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Virtual reality in heritage education for enhanced learning experience: a mini-review and design considerations

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Heritage education is a key approach to preserving and transmitting a community's history and culture embedded in its collective memory, fostering social cohesion, and cultivating a sense of identity among different populations. Bridging the gap between historical narratives and contemporary audiences is central to promoting educational outcomes. In recent years, rapid advances in digital technologies have provided unprecedented opportunities for the preservation, inheritance, and dissemination of cultural heritage. Virtual reality (VR), with its ability to create three-dimensional representations of real or imagined locations, provides a compelling sense of realism, illustrating its potential for various applications in cultural heritage preservation, such as 3D historical reconstruction, enhanced tourism engagement, gamified learning, and pedagogical cultural heritage programs. This mini-review focuses on VR-enhanced heritage education, a field that involves transdisciplinary studies on the dynamics of user engagement and virtual experiences tailored for cultural heritage education. The aim of this mini-review is to investigate the current status, identify limitations, and outline prospective design considerations for integrating VR technology into heritage education. In this study, we will provide insights into future design considerations for designers, developers, and educators in order to create better heritage education experiences, contributing to developing interactive approaches to heritage education.

KEYWORDS

virtual reality, cultural heritage, heritage education, user experience, human–computer interaction

1 Introduction

Heritage education has served as an important strategy to teach young people to understand their own culture from the past to the present (Hao, 2022). It also plays a key role in the preservation and education of tangible and intangible heritage. As digital technology becomes more prevalent, heritage education faces the challenge of continuously

updating methods and resources to achieve high-quality education (Dordio et al., 2024). In this context, VR refers to "an advanced human–computer interface that simulates a realistic environment and allows participants to interact with it" (Latta and Oberg, 1994), allowing users to explore the elements of cultural heritage where the physical and digital worlds converge. Specifically, VR technology breaks the boundaries of spatial-temporal frames to allow users to experience lost cultural scenes in a modern way (Checa and Bustillo, 2020; Bekele et al., 2018). Unlike traditional static displays, VR allows users to explore and practice by manipulating objects in the virtual environment to deepen their understanding and memory of cultural heritage through interactive learning (Jung and Tom Dieck, 2017; Freina and Ott, 2015). VR also contributes to the transmission of cultural heritage and local wisdom, especially for recording and reconstructing intangible heritage to prevent the loss of valuable cultural heritage, such as traditional crafts and performing arts (Liu et al., 2024; Cozzani et al., 2017; Gaitatzes et al., 2001). Various applications, which include serious games, 3D virtual reconstructions, and other information technologies (Luigini et al., 2020; Paolanti et al., 2023; Di Blas and Poggi, 2006; Mendoza et al., 2015), have the advantage of involving students and promoting extrinsic and intrinsic motivation in learning tasks.

Current VR interaction methods, such as gesture-based interaction, controller-based interaction, speech recognition, eye tracking, spatial navigation, and interactive narratives, contribute to bridging the past and future with user experience through methods such as immersion, interactivity, and learning outcomes. Therefore, interaction methods and user experience are of significant importance in improving the quality of heritage education (Paolanti et al., 2023; Hulusic et al., 2023). However, the understanding of how different interaction methods bridge the past and future of cultural heritage while improving the user experience and educational effects is still limited (Mortara et al., 2014). The application of VR in heritage education with design considerations is relatively new and under-researched (Hu et al., 2019). In this mini-review, we investigate and reflect on the interaction methods of VR in heritage education and future design considerations. We surveyed the database of Web of Science and Scopus with the keywords "virtual reality" and "heritage education," then conducted a general survey of the titles, abstracts, and introductions of the articles and selected 12 out of 40 papers as eligible for review and analysis. This review leads to the following research questions:

RQ1: What are the components of human–computer interaction in current VR heritage education applications?
RQ2: What are the advantages and limitations of existing VR heritage education applications in terms of improving user experience and educational impact?
RQ3: How can better VR experiences be designed and developed to enhance heritage education in the future?

