HeritageSite AR: Design and Evaluation of a Mobile Augmented Reality Exploration Game for a Chinese Heritage Site

NINGNING XU, School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China and Zhejiang Wanli University, Ningbo, China
YUE LI, Department of Computing, School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China
JIACHEN LIANG, School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China and School of Architecture, University of Liverpool, Liverpool, UK
KEXIANG SHUAI, YUWEN LI, and JIAQI YAN, School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China
CHENG ZHANG, Department of Civil Engineering, Design School, Xi'an Jiaotong-Liverpool University, Suzhou, China
YIPING DONG, Department of Architecture, Design School, Xi'an Jiaotong-Liverpool University, Suzhou, China

This article explores the use of a mobile Augmented Reality (AR) exploration game to enhance immersive storytelling and enrich cultural experiences. Specifically, we present the prototype design and evaluation of HeritageSite AR, an AR exploration game for a Chinese heritage site known as the *Relics of Arhat Monastery and Twin Pagoda*, or *Shuangta*. To develop the AR game for use in heritage sites, we employed a holistic approach, beginning with a review of technical means for cultural application development. We then conducted semi-structured interviews with domain experts and administered an online survey to identify user requirements and design goals, which informed our prototype design. An evaluation study showed positive feedback regarding the impact of game design on meaningful and playful cultural heritage site experience and identified areas for potential refinements in future iterations. We discuss the implications and lessons learned for our future work, which may also interest researchers and practitioners exploring the use of AR technologies and game design in heritage site contexts.

This work was supported by the Suzhou Science and Technology Development Planning Programme (2022SS51) and the National Natural Science Foundation of China (62207022).
Authors' Contact Information: Ningning Xu, School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China and Zhejiang Wanli University, Ningbo, China; e-mail: ningning.xu@zwu.edu.cn; Yue Li (corresponding author), Department of Computing, School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China; e-mail: yue.li@xjtlu.edu.cn; Jiachen Liang, School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China and School of Architecture, University of Liverpool, Liverpool, UK; e-mail: jiachen.liang21@student.xjtlu.edu.cn; Kexiang Shuai, School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China; e-mail: kexiang.shuai20@student.xjtlu.edu.cn; Yuwen Li, School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China; e-mail: yuwen.li17@student.xjtlu.edu.cn; Jiaqi Yan, School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China; e-mail: jiaqi.yan22@student.xjtlu.edu.cn; Cheng Zhang, Department of Civil Engineering, Design School, Xi'an Jiaotong-Liverpool University, Suzhou, China; e-mail: cheng.zhang@xjtlu.edu.cn; Yiping Dong, Department of Architecture, Design School, Xi'an Jiaotong-Liverpool University, Suzhou, China; e-mail: yiping.dong@xjtlu.edu.cn.

ACM 1556-4711/2024/12-ART67
https://doi.org/10.1145/3700881

CCS Concepts: • **Human-centered computing** → **Human computer interaction (HCI)**; **Mixed / augmented reality**; **User centered design**;

Additional Key Words and Phrases: augmented reality, cultural heritage, game design, immersive storytelling

ACM Reference format:
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 J. Comput. Cult. Herit.* 17, 4, Article 67 (December 2024), 29 pages.
https://doi.org/10.1145/3700881

1 Introduction

The preservation of **Cultural Heritage (CH)** plays a vital role in promoting sustainable development of environmental, economic, and social aspects [52]. Over the past decades, the Chinese government has actively engaged in preserving and promoting Chinese CH sites. The digitization and communication of CH have evolved, moving beyond the creation of digital archives to emphasize the proper and effective use of these digital assets and enhance visitor experience in cultural services. CH sites sometimes heavily rely on static labels and displays containing text and images to present information and guide visitors. This passive approach is limited to facilitate learning and hinders the development of essential social and emotional skills [21]. On the other hand, informal and participatory learning approaches have been proven effective in engaging visitors in site visits and enhancing the visitor experience through gameplay [10, 33]. In this context, the integration of handheld mobile devices has become an affordable way to enrich CH visits [7], enabling interactive, engaging, and personalized experiences. This includes the use of **Augmented Reality (AR)** technologies with rich visual displays and interactive features.

Location-based mobile AR applications for CH visits have a unique advantage, providing contextual clues through exploration to facilitate visitors' meaning-making of the historical and cultural insights [69]. This approach not only facilitates engagement with physical artifacts and sites but also provides visitors with interactive and immersive media content, thereby greatly enhancing the digital competitiveness of CH sites. Moreover, previous research has explored the incorporation of location data, historical images, and narratives to stimulate reinterpretation and reflection on historical topics [34]. These AR applications often involve game design that engages players in interactions with the physical environment and sometimes virtual spaces. Narratives, in particular, which blend storytelling and history, serve as a means to comprehend the surrounding environments and one's own identity [3]. In addition, treasure hunt contributes to players' motivation to search for hidden information. The exploration of unknown settings comes with a sense of mystery that reinforces players' connections with cultural content [45]. Furthermore, role-playing was also found to help players understand the worlds, roles, and rituals, thereby conveying deeper notions of culture [8]. By integrating these game elements with interactive technologies, the CH experience can be more engaging and educational for visitors.

Our work was conducted at a local heritage site, the *Relics of Arhat Monastery and Twin Pagoda*, commonly referred to as *Shuangta*. Located in the center of the millennia-old town of Suzhou, China, this site is renowned for its two nearly identical pagodas standing side by side [51]. *Shuangta* was built during the Northern Song Dynasty (960–1126). It preserves carved stone pillars of the *Relics of the Main Hall of Arhart Monastery* and houses historical stone statues and inscriptions spanning over a millennium. This site is of significant historical and cultural research values that foster intercultural conversation and raise public awareness of heritage preservation. In this article, we introduce our prototype design of HeritageSite AR, an AR exploration game that supports playful learning experiences for site visits at *Shuangta*. In the following sections, we detail our research motivation and the key insights that guide our work, which are structured based on the three components of **Triadic Game Design (TGD)** [27]: *reality*, *meaning*, and *play*. We adopted this framework as it is highly relevant to the design of AR games and has demonstrated effectiveness in prior studies within a similar context of cultural learning [12, 17].

1.1 Reality: Multimedia Guide and Location-Based AR

Reality refers to the representation and simulation of real items, aiming to provide players with a digital environment that mirrors actual situations, places, or objects. At present, many CH sites have implemented digital guides to recreate their past glory, providing users with an immersive experience [57, 59]. Digital reconstructions based on historical evidence allow users to immerse themselves in a lifelike cultural experience. Advanced digital imaging techniques, such as 3D scanning and photogrammetry, facilitate the creation of high-resolution replicas, which serve as references for digital restoration, contributing to efficiency and convenience for the purpose of popularization [24, 36]. In this trend, interactive displays and multimedia guide systems have been adopted to delve deep into the historical, cultural, and societal significance [38]. Historical sites could embed in-depth information exploration to the tour and enhance the appeal of CH [68]. Previous work has highlighted the advantages of multimedia guides in extending the duration of visitors' tours beyond a typical visit [62]. The authors argued that the effective design of the information presentation contributed to the prolonged visitor engagement in the artwork, despite the potential distraction posed by the display. Notably, incorporating portable devices (e.g., smartphones) into site visits is a cost-effective solution for cultural institutions that lack dedicated equipment and technical staff support [55]. By utilizing users' own devices and providing digital content that is self-explanatory in the multimedia guide, CH sites can enhance visitor engagement and create a playful experience.

Within a heritage site, multimedia guide information is sometimes conveyed through a location-based approach. It takes advantage of users' own devices and enhances contextual navigation in cultural spaces without setting up screen displays among the sites. AR technologies, when combined with physical locations, have the potential to create embodied cultural knowledge and situated experiences in a hybrid space [79]. Various techniques, such as realistic visual renderings, spatial mapping, and audio effects, can be employed to enhance the realism of location-based AR experiences [30]. For instance, Oppermann et al. [54] presented a personalized location-based museum guide that integrates AR components and audio output for interactive annotations with multi-modal information about the surrounding environment. It is crucial to note that AR applications allow users to experience digital content integrated with the real-world environment. It differs from **Virtual Reality (VR)** systems which present virtual environments that are completely simulated. In location-based AR, the connection between digital content and the real world plays a vital role in the user experience. We aim to explore how to effectively integrate multimedia technologies and guiding information into a location-based AR application to develop immersive, educational, and engaging CH experiences that seamlessly combine physical and digital content.

1.2 Meaning: Digital Storytelling for Heritage Sites

Meaning includes the information a game conveys, to which the players resonate with and perceive value, obtain knowledge, or learn lessons beyond playing. Meaning-making is a cognitive process. Previous studies have revealed the effectiveness of storytelling in supporting cognitive activities [58, 63]. It presents information in a logical and structured way, and individuals could relate the narrative with their previous experiences. This approach facilitates knowledge acquisition and retention, following the constructive learning theory. In particular, digital storytelling was found effective in enhancing the CH experiences of young audiences [7]. The young demographic is familiar with the use of digital technologies on the go. While walking through the site guided by the narratives, visitors are involved in the exploration and informal learning within the site. From the educational perspective, this kind of user engagement is a prerequisite of learning and contributes to knowledge comprehension, learning outcomes, personal skill enhancement, and the evolution of values and attitudes [28]. Aside from the positive effects of digital storytelling on learning, narratives also transform CH experiences into a societal service, contributing to CH preservation and communication [13]. The narratives add cultural value to physical sites and reinforce the public's historical memories. In particular, avatars, as a part of the narrative, contribute to immersing visitors in the storytelling and communicating the narrative and underlying historical

and cultural meaning [73]. This process also facilitates the broader social, collective involvement in creation and sharing, which further broadens the outreach and significance of the narratives.

Digital storytelling serves as a fundamental approach in the user experience design of site-specific AR—the narratives could shape an immersive and cohesive experience within the site. Despite previous work has demonstrated the effectiveness of integrating digital storytelling approaches in CH applications [64], challenges still remain in the design and development of such systems. In contrast to the linear storytelling found in textual formats like books, digital storytelling may introduce the risk of narrative fragmentation. This fragmentation can interrupt and alter the narratives, potentially disrupting the user experience and impeding the learning process [61]. Visitors' visiting trajectories in CH sites also vary and may deviate from the suggested path. Consequently, the narrative design in CH sites should provide visitors the freedom to explore the physical environment, while satisfying the need for communicating the historical and cultural information about the artifacts and sites.

1.3 Play: Design of AR Exploration Games

Play involves the interaction, enjoyment, engagement, and challenge in the game. Specifically, it outlines how the player interacts with the game and how the game responds to the player's actions, decisions, and strategies. Enjoyment and engagement are integral and prerequisite aspects of playful learning in shaping the overall experience [77]. Cultural applications should go beyond the role as information presentation channels such as books, documentaries, and guided tours, but to realize an experiential, interactive, and enjoyable experience of CH [45]. Unlike other educational games, CH games focus on preserving, reproducing, and facilitating the appreciation of cultural content [40]. While cultural learning is an implicit component of the game, it is crucial to prioritize the "fun" in gameplay besides its content or value [81]. For instance, the CubeMuseum AR [78] provides users with playful interactions through discovery activities, animations, and collection of museum artifacts. These playful features were found to have contributed to the user engagement and CH learning. Such AR applications could serve as an effective and enjoyable alternative to conventional CH learning methods. By incorporating well-designed interfaces and interactions, AR technology offers an enriching experience that strengthens the connection between visitors and cultural content.

The development of gameplay in location-based AR games is closely tied to the specific information related to the site. Previous AR applications for CH sites have leveraged landmarks to acquaint players with locations and incorporated puzzles and quizzes to engage them with the CH knowledge related to the surrounding environment [6, 25, 39]. These practices are aligned with the situated cognition and social constructivism theory, promoting learning through active participation and collaborative tasks. Additionally, treasure hunt and role-playing are two fundamental elements that could shape the game experience [8, 16, 45]. However, the related game plots and scripts should be carefully designed concerning with historical accuracy and narrative coherence. Furthermore, the main challenge lies in balancing the complexity of clues to ensure they do not overwhelm visitors [7]. Therefore, our emphasis is on the element of "play" to captivate and motivate users during their cultural visits, making the experience both educational and engaging.

1.4 The Current Study

We posit that a location-based AR exploration game has the potential to significantly improve user experience and learning during visits to CH sites. This research topic is of a common interest between the communities of CH and **Computer-Human Interaction (CHI)**. In this article, we address the following **Research Questions (RQs)**:

RQ1: What are the technical means to design games for cultural experiences within the CH and CHI communities?
RQ2: What are the design requirements for an AR exploration game at *Shuangta*?
RQ3: How to communicate historical knowledge about *Shuangta* in an AR exploration game?
RQ4: To what extent does the AR exploration game support the site visiting at *Shuangta*?

