RESTORATIVE: Improving Accessibility to Cultural Heritage with AI-Assisted Virtual Reality

Tuğçe Ballı[1[0000-0002-6509-3725]], Hasan Peker[2[0000-0002-4290-5858]], Şenol Pişkin[3[0000-0002-8799-9472]], E. Fatih Yetkin[1[0000-0003-1115-4454]]

[1] Management Information Systems Department, Kadir Has University, Fatih, İstanbul, Turkey
[2] Faculty of Literature, Ancient Languages and Cultures, Hittitology, İstanbul University, Fatih, İstanbul, Turkey
[3] Faculty of Engineering and Natural Sciences, Department of Mechanical Engineering, İstinye University, Sarıyer, İstanbul, Turkey
tugce.balli@khas.edu.tr, hasan.peker@istanbul.edu.tr, senol.piskin@istinye.edu.tr, fatih.yetkin@khas.edu.tr

Abstract. Digitalization of the cultural heritage can be considered from multiple perspectives. In this work, we present a case study based on the ancient city of Karkemish to propose a structured pipeline for developing an Artificial Intelligence (AI)-assisted Virtual Reality (VR) system. The framework outlines a roadmap for creating a user-friendly and gamified VR interface, incorporating qualitative and quantitative evaluation methods before deployment. Qualitative assessments focus on User Interface/User Experience (UI/UX) design, while quantitative evaluations utilize electroencephalogram (EEG) data to monitor cognitive and emotional responses, aiming to promote a positive user experience. Moreover, we introduce a privacy-preserving approach to ensure the user's privacy during the system interaction. The study's aim is twofold: a) preservation and dissemination of endangered cultural heritages, and b) improving the quality of life for individuals with limited mobility (handicapped, elderly, heritage site restrictions, poverty) by enabling virtual access to cultural heritages.

Keywords: AI Story Telling, VR Systems, EEG-based Evaluation, Karkemish, Cultural Heritage Digitalization.

1 Introduction

Europe is getting older. According to projections by Eurostat (Eurostat, 2020), the median age in the EU countries is estimated to increase by 4.5 years between 2019 and 2050 and reach 48,2. This demographic shift not only creates socio-economic challenges but also emphasizes the urgent need for innovative solutions aimed at improving the quality of life for older adults. Therefore, to handle age-related conditions, particularly dementia, there is growing scientific interest in the development of non-pharmacological interventions (Lee & Strong, 2021). Cultural participation has been linked to improvements in cognitive stimulation, emotional well-being, and social inclusion

Digital Presentation and Preservation of Cultural and Scientific Heritage, Vol. 15, 2025.
Sofia, Bulgaria: Institute of Mathematics and Informatics – BAS. ISSN: 1314-4006, eISSN: 2535-0366