The research content and contributions are as follows:

(1) We identified the interaction methods that contribute to positive emotional experiences in heritage education cases. In addition, we also examined the advantages and limitations of VR in heritage education in improving user experience and educational effects.

(2) Based on the results of the review, we proposed a design framework to guide the future design process of the VR system in heritage education, with the goal of improving the user experience and educational effects. The framework includes the use of scene theory to integrate tangible and intangible cultural heritage, participatory design to involve multi-stakeholders, and an immersion cycle for high-quality education.

2 Methodology

In this section, the methodology of this mini-review is presented. We conducted a literature search through ACM Digital Library, Scopus, and Web of Science to identify publications related to VR applications in heritage education contexts, using the following search terms: (virtual reality OR VR) AND (heritage education). The inclusion criteria of the searched literature are as follows: 1) published between 2009 and 2024 (15 years), 2) must apply VR technology in heritage education contexts, and 3) must contain a user study to explore how users (learners) engage in heritage education through VR. Finally, 12 eligible studies were included in this mini-review study.

3 Results

In this section, the results of this mini-review are reported in accordance with the first two research questions proposed in the Introduction section. These results provide a general overview and analysis of the included papers; following this section, we will synthesize all the information to reflect on the future design considerations for the design of immersive VR applications for heritage education (next section).

3.1 Components of human–computer interaction in VR heritage education

To answer RQ1, the components of human–computer interaction in VR for heritage education were summarized in Table 1 (see Supplementary Materials). Based on the research by Kanade, the human–computer interaction (HCI) system has four key components, namely, user, goal-oriented task, interface, and context (Kanade, 2022). The user component refers to users' goals, needs, and interactions, with participation in a common task (Kanade, 2022). The term goal-oriented task refers to an objective or goal that a user has in mind before operating a computer system that contains digital representations to meet this goal (Kanade, 2022). The interface aims to enhance the user's interaction experience by considering various interface-related aspects, such as type, screen resolution, and display size (Kanade, 2022). The context refers to factoring in the context and environment in which the system is accessed (Kanade, 2022). This framework inspired us to classify how VR technology is applied in heritage education. In this review, "subjects" refers to users, "goal-oriented task" refers to heritage education scenarios and "interaction task", and "interactive method" and "VR content" refer to contexts. All the included articles used VR as the interface.

Considering the goal-oriented task, 11 out of 12 articles addressed specific heritage sites (Table 1, see Supplementary Materials). These articles were divided into five types based on heritage education scenarios: five articles on historic buildings and the environment, one on cultural landscapes, three on heritage sites, one on historic cities, and one on intangible heritage. The interactive methods of these articles were divided into four types: seven articles on interactive visiting, one on web interfaces, two on game control buttons, and one article on smartphone apps and VR boxes. Among them, interactive visiting was found to be the most widely used method to interact with historical and heritage elements. In this review, we have also included a study on non-specific types of heritage education scenarios, along with a focus on the application of VR in heritage education. The interactive tasks can be divided into three types. Two articles focused on improving the quality of teaching. For example, Hu et al. (2019) used the Google Street View app to take at least one spherical photo of a heritage site, with the goal of generating a basic VR story for reuse as part of a digital collection course task. Paolanti et al. (2023) evaluated the learning outcomes of digitizing the archaeological remains of a Roman theater and found a compensatory function with an irreplaceable role for teachers in guiding learners to learn. One article aimed to emphasize the long-term value of the cultural resource. Bozzelli et al. (2019) highlighted the overlap and integration of the actual scenario with the 3D reconstruction of the archaeological site, which can enable a new way of experiencing cultural heritage. Seven articles discussed the interactive task of designing audience-centered digital ways to learn history and stimulate interest.