To address these RQs, we first reviewed the recent literature to investigate the state-of-the-art application of CH and then discussed the main technical means for design. Based on the user-centered design approach, we identified the design requirements based on our findings obtained from expert interviews (n = 3) and an online survey (n = 174). We also conducted onsite fieldwork and gathered information about visitors' feelings. These empirical studies allowed us to formulate design goals and implement the design, taking into account both perspectives of cultural and game experience. Ten participants were invited to use the HeritageSite AR application onsite and provided their feedback and suggestions about our design. Our study confirms that the game content aligns with the design goals, and furthermore, the implementation enhances the user experience via technical means. We also discuss the limitations and lessons learned that may bring insights into future design and adoption of exploration games in CH sites.

The contributions of this article are threefold. First, we present HeritageSite AR, a prototype design of an AR exploration game for a local heritage site. By interweaving game features with historical narratives, we demonstrate the use of treasure hunt, role-playing, clue, collection, storytelling, and puzzle to facilitate the personal engagement in CH sites, and the inclusion of photo-taking, storyboard, and social sharing to foster social engagement. Our prototype was shown to contribute to a meaningful and playful user experience in the heritage site. Second, our findings gathered from in-depth interviews and substantial survey data provide valuable insights for CH institutions, enabling them to enhance the development of educational experiences and foster public interest and engagement in CH. Third, the design process along with the technical means and design requirements reported in the current work has methodological implications for future development of mobile AR applications and games to support user engagement during CH site visits.

2 State-of-the-Art CH Applications

To answer *RQ1: "What are the technical means to design games for cultural experiences within the CH and CHI communities?,"* we reviewed papers published within the recent 5 years related to our research topic. Specifically, we followed the review guideline [49] and conducted a review for our study, prioritizing the depth of analysis over the breadth of review coverage. We selectively included papers from the *ACM Journal on Computing and Cultural Heritage (JOCCH)* and the *ACM Conference on Human Factors in Computing Systems (CHI)*. JOCCH is dedicated to the intersection of computing and CH and demonstrates a significant relevance with our research context. CHI is one of the core research communities working in this field and includes rich and timely discussions of the latest technological advancements, trends, and challenges. Both venues present peer-reviewed works of high credibility and quality and have a broad readership of researchers and practitioners. This resource-efficient approach reduces the need for extensive searches across multiple databases and journals, thus allowing us to focus our efforts on thoroughly analyzing a more concentrated set of literature. By limiting the review sources, we ensure a high degree of relevance and specificity to the topic at hand and provide an in-depth analysis of the literature within this specific research area. A total number of 18 key articles [7, 9, 11, 15, 20, 23, 24, 29, 34, 37, 41, 46, 53, 56, 66, 67, 80] were synthesized in Figure 1. Here, we discuss the specific features used in the applications.

2.1 Storytelling, Avatar, and Map

Through storytelling and avatar guides, users establish emotional connection with the artifacts and environments [7]. Elesini et al. [67] exemplify this through the creation of character-driven stories that were chosen among various milestones in the history. The avatars had a unique graphic identity and acted as the first-person narrators of the texts, written as a dialogue between the characters and the visitor. A similar avatar and story-based learning approach was taken in several other CH applications [46, 80]. In this case, visitors were engaged in dialogues with avatars when solving challenges. The interactive narratives not only facilitated historical learning but also enhanced users' emotional engagement with CH. Moreover, map is one of the most common elements adopted in game design, playing an important role in visualizing the location-based information [46, 66]. In particular, it

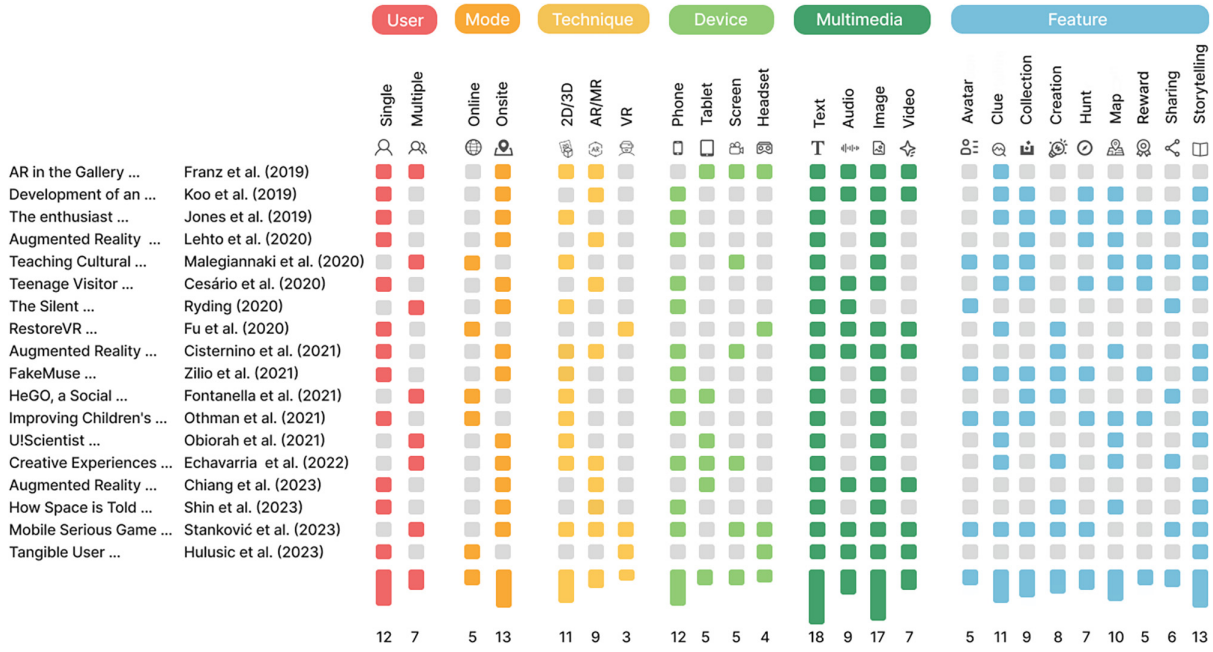

Fig. 1. We reviewed 18 key articles from 2019 to 2023 in ACM JOCCH and CHI and summarized the taxonomy of CH applications from six dimensions. The boxes with different colors represent User, Mode, Technique, Device, Multimedia, and Feature.

guides visitors in exploring multiple points of interest in CH sites [34, 37]. In the study by Shin and Woo [66], the authors showed ways to map a linear narrative to the corresponding spatial trajectory. Maps help visitors navigate the sites and reduce their memory load. Storytelling in conjunction with maps is particularly effective in composing narratives of AR stories for CH sites [34].

2.2 Clue, Hunt, Collection, and Reward

Onsite CH exploration games are often designed with gamification mechanics such as clue, hunt, and collection to engage visitors in exploring the surroundings [7, 56]. Specifically, when designing a location-based game to support cultural visits, treasure hunt transforms the site into an inquisitive space and encourages visitors to freely explore the site. For example, Jones et al. [34] identified groups of *enthusiastic* and *interested* users who appreciated the freedom of movement choice, acknowledging the intrinsic value in the linking of points of interest in the city, CH, and history to encourage reflection. In addition, the integration of clues and collection helps visitors to orient specific locations, allowing a close look into details [7]. For example, in the study by Elesini et al. [67], the children were asked to examine the clues on the mobile phone and then search for the answer in the museum exhibition. In this case, visitors actively explored the venues when collecting the related items. During this process, a reward system with incentives could engage visitor in continued exploration and reflections during interactions [15, 34, 37, 67]. Embedding these gamification elements help enrich the cultural experience by motivating visitors in the exploration, play and learning process.

2.3 Creation and Sharing

Additionally, some CH applications have involved visitors in activities such as creation and sharing [46, 66]. For example, Echavarria et al. [15] involved children in the participatory narrative development by creating physical

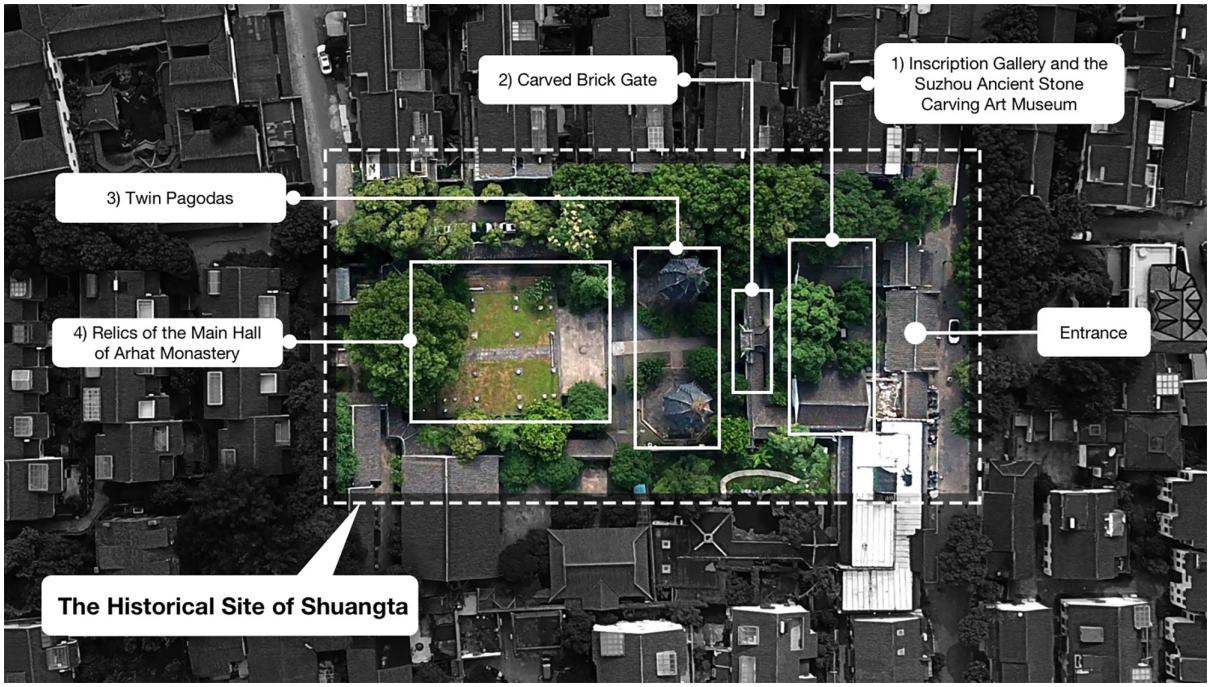

Fig. 2. A drone aerial view showing the spatial layout of the four main spots in the historical site of *Shuangta*: (1) Inscription Gallery and the Suzhou Ancient Stone Carving Art Museum, (2) Carved Brick Gate, (3) Twin Pagodas, and (4) Relics of the Main Hall of Arhart Monastery.

models using cardboard. These models were then digitized and visualized in an AR map. In the work by Jones et al. [34], visitors were encouraged to share their reflections and interpretations of the city's history, contributing to a shared collective memory. The creation and sharing of user-generated content are valuable to achieve user stickiness and foster a sense of community. Overall, these strategies contribute to user engagement and social interactions in CH experience.

2.4 Implications for the *Shuangta* Game Design

User: Primarily Single. Our review results indicated that user experiences are both personal and social, hence requiring a balance between independent exploration and social interactions for effective learning. While multiuser games tend to enforce the involvement of a group of users, single-player games have a wider range of usage scenarios. As a starting point, we aim to design a single-player game with social features that engage users in the exploration of the *Shuangta* site. Yet, users can still use the application together with their friends and families even if the game does not engage them in collaborative activities.

Mode: Onsite (Indoor and Outdoor). Our stakeholders from the organization running the site hoped the local community could be attracted to the site visits. They explained that an onsite experience better allows visitors to relate with the ancient ruins and understand the stories described in the inscriptions. Thus, our work adopts an onsite mode with both indoor and outdoor environments (see Figure 2).

Device and Technique: Mobile AR. Aside from the need of being onsite, stakeholders also required the game to be used without the need of additional devices and operational support. Smartphone was found to be the most adopted device in our review. Considering the technology readiness and acceptance of the *Shuangta* community,

we let visitors use their own devices when developing cultural content, as their portability is suitable for onsite CH visits. It circumvents logistics and operational costs in procuring or leasing equipment, allocating storage space, and ensuring the recharging of equipment [31]. We excluded VR from our design as it requires the use of head-mounted displays, which can be intrusive onsite. On the other hand, previous works indicated that AR systems are suitable for outdoor use [4], which meet the context of use at *Shuangta*.

Multimedia and Feature. Previous works showed the use of various types of multimedia presentation and gamified features in CH applications. However, it is not sensible to adopt all media forms and game features in the game design. These should be further determined with more careful considerations of user requirements for CH visits at *Shuangta*.

3 Requirement Gathering

From the previous study, we identified the technical means to support CH visits and learning. To further explore the design requirement and understand *RQ2: "What are design requirements for an AR exploration game at Shuangta?,"* we held semi-structured interviews and an online survey to gather insights. It helps us better determine the design goals for the AR exploration game. This study is approved by the University Ethics Committee of Xi'an Jiatong-Liverpool University.

3.1 Expert Interview

To understand the feasibility of applying digital technology and gamification and the gap of background knowledge about the site between experts and the public, we invited three experts, one female and two males (age M = 30.67, SD = 11.55), and conducted in-depth interviews. They have professional insights in the domain of historical architecture (E1), heritage conservation in Suzhou (E2), and museum studies (E3). We conducted one-to-one online interviews in their native language and each interview lasted approximately 1 hour. Experts were asked to discuss broadly on the following aspects with specific examples of *Shuangta*: (1) the meaning of cultural popularization, (2) factors to consider in CH experiences, and (3) the use of digital technology in CH learning.