among older individuals. A study conducted by Dresden University reported that regular visits to museums significantly alleviate caregiver burden and contribute to enhanced quality of life, psychological well-being, and both physical and mental health outcomes for elderly individuals (Wachten, et.al., 2025). Moreover, a significant portion of cultural heritage sites—including the case study area of this research, Karkemish—are located in geographically challenging regions that are difficult to access, even for individuals without any physiological problems. In this context, Virtual Reality (VR) technologies may offer a promising solution by enabling distant experiences that can reconstruct and present the ancient appearance of such sites as well. These digital reconstructions not only may enhance accessibility but also significantly improve the dissemination of cultural heritage. This work aims to integrate artificial intelligence (AI) and virtual reality (VR) technologies to facilitate inclusive access to cultural heritages, namely the Karkemish area as a case study. The Kingdom of Karkemish, whose capital is Karkemish, is one of the 3 major administrative units of the Hittite Empire, the first empire established in Anatolia. The city of Karkemish, which went under Hittite rule at the end of the 14th century BCE, continued to exist as the center of the administrative, cultural, and historical presence of the Hittite Empire in Syria and the Eastern Mediterranean after the Hittite Empire collapsed. The city of Karkemish is a city where Hittite speakers, the oldest attested member of the Indo-European Language Family, followed by Luwian speakers, one of the oldest known members of the Indo-European Language Family, left behind inscriptions in Anatolian Hieroglyphic script, which was invented in Anatolia together with Hittite speakers and used for about 1000 years. The ruins of the city, dated between the 10th-8th centuries BCE, were unearthed during excavations in Karkemish, spread over an area of approximately 100 hectares. Today, the ruins of the ancient city are located within the borders of Karkamış District of Gaziantep (Türkiye) and Jarablus (Syria). It is attested in the cuneiform and hieroglyphic archives of the Hittite Empire, in the archives of Greater Mesopotamia and Ancient Egypt, and in the Bible, the city of Karkemish and the Sons of Het (inhabitants of the Hittite and Late Hittite Kingdoms, including the Luwian-speaking inhabitants) have left a record in the memory of humanity for nearly a millenium. The Turkish-Italian team, which has been working in Karkemish since 2011, has documented the ruins of the city's palaces and temples with inscriptions, relief orthostats, and scientific virtual 3D reconstructions[1]. This data on the city, together with data from written documents (Peker 2016; Peker 2023; Hawkins 2024), will be used in augmented reality and/or virtual reality scenarios that closely reflect scientific facts.

The objective of this work is to propose a novel computational pipeline to create an AI-assisted VR platform that overcomes traditional barriers such as age, socio-economic status, physical limitations, or motivational or economic challenges for accessing the target cultural heritage area while considering the impact of the system on cognitive processes and privacy-related concerns. In parallel, the proposed AI-assisted VR creation pipeline will help to preserve and disseminate cultural heritages while simultaneously addressing the social, emotional, and cognitive needs of an aging population.

[1] https://www.orientlab.net/3d-kark/

The rest of the paper is organized as follows. In the next section, the methodological approach will be explained with current literature for digital protection of cultural heritages, including the AI-assisted VR technologies, and finally, in the last section, we will discuss the future works.

2 Methodological Approach

2.1 Preparation of AI-Assistance Pipeline

The main interest of this work is to suggest a digitalization approach for a well-known historical heritage, such as The Karkemish, which is in the Mesopotamia area. There are many encrypted texts from this region. As an initial step, we aim to utilize these ciphered ancient texts to generate historically accurate narrative stories by fine-tuning an appropriate Large Language Model (LLM). This process falls under the domain of Automated Story Generation (ASG), a concept in computer science defined as the use of artificial intelligence systems to produce fictional or semi-fictional narratives from minimal text inputs. Early approaches to ASG primarily relied on schema-based planning (Rumelhart, 1975). While traditional methods were rule-based (Thorndyke, 1977) or symbolic in nature, modern approaches predominantly employ machine learning (Riedl & Young, 2010) and deep learning techniques, which we also adopt in this study. One notable approach is the **Scheherazade** system, which kept the plot of the generative story as a partially ordered graph (Li et. al, 2012) . Another recent approach is using Recurrent Neural Networks to generate the story plots from a few inputs (Roemmele & Gordon, 2018).

There are also some attempts in the literature to employ Reinforcement Learning for story generation (Harrison, et.al, 2017). In the next stage, the constructed narrative will be translated into the corresponding ancient language by integrating and fine-tuning a suitable large language model (e.g., Akkademia) within the processing pipeline (Gutherz, et.al, 2023). Then, by using the available phonetics, generative AI models can be employed to propose a possible vocalization for the narrative stories (Kamath, et. al, 2024). To feed the VR system, in addition to existing visual materials, open-source generative AI tools such as ID.8 will be utilized (Antony & Huang, 2025). The overall pipeline for proposed system is illustrated in Fig. 1.