Three main types of VR content were used in these articles: one article focused on the reconstruction of cultural landscapes in different historical periods. For instance, Tost and Economou (2009) focused on the reconstruction of the ancient agora of Athens in three different periods, aiming to interact with visitors to understand the history and function of buildings in different periods. One article described how to upload a Google Street View photo to the web interface of Stories 360 to generate a basic VR story. Hu et al. (2019) focused on the use of cultural heritage photographs for students to create their own VR heritage narratives.

In addition, nine articles were found on the 3D reconstruction model of cultural heritage. Of the nine 3D reconstruction articles, eight used 3D technology to represent disappearing historical sites, buildings, and heritage remains or to present the disappearing history of selected cultural landscapes. For example, Bozzelli et al. (2019), Paolanti et al. (2023), and Ali (2024) developed 3D reconstruction models to help participants understand the past conditions of heritage sites. Hain and Hajtmanek (2019), O'Connor et al. (2020), and Leow and Ch'ng (2021) used the 3D reconstruction of the historical environment to interact with participants to provide the contextual and interactive reading of historical information. To enhance immersive interaction, Montusiewicz and Milosz (2021) introduced a 3D model of the historical city of Lubin to provide players with an immersive experience and understanding of the history of Poland. Innocente et al. (2024) built a 3D VR model of the Town Hall Square as a historical environment for interacting with intangible elements. Finally, there is one article on the metaverse of museums. Aditama et al. (2023) employed the metaverse and the virtual reality museum of Lontar Prasi Bali to gather more information and storylines.

3.2 Benefits and limitations of VR heritage education applications

In this subsection, the benefits and limitations of VR heritage education applications are introduced.

3.2.1 Benefits of improving user experience

In order to answer RQ2, the results of the user interactive methods and the types of data measured by user tests were reviewed with the aim of investigating what benefits VR-relevant heritage education can bring to users by improving the user experience. In this section, the benefits are analyzed based on the results of user interactive methods and types of data measured by user tests based on the previously mentioned case studies of heritage education.

The interaction methods were divided into six categories: one article with guides and instruments, one article on the web interface, three articles guided in the experiential path directly from the VR application, five articles that are interactive by directly visiting the virtual exhibition and environment, one article through the control buttons on the digital version, and one article with no interactive method. The types of data measured by user tests were divided into four categories: two articles on interviews with questionnaires, two articles on scales, five articles on only questionnaires, and three articles on only interview questions.

The benefits of improving the user experience were summarized in three points. The first step was to improve the quality of the heritage education experience for students and young people. As a measure of satisfaction with the VR storytelling experience, Hu et al.'s (2019) questionnaire results showed that the majority of students were in favor of using VR storytelling in future cultural heritage studies. Aditama et al. (2023) and Montusiewicz and Milosz (2021) presented that VR contributes to introducing culture by providing different experiences and interactions that deepen young people's knowledge and understanding. Montusiewicz and Milosz (2021) also found that the use of different game elements and interactions with real 3D models of historical architecture can help public participants spend more time with the experience. Innocente et al. (2024) compared the user experience between a smartphone group and a VR headset group, and the obvious result showed that the VR group had a higher level of engagement. Paolanti et al. (2023) also showed that VR in teaching increases the experiential value and involvement of students and plays the role of a compensatory function to support the irreplaceable role of teachers.

The second step was to improve the perceptual experience of heritage education for the visitors and the public. Leow and Ch'ng (2021) used questionnaires to collect users' reflections on freely roaming the Sanjiangkou site using the motion controller HTC VIVE, and the result showed that a constructive learning approach combined with an immersive virtual environment can support cultural heritage learning for visually oriented learners. O'Connor et al. (2020) conducted a trial and question session with focus groups interacting with a serious game and found that gamified mechanics combined with virtual reality can enhance the perceptual experience of education while also engaging a wide audience. Based on the personal narratives resulting from user feedback in the survey questions, Leow and Ch'ng (2021) indicated that storytelling

processes in building virtual cultural heritage sites can expand participants' imagination of events and scenarios of the past conditions of heritage sites. Using semi-structured interviews and questionnaires with museum visitors, Tost and Economou (2009) found that the multi-user VR application in the Hellenic Cosmos exhibition was enjoyable and engaging.

