, and Unreal Engine 5 opens the way for transformative change. This research exemplifies the potential to recreate physical environments in the virtual realm, promote immersive education, and catalyze advancements in various fields. This paper provides a series of technical routes and design insights for using a combination of point-cloud modeling, generative AI, and VR technologies to support immersive teaching and learning experiences with the preservation and digitization of historic architectural heritage. With uncharted territories awaiting exploration, this innovative approach signifies the inception of a paradigm shift.

Appendices and other relevant metadata are available at:
https://github.com/gaohaoting/VR_AI-driven-travel_Oculus_Unreal.

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