We summarize three main takeaway messages from the expert interviews. First, all experts agreed on the importance and necessity of cultural popularization activities for the public. Experts pointed out that through their daily observations, visitors are particularly interested in the stories behind CH. For example, "*why were Shuangta built here? What happened during the building process?*" (E3). They also identified that the story of *Shuangta* is not clearly presented at the site. For example, the ancient inscriptions on the stone statues could barely be understood by visitors. In addition, some instructions are needed to avoid confusion among visitors. For example, E2 identified that the stone statues inside the wing room are not related to the *Shuangta* history, but are often misunderstood by visitors. Second, factors such as route setting and visual presentations should be considered in the design of CH guides. For example, E1 pointed out that "*setting a route for visitors to follow is important. It helps create a coherent and immersive experience.*" Third, the multimedia and multisensory features are the key benefits of digital technologies pointed out by experts. E3 raised that "*with VR, AR, and other digital guides, users can have rich sensory experiences and better understand the history of the site.*" These lessons learned from the expert interviews provided inspiration for the design of our subsequent survey.

3.2 Online Survey

We conducted an online survey targeting the general public to better understand people's familiarity with CH, the awareness of advanced technology, and the need for AR exploration games to support CH learning. The questionnaire structure was constructed based on the findings from expert interviews. Details are presented in Appendix A.

Survey Structure. Aside from the six demographic questions (Q1–Q6), the main part of the survey consists of three sections: (1) advanced technology experience (Q7–Q10), (2) culture heritage experience (Q11–Q14), and (3)

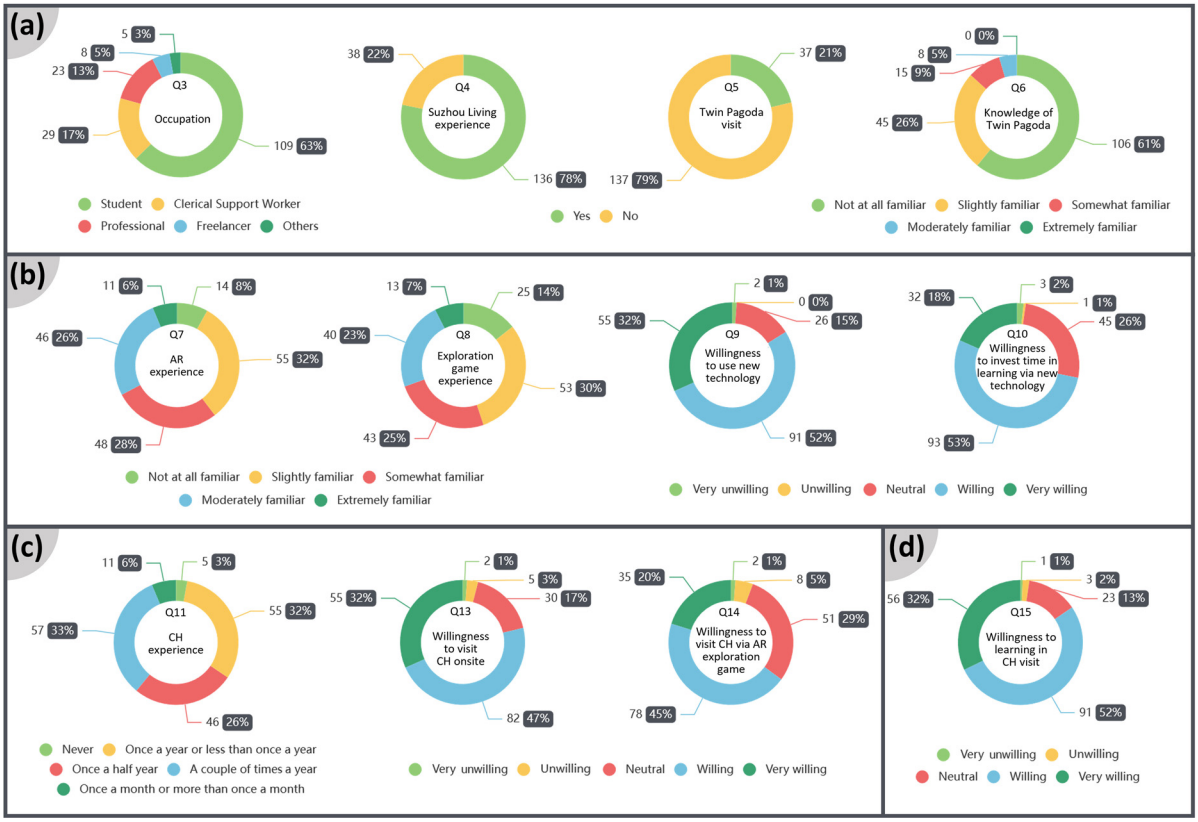

Fig. 3. Survey results of (a) demographics, (b) advanced technology experience, (c) culture heritage experience, and (d) culture heritage learning.

culture heritage learning (Q15–Q18). Question formats include five-point Likert scales using standard response anchors [71] (Q7–Q11, Q13–Q15) and multiple-choice questions (Q12, Q16–Q18).

Data Collection and Analysis. The survey starts with an introduction of the research aims and the collection of informed consent. Participants took an average of 2 minutes to complete the survey. The online survey was created using Sojump and shared on various social media platforms for 3 days. Data were analyzed using IBM SPSS Statistics. Figure 3 shows the analysis results of the survey.

Demographics. In total, we received 174 valid responses (94 females and 80 males), aged between 13 and 59 ($M = 30.77, \mathrm{SD} = 9.88$). The two primary occupations of the respondents were students (62.64%) and clerical support workers (16.67%) (shown in Figure 3(a), Q3). We also received responses from professionals (11.49%), business people (1.72%), and freelancers (4.02%). The majority of respondents (78.16%) had lived in or visited Suzhou, China, where *Shuangta* is located (Q4). However, most respondents (78.74%) had not visited the *Shuangta* (Q5), and 60.92% of respondents were not familiar with it at all (Q6).

Results. From the results, we can see that overall respondents are somewhat familiar with AR ($M = 2.91$, $\mathrm{SD} = 1.07$) (shown in Figure 3(b), Q7) and exploration game ($M = 2.79, \mathrm{SD} = 1.17$) (Q8). The results of Q9 showed that more than half (52.3%) of the respondents are willing to experience new technologies. Furthermore, 53.45% of respondents are willing to spend time on learning activities through new technologies (Q10). As for the CH experience, almost all (97.13%) respondents have had CH visiting experiences (shown in Figure 3(c), Q11). We also

asked some multiple-choice questions to elicit specific requirements. In terms of the activities they are willing to do while visiting CH sites (Q12), 70.69% of respondents would take photos, and half (50.57%) of them were willing to share experiences with friends and family. In response to the willingness to visit CH onsite (Q13), almost half (47.3%) of the respondents reported that they were willing to do so. Compared to the traditional way of visiting, near half of them (44.83%) reported that they were willing to use AR exploration games for CH activities (Q14). Moreover, more than half (52.3%) of respondents indicated that they were willing to invest time in learning CH ($M = 4.14, \mathrm{SD} = 0.75$) (shown in Figure 3(d), Q15). The majority of respondents were willing to learn about history (86.78%), the restoration of the artifacts (70.69%), and architectural structures (64.37%) during their CH visit (Q16). As for the ways of learning about CH (Q17), watching promotional videos containing history and culture was the most popular choice (74.14%), followed by experiencing the interactive game with cultural characteristics (69.97%). For CH AR exploration games specifically, Q18 showed that immersive storytelling is the most popular content (81.61%).

Findings. The survey results indicate that (1) people generally have some knowledge about AR technology and exploration games, and most people are willing to use new technologies for learning; (2) people have intense interest in CH visits with rich content of social activities and entertainment experiences; (3) learning is an intrinsic activity for CH visits, and there is strong potential for the use of AR in CH learning; and (4) our design ideas have been confirmed with users and we see the priority of game features to be implemented from the percentages of the user agreement.

3.3 Fieldwork and Construction of the User Journey Map

To effectively illustrate the findings and requirements gathered from expert interviews and the online survey, we constructed a user journey map. In addition, we conducted fieldwork studies within the site and interviewed visitors to collect information about their feelings to understand the pain points. A user journey map is a visual representation of the different steps and touchpoints that a customer goes through while interacting with a product or service. We use it as a tool to understand the visitors' tour experience and identify areas for improvement. Based on the expert interviews and online survey results, we represent visitors' actions and feelings during the visit at *Shuangta* with visual elements to improve the CH experience to meet the needs and expectations of the visitors.

As shown in Figure 4, we divided the whole process into three stages, namely, before, during, and after visits. During the interviews, experts described their observations of visitor behaviors at *Shuangta*. Based on their narratives, we gathered information about the standard visiting route with four main spots and summarized the corresponding actions of each stage. The descriptions of feelings were reported by visitors we interviewed at the site during the fieldwork. The feelings are classified in three levels according to the emotional states of positive, neutral, and negative. The negative feelings are on the low points of the emotion line chart, which can be summarized into disappointing issues, also called pain points (P). Combining the survey results and the pain points, we summarized the opportunities (O) for improving the CH experience.

3.4 Identifying the Design Goals

The user journey map reflects the sequential visiting trajectory and user activities, showing practical implications (summarized in opportunities) for the design of the *Shuangta* game. To add an additional lens of seeding and growing user engagement with the site, we incorporated the design framework by Vermeeren and Calvi [72], which describes an increasing level of museum engagement in the four stages of museum experiences: *trigger*, *engage*, *consolidate*, and *relate*. Specifically, four design goals are drawn based on the pain points and opportunities.

DG1 Trigger. Provide an informative guide to support knowledge acquisition. First, we hope to express the information precisely about *Shuangta*. Based on *P1*, we are committed to avoiding the misunderstandings caused

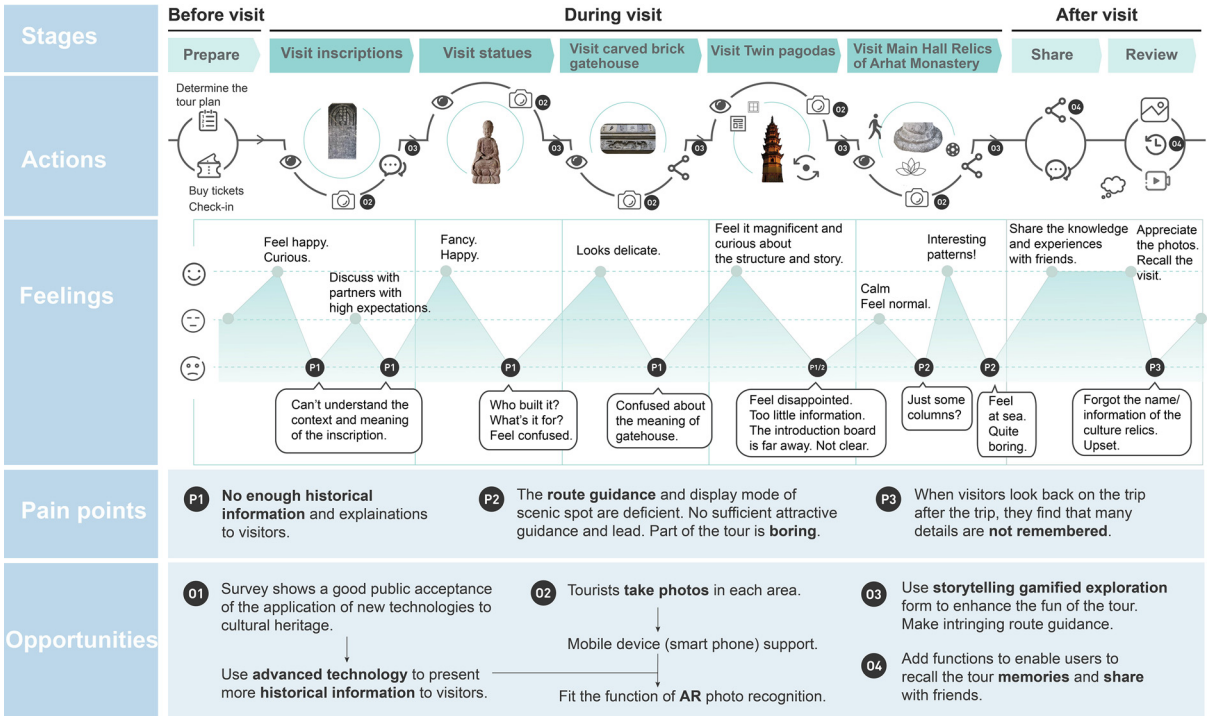

Fig. 4. User journey map of visitors' experience in *Shuangta*. Actions are summarized from expert interviews; feelings are reported by visitors of *Shuangta* during the fieldwork; pain points (P) and opportunities (O) are summary results of expert interviews, online survey, and fieldwork data.

by the lack of the information provided. We will help visitors access the content of the *Shuangta*'s inscriptions by providing the modern Chinese translations in context using emerging technologies (*O1*).