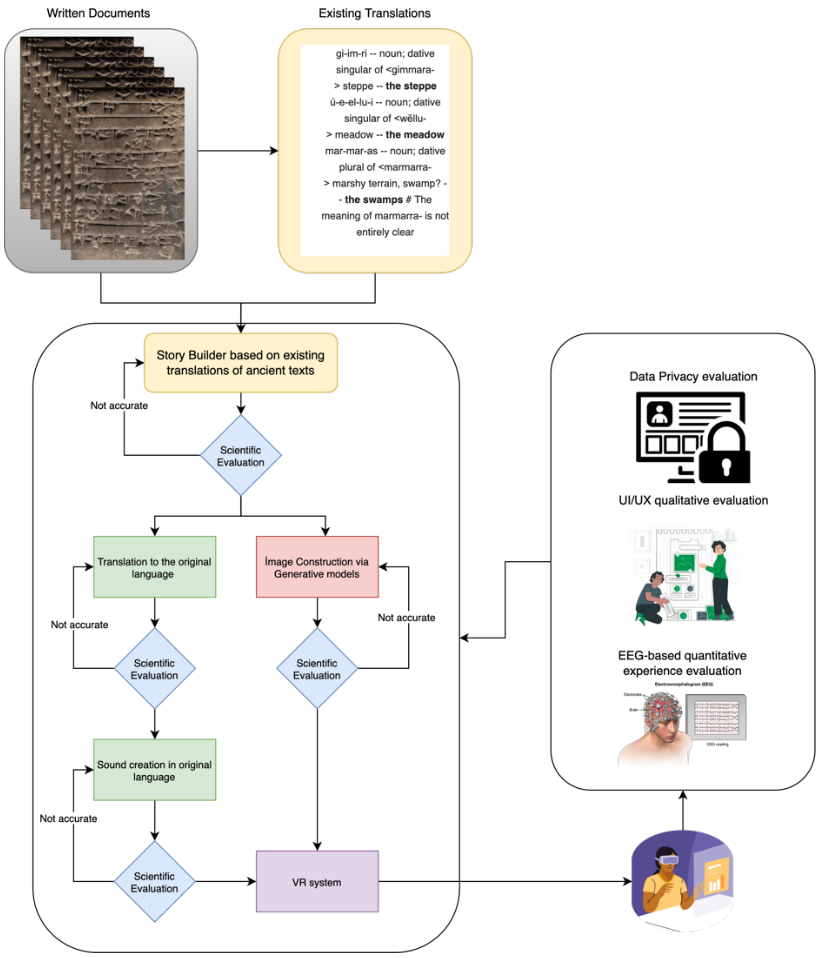

Fig. 1: The illustrative flowchart of the proposed pipeline.

The biggest computational challenge for the methodological part lies in the integration of diverse AI models. Furthermore, to ensure data privacy and transparency, all models will be sourced from the open-source community and trained on local computational infrastructure. As shown in Fig. 1, all outputs generated by the various AI models will be scientifically evaluated by the team of domain experts to ensure scientific validity and accuracy.

