ARTimeTravel: Understanding Spatial Changes in Heritage Sites Over Time through Web-Based Augmented Reality Serious Games

Jiachen Liang
School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, Jiangsu, China
Jiachen.Liang21@student.xjtlu.edu.cn

Gengyuan Zeng
School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, Jiangsu, China
gengyuan.zeng22@student.xjtlu.edu.cn

Yue Li*
Department of Computing, School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, Jiangsu, China
yue.li@xjtlu.edu.cn

Yiping Dong
Department of Architecture, Design School
Xi'an Jiaotong-Liverpool University
Suzhou, Jiangsu, China
yiping.dong@xjtlu.edu.cn

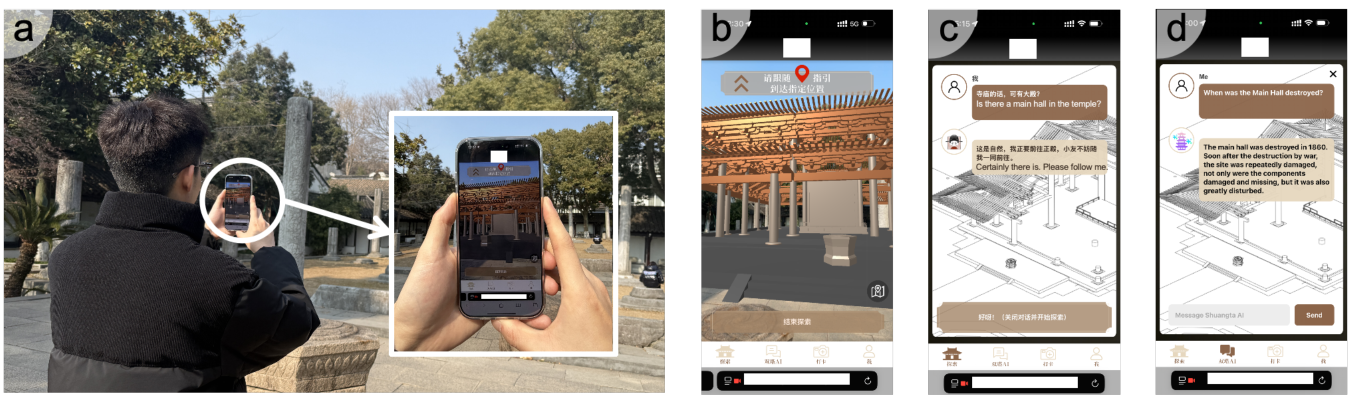

Figure 1: The demonstration of the *ARTimeTravel*. (a) a visitor using the system in the heritage site; (b) a visitor viewing the reconstructed ruins overlaid onto the real world; The screenshot of (c) NPC narrative and (d) the LLM chatbot user interface.

Abstract

Heritage sites, as dynamically evolving social spaces, undergo spatial and cultural changes over time that are important for cultural heritage conservation and visitor experience. Despite this importance, existing research has gaps in illustrating these temporal changes, especially in the use of Augmented Reality (AR) for spatial change demonstrations. In this paper, we propose *ARTimeTravel*, an AR-based serious game grounded in the three guiding principles of Heritagescape theory: boundaries, cohesion, and visibility. *ARTimeTravel* aims to demonstrate spatial changes in heritage sites over time through immersive experiences. Evaluation results indicated that it greatly enhances users' understanding of these changes. We anticipate that future research will provide a more comprehensive solution for the presentation of heritage sites, thus contributing to cultural heritage preservation and education.

CCS Concepts

• **Human-centered computing → HCI design and evaluation methods**.

Keywords

Cultural Heritage, Augmented Reality, Serious Game

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*Corresponding Author.

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1 Introduction

Heritage sites, as preservers of history, play an important role in cultural heritage education. These sites are dynamic, ever-changing social spaces rather than static, homogenized entities [7]. This dynamism implies that heritage sites change over time in terms of physical structure and cultural value reassessment, offering visitors unique opportunities to engage with the past meaningfully [15]. However, effectively communicating these changes to visitors remains a challenge. It necessitates a comprehensive understanding of the site's historical evolution and innovative approaches to presenting this information engagingly and accessibly.

Traditional methods of interpreting heritage sites, such as static displays, guided tours, and printed leaflets, provide valuable information but often fail to capture users' interest [28] and lack interactivity [21]. In recent years, digital experiences have emerged as viable solutions to these challenges. Current research trends emphasize the development of augmented reality (AR) in the tourism field, including visits to historical landmarks and cultural heritage sites. AR serves as a tool that provides more information about visualized items while maximizing tourist satisfaction and enhancing their experience [5]. Some AR applications allow users to select a historical period and view corresponding AR visualizations, blending past and present with 3D models or 2D images [14]. However, these applications often have limited user interaction capabilities.

With the proven effectiveness of enhancing engagement and interactivity in the learning process, scholars are increasingly exploring the application of serious games (SGs) in promoting cultural heritage [12, 19]. Nonetheless, few serious games specifically focused on communicating the spatial changes of heritage sites over time. Therefore, this study proposes an AR SG design framework specifically for showcasing the spatial changes of heritage sites over time and explores its potential to enhance cultural heritage education. Specifically, our study aims to answer:

RQ1: *How to design an AR serious game that effectively showcases the spatial changes of a heritage site over time?*

RQ2: *To what extent can the AR serious game enhance users' understanding of the spatial changes of the heritage site over time?*

We conducted design practices around a thousand-year-old heritage site (i.e., *Shuangta*) in Suzhou, China. To begin with, we explored the spatial changes and cultural values under the theoretical guidance of Scene Theory [18]. The findings were integrated into the AR SG design process. Based on the proposed framework, we designed an AR SG (*ARTimeTravel*), and assessed its effectiveness with 12 participants using a combination of quantitative and qualitative methods. The evaluation results indicated that *ARTimeTravel* significantly enhances users' understanding of the changes. Furthermore, high scores in user experience and system usability suggested that *ARTimeTravel* offered excellent interactivity and ease of use.