DG2 Engage. Engage visitors in active onsite explorations. From *P2*, we see the urgent need in multimedia guide to attract the users' attention during visits. The research by Neale et al. [50] on virtual museum artifacts indicates that users are more likely to engage in learning if greater interactivity is supported. Therefore, we intend to integrate game features into onsite CH visits such as collection and clues [7] (*O3*).

DG3 Consolidate. Facilitate personal meaning-making and user memory. Visitors act in different roles with different purposes in CH visits [18]. Supporting the personal context of learning and visitors' meaning-making of their visits will further increase their engagement within the site. We aim to construct the emotional link between the visit and their daily life to capture the memory and relate with families and friends (*P3* and *O4*).

DG4 Relate. Develop relevance through social interactions. CH experience is a trajectory that could be extended after visiting [5]. Our online survey results showed that users expect to have social activities and entertainment in CH visits. Thus, satisfying this preference to encourage social activities (e.g., photo-taking, social sharing) becomes our final design goal (*O2*).

4 The Design Process

We summarized the key phases that we underwent in the design process in Figure 5, aiming to answer *RQ3: "How to communicate historical knowledge about Shuangta in an AR exploration game?"* At the beginning of the design, we conducted fieldwork and gathered information about the *Shuangta* site to get familiar with the guide route and the historical knowledge. These contents were double-checked by domain experts in several online meetings.

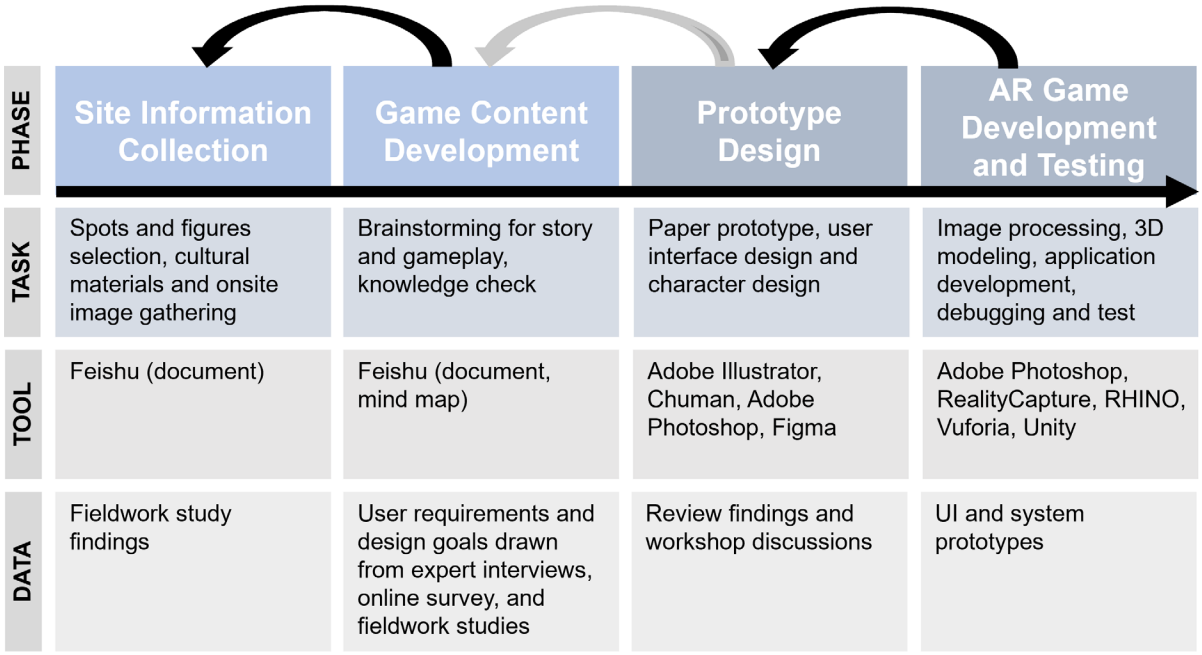

Fig. 5. Our iterative design process, showing the tasks in each phase, the used tools, and the data informed the design phase. Stages 1 and 2 involve the design of game content; stages 3 and 4 involve the development of the game application.

Based on that, we brainstormed the storytelling about the heritage site and the gameplay. The collection of site information and the development of game content were interrelated, just as the two phases of game application design, which encompassed the design of prototypes and the development and testing of the AR game. We also had some iterations between phase 2 (game content development) and phase 3 (prototype design), although these occurred less often.

4.1 Site Information Collection

As we described in Section 2.4, *Shuangta* site can be divided into four main spots: (1) Inscription Gallery and the Suzhou Ancient Stone Carving Art Museum, (2) Carved Brick Gate, (3) Twin Pagodas, and (4) Relics of the Main Hall of Arhart Monastery. Considering the spatial layout and the visiting trajectory suggested by experts, these four spots were integrated into the game content development (see Figure 4) and guided the visitor to explore various points of interest around the spots.

With the help from domain experts, we conducted historiographical research to identify the key knowledge based on the existing site information and relevant literature about the spots. These formed the basis for constructing the narratives. We then contextualized the key knowledge and points of interest by weaving them into dialogues conveyed by five historical figures related to these spots (as shown in Table 1). The figures were selected as they were the key characters that are closely related to the history of *Shuangta*. Specifically, Miao Si, Sheng Chu, and Wang Wenhan were mentioned in the stone inscriptions, and they were involved in the restoration history of *Shuangta*. Cheng Congzhou and Liu Dunzhen were experts in gardens and architecture who have a strong influence on the historical research of *Shuangta*. Images of these figures were collected via online searching based on their names, identities, and times information, which were taken as references to character design in the game.

Table 1. Summary of Site Information Collection Results for Game Content Development

Spot	Key Knowledge	Point of Interest	Main Figure (with images by reference or historical photo)	
Inscription Gallery	It documents the key timeline of the construction, restoration, reconstruction of the monastery and the related architecture, including the Pagodas and the main hall.	Meaning of the inscriptions	Miao Si (妙思), Abbot, who completed the inscriptions construction of Arhat Monastery in 1186 during the Southern Song Dynasty.	
Suzhou Ancient Stone Carving Art Museum	It displays the stone statues from various dynasties.	History of the artifacts	Sheng Chu (盛楚), Scholar, who built the Arhat Monastery in 861 during the Tang Dynasty.	
Carved Brick Gate	It bears the inscription "Shou Ning Wan Sui". The upper part is the roof, and the middle part consists of upper, middle, and lower lintels.	The structure of the Carved Brick Gate, inscription	Chen Congzhou (陈从周, 1918–2000), Garden Expert, who rewrite the Monastery Name Plaque in the 1980s.	
Twin Pagodas	A pair of ancient pagodas, with nearly identical appearances.	The architectural detail of the Twin Pagodas, the dimension information	Wang Wenhan (王文罕), Judge, who financed the construction of Twin Pagodas with his brothers from 984 to 987 in Northern Song Dynasty.	
Main Hall Relics of Arhat Monastery	The temple was almost completely destroyed at that time, leaving only some stone pillars.	The pattern, the shape of the pillars, the structure of the hall	Liu Dunzhen (刘敦桢, 1897–1968), Architectural Historian, who investigated *Shuangta* site with the modern architectural survey and historical data.	

4.2 Game Content Development

The purpose of the game is to engage visitors in four historical narratives of *Shuangta* through treasure hunt and role-playing. Visitors experience a time travel to the past and discuss the site restoration history with **Non-Player Characters (NPCs)**, who are historical figures acting as the narrators and provide clues for visitors to complete the tasks. Seven interactive learning tasks were embedded in the gameplay with figures and facilitated by AR. We did not enforce a narrative sequence based on recommended route at *Shuangta* to provide visitors the freedom to start anywhere and skip spots. Each of the four narratives stands on their own.

Games in CH sites allow visitors to engage with the site information and have social interactions centered on experiential learning to form reflections and foster personal comprehension [1]. Task-based learning [74, 75] is particularly suited to creating knowledge paths in context scenarios, which is frequently implemented as mini-games to deliver tasks to enhance the overall game experience and meet the learning objectives. However, it tends to overlook higher-order cognition [1]. We need to carefully align the learning content with the gameplay and design goals. To do this, we conducted a series of three workshops within our research group throughout the development process. In the first workshop (60 minutes), we brainstormed ideas and mapped the site information with possible game design for the location-based mobile AR experience at *Shuangta*. In the second workshop

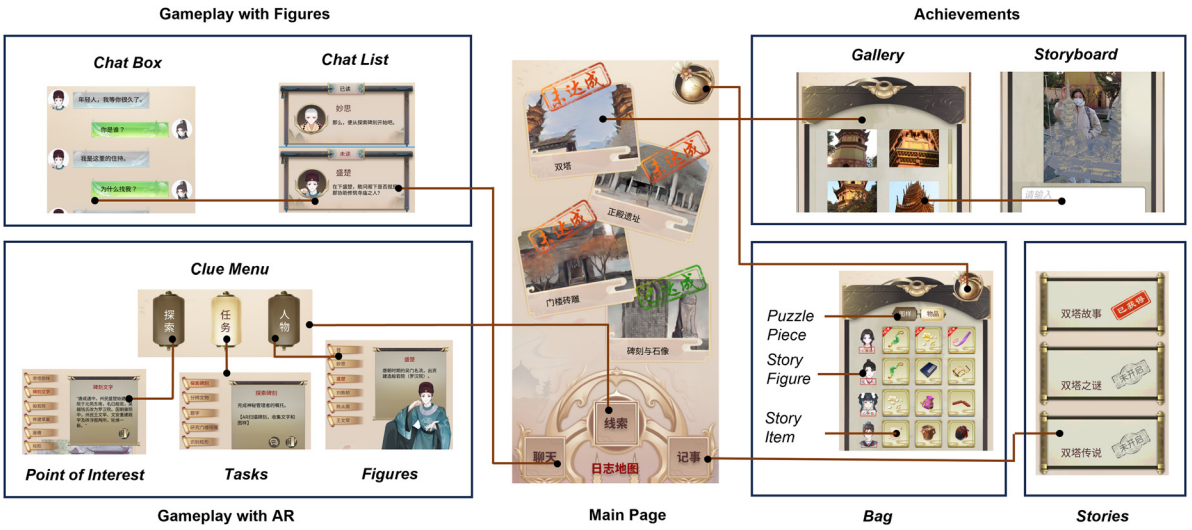

Fig. 6. The prototype design of HeritageSite AR, with legends explaining the corresponding interfaces (i.e., main page, gameplay with figures, gameplay with AR, achievements, bag, and stories) and specific game elements (i.e., chat box, chat list, clue menu, points of interest, tasks, figures, gallery, and storyboard). The lines indicate the logic between the interfaces.

(90 minutes), we focused on evaluating and determining specific game mechanics to support users' learning and recreation. The third workshop (90 minutes) was dedicated to crafting the complete storyline, including the creation of text scripts for the narrative dialogues. This workshop series allowed us to brainstorm ideas for game design, assess potential game mechanics, and finalize the narrative elements, contributing to the overall development of the game content. We shared our research findings on a shared document using Feishu,[1] a collaborative work platform. Throughout the design process, we constantly reviewed our ideas to ensure that they were aligned with the design goals and were centered around the key knowledge and points of interest identified in the previous stages of our research, including the expert interview, online survey, and fieldwork. The results were organized into a mind map of narratives with dialogues, which directly informed the prototype design (see Figure 6).

Location-based games often adopt techniques such as storytelling to allow players to explore the plots and piece the snippets together [26]. Similarly, to align with the *DG2* and engage visitors in onsite explorations, HeritageSite AR presents the narratives as a puzzle to be explored and solved, where the visitor' choices or actions will trigger subsequent game dialogues. As a result of our game content development, we included a combination of treasure hunt and role-playing in the design of HeritageSite AR. We used treasure hunts as the primary game mechanic to sustain visitor engagement in collecting clues, completing tasks, and unlocking the narratives and NPCs of historical figures. The storytelling content is unfolded in conversation with NPCs. Additionally, photo-taking and storyboard are also integrated as the main game features as meaningful records. This approach was instrumental in preserving visitors' engagement throughout the overall *Shuangta* visits. Here we provide some example dialogues and game activities within the four historical narratives shown on the main page:

—Inscription Gallery and the Suzhou Ancient Stone Carving Art Museum: scan to trigger AR texts in simplified Chinese; chat with Miao Si and find the statue of interest (Key NPC: Miao Si)
—Carved Brick Gate: scan to see the 3D structure and trigger the calligraphy task (Key NPC: Chen Congzhou)

[1] https://www.feishu.cn/

—Twin Pagodas: scan to see the 3D structure and provide the idea of Twin Pagodas construction to Wang Wenhan (Key NPC: Wang Wenhan)
—Relics of the Main Hall of Arhart Monastery: discuss the pillar shapes and patterns with Liu Dunzhen and Sheng Chu (Key NPCs: Liu Dunzhen and Sheng Chu)

The setup of NPC-triggered narratives guide visitors to explore the points of interest within the site and encourage them to complete tasks in the game based on the key knowledge spanning different historical dynasties *(DG1)*. Visitors were constantly encouraged to engage in onsite explorations of new clues, captured through an AR camera *(DG2)*. The clues are information overlaid onto the real-world surroundings, such as the vernacular translations of ancient texts. Accordingly, narratives were triggered and conveyed through dialogues with historical figures. Through these narratives, visitors could unlock new tasks, encouraging them to further explore the site and start dialogues with new NPCs. The implementation of AR allows visitors to better interact with the surrounding environment with the help of visual aids and augmented interactions, establishing an emotional connection with the site and historical figures and contributed to personal meaning-making *(DG3)*. Specifically, users used AR via the mobile phone camera to gain text clues, observe 3D structure of architectures, and take photos with the augmented content. The overlapped information offers an immersive experience and engaged users with active interaction with the historical knowledge. A spot on the main page is marked as unlocked with an achievement stamp once all task activities in this area are completed. To sum up, seven learning tasks were presented (see Table 2) through various means such as text decryption, AR camera scanning, interactive gameplay (e.g., calligraphy reproduction), and social sharing functions to keep user motivation in play *(DG4)*.