2.2 VR Integration Pipeline

To bridge AI-generated content with an immersive Virtual Reality (VR) experience (Du, et.al, 2025; Chamola, et.al, 2024), we will implement a modular VR integration pipeline comprising three layers: content preparation, real-time rendering, and user interaction. a) **Content Preparation:** 3D reconstructions of Karkemish ruins are derived from photogrammetry and LiDAR scans, producing high-fidelity meshes and textures. These assets are optimized (polygon decimation, texture atlasing) and semantically annotated to link virtual objects with AI-generated narrative nodes. **b) Rendering Engine:** We employ Unity 3D (LTS version) with a custom C# or Unreal Engine 5 with a custom C++ framework to stream narrative scripts dynamically. A client–server architecture routes AI prompts from the LLM service to the VR client via an API. A middleware module pre-fetches narrative segments and synchronizes audio-visual cues, such as ambient sounds, with user navigation. **c) User Interaction & Accessibility:** The interface uses VR headsets (HTC Vive Pro 2 or Oculus Quest 3 in tethered mode) with motion controllers. Interaction metaphors include gaze-based selection, teleportation locomotion, and contextual menus that appear on controller input. An adaptive UI layer adjusts font size, contrast, and audio levels based on user profiles (age, visual acuity, hearing sensitivity). Gamified elements—collectible artifacts and narrative checkpoints—encourage exploration and maintain engagement. To ensure accessibility for older or mobility-impaired users, we integrate seated-mode operation and simplified navigation controls. Haptic feedback via vibrating controllers reinforces immersion without causing fatigue. The VR client also logs detailed telemetry (head orientation, controller usage, session duration) for subsequent quantitative analysis. As an alternative to immersive head-mounted VR, we propose a semi-immersive configuration using large, curved panoramic screens combined with wireless motion-detection headbands. This is especially useful for users with motion sickness or difficulty wearing large VR headsets. In this setup, high-resolution 210° curved LED screens surround the participant on three sides, rendering the reconstructed Karkemish environment in real time. User orientation and head movements are captured via an IMU-equipped soft headband (e.g., Xsens MVN Link), which streams yaw, pitch, and roll data via Bluetooth to the rendering engine (Zhou, et.al, 2025). This allows naturalistic viewpoint control—turning, nodding, and leaning translate directly into virtual camera adjustments—without requiring a headset.

2.3 User Experience, Cognitive Evaluation and Privacy Assurance Pipeline

Before being widely used, AI-supported virtual reality (VR) systems for older adults must go through careful testing. The user interface (UI) and user experience (UX) should be designed to match the needs of users with different levels of technical skills, age, education, and cognitive abilities. The system should be flexible enough to provide different versions of the interface based on these user differences. At the same time, it is important to consider possible negative effects on cognitive health, especially for elderly users with conditions like dementia. For this reason, it is necessary to include brain signal analysis and neurological inspection in the evaluation process. One possible way is to employ electroencephalogram (EEG) recordings to measure brain activity and engage experts from neuroscience for the evaluation. Two main goals will be considered for the EEG-based evaluation: (a) comparing users' brain response to the virtual experience versus a real-life experience in a controlled experiment, and (b) studying the brain's reaction to using an AI-based VR system, focusing on mental workload, emotional responses, and sensory effects. The results will help to improve the system design and make sure it is safe and suitable for elderly users. The final concern for such a system will be the privacy and protection of personal data. Hence, the overall AI-assisted system should provide a privacy-utility balance, and the design steps should offer a parametric approach to improve the privacy of the personal data (such as EEG signals, voice, and personal choices).

3 Conclusions

In this study, we proposed a pipeline that integrates state-of-the-art deep learning techniques to generate historically accurate narratives for use in a virtual reality (VR) system. To ensure the system's accessibility and relevance for users facing various challenges, such as health limitations, financial constraints, or lack of motivation, it will be evaluated from multiple perspectives, including neuroscience, UI/UX design, and data privacy. As future work, we plan to initiate the implementation of a case study focused on the Karkemish area and develop an open-source tool to facilitate the integration of cultural heritage sites from around the world.

References

Antony, V. N., & Huang, C. M. (2025). ID. 8: Co-creating visual stories with generative AI. *ACM Transactions on Interactive Intelligent Systems*, *14*(3), 1–29.