Our study made the following contributions: (1) We proposed an AR SG design framework specifically for showing spatial changes over time in heritage sites. (2) Based on the proposed framework, we developed an AR SG (*ARTimeTravel*) for a local heritage site, providing users with a cohesive experience. (3) Through an in-the-wild study, we evaluated the understanding level that *ARTimeTravel* provides, as well as the system usability and user experience.

2 Related Work

2.1 Augmented Reality in Heritage Sites

Heritage sites are repositories of historical and cultural significance, and understanding and representing their changes over time is critical to preserving cultural heritage and promoting a deeper understanding of the past for contemporary audiences [16]. Many studies have integrated AR systems to offer historically accurate visual perspectives of landscapes and objects that no longer exist in their entirety, achieved through digital restoration. For instance, Skowronski et al. [23] realized the display of reconstructed models from different periods of the Temple of Bel overlaid on a map. Liestol et al. [11] employed AR technology to overlay 3D models of historical buildings onto modern scenes in a historical square in Estonia. Similarly, the works of [14] and [3] involve superimposing virtual reconstructions onto actual archaeological sites. However, users in these studies primarily remain passive observers, viewing the integration of virtual historical scenes with the real world through devices, resulting in limited interactivity.

In recent years, AR SGs have demonstrated effectiveness in enhancing user interactivity and promoting cultural heritage knowledge. Gao et al. [6] introduced a prototype utilizing AR technology to engage students with campus cultural heritage, enabling them to explore the site through images and captions of monuments similar to those found at the university. Xu et al. [27] showed efforts to enhance visitors' immersive storytelling and cultural experiences at historical sites through a mobile AR exploration game. Their findings indicate that user connections to cultural heritage can be strengthened by incorporating game features that enhance interaction. Despite these advancements, the understanding of how heritage sites evolve over time and relate to one another remains limited [7]. Therefore, we aim to provide a coherent approach to illustrate the spatial changes in heritage sites over time.

2.2 Theoretical Frameworks for Analyzing Heritage Sites

Previous studies have presented several theoretical frameworks for analyzing heritage sites. The Historical Urban Landscape (HUL) [24] is the main theoretical framework for analyzing the significant landscape changes of the heritage site. In addition, the Scene Theory [18] facilitates the analysis of cultural spaces and their impact on society. The theory highlights four objective structure levels, including *neighborhood*, *physical structure* (e.g., architecture), *persons*, and specific *activities*. In addition, a subjective cognitive level of *values* nurtured in the scene can be interpreted. This theory allows a comprehensive analysis of the complex relationships between heritage site spaces, cultural activities, and broader value patterns.

Moreover, Garden et al. [7] introduced the concept of "Heritagescape" as an analytical framework for conducting in-depth analyses of heritage sites, providing new perspectives and approaches to understanding their temporal evolution and social construction. Heritagescape examines the components of a heritage site and their interrelationships through three guiding principles: boundaries, cohesion, and visibility. Boundaries define a site's spatial extent and its relationship to its surroundings. Cohesion refers to the integration of site components, providing a sense of place. Visibility involves

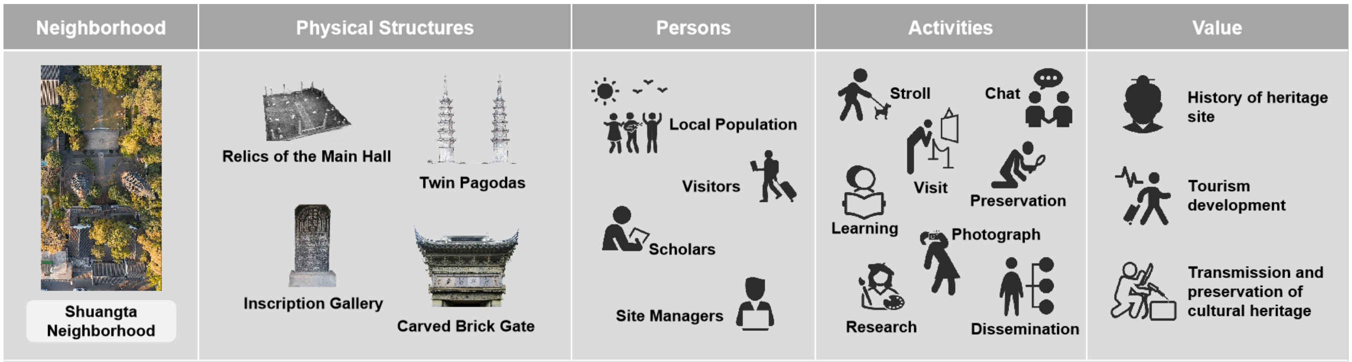

Figure 2: Summary of the cultural heritage elements identified and selected according to the five categories of Scene Theory.

the physical and cultural visibility of site elements, influencing user perception. Building on these principles, six dimensions can be identified: defining and changing boundaries, visible and invisible cohesion, and physical and cultural visibility. These theories have been investigated in previous cultural scenarios [2, 25], and we aim to apply and extend these theoretical frameworks to help design an AR serious game effectively.