4.3 Prototype Development, AR Game Development, and Testing

Prior to the development of the AR game application, we conducted several field surveys at *Shuangta* to collect data for 3D reconstruction. The Twin Pagodas and the Carved Brick Gate were scanned and reconstructed in RealityCapture[2] using images captured from drones and cameras. The model was edited using Rhino, with annotation of dimensions added to enrich the AR information display (see Figure 7).

For the AR game development, we used Unity (version 2020 3.33f1c2) and the Vuforia[3] Software Development Kit from Qualcomm (version 9.8.31). Vuforia offers support for a range of features, including 2D and 3D image target recognition, as well as markerless and multi-target tracking. It is compatible with native development for both iOS and Android platforms and seamlessly integrates with the Unity game engine for AR application development. Several key factors were considered in the AR game development and testing, including the available resources, hardware requirements, and the usability of the implemented game design. For example, we made some efforts to simplify the 3D models so that they could be used in low-end mobile devices without causing noticeable delays. We also assessed the size and quality of the image targets used for AR, ensuring that they were under 2 MB in size and achieved a minimum recognition rating of three stars (out of a total of five). To test the quality of image targets in use, we connected to a Redmi Note 11T Pro+ smartphone using the USB debugging tool (see Figure 8). During testing, we addressed some issues caused by the overlapping positions of the models on the mobile interface and issues related to lighting and rendering effects.

5 HeritageSite AR

We followed the design goals to implement the application and conducted the evaluation with three domain experts and seven volunteers, ensuring the content was properly and accurately presented. The design was analyzed and verified from the perspectives of CH experience and game experience during the implementation

[2] https://www.capturingreality.com/
[3] https://developer.vuforia.com/

Table 2. The Learning Tasks, Gameplay, and Game Elements in the Four Main Spots of HeritageSite AR

Spots	Points of Interest	Learning Task	Gameplay with Figures	Gameplay with AR	Game Features
Inscription Gallery	Inscription text	(1) Read inscriptions	Unlock the figures mentioned in text clues and start dialogues with them.	Scan to see explanation, gain text clues and puzzle pieces.	Clue, text decryption
Suzhou Ancient Stone Carving Art Museum	A statue	(2) Identify the statue related to the Main Hall	Ask Miao Si about puzzle pieces and get to know Shen Chu.	Merge puzzle pieces to unlock the statue to view.	Clue, hunt, puzzle
Carved Brick Gate	Inscription of the gate	(3) Explore the carved brick gate	Find inscription contents related to Chen Congzhou.	Scan to see its 3D structure and trigger the calligraphy task.	Hunt, text decryption, social sharing
Twin Pagodas	The planning of Twin Pagodas	(4) Explore the Twin Pagodas	Provide the idea of Twin Pagodas construction to Wang Wenghan.	Scan to see its 3D structure.	Hunt
Relics of the Main Hall of Arhart Monastery	Pillar shape	(5) Identify the pillar shapes	Investigate and discuss the pillar shapes with Liu Dunzhen.	Use site plan to find pillar shapes.	Site plan (map), photo-taking, hunt
	Pillar pattern	(6) Identify the pillar patterns	Investigate and discuss the pillar pattern with Liu Dunzhen.	Use site plan to find pillar patterns.	Site plan (map), photo-taking, hunt
	The planning of Main Hall	(7) Explore the Main Hall	Discuss the Main Hall construction with Sheng Chu.	Scan to see its 3D structure.	Hunt, quiz

and evaluation, respectively. It provides strong empirical evidence to address the *RQ4: "To what extent does the AR exploration game support the site visiting at Shuangta?"*

5.1 Implementation

HeritageSite AR is a location-based exploration game for CH visit and learning. Visitors can follow the dialogues with five historical figures who are represented as NPCs, to explore the map and historical events about *Shuangta*. Visitor can start or continue the dialogues based on the collected clues they found (see Figure 9(a)). Through the dialogues, visitor will be guided to the corresponding places for exploration. Visitor can trigger the augmented images and text information to interact with the relics (*DG1*), unlocking new clues or items for further exploration *DG2* (see Figure 9(b)). The collection of items throughout the visits provides a sustainable experience (see Figure 9(c)) with social activities, such as photo-taking and sharing (see Figure 9(d)). These design elements contribute to *DG3* and *DG4*. We explain how we integrate the game elements into the four stages of CH visits.

Trigger Stage: Storytelling, Avatar, and Map for Guide. In *trigger* stage, we show basic information about the visit to manage their expectations and motivate them in the following activities. An informative guide is designed to

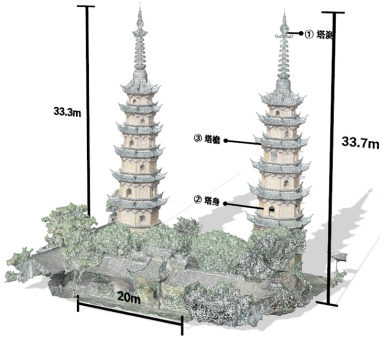

Fig. 7. Three-dimensional reconstruction with annotated information about the components: (1) finial, (2) eave, (3) body of the pagoda; and the size information.

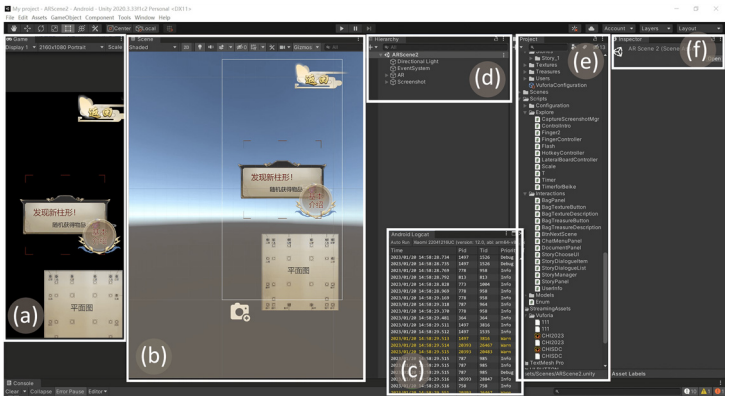

Fig. 8. System development and USB debugging interface in Unity. (a) Game view; (b) Scene; (c) Android Logcat; (d) Hierarchy of the AR scene; (e) Project asset; and (f) Inspector.

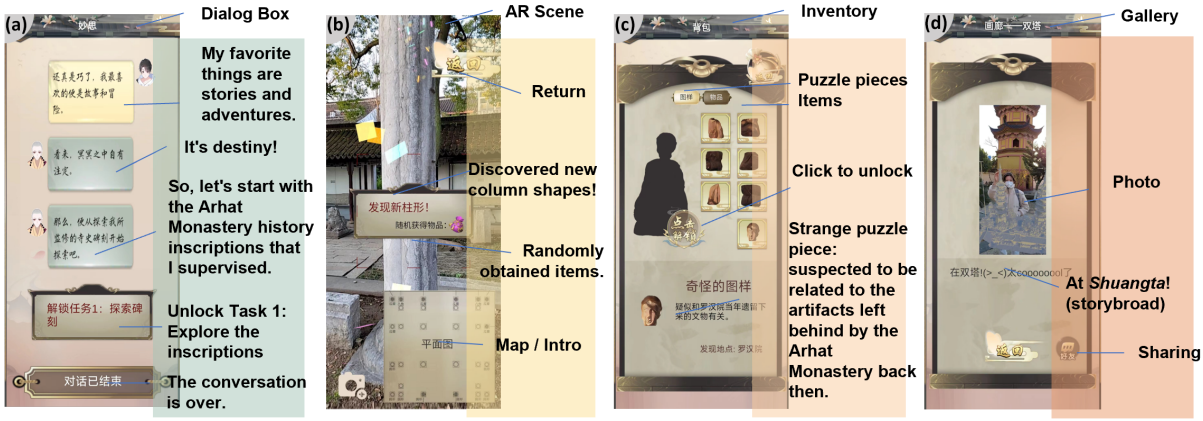

Fig. 9. Example screenshots of HeritageSite AR interfaces: (a) dialog box; (b) AR scene; (c) inventory; and (d) gallery.

support knowledge acquisition, using storytelling with NPCs to present the historical event about *Shuangta* (*DG1*). It guides the visitors through the game, giving them clues and encouraging them to think about some *Shuangta* related questions using dialogues. A map is provided to show an overview of the exploration (see Figure 9(b)).

Engage Stage: Clue, Hunt, and Collection for Exploration. In *engage* stage, we provide diverse interactive support to stimulate curiosity for further exploration. For example, users can find contextual clues through tasks and dialogues, which are associated with the site and objects (*DG2*). This engages them to move around in the environment. We also set an inventory for visitors to store the items and puzzle pieces they collected throughout the game (see Figure 9(c)). Visitors would acquire items related to the *Shuangta* legend to see the complete plot. Hunt emphasizes the value of items and is accompanied by extrinsic rewards and achievements that motivate the visitors. The puzzle pieces can be gathered with augmented information triggered from the task about inscriptions. They can be merged to color the shadow to find the corresponding statue belonging to *Shuangta*.

Consolidate Stage: Gallery and Storyboard for Meaning-Making and Memory. In *consolidate* stage, visitors have gained relevant knowledge and experience from visiting, which can be retained and recalled. We encourage them to leave some memories of the visit. For example, a gallery is used to store the photos-taking during the visits

(*DG3*). Via the AR camera, visitors not merely record the scenery shots but also the interaction moments with the site (see Figure 9(d)). In addition, we also allow users to express their making of meanings in storyboard after the visits to enhance relations between the visit and learning.

Relate Stage: Creation and Sharing for Social Interaction. In *relate* stage, we aim to establish emotional connections and create a sense of belonging by encouraging them to be part of the CH community. We integrated creation functions such as AR photo-taking and inscription writing that attach their personal values to CH visits (*DG4*). The creations and personal values could motivate visitors to share, as well as social interactions with NPCs to access more activities.

5.2 Evaluation

A formative evaluation study was conducted to understand the extent to which a CH application contributes to users' experience in CH learning and site visiting. We referred back to the three factors (*reality*, *meaning*, and *play*) of the TGD to evaluate and reflect our design for the onsite visits at *Shuangta*. The three elements of TGD have been addressed while defining the scenarios. The *reality* dimension addressed elements that are derived from users' real-life situations, such as the environment, weather, light, device used, co-visitors (e.g., friends and families), realistic communication means, and other physical attributes. Specifically, it could be evaluated based on three criteria: flexibility, fidelity, and validity [27]. The *meaning* dimension is defined as the value that users perceive, such as the CH knowledge they gained, their interest and motivation to explore and learn, the perceived necessity, and the ability to transfer the experience to other scenarios. In addition, we asked about their possible actions and interactions to measure *play*, including those with the site, objects onsite such as the carved stone pillars, and social interactions with other people. This factor is closely related to three closely interrelated criteria: engagement, immersion, and fun. The evaluations were conducted through onsite interviews and we mainly gathered qualitative feedback.

Our evaluation study involved seven volunteers ($M = 23.57, \mathrm{SD} = 1.81$) and three domain experts ($M = 30.67, \mathrm{SD} = 11.55$), a total of six females and four males ($M = 25.70, \mathrm{SD} = 6.60$). All of them have visited *Shuangta* before, and seven of them have some AR experience. They were invited to use the app deployed on a Samsung S21 smartphone (see Figure 10). A semi-structured interview was conducted and analyzed using theme-based content analysis. For experts, we further ask their attitudes about the HeritageSite AR from the perspective of its potential values. The results showed that HeritageSite AR has a neutral performance in the *reality* dimension, but users found it to have made the CH visits more *meaningful* and *playful* (see Figure 11). Here, we report our qualitative findings from the interviews (see Table 3).