The final step was to enhance cultural identity and dissemination. Tost and Economou (2009) used interviews and questionnaires to test the visitor experience and found that the VR experience in the machine halls and the high level of immersion in a historical environment had clear educational benefits on how to make the lost heritage appear, an appropriate and meaningful use of VR. Bozzelli et al. (2019) used the User Engagement Scale (UES) questionnaire to assess users' VR experience with the 3D reconstruction of the archaeological site, and the results confirmed a significant interest in visual scenarios of reconstruction quality. Through a questionnaire, Ali (2024) found that VR games can consistently inspire young people to explore cultural heritage and increase their interest in culture and history for further study.

3.2.2 Limitations of VR applications in heritage education

To further investigate RQ2, the existing limitations of VR applications in heritage education for improving user experience and educational effects from the included studies were summarized. The limitations included three aspects, namely, technical limitations and lack of interactions on VR visual experience, lack of participation when considering multi-stakeholders, and the lack of consideration of individual case situations.

First, the technical problems and lack of interactions in the VR visual experience were frequently discussed in selected articles. Tost and Economou (2009) suggested that the limitations of the interface and the communication language limit the real connection between VR content and users. They also mentioned the limitations of learning in cultural heritage environments due to the spatial navigation of educational applications. Through the evaluation of user engagement, Hu et al. (2019) showed that technical limitations lie in the difficulty of taking spherical photos with regular smartphones, slow loading speed, inflexible operation, and the need to improve the platform features. In addition, Ali (2024) mentioned that the technical problem resulted in dizziness among the participants.

In addition, the lack of participant participation when considering multi-stakeholders remains a major challenge for VR applications in heritage education. Leow and Ch'ng (2021) found that engaging young audiences and clarifying cultural disparities are critical components of heritage education. Montusiewicz and Milosz (2021) suggested that when developing a prototype board game, multiple stakeholders such as visually impaired and blind people should be considered by preparing a 3D model and a corresponding board with integrated descriptions in Braille.

Finally, one article discussed the lack of consideration of individual features of users. Paolanti et al. (2023) found that disciplinary and learning skills need to be reshaped based on individual situations when evaluating student learning outcomes using the quantitative method. Therefore, the task of making nonuniform evaluations has been a limitation to the quality improvement of heritage education.

4 Design considerations of immersive VR experience for future heritage education

Through the insights obtained from the previous section, in this section, we aimed to answer RQ3. In particular, we proposed a design framework with three design considerations. The future research agenda is to design more interactive and immersive VR heritage education.

4.1 Design consideration 1: using scene theory to integrate tangible and intangible cultural heritage

Aside from the technological problems related to digital engineers with current technical dilemmas, the lack of interaction in the VR visual experience can be improved by broadening the scope of VR objectives. Among the abovementioned 12 articles, only 2 articles constructed a 3D model of a landscape or a historical city through games, whereas the majority of the references still focused on an individual heritage site, a historical building, or an intangible cultural heritage. Therefore, we encourage readers to consider the scene theory proposed by Terry Clark of the New Chicago School (Silver and Clark, 2016). The theory calls for integrating physical, social, cultural, and economic environments as a whole to support a scene. In recent years, scene theory has been applied to the digital active protection method of cultural heritage to enrich the integration of tangible and intangible cultural heritage elements (Tang, 2021). In view of this, the paper proposes to consider using scene theory to create the VR scene, such as the reconstruction of historical buildings, the representation of festivals, handicrafts, local community living spaces, and other heritage elements into a scene in a narrative way to enrich the interaction methods of current heritage education.