3 Design and Implementation

3.1 Content Development and Requirement Analysis

To understand *Shuangta*'s historical evolution and organize cultural elements in the AR experience, we conducted two workshops with six stakeholders (4 females and 2 males, aged between 21 and 45): three heritage conservation experts, one historic architecture expert, and two tourists. Each workshop, lasting about an hour and conducted in participants' native languages, focused on: (1) *Shuangta*'s historical period, (2) its architectural composition, and (3) its cultural value.

The workshop results were summarized into five categories from Scene Theory [18, 29], as explained in Section 2.2 and illustrated in Figure 2. Guided by HUL [24], the historic architecture expert has decoded the key changes for the architectural activity and conservation practice *Shuangta* heritage site. Four physical structures were selected: the main hall relics, twin pagodas, inscription gallery, and carved brick gate. Key groups include locals, visitors, scholars, and managers, engaging in activities like strolling, chatting, photographing, research, and heritage preservation. The site generates value through its history, tourism, and cultural heritage preservation. Furthermore, participants identified five key periods of creation and destruction of the physical structures: Tang Dynasty, Northern Song Dynasty, Southern Song Dynasty, Modern China, and Contemporary China. In addition, five key figures (i.e., Sheng Chu[1], Wang Wenhan[2], Miao Si[3], Chen Congzhou[4], and Ms. Zhao[5]) related to the different periods were frequently mentioned, as they played a significant role in the spatial changes and protection of *Shuangta*.

3.2 Extending the *Heritagescape* Framework

Based on six dimensions identified in the Heritagescape framework [7] (see Section 2.2), we propose six key factors (as illustrated in Figure 3) to enhance the spatiotemporal representation of heritage sites through AR serious games. Traditionally seen as static representations, maps also convey temporal changes and historical developments, as noted by Hagen et al. [8]. Thus, we utilize the **site map** to define and visualize spatial boundaries. Previous research has demonstrated the importance of AR technology in route planning for enhancing users' comprehension of spatial relationships [30]. Accordingly, we employ **route planning** to facilitate users'

[1] Tang Dynasty, Scholar
[2] Northern Song Dynasty, Judge
[3] Southern Song Dynasty, Abbot
[4] Modern China, Garden Expert
[5] Contemporary China, Heritage Conservation Expert

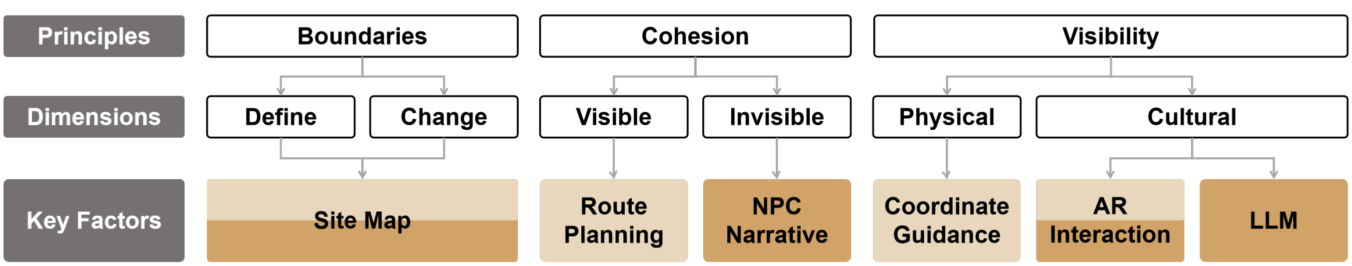

Figure 3: Our proposed AR SG design framework is based on Heritagescape principles. ▢ represents spatial-related factors, ▢ represents time-based factors, NPC = Non-Player Character, AR= Augmented Reality, and LLM = Large Language Model.