Reality. We identified three themes for this dimension. (1) Easy access (40.00%, n = 4). For example, P1 said that "*acquiring heritage information using a mobile phone is convenient because I don't need a guide.*" (2) Weather (20.00%, n = 2). P2 used it on a rainy day and said that, "*I would expect a better experience if the weather was good.*" (3) Realistic means of communication (20.00%, n = 2). For example, P7 reported that "*I did gain more knowledge from this AR exploration compared to my own visit, and I would recommend it to family and friends.*"

Meaning. All participants acknowledged the meaning of HeritageSite AR in terms of CH knowledge popularization. (1) Knowledge popularization (42.86%, n = 6). As P4 said, "*this app enabled me to better read the inscriptions that I once could not understand.*" (2) Learning interest (14.29%, n = 2). P6 reported that "*I think it makes visiting interesting, so I purposely look up information to learn about it.*" (3) Route guidance (28.57%, n = 4). As P5 said, "*the map gave me a clear guided tour and overview of the visit.*" Nevertheless, some participants showed less care about learning, or the use of additional tools during the visit.

Play. Participant evaluations on this dimension were positive. (1) Interaction (56.25%, n = 9). P3 expressed that, "*my favorite part is the 3D model of the Shuangta. I could observe the model in all directions and take picture with it. It was interesting.*" (2) Communication (31.25%, n = 5). For example, E2 commented that "*I am immersed in talking with NPCs, and I felt obligated to help them solve the problems.*" However, one participant pointed out the issue in

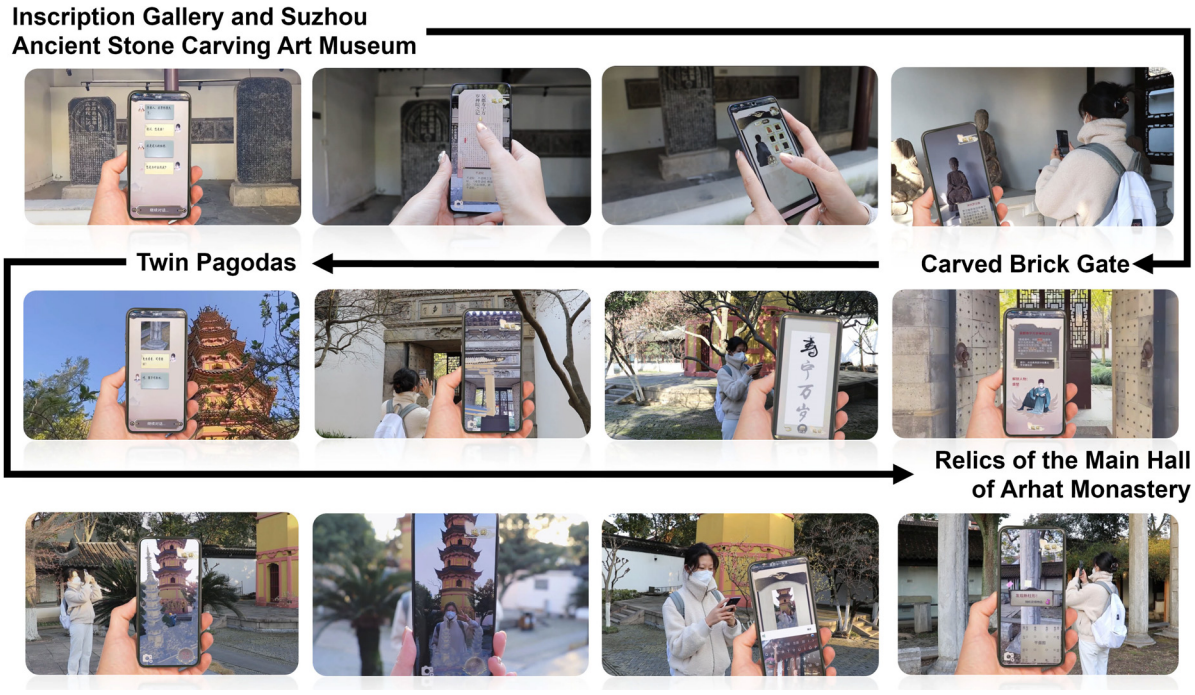

Fig. 10. A flowchart showing a volunteer testing the use of the HeritageSite AR prototype at *Shuangta*.

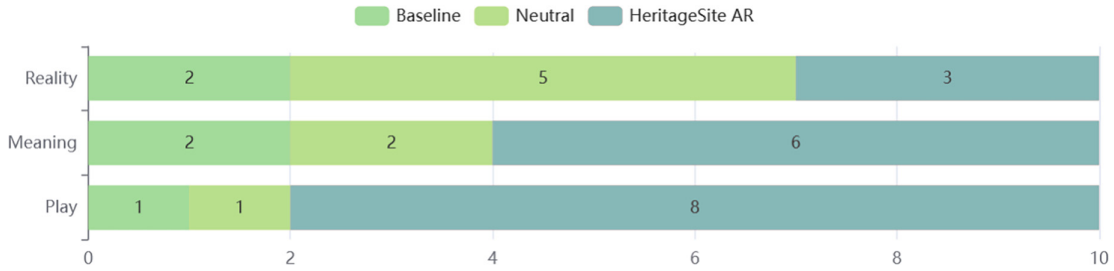

Fig. 11. User preferences in reality, meaning, and play comparing the baseline (without HeritageSite AR) and using HeritageSite AR.

AR recognition, "*I feel that AR is affected by the light and weather, the recognition sometimes takes more time than I expected*" (P2).

6 Discussion

Our work has addressed the four RQs that concern the design and evaluation of HeritageSite AR. First, to understand the technical means to design games for cultural experiences within the CH and CHI communities (*RQ1*), we reviewed the recent literature about CH games. By examining the six dimensions of their design (user, mode, technique, device, multimedia, and game feature), we found that using personal handheld AR devices could effectively integrate game elements into the CH site visits, pointing out a trend of technical development in CH sites. In response to *RQ2* about design requirements, we worked closely with domain experts and surveyed the public opinion, which identified four design goals for our game design for CH visits at *Shuangta*. We further

Table 3. HeritageSite AR Perceived by Participants in the Dimensions of Reality, Meaning, and Play

Elements	User Perception	Participant ID
Reality	(+) Easy access (4)	P1, P6, P7, E1
	(–) Weather (2)	P2, E2
	(+) Realistic means of communication (2)	P1, P7
Meaning	(+) Knowledge popularization (6)	P1, P4, P6, E1, E2, E3
	(+) Learning interest (2)	P2, P6
	(+) Route guidance (4)	P3, P6, E1, E3
Play	(+) Interaction (9)	P1, P2, P3, P4, P5, P7, E1, E2, E3
	(+) Communication (5)	P2, P3, P5, P6, E2
	(–) AR recognition (1)	P2

summarized these goals and aligned them with the *Relevance by Play* framework [72], showing that it is necessary to support knowledge acquisition, onsite exploration, social interactions, and the formation of memorable experiences. To meet these design goals and effectively communicate the historical knowledge about *Shuangta* (*RQ3*), we present our four-phase iterative design process that encompasses two phases of game content design and two phases of game application development. We show how various game elements (e.g., treasure hunt and role-playing) can be integrated into the design to support the communication of key knowledge derived from historiographical research and engage visitors in exploring the points of interest at the site. The development of an AR application in this project shows how CH sites can offer an innovative and playful alternative to traditional tour services.

Finally, we investigated the effect of AR exploration game on supporting CH learning and site visiting at *Shuangta* (*RQ4*) by evaluating our prototype design onsite. The results identified its strength in supporting the *meaning* and *play* component of the TGD framework [27], but exhibited limitations in supporting the *reality* component. AR exploration games offer opportunities to enhance CH site visits and learning by making the experience meaningful and playful. Nevertheless, our current study has some limitations, and we discuss these limitations alongside opportunities, summarize our findings, and provide design implications and lessons learned for gamified AR cultural applications.

6.1 Limitations and Future Work

We acknowledge some limitations of our research. First, our review sample included only two venues. While conducting a comprehensive literature review is out of the scope of our current work, it could offer deeper and broader insights into the technical means for CH game development. Second, CH experiences are both personal and social [65]. Our current prototype design has placed limited concern on onsite social interactions to support CH learning. Incorporating a combination of social play and team collaboration could potentially enhance the overall visiting experience and improve learning efficiency. Third, our evaluation showed that users have a great interest in experiencing CH restoration. However, creating visual representations of historical architectures demands extensive domain knowledge and technical expertise. It requires long-term collaborative efforts from researchers in historical architecture and the technology development team. Fourth, our evaluation was conducted with some volunteers who are not representative of the general public and the results are formative. Previous work suggested that the involvement of main target users and expert users and the collection of qualitative feedback in the evaluation facilitate comprehensive understanding of the problem space [47]. Although we included these group of people in our evaluation, the sample size and diversity of our evaluation study were limited. In our future work, we plan to conduct in-the-wild summative studies involving actual visitors from diverse age groups and different visitor profiles to obtain a deeper and more comprehensive understanding of the users and the

effectiveness of the system. In addition, physiological measures have been adopted in recent studies to gauge user engagement in museum experience [42]. It is a viable approach to use wearable devices and sensors in future systematic evaluations to obtain objective measures of emotions and engagement.

Our evaluation feedback has indicated several potential directions for future work. For example, some users suggested that the menu design could be simplified to improve the overall flow of the game. A managerial staff at *Shuangta* also raised the concern that requiring visitors to install an application might deter them from using it at the first place. They suggested that the game should be accessible through a QR code that users can scan and play directly in their web browser. We also plan to develop game content related to the 3D visualization of the ancient Relics of Arhat Monastery to facilitate better communication of the historical values. By the end of this project, our goal is to have a functional version ready for visitors to access, enabling us to evaluate its use at *Shuangta* and verify its impact on the learning and site visiting experiences of the broader public.

6.2 Design Implications

In this study, we adopted a user-centered design method to identify core factors for CH visit and learning. The design requirements of HeritageSite AR were gathered from stakeholders through expert interviews and an online survey. We further designed alternatives with prototypes and evaluated the designs to create narratives that fulfill the requirements and functionalities for CH learning and visits. The iterative design process consists of interconnected phases that influence the development of the game content and application. The evaluation showed that HeritageSite AR is a suitable game for CH learning, providing improved experiences in the three dimensions (reality, meaning, and play) of the TGD framework [27].

Generally, the evaluation has confirmed the positive effect of gamified design on informal learning. For example, P2 said, "*it (the game) serves as a catalyst for knowledge gains. I don't need to manually search for information and it just made the learning experience engaging and effortless.*" Participants also spoke highly on the application of gameplay and narratives within CH sites. One participant expressed their sentiment by stating, "*the conversations in the chat box made me feel like I was talking to the historical figures, and these events were actually taking place*" (P1). On the other hand, many participants also expressed their expectation to see the application support collaborative learning, which reflects the social nature of CH visits [19]. Participants reported several factors that influenced their experience. In most cases, participants acknowledged that AR interactions enhance their perception of both reality and virtual content. However, adverse weather conditions had a negative impact on their experience because they led to a reduced recognition rate.

Our findings from TGD evaluation of HeritageSite AR align with the previous informal learning research [17, 32]. Learning motivation, engagement, and performance were identified as key factors for game-based learning [32], and our design took these factors into account to balance reality, meaning, and play. We found that the playfulness was highly perceptive as long as some game elements were properly used in the game design, yet some technical glitches (e.g., inaccurate recognition) could impose a negative effect. Concerning meaning, we found that understanding user requirements for CH visits and eliciting the design goals contribute to a meaningful experience. Participants appreciated the richness of knowledge and were interested in the location-based guide information. The reality component could perhaps be improved if the ancient architecture could be digitally restored and visualized in high fidelity, as mentioned by several participants. This could establish a strong connection between the digital representations and the sites in reality.

Moreover, participants agreed that we conveyed cultural values as far more diverse than imagined. Our work affirms the significance of local heritage sites to the sustainable development of CH and lifelong learning for the public. E2 indicated that "*the inscriptions involve research on ancient urban planning and contribute to modern city construction.*" Many participants pointed out the benefits of digitization, such as our AR inscription translation, for CH preservation to keep the retention of national cultural memory. In addition, some experts commented that CH popularization will enable the public to understand cultural connotations. As E3 mentioned, "*it will help the*

public to better understand the community and make meanings of our lives." Participants enjoyed the preservation of local CH in gameplay and showed intention to join voluntary work in the local community. Our design could bring ticket revenue to the site and can be adapted in cultural and creative product design. As public interest and participation in CH increases, job opportunities and cultural consumption will emerge and prosper. Consequently, it will contribute to sustainable local tourism and economic growth.

6.3 Lessons Learned

Based on our study, we summarize some lessons learned for the design of AR exploration game in CH context by reflecting on the design goals.

Content Is King. Most of the gamified CH applications (e.g., [7, 14, 20]) focused on gameplay in the design process to ensure user engagement. Few work prioritized the development of game *content*, which is key of CH promotions. The rigor of historical, cultural, and ancient architectural knowledge should always be prioritized in designing applications for CH. We encourage the involvement of domain experts by all means as the content forms the basis for *DG1* (knowledge acquisition), the subsequent design of narratives and gameplay, and the use of technical means. Furthermore, we learned from our expert interviews that it is necessary to provide sufficient explanations to address any misconceptions visitors may have about CH. This will help them develop a more accurate and comprehensive understanding of the subject matter.