Chamola, V., et al. (2024). Beyond reality: The pivotal role of generative AI in the metaverse. *IEEE Internet of Things Magazine*, *7*(4), 126–135. https://doi.org/10.1109/IOTM.001.2300174

Du, Q., Wei, X., Li, J., Kuang, E., Hao, J., Weng, D., & Fan, M. (2025). AI as a bridge across ages: Exploring the opportunities of artificial intelligence in supporting intergenerational communication in virtual reality. *Proceedings of the ACM on Human-Computer Interaction*, *9*(CSCW2), Article CSCW026, 29 pages. https://doi.org/10.1145/3710924

Eurostat. (2020, July). *Ageing Europe – statistics on population developments*. Statistics Explained. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Ageing_Europe_-_statistics_on_population_developments

Gutherz, G., Gordin, S., Sáenz, L., Levy, O., & Berant, J. (2023). Translating Akkadian to English with neural machine translation. *PNAS Nexus*, *2*(5), pgad096. https://doi.org/10.1093/pnasnexus/pgad096

Harrison, B., Ehsan, U., & Riedl, M. O. (2017). Guiding reinforcement learning exploration using natural language. *arXiv Preprint*, arXiv:1707.08616. https://arxiv.org/abs/1707.08616

Hawkins, J. D. (2024). *Corpus of Hieroglyphic Luwian Inscriptions: Volume III: Inscriptions of the Hittite Empire and new inscriptions of the Iron Age*. De Gruyter.

Kamath, P., Morreale, F., Bagaskara, P. L., Wei, Y., & Nanayakkara, S. (2024, May). Sound designer–generative AI interactions: Towards designing creative support tools for professional sound designers. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (pp. 1–17). ACM.

Lee, J., & Song, C. (2021). Creative art therapy as a non-pharmacological intervention for dementia: A systematic review. *Journal of Alzheimer's Disease Reports*, *5*(1), 387–400. https://doi.org/10.3233/ADR-201002

Li, B., Lee-Urban, S., Appling, D. S., & Riedl, M. O. (2012). Crowdsourcing narrative intelligence. *Advances in Cognitive Systems*, *2*(1).

Peker, H. (2016). *Texts from Karkemish I: Luwian hieroglyphic inscriptions from the 2011–2015 excavations (OrientLab Series Maior 1)*. Ante Quem.

Peker, H. (2023). *Anadolu Hiyeroglif Yazılı Belgeler 1: Geç Hitit Karkamış Krallığı Yazıtları*. Ante Quem.

Riedl, M. O., & Young, R. M. (2010). Narrative planning: Balancing plot and character. *Journal of Artificial Intelligence Research*, *39*, 217–268. https://doi.org/10.1613/jair.2858

Roemmele, M., & Gordon, A. S. (2018, March). Automated assistance for creative writing with an RNN language model. In *Companion Proceedings of the 23rd International Conference on Intelligent User Interfaces* (pp. 1–2). ACM. https://doi.org/10.1145/3180308.3180364

Rumelhart, D. E. (1975). Notes on a schema for stories. In D. G. Bobrow & A. Collins (Eds.), *Representation and understanding* (pp. 211–236). Morgan Kaufmann. https://doi.org/10.1016/B978-0-12-108550-6.50013-2

Thorndyke, P. W. (1977). Cognitive structures in comprehension and memory of narrative discourse. *Cognitive Psychology*, *9*(1), 77–110. https://doi.org/10.1016/0010-0285(77)90005-6

Wächter, M., Voigt, K., & Rettich, A. (2025, March 14). "Erinnerungs_reich" project of the TUD Faculty of Medicine: Museums as medicine for people with dementia offer great benefits at low cost. *TU Dresden*. https://tu-dresden.de/tu-dresden/newsportal/news/projekt-erinnerungs-_reich-der-medizinischen-fakultaet-der-tud-museen-als-medizin-fuer-menschen-mit-demenz-bieten-hohen-nutzen-bei-geringen-kosten

Zhou, Y., Loh, E., Dickey, J. P., Walton, D. M., & Trejos, A. L. (2018). Development of the circumduction metric for identification of cervical motion impairment. *Journal of Rehabilitation and Assistive Technologies Engineering*, *5*, 1–9. https://doi.org/10.1177/2055668318777984

Received: May 01, 2025
Reviewed: May 19, 2025
Finally Accepted: May 30, 2025