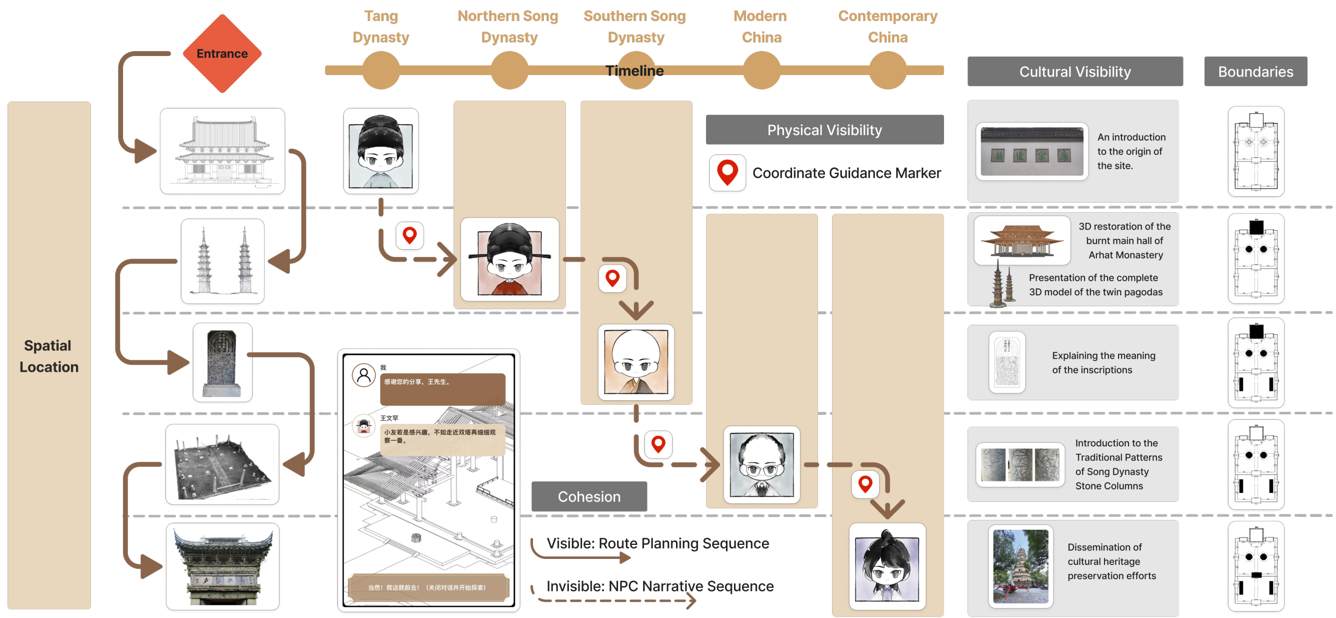

Figure 4: The design of *ARTimeTravel* based on the proposed framework.

visual integration of various parts of the heritage site. Additionally, **AR coordinate guidance** supplements real-world location markers, thereby improving physical visibility. Narratives delivered by avatars can significantly enhance users' understanding of historical and cultural contexts [13]. Therefore, we aim to strengthen the invisible cohesion of site locations through **non-player characters (NPCs) narratives**. Cultural visibility is achieved through **AR interactions**, a method proven to improve user comprehension and engagement with cultural heritage content significantly [9]. Finally, given the potential of **large language models (LLMs)** to offer personalized information about heritage sites [26] and significantly enhance user interactivity in cultural heritage education [4], we consider them a complementary approach to achieving cultural visibility.

3.3 Design of *ARTimeTravel*

We designed a web-based AR SG, *ARTimeTravel*, to enhance visitors' understanding of the spatial evolution of the heritage site over time, as illustrated in Figure 4. It was designed based on the three critical aspects of the AR SG framework (see Section 3.2): Boundaries, Cohesion, and Visibility.

Boundaries. We use period-specific 2D maps in application to illustrate boundaries definitions and boundaries change, helping visitors understand the site's spatial evolution.

Cohesion. We achieve visible cohesion through planned tour routes, linking areas like the main hall, twin pagodas, inscription gallery, and carved brick gate, enhancing visitors' understanding of the site's structure. Invisible cohesion is achieved via NPC narratives, with characters from different periods sharing stories and historical contexts, deepening cultural connections.

Visibility. In addition to the signboards given by the site organizers, we enhance physical visibility with AR coordinate markers and real-time distance indicators. Cultural visibility is achieved through AR interactions and LLM-generated information, allowing users to explore 3D reconstructions and access an LLM-empowered chatbot for site-related inquiries.

3.4 Interfaces and Interactions

Figure 1 illustrates the interface components and interactions implemented in *ARTimeTravel*. To begin with, users access the application by scanning a QR code or directly clicking on a web link to open the web app in the browser on their mobile device. The interface includes four main pages that users can navigate: *AR Exploration*, *Chatbot*, *Checkpoints*, and *Profile* (see Figure 1b-d. On the *AR Exploration* page, users engage in conversations with a historical figure of the time period and are guided to complete tasks, such as searching for a pattern on a stone pillar, and triggering the reconstructed Arhat Monastery in AR. Completing all tasks at a specific spatial location will trigger the switch between the site maps of the next time period (see Figure 4). Users can interact with the LLM-empowered chatbot at any time by clicking on the *Chatbot* icon. The *Checkpoints* page allows users to take pictures and create their own collections. These collections as well as their personal information can be accessed and edited on the *Profile* page.

3.5 Technical Implementations

As indicated in previous studies [27], avoiding the need for app download and catering for a wide range of device compatibility are often desired by stakeholders of heritage sites. Therefore, we developed a web-based system for easier access. The system, hosted on an Aliyun cloud server[6] for stable delivery, integrates AR technology and an LLM chatbot. The technical architecture can be found in Figure 5.

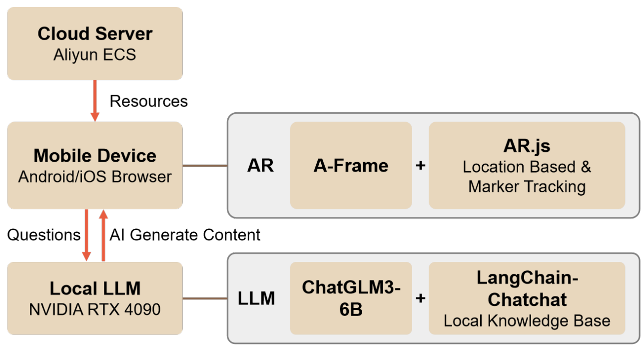

Figure 5: The conceptual diagram illustrating the technical architecture of *ARTimeTravel*.

For **web-based AR**, we used: (1) *A-Frame*[7], allows creation of complex 3D and AR scenes using HTML. (2) *AR.js*[8], a lightweight, web-based AR library that supports image tracking, location-based AR, and marker tracking. The system uses AR.js to implement location-based AR by predefining geographic coordinates (latitude and longitude) for a defined physical structure. It continuously tracks the user's geographic location and calculates real-time distances and viewing angles to these points, enabling dynamic AR.