Immerse Visitors, Not Just Visually, but Mentally. In CH learning, a high level of immersion can lead to improved learning outcomes [70]. Explorations at historical sites inherently offer the advantage of immersing visitors in ancient historical environments with authentic visual effects. However, previous research identified that visitors may not have strong interests in CH activities and there is a lack of mechanics to encourage and reward them [44]. Our observations showed that using NPCs as narrators could be a potential solution to address this issue—visitors were motivated to unlock new narratives by completing learning tasks. By immersing visitors in the perspectives of the characters portrayed in the story, similar to time travel experiences [60, 80], they can delve themselves into the storytelling through dialogues with historical figures and the gameplay. This approach contributes greatly to *DG2* (active onsite explorations), allowing visitors to derive psychological involvement and a sense of achievement by successfully completing the tasks.

Extend the Visits and Connect with the Local Community. Through our design, we recognize the opportunity to integrate CH into the daily lives of local residents and foster their emotional connection with *Shuangta*, the urban neighborhood renowned for its rich history and culture in Suzhou. Future design should strive to fulfill *DG3* (extend the visits) and strengthen the bond between community residents, exploring how technological capabilities, such as AR's capacity to transcend time [35] and space [48], can contribute to the development of personal [43] and collective memory [2] within the community.

Design for Co-Visits. Our current prototype design incorporates features (e.g., social media sharing) that facilitate social interactions between visitors and their online connections, scaling the CH visits to a wider audience (*DG4*). However, it has limited support for group visits to a site, even though they are more common than individual visits. Recent research has also explored to extend personalized experiences with co-visitors [22, 76]. We posit that designing to engage visitors in co-visits with friends or even other visitors, fostering social encounters in the same time or space, could create novel visiting experiences.

7 Conclusion

In this article, we present our prototype design on HeritageSite AR, an exploration game to support CH visiting and learning at *Shuangta*, an important yet unvisited heritage site in Suzhou, China. We reviewed the state-of-the-art applications for CH visits to extract the main technical means for our design. Based on requirements gathered from in-depth expert interviews and online surveys, we summarized the findings by creating a user journey map and further identified the design goals in four stages (i.e., *trigger, engage, consolidate*, and *relate*). We

developed the game content based on the site information about *Shuangta* and iteratively built our prototype design. The AR game was evaluated with respect to three game design components (i.e., *reality, meaning,* and *play*). The results demonstrate that our prototype design has effectively incorporated elements of playfulness and meaningful engagement into the site visits at *Shuangta*. However, participants also highlight specific areas where improvements can be made in future iterations. Our design provides insights for researchers and CH institutions in exploration game design to support onsite CH visits and learning. We plan to improve the current design based on the lessons learned and evaluate its effectiveness of use with the public.

Acknowledgment

The authors sincerely thank their stakeholders and participants for their time and valuable comments.

References

[1] Sylvester Arnab, Theodore Lim, Maira B. Carvalho, Francesco Bellotti, Sara de Freitas, Sandy Louchart, Neil Suttie, Riccardo Berta, and Alessandro De Gloria. 2015. Mapping Learning and Game Mechanics for Serious Games Analysis. *Br. J. Educ. Technol.* 46, 2 (2015), 391–411. DOI: https://doi.org/10.1111/bjet.12113

[2] Jan Assmann and John Czaplicka. 1995. Collective Memory and Cultural Identity. In *New German Critique*. Duke University Press, New York, NY, 125–133.

[3] Leslie Bedford. 2001. Storytelling: The Real Work of Museums. *Curator: Mus. J.* 44, 1 (2001), 27–34. DOI: https://doi.org/10.1111/j.2151-6952.2001.tb00027.x

[4] Mafkereseb Kassahun Bekele, Roberto Pierdicca, Emanuele Frontoni, Eva Savina Malinverni, and James Gain. 2018. A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. *J. Comput. Cult. Herit.* 11, 2, Article 7 (2018), 36 pages. DOI: https://doi.org/10.1145/3145534

[5] Steve Benford, Gabriella Giannachi, Boriana Koleva, and Tom Rodden. 2009. From Interaction to Trajectories: Designing Coherent Journeys through User Experiences. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '09)*. ACM, New York, NY, 709–718. DOI: https://doi.org/10.1145/1518701.1518812

[6] Vanessa Cesário. 2019. Guidelines for Combining Storytelling and Gamification: Which Features Would Teenagers Desire to Have a More Enjoyable Museum Experience? In *Proceedings of the Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (CHI EA '19)*. ACM, New York, NY, 1–6. DOI: https://doi.org/10.1145/3290607.3308462

[7] Vanessa Cesário, Daniela Petrelli, and Valentina Nisi. 2020. Teenage Visitor Experience: Classification of Behavioral Dynamics in Museums. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. ACM, New York, NY, 1–13. DOI: https://doi.org/10.1145/3313831.3376334

[8] Erik Champion. 2015. Roleplaying and Rituals for Cultural Heritage-Orientated Games. In *Proceedings of DiGRA 2015 Conference*. DiGRA, Tampere, 16 pages. DOI: https://dl.digra.org/index.php/dl/article/view/724

[9] Kai-Chun Chiang, Cathy Weng, Abirami Rathinasabapathi, Hsuan Chen, and Jin-Hwei Su. 2023. Augmented Reality Supported Learning for Cultural Heritage of Taiwan in On-Site and Off-Site Environments: The Case of a Daxi Old Street. *J. Comput. Cult. Herit.* 16, 3, Article 50 (2023), 17 pages. DOI: https://doi.org/10.1145/3589231

[10] Eugene Ch'ng, Yue Li, Shengdan Cai, and Fui-Theng Leow. 2020. The Effects of VR Environments on the Acceptance, Experience, and Expectations of Cultural Heritage Learning. *J. Comput. Cult. Herit.* 13, 1, Article 7 (Feb. 2020), 21 pages. DOI: https://doi.org/10.1145/3352933

[11] Doriana Cisternino, Laura Corchia, Valerio De Luca, Carola Gatto, Silvia Liaci, Liliana Scrivano, Anna Trono, and Lucio Tommaso De Paolis. 2021. Augmented Reality Applications to Support the Promotion of Cultural Heritage: The Case of the Basilica of Saint Catherine of Alexandria in Galatina. *J. Comput. Cult. Herit.* 14, 4, Article 47 (2021), 30 pages. DOI: https://doi.org/10.1145/3460657

[12] António Coelho, Leonel Dias, Rui Almeida, Nuno Castro, and Pedro Gonçalves. 2014. The Fifth Empire: The Reinterpretation of Portuguese and European History in an Action Adventure Game. In *Proceedings of the 2014 9th Iberian Conference on Information Systems and Technologies (CISTI '14)*. IEEE, Barcelona, Spain, 1–6. DOI: https://doi.org/10.1109/CISTI.2014.6877077

[13] Denis Cosgrove. 2008. Cultural Cartography: Maps and Mapping in Cultural Geography. *Annales géogr.* 660–661, 2 (2008), 159–178. DOI: https://doi.org/10.3917/ag.660.0159

[14] Christian Dindler, Ole Sejer Iversen, Rachel Smith, and Rune Veerasawmy. 2010. Participatory Design at the Museum: Inquiring into Children's Everyday Engagement in Cultural Heritage. In *Proceedings of the 22nd Conference of the Computer-Human Interaction Special Interest Group of Australia on Computer-Human Interaction (OZCHI '10)*. ACM, New York, NY, 72–79. DOI: https://doi.org/10.1145/1952222.1952239

[15] Karina Rodriguez Echavarria, Myrsini Samaroudi, Laurie Dibble, Edward Silverton, and Sophie Dixon. 2022. Creative Experiences for Engaging Communities with Cultural Heritage through Place-Based Narratives. *J. Comput. Cult. Herit.* 15, 2, Article 33 (2022), 19 pages. DOI: https://doi.org/10.1145/3479007

[16] Daphne Economou, Vassiliki Bouki, Thanos Kounenis, Markos Mentzelopoulos, and Nektarios Georgalas. 2015. Treasure Hunt Pervasive Games in Cultural Organisations. In *Proceedings of the 2015 International Conference on Interactive Mobile Communication Technologies and Learning (IMCL '15)*. IEEE, Thessaloniki, Greece, 368–372. DOI: https://doi.org/10.1109/IMCTL.2015.7359621

[17] Annebeth Erdbrink, Janna Michael, Rens Kortmann, Micha Hamel, Koen Van Eijck, and Alexander Verbraeck. 2021. Listening Space: An Exploratory Case Study on a Persuasive Game Designed to Enrich the Experience of Classical Music Concerts. *J. Comput. Cult. Herit.* 14, 4, Article 49 (2021), 20 pages. DOI: https://doi.org/10.1145/3458677

[18] John H. Falk. 2016. *Identity and the Museum Visitor Experience*. Routledge, New York, NY.

[19] John H. Falk and Lynn D. Dierking. 2013. *The Museum Experience Revisited*. Left Coast Press, New York.

[20] Francesco Fontanella, Mario Molinara, Arturo Gallozzi, Michela Cigola, Luca Senatore, Riccardo Florio, Paolo Clini, and Flavio Celis. 2021. HeGO, a Social Game as a Tool for Cultural Heritage Valorization: The Case Study of the Atina Historical Center. *J. Comput. Cult. Herit.* 14, 2, Article 12 (2021), 16 pages. DOI: https://doi.org/10.1145/3431926

[21] World Economic Forum. 2016. New Vision for Education: Fostering Social and Emotional Learning through Technology, 19–20.

[22] Lesley Fosh, Steve Benford, Stuart Reeves, and Boriana Koleva. 2014. Gifting Personal Interpretations in Galleries. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, 625–634. DOI: https://doi.org/10.1145/2556288.2557259

[23] Juliano Franz, Mohammed Alnusayri, Joseph Malloch, Akshay Gahlon, and Derek Reilly. 2019. AR in the Gallery: The Psychogeographer's Table. In *Proceedings of the Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (CHI EA '19)*. ACM, New York, NY, 1–6. DOI: https://doi.org/10.1145/3290607.3312898

[24] Xinyi Fu, Yaxin Zhu, Zhijing Xiao, Yingqing Xu, and Xiaojuan Ma. 2020. RestoreVR: Generating Embodied Knowledge and Situated Experience of Dunhuang Mural Conservation via Interactive Virtual Reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. ACM, New York, NY, 1–13. DOI: https://doi.org/10.1145/3313831.3376673

[25] Manuel Gentile, Davide Taibi, Luciano Seta, Marco Arrigo, Giovanni Fulantelli, Onofrio Di Giuseppe, and Gaspare Novara. 2007. Social Knowledge Building in a Mobile Learning Environment. In *On the Move to Meaningful Internet Systems 2007: OTM 2007 Workshops*. Robert Meersman, Zahir Tari, and Pilar Herrero (Eds.). Springer, Berlin, 337–346.

[26] Mads Haahr. 2017. Creating Location-Based Augmented-Reality Games for Cultural Heritage. In *Serious Games*. Mariano Alcañiz, Stefan Göbel, Minhua Ma, Manuel Fradinho Oliveira, Jannicke Baalsrud Hauge, and Tim Marsh (Eds.), Springer International Publishing, Cham, 313–318.

[27] Casper Harteveld. 2011. *Triadic Game Design: Balancing Reality, Meaning and Play* (1st. ed.). Springer Publishing Company, Incorporated, London, UK.

[28] E. Hooper-Greenhill. 2007. *Museums and Education: Purpose, Pedagogy, Performance*. Taylor & Francis, London, UK.

[29] Vedad Hulusic, Linda Gusia, Nita Luci, and Michael Smith. 2023. Tangible User Interfaces for Enhancing User Experience of Virtual Reality Cultural Heritage Applications for Utilization in Educational Environment. *J. Comput. Cult. Herit.* 16, 2 (2023), 1–24. DOI: https://doi.org/10.1145/3593429

[30] Keiichi Ihara and Ikkaku Kawaguchi. 2023. Virtual Object Placement in MR Space Using a 3D Miniature Model of a Room. In *Proceedings of the Asian HCI Symposium 2022 (Asian HCI '22)*. ACM, New York, NY, 23–29. DOI: https://doi.org/10.1145/3516492.3558789

[31] Chiara Innocente, Luca Ulrich, Sandro Moos, and Enrico Vezzetti. 2023. A Framework Study on the Use of Immersive XR Technologies in the Cultural Heritage Domain. *J. Cult. Herit.* 62 (2023), 268–283. DOI: https://doi.org/10.1016/j.culher.2023.06.001

[32] Seung-Gon Jeon, Jaeho Han, Yonggeol Jo, and Kyungsik Han. 2019. Being More Focused and Engaged in Firefighting Training: Applying User-Centered Design to VR System Development. In *Proceedings of the 25th ACM Symposium on Virtual Reality Software and Technology (VRST '19)*. ACM, New York, NY, Article 7, 11 pages. DOI: https://doi.org/10.1145/3359996.3364268

[33] Catherine Emma Jones, Antonios Liapis, Ioanna Lykourentzou, and Daniele Guido. 2017. Board Game Prototyping to Co-Design a Better Location-Based Digital Game. In *Proceedings of the Conference on Human Factors in Computing Systems*, 1055–1064. DOI: https://doi.org/10.1145/3027063.3053348

[34] Catherine Emma (Kate) Jones, Stathis Theodosis, and Ioanna Lykourentzou. 2019. The Enthusiast, the Interested, the Sceptic, and the Cynic: Understanding User Experience and Perceived Value in Location-Based Cultural Heritage Games Through Qualitative and Sentiment Analysis. *J. Comput. Cult. Herit.* 12, 1, Article 6 (2019), 26 pages. DOI: https://doi.org/10.1145/3297716

[35] Georgios Kallergis, Marios Christoulakis, Aimilios Diakakis, Marios Ioannidis, Iasonas Paterakis, Nefeli Manoudaki, Marianthi Liapi, and Konstantinos-Alketas Oungrinis. 2020. Open City Museum: Unveiling the Cultural Heritage of Athens through an -Augmented Reality Based- Time Leap. In *Culture and Computing*. Matthias Rauterberg (Ed.), Springer International Publishing, Cham, 156–171.