4.2 Design consideration 2: involving and expanding multi-stakeholder engagement in the design process

Regarding the limitations of not enough multi-stakeholders and the engagement of VR experience, a multi-stakeholder approach can involve different actors at various phases of the design process, from the initial discovery of multi-stakeholder needs to the final evaluation of the system (Mackay and Beaudouin-Lafon, 2023). The first participatory design workshop can be held after confirming the heritage education scene after the field survey in order to collect ideas from multi-stakeholders to identify their attitudes, VR experience needs, and the cultural heritage elements they are most interested in. Then, the identified cultural heritage elements and ideas will be used to contribute to the codesign with the indigenous community, tourists, and educators to present the VR design to them and allow different educators to experience and comment. The co-creation of heritage element narratives also provides a way to solve the problem of how to combine local knowledge, expertise, and culture with global heritage education (Westin, 2018; Li et al., 2024). The user experience of the result of

participatory design will, in turn, provide designers with validation and feedback from various stakeholders.

4.3 Design consideration 3: following the immersion cycle throughout the design process

Regarding the problem of lack of interaction and lack of consideration of the individual situation, the adaptation of the immersive cycle can guide the entire design process to ensure the ideation and conceptualization for designers and developers from the user-centered perspective, with the goal of developing immersive experiences based on the individual situation of heritage education goals (Lucho Lingan et al., 2021). The conceptualization of the immersive cycle can help multi-stakeholders to construct a step-by-step VR experience. To resonate with the argument of Tost and Economou (2009) that the essential definition of VR makes it suitable for real participation in historical events (presence) or manipulation of archaeological data (discovery learning), the immersive cycle can accurately supervise the modeling of heritage elements with historical background identified by multi-stakeholders and create a multisensory experience (Dai and Zheng, 2021; Dai et al., 2021) using VR and augmented reality.

In summary, in this review, we proposed a codesign framework for immersive VR experience in heritage education. The overall design framework for VR experience in heritage education can be divided into four general steps. Based on the educational objectives, first, the first round of field surveys was conducted, and the cultural heritage elements were then identified based on scene theory to create the VR scene. Second, participatory design workshops were used to collect ideas and opinions from multi-stakeholders to identify their attitudes, needs, and heritage elements of interest. Third, by co-creating the VR scene with residents, tourists, and educators, the VR design will be improved and become more user-oriented. The user experience of the result of participatory design would provide designers with validation and feedback from various stakeholders. Finally, the immersive cycle will be used to accurately model the heritage elements and create a multisensory experience using VR technologies.

5 Conclusion

In conclusion, in this mini-review, we analyzed 12 studies related to VR applications in heritage education, summarizing the components of human–computer interaction and design considerations from a user-centered perspective. The review also highlighted the benefits and limitations of VR applications in enhancing the user experience and improving the quality of heritage education. The significance of this review lies in providing a multidisciplinary perspective on VR applications in heritage education, contributing to the understanding of how human–computer interaction can improve the learning experience. The reviewed literature underscored the transformative potential of VR in heritage education, offering immersive and interactive experiences that enhance cultural understanding and learning. In this work, we provided valuable insights into the intersection of VR and heritage education and design considerations to address current limitations from a user experience perspective. Future research could focus on the long-term impact of VR in heritage education, explore ways to enhance accessibility for diverse learners, and investigate adaptive technologies to further improve user engagement. In addition, there is potential to deepen the understanding of multi-stakeholder involvement in the design process, which could contribute to more inclusive and relevant VR experiences.

Author contributions

YZ: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing–original draft, and writing–review and editing. YL: writing–original draft and writing–review and editing. TD: supervision, validation, and writing–review and editing. CS: supervision, validation, and writing–review and editing. XW: supervision, validation, and writing–review and editing. WJ: supervision, validation, writing–review and editing, and funding acquisition. JL: supervision, validation, and writing–review and editing. KZ: supervision, validation, and writing–review and editing. BZ: supervision, validation, writing–review and editing, and funding acquisition. ML: supervision, validation, writing–review and editing, funding acquisition, and project administration. RL: writing–review and editing.

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Supplementary material

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