For **LLM integration**, the site chatbot is deployed and hosted on a computer with an NVIDIA RTX4090 (24GB VRAM) for high-speed processing and precision (FP16). Key tools include: (1) *ChatGLM3-6B*[9]: An open-source LLM for answering visitor questions. (2) *Langchain-Chatchat*[10]: Facilitates question-answering by processing historical documents into a knowledge base. The system uses HTTP POST for API communication, enabling real-time interaction with LLM.

[6]https://www.aliyun.com/
[7]https://aframe.io/
[8]https://ar-js-org.github.io/AR.js/
[9]https://github.com/THUDM/ChatGLM3
[10]https://github.com/chatchat-space/Langchain-Chatchat

4 Evaluation

4.1 Procedure

The pilot study was conducted in the public area of the heritage site. Participants were randomly selected from visitors of the heritage site and guided through the three experiment phases (see Figure 6). **(1) Pre-experiment Phase**: Participants were introduced to the research, provided informed consent, and received task instructions, and completed demographic and pre-experiment questionnaires. **(2) Experiment Phase**: Guided by a trained experimenter, participants explored the site using *ARTimeTravel*, and completed the tasks of chatting with NPCs, navigating to destinations with coordinate guidance, completing AR interactions, chatting with LLM chatbot, and viewing maps of the different eras through a time machine in turn. **(3) Post-experiment Phase**: Participants completed a post-experiment questionnaire and participated in an interview to provide further insights. Ethics approval has been obtained from our institution's ethics committee prior to any data collection.

4.2 Measures

This study collected both quantitative and qualitative data to assess users' level of understanding, user experience, and system usability. The detailed measures can be found in Appendix A.

Level of Understanding: We used five multiple-choice questions about the site's spatial composition across different periods to evaluate understanding. Each question had four options plus an "I don't know" choice. Correct answers earned 1 point, omitted answers earned 0.5 points, and incorrect answers earned no points. The total test score (TS) calculated as $\sum_{i=1}^{5} \mathrm{TS}_i$.

System Usability: Measured by the System Usability Scale (SUS) [1], comprising 10 questions on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). After reversing scores for even-numbered questions, the usability score is calculated as $\sum_{i=1}^{10} (sus_i - 1) * 2.5$, with 68 as the average usability threshold.

User Experience: Assessed using the short version of the User Experience Questionnaire (UEQ-S) [22], which includes pragmatic and hedonic quality subscales, along with a total score. The UEQ-S consists of 8 items scored from -3 (horribly bad) to 3 (excellent). Scores between -0.8 and 0.8 are neutral, while above 0.8 are positive.

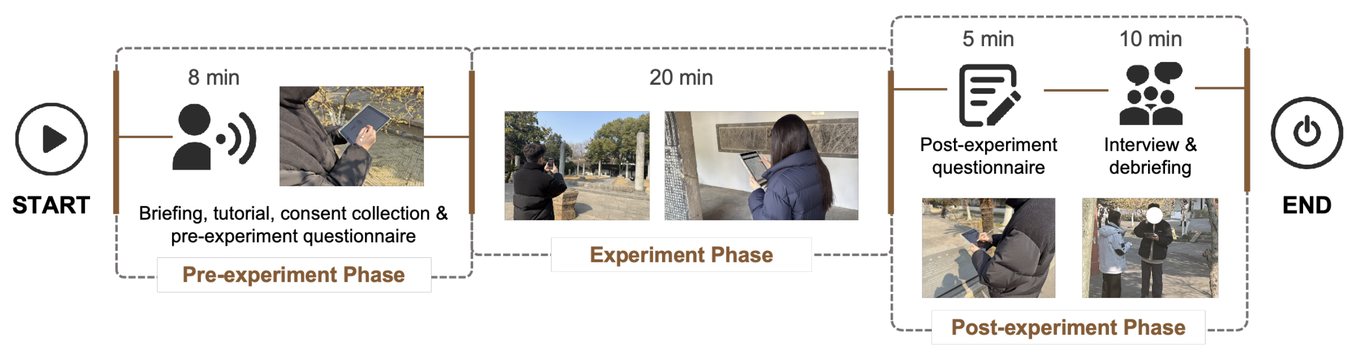

Figure 6: A flow chart showing the experiment procedure, including pre-experiment, experiment, and post-experiment phases.

4.3 Participants

In total, we received 12 responses (7 females and 5 males) between 20 and 54 ($M = 33.75, SD = 13.10$), among which 5 of them visited the site for the first time. As for the careers, four of them are clerical support workers, followed by students ($n = 3$), professionals ($n = 2$), and one freelancer. Participants' self-evaluations were recorded on a five-point Likert scale, ranging from 1 (not at all familiar) to 5 (extremely familiar). They showed a moderate familiarity with AR ($M = 2.75, SD = 1.60$), LLM ($M = 2.75, SD = 1.23$), and video games ($M = 2.67, SD = 1.30$). The detailed demographic information can be found in Appendix B.

5 Analysis and Results

We used IBM SPSS Statistics (version 29) to conduct the data analysis. Shapiro-Wilk tests were conducted to examine the data distributions. For data that did not conform to a normal distribution, we conducted the Wilcoxon Signed-Rank Test. The qualitative data collected from the participants were transcribed and translated into English by one researcher and checked by another researcher. The data were analyzed using the theme-based content analysis [17].

5.1 Quantitative Results

Level of Understanding. The results of the Wilcoxon Signed-Rank Test revealed a significant increase in the understanding level from the pre-test ($M = 1.63, SD = 1.09$) to the post-test ($M = 4.04, SD = 1.01$), $Z = -3.01, p = 0.003$ (see Figure 7 for details). This finding indicates the utilization of *ARTimeTravel* was effective in significantly enhancing participants' understanding.

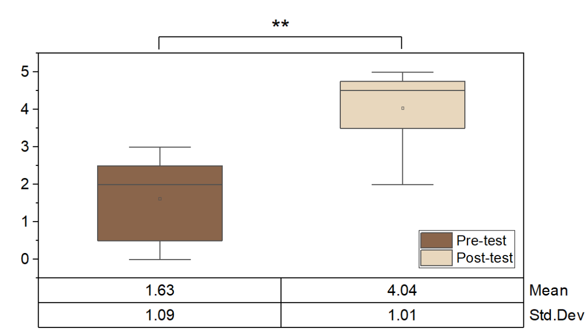

Figure 7: The results of understanding levels of space changes over time in the heritage site.

System Usability. The mean SUS score of the *ARTimeTravel* was 79.38, which exceeded the threshold value of 68.00, indicating satisfactory usability of the system.

User Experience. The UEQ-S results also showed positive ratings (as shown in Figure 8). The pragmatic quality, hedonic quality, and overall experience had mean scores of 2.31 ($SD = 0.72$), 2.42 ($SD = 0.92$), and 2.37 ($SD = 0.68$), respectively, exceeding the threshold value of 0.8 [10]. The results indicate that users had a positive experience with *ARTimeTravel*. Compared to the UEQ benchmark dataset [10], the pragmatic quality. hedonic quality, and overall experience of the *ARTimeTravel* were *Excellent* (top 10%).

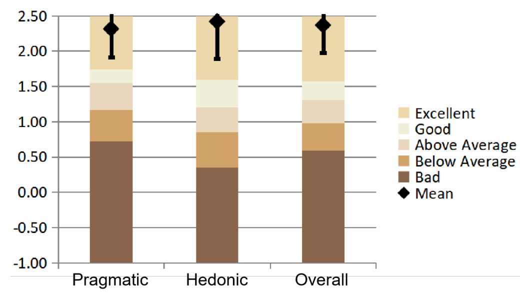

Figure 8: The results of user experience, showing the pragmatic quality, hedonic quality, and overall experience.

5.2 Qualitative Results

Participants generally acknowledged *ARTimeTravel* effective in enhancing their understanding of spatial changes over time. As P2 said, "I like that it sorts out spatial changes according to the timeline". The web-based access was particularly praised, with participants appreciating the convenience: "*I really like being able to access it from a browser; if I had to download an app, I wouldn't bother to use it.*" (P4). P10 expressed interest in the educational benefits for children, indicating a willingness to pay for the experience.

In the meantime, participants highlighted areas of improvement. P2 emphasized the need for more direct AR route guidance to avoid navigation issues, as she noted *"I expect a direct AR route guidance rather than AR marker. This will prevent navigation issues caused by physical barriers within the site"*. Two participants appreciated the "Time Machine" feature for its ability to illustrate spatial changes and suggested that it should be further highlighted. Additionally, participants ($n = 4$) generally acknowledged the convenience and high degree of freedom offered by LLM-empowered chatbot in providing information. However, this freedom also introduces certain challenges, particularly regarding uncertainty about what to ask, such as P7 expressed that *"I don't know what I can ask"*.

6 Discussion and Conclusion

In response to **RQ1**, Our findings show that the proposed design framework based on boundaries, cohesion, and visibility effectively guided the development of the AR SG for heritage sites. This shows that AR SG is effective in communicating the spatial changes in historical sites to the visitors. Compared with previous studies, this study further verifies the effectiveness of AR technology in cultural heritage education. Notably, the web-based implementation and integration of an LLM-empowered chatbot introduce new levels of convenience and accessibility, distinguishing this study from previous mobile application-based research. Our results also showed that the *ARTimeTravel* significantly improves users' understanding of the spatial changes of the site, answering **RQ2**. Consistent with the study of Nilsson et al. [20], our study also demonstrated that AR SG can enhance user learning effects. By offering real-time interactions and narrative-driven exploration, the AR serious game fosters a deeper understanding of the site's historical context, thus verifying the effectiveness of AR technology in cultural heritage education.

Our field study found that many heritage site visitors tend to come in groups. When invited to experience an AR application, one person would use the application while another observed. This behavior highlights opportunities to design AR experiences that cater to multiple users simultaneously, thereby enhancing social interactions and learning outcomes. Furthermore, while LLMs offer significant advantages in terms of information retrieval, they also present challenges. The ethical considerations of LLMs and the challenges of inclusiveness and accuracy cannot be ignored [26]. Additionally, we found that users were unsure of how to effectively interact with the system. Some participants expressed confusion about how to utilize its features. Future work could provide clearer guidance and support to help users ask questions and fully utilize the potential of LLMs.

In conclusion, this study focused on the dynamic nature of heritage sites and the importance of innovative approaches to communicate their spatial and time transformations. By developing and evaluating the AR SG *ARTimeTravel* based on the proposed design framework, we demonstrated its effectiveness in enhancing understanding, which contributed to the integration of AR and serious games in heritage education. Future work will address user suggestions and conduct a more thorough evaluation of *ARTimeTravel*, including comparison of understanding levels with traditional methods (guided tours, leaflets, etc.), long-term impact on education and engagement, to further advance AR-based heritage solutions.

Acknowledgments

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References

[1] John Brooke. 1996. SUS: A "quick and dirty" usability scale. *Usability evaluation in industry* 189, 3 (1996), 189–194.
[2] Susanna Heldt Cassel and Albina Pashkevich. 2014. World Heritage and tourism innovation: Institutional frameworks and local adaptation. *European Planning Studies* 22, 8 (2014), 1625–1640.
[3] Jan Čejka, Attila Zsíros, and Fotis Liarokapis. 2020. A hybrid augmented reality guide for underwater cultural heritage sites. *Personal and Ubiquitous Computing* 24 (2020), 815–828.
[4] Nicolas Constantinides, Argyris Constantinides, Dimitrios Koukopoulos, Christos Fidas, and Marios Belk. 2024. Culturai: Exploring mixed reality art exhibitions with large language models for personalized immersive experiences. In *Adjunct Proceedings of the 32nd ACM Conference on User Modeling, Adaptation and Personalization*. Association for Computing Machinery, Cagliari, Italy, 102–105.
[5] Mihai Duguleana, Raffaello Brodi, Florin Girbacia, Cristian Postelnicu, Octavian Machidon, and Marcello Carrozzino. 2016. Time-travelling with mobile augmented reality: A case study on the piazza dei miracoli. In *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection: 6th International Conference, EuroMed 2016, Nicosia, Cyprus, October 31–November 5, 2016, Proceedings, Part I 6*. Springer, Springer, Nicosia, Cyprus, 902–912.
[6] Gege Gao, Yuxuan Zhang, Cheng Cheng, Yi Bu, and Patrick C Shih. 2018. Designing to enhance student participation in campus heritage using augmented reality. In *2018 3rd Digital Heritage International Congress (DigitalHERITAGE) held jointly with 2018 24th International Conference on Virtual Systems & Multimedia (VSMM 2018)*. IEEE, IEEE, San Francisco, CA, USA, 1–4.
[7] Mary-Catherine E Garden. 2006. The heritagescape: Looking at landscapes of the past. *International Journal of Heritage Studies* 12, 5 (2006), 394–411.
[8] Joshua Hagen. 2021. Time in Maps: From the Age of Discovery to Our Digital Era. *The AAG Review of Books* 10 (2021), 28 – 29. https://api.semanticscholar.org/CorpusID:260605805
[9] Yaqin Huang, Karina Rodriguez-Echavarria, and Simon Julier. 2020. Engaging audiences with Cultural Heritage through Augmented Reality (AR) Enhanced Pop-Up Books. In *GCH*. The Eurographics Association, The Eurographics Association, Geneva, Switzerland, 53–62.
[10] Bettina Laugwitz, Theo Held, and Martin Schrepp. 2008. Construction and Evaluation of a User Experience Questionnaire. In *HCI and Usability for Education and Work*, Andreas Holzinger (Ed.). Springer, Berlin, Heidelberg, 63–76.
[11] Gunnar Liestøl. 2018. The photo positioning puzzle: Creating engaging applications for historical photographs by combining mobile augmented reality and gamification. In *2018 3RD Digital Heritage International Congress (Digitalheritage) held Jointly with 2018 24th International Conference on Virtual Systems & Multimedia (VSMM 2018)*. IEEE, IEEE, San Francisco, CA, USA, 1–8.
[12] Zhizheng Liu, Ding Chen, Chi Zhang, and Jian Yao. 2024. Design of a virtual reality serious game for experiencing the colors of Dunhuang frescoes. *Heritage Science* 12, 1 (2024), 1–31.
[13] Zixiao Liu, Shuo Yan, Yu Lu, and Yuetong Zhao. 2022. Generating Embodied Storytelling and Interactive Experience of China Intangible Cultural Heritage "Hua'er" in Virtual Reality. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*. Association for Computing Machinery (ACM), New York, NY, USA, 1–7.
[14] Anabela Marto, Alexandrino Gonçalves, and A Augusto de Sousa. 2019. DinofelisAR: Users' perspective about a mobile AR application in cultural heritage. In *VR Technologies in Cultural Heritage: First International Conference, VRTCH 2018, Brasov, Romania, May 29–30, 2018, Revised Selected Papers 1*. Springer, Springer, Brasov, Romania, 79–92.
[15] Milena Metalkova-Markova. 2024. The heritage of Tyneham as a living memorial: between complex historical narratives and suggestive performing traditions. *Architecture_MPS* 29, 1 (2024), 1–14.
[16] Charalambous Nadia. 2007. Social and spatial Patterns of cultural Heritage. In *XXI International CIPA Symposium, 01-06 October 2007, Athens, Greece*. Space Syntax Laboratory, University College London (UCL), London, UK.
[17] H. Neale and S. Nichols. 2001. Theme-based content analysis: a flexible method for virtual environment evaluation. *International Journal of Human - Computer Studies* 55, 2 (2001), 167–189.
[18] Terry Nichols Clark. 2003. *The city as an entertainment machine*. Emerald Group Publishing Limited, Bingley, UK.
[19] Andreas Nikolarakis and Panayiotis Koutsabasis. 2024. Mobile AR Interaction Design Patterns for Storytelling in Cultural Heritage: A Systematic Review. *Multimodal Technologies and Interaction* 8, 6 (2024), 52.
[20] Susanna Nilsson, Mattias Arvola, Anders Szczepanski, and Magnus Bång. 2012. Exploring place and direction: mobile augmented reality in the Astrid Lindgren landscape. In *Proceedings of the 24th Australian Computer-Human Interaction Conference*. Association for Computing Machinery (ACM), Melbourne, VIC, Australia, 411–419.
[21] Hafizur Rahaman and Tan Beng Kiang. 2017. Digital Heritage Interpretation: Learning from the Realm of Real-World. *Journal of Interpretation Research* 22 (2017), 53 – 64. https://api.semanticscholar.org/CorpusID:150754871
[22] Martin Schrepp, Andreas Hinderks, and Jörg Thomaschewski. 2017. Design and evaluation of a short version of the user experience questionnaire (UEQ-S). *International Journal of Interactive Multimedia and Artificial Intelligence, 4 (6), 103-108.* 4, 6 (2017), 103–108.
[23] Moritz Skowronski, Jonathan Wieland, Marcel Borowski, Daniel Fink, Carla Gröschel, Daniel Klinkhammer, and Harald Reiterer. 2018. Blended Museum: The Interactive Exhibition "Rebuild Palmyra?". In *Proceedings of the 17th International Conference on Mobile and Ubiquitous Multimedia* (Cairo, Egypt) *(MUM '18)*. Association for Computing Machinery, New York, NY, USA, 529–535. https://doi.org/10.1145/3282894.3289746
[24] Gábor Sonkoly. 2017. *Historical urban landscape*. Springer, Cham, Switzerland.
[25] Daniel Svensson, Sverker Sörlin, and Katarina Saltzman. 2021. Pathways to the trail–landscape, walking and heritage in a Scandinavian border region. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography* 75, 5 (2021), 243–255.
[26] Georgios Trichopoulos. 2023. Large language models for cultural heritage. In *Proceedings of the 2nd International Conference of the ACM Greek SIGCHI Chapter*. Association for Computing Machinery (ACM), Athens, Greece, 1–5.
[27] Ningning Xu, Yue Li, Jiachen Liang, Kexiang Shuai, Yuwen Li, Jiaqi Yan, Cheng Zhang, and Yiping Dong. 2024. HeritageSite AR: Design and Evaluation of a Mobile Augmented Reality Exploration Game for a Chinese Heritage Site. *ACM Journal on Computing and Cultural Heritage* 17, 4 (2024), 1–29.
[28] Ningning Xu, Yue Li, Xingbo Wei, Letian Xie, Lingyun Yu, and Hai-Ning Liang. 2024. CubeMuseum AR: A tangible augmented reality interface for cultural heritage learning and museum gifting. *International Journal of Human–Computer Interaction* 40, 6 (2024), 1409–1437.
[29] Ying Zhang. 2017. Urban Development from the Perspective of Scene Theory-Jingdezhen Post-industrial Era. In *7th International Conference on Education, Management, Information and Mechanical Engineering (EMIM 2017)*. Atlantis Press, Atlantis Press, Shenyang, China, 1924–1927.
[30] Stefanie Zollmann, Christof Hoppe, Tobias Langlotz, and Gerhard Reitmayr. 2014. FlyAR: Augmented Reality Supported Micro Aerial Vehicle Navigation. *IEEE Transactions on Visualization and Computer Graphics* 20 (2014), 560–568. https://api.semanticscholar.org/CorpusID:6021592

Appendix A The Questionnaire Details

Aspects	Code	Questions
Level of Understanding	LU1	During the Tang Dynasty, which of the following architectures did the historical site contain?
	LU2	During the North Song Dynasty, which of the following architectures did the historical site contain?
	LU3	During the South Song Dynasty, which of the following architectures did the historical site contain?
	LU4	During the modern period, which of the following architectures did the historical site contain?
	LU5	Nowadays, which of the following architectures does the historical site contain?
SUS [1]	SUS1	I think that I would like to use this system frequently.
	SUS2	I found the system unnecessarily complex.
	SUS3	I thought the system was easy to use.
	SUS4	I think that I would need the support of a technical person to be able to use this system.
	SUS5	I found the various functions in this system were well integrated.
	SUS6	I thought there was too much inconsistency in this system.
	SUS7	I would imagine that most people would learn to use this system very quickly.
	SUS8	I found the system very cumbersome to use.
	SUS9	I felt very confident using the system.
	SUS10	I needed to learn a lot of things before I could get going with this system.
UEQ-S [22]	UEQ1	Obstructive - Supportive
	UEQ2	Complicated - Easy
	UEQ3	Inefficient - Efficient
	UEQ4	Confusing - Clear
	UEQ5	Boring - Exciting
	UEQ6	Not Interesting - Interesting
	UEQ7	Conventional - Inventive
	UEQ8	Usual - Leading Edge

Appendix B Participants' Demographic information

Participant ID	Age	Gender	Occupation	Visited *Shuangta*	Familiarity with AR	Familiarity with LLM	Familiarity with Video Games
P1	45	Female	Professional (e.g., instructor, lawyer, doctor, engineer)	Yes	4	2	1
P2	26	Male	Clerical support worker	Yes	3	2	4
P3	27	Female	Clerical support worker	Yes	2	3	3
P4	20	Male	Student	No	4	5	4
P5	24	Female	Clerical support worker	Yes	2	2	1
P6	49	Female	Professional (e.g., instructor, lawyer, doctor, engineer)	No	1	2	2
P7	54	Male	Business people	No	1	3	2
P8	24	Female	Clerical support worker	No	4	3	3
P9	54	Male	Business people	Yes	1	1	1
P10	35	Female	Freelancer	No	1	2	3
P11	26	Female	Student	Yes	5	3	3
P12	21	Male	Student	Yes	5	5	5