[36] Suzanne Kobeisse. 2021. Touching the Past: Developing and Evaluating a Heritage Kit for Visualizing and Analyzing Historical Artefacts Using Tangible Augmented Reality. In *Proceedings of the 15th International Conference on Tangible, Embedded, and Embodied Interaction (TEI '21)*. ACM, New York, NY, Article 73, 3 pages. DOI: https://doi.org/10.1145/3430524.3443691

[37] Seungbum Koo, Jinyoung Kim, Changhyuk Kim, Jeeyeop Kim, and Hee Sung Cha. 2019. Development of an Augmented Reality Tour Guide for a Cultural Heritage Site. *J. Comput. Cult. Herit.* 12, 4, Article 24 (2019), 24 pages. DOI: https://doi.org/10.1145/3317552

[38] Galena Kostoska, Denise Fezzi, Beatrice Valeri, Marcos Baez, Fabio Casati, Samuela Caliari, and Stefania Tarter. 2013. Collecting Memories of the Museum Experience. In *Proceedings of the Extended Abstracts on Human Factors in Computing Systems (CHI EA '13)*. ACM, New York, NY, 247–252. DOI: https://doi.org/10.1145/2468356.2468401

[39] George Koutromanos and Georgios Styliaras. 2015. "The Buildings Speak about Our City": A Location Based Augmented Reality Game. In *Proceedings of the 2015 6th International Conference on Information, Intelligence, Systems and Applications (IISA '15)*. IEEE, Corfu, Greece, 1–6. DOI: https://doi.org/10.1109/IISA.2015.7388031

[40] Fedwa Laamarti, Mohamad Eid, and Abdulmotaleb El Saddik. 2014. An Overview of Serious Games. *Int. J. Comput. Games Technol.* 2014, Article 11 (2014), 15 pages. DOI: https://doi.org/10.1155/2014/358152

[41] Anttoni Lehto, Nina Luostarinen, and Paula Kostia. 2020. Augmented Reality Gaming as a Tool for Subjectivizing Visitor Experience at Cultural Heritage Locations—Case Lights On! *J. Comput. Cult. Herit.* 13, 4, Article 28 (2020), 16 pages. DOI: https://doi.org/10.1145/3415142

[42] Yue Li, Eugene Ch'ng, and Sue Cobb. 2023. Factors Influencing Engagement in Hybrid Virtual and Augmented Reality. *ACM Trans. Comput.-Hum. Interact.* 30, 4, Article 65 (2023), 27 pages. DOI: https://doi.org/10.1145/3589952

[43] Jiachen Liang, Yue Li, Xueqi Wang, Ziyue Zhao, and Hai-Ning Liang. 2024. MemoryVR: Collecting and Sharing Memories in Personal Virtual Museums. In *Proceedings of the 2024 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW '24)*, 1021–1022. DOI: https://doi.org/10.1109/VRW62533.2024.00307

[44] 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 *Proceedings of the Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems (CHI EA '22)*. ACM, New York, NY, Article 439, 7 pages. DOI: https://doi.org/10.1145/3491101.3519761

[45] Irini Malegiannaki and Thanasis Daradoumis. 2017. Analyzing the Educational Design, Use and Effect of Spatial Games for Cultural Heritage: A Literature Review. *Computers & Education* 108 (2017), 1–10. DOI: https://doi.org/10.1016/j.compedu.2017.01.007

[46] Irini A. Malegiannaki, Thanasis Daradoumis, and Symeon Retalis. 2020. Teaching Cultural Heritage through a Narrative-Based Game. *J. Comput. Cult. Herit.* 13, 4, Article 27 (2020), 28 pages. DOI: https://doi.org/10.1145/3414833

[47] Michael McCurdy, Christopher Connors, Guy Pyrzak, Bob Kanefsky, and Alonso Vera. 2006. Breaking the Fidelity Barrier: An Examination of Our Current Characterization of Prototypes and an Example of a Mixed-Fidelity Success. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '06)*. ACM, New York, NY, 1233–1242. DOI: https://doi.org/10.1145/1124772.1124959

[48] David McGookin, Koray Tahiroglu, Tuomas Vaittinen, Mikko Kytö, Beatrice Monastero, and Juan Carlos Vasquez. 2017. Exploring Seasonality in Mobile Cultural Heritage. In *Proceedings of the Conference on Human Factors in Computing Systems*, 6101–6105. DOI: https://doi.org/10.1145/3025453.3025803

[49] David Moher, Alessandro Liberati, Jennifer Tetzlaff, Douglas G. Altman, and PRISMA Group. 2009. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *Annals Intern. Med.* 151, 4 (2009), 264–269.

[50] Steven Neale, Winyu Chinthammit, Christopher Lueg, and Paddy Nixon. 2014. Facilitating Learning through Hands-on Engagement with Virtual Museum Artefacts. In *Proceedings of the 28th International BCS Human Computer Interaction Conference on HCI 2014 - Sand, Sea and Sky - Holiday HCI (BCS-HCI '14)*. BCS, Swindon, GBR, 222–227. DOI: https://doi.org/10.14236/ewic/hci2014.27

[51] Nicholasabateman. 2019. Luohanyuan Shuangta. Retrieved 9 January 2023 from Retrieved from https://www.atlasobscura.com/places/luohan-shuangta-twin-pagodas/

[52] Francesca Nocca. 2017. The Role of Cultural Heritage in Sustainable Development: Multidimensional Indicators as Decision-Making Tool. *Sustainability* 9, 10 (2017), 1–28. DOI: https://doi.org/10.3390/su9101882

[53] Mmachi God'sglory Obiorah, James K. L. Hammerman, Becky Rother, Will Granger, Haley Margaret West, Michael Horn, and Laura Trouille. 2021. U!Scientist: Designing for People-Powered Research in Museums. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. ACM, New York, NY, Article 675, 14 pages. DOI: https://doi.org/10.1145/3411764.3445334

[54] Reinhard Oppermann, Marcus Specht, and Igor Jaceniak. 1999. Hippie: A Nomadic Information System. In *Handheld and Ubiquitous Computing*. Hans-W. Gellersen (Ed.), Springer, Berlin, 330–333.

[55] Mohd Kamal Othman. 2012. *Measuring Visitors' Experiences with Mobile Guide Technology in Cultural Spaces*. Ph.D. Dissertation. University of York Toronto, Canada.

[56] Mohd Kamal Othman, Shaziti Aman, Nurfarahani Norman Anuar, and Ikram Ahmad. 2021. Improving Children's Cultural Heritage Experience Using Game-Based Learning at a Living Museum. *J. Comput. Cult. Herit.* 14, 3, Article 39 (2021), 24 pages. DOI: https://doi.org/10.1145/3453073

[57] Ruth Owen, Dimitrios Buhalis, and Daniël Pletinckx. 2005. Visitors' Evaluations of ICTs Used in Cultural Heritage. In *Proceedings of the 6th International Conference on Virtual Reality, Archaeology and Intelligent Cultural Heritage (VAST '05)*. Eurographics Association, Goslar, DEU, 129–136.

[58] Dimitra Petousi, Akrivi Katifori, Katerina Servi, Maria Roussou, and Yannis Ioannidis. 2022. Interactive Digital Storytelling in Cultural Heritage: The Transformative Role of Agency. In *Interactive Storytelling*. Mirjam Vosmeer and Lissa Holloway-Attaway (Eds.), Springer International Publishing, Cham, 48–67.

[59] Jiamin Ping, Yue Liu, and Dongdong Weng. 2020. Study on Mobile AR Guide System to Enhance User Experience in Cultural Heritage Sites. In *Proceedings of the 2020 International Conference on Virtual Reality and Visualization (ICVRV '20)*. IEEE, Recife, Brazil, 79–86. DOI: https://doi.org/10.1109/ICVRV51359.2020.00027

[60] David A. Plecher, Florian Herber, Christian Eichhorn, Alexander Pongratz, Gilles Tanson, and Gudrun Klinker. 2020. Hieroquest - A Serious Game for Learning Egyptian Hieroglyphs. *J. Comput. Cult. Herit.* 13, 4 (2020), 1–20.

[61] Lydia Plowman, Rosemary Luckin, Diana Laurillard, Matthew Stratfold, and Josie Taylor. 1999. Designing Multimedia for Learning: Narrative Guidance and Narrative Construction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '99)*. ACM, New York, NY, 310–317. DOI: https://doi.org/10.1145/302979.303098

[62] Nancy Proctor and Jane Burton. 2004. Tate Modern Multimedia Tour Pilots 2002–2003. In *Learning with Mobile Devices*. Jill Attewell and Carol Savill-Smith (Eds.), Learning and Skills Development Agency, UK, 127–130.

[63] Laia Pujol, Maria Roussou, Stavrina Poulo, Olivier Balet, Maria Vayanou, and Yannis E. Ioannidis. 2012. Personalizing Interactive Digital Storytelling in Archaeological Museums: The CHESS Project. In *Proceedings of the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology*. Amsterdam University Press, Netherlands, 93–100.

[64] Irene Rubino, Claudia Barberis, Jetmir Xhembulla, and Giovanni Malnati. 2015. Integrating a Location-Based Mobile Game in the Museum Visit: Evaluating Visitors' Behaviour and Learning. *J. Comput. Cult. Herit.* 8, 3, Article 15 (2015), 18 pages. DOI: https://doi.org/10.1145/2724723

[65] Karin Ryding. 2020. The Silent Conversation: Designing for Introspection and Social Play in Art Museums. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. ACM, New York, NY, 1–10. DOI: https://doi.org/10.1145/3313831.3376357

[66] Jae-Eun Shin and Woontack Woo. 2023. How Space Is Told: Linking Trajectory, Narrative, and Intent in Augmented Reality Storytelling for Cultural Heritage Sites. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems (CHI '23)*. ACM, New York, NY, Article 241, 14 pages. DOI: https://doi.org/10.1145/3544548.3581414

[67] Urška Stanković Elesini, Hlede Miha, David Kristan, Andreja Korošec, Eni Protić, Andrej Učakar, Urška Vrabič Brodnjak, and Jože Rugelj. 2023. Mobile Serious Game for Enhancing User Experience in Museum. *J. Comput. Cult. Herit.* 16, 1 (2023), 1–26. DOI: https://doi.org/10.1145/3569088

[68] Youngjung Suh, Choonsung Shin, Woontack Woo, Steven Dow, and Blair MacIntyre. 2011. Enhancing and Evaluating Users' Social Experience with a Mobile Phone Guide Applied to Cultural Heritage. *Pers. Ubiquitous Comput.* 15, 6 (2011), 649–665. DOI: https://doi.org/10.1007/s00779-010-0344-2

[69] Unal and Fatma. 2012. Observation of Object Preferences of Interest by Children Aged between 4 and 8 in Museums: Antalya Museum Examples. *Procedia Soc. Behav. Sci.* 51 (2012), 362–367.

[70] Aldo Uriarte-Portillo, María-Blanca Ibáñez, Ramón Zataraín-Cabada, and María-Lucía Barrón-Estrada. 2022. Higher Immersive Profiles Improve Learning Outcomes in Augmented Reality Learning Environments. *Information* 13, 5 (2022), 218.

[71] Wade M. Vagias. 2006. Likert-Type Scale Response Anchors. In *Clemson International Institute for Tourism & Research Development, Department of Parks, Recreation and Tourism Management*. Clemson University, 2 pages.

[72] Arnold P. O. S. Vermeeren and Licia Calvi. 2019. Relevance by Play: An Integrated Framework for Designing Museum Experiences. In *Proceedings of the Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (CHI EA '19)*. ACM, New York, NY, 1–6. DOI: https://doi.org/10.1145/3290607.3312960

[73] Steven Wark and Marcin Nowina-Krowicki. 2016. Generating Multimedia Narrative for Virtual Humans. In *Proceedings of the Australasian Computer Science Week Multiconference (ACSW '16)*. ACM, New York, NY, Article 52, 10 pages. DOI: https://doi.org/10.1145/2843043.2843368

[74] Jane Willis. 2021. *A Framework for Task-Based Learning*. Intrinsic Books Ltd, UK.

[75] Jane Willis and Dave Willis. 1996. *Challenge and Change in Language Teaching*. Macmillan Education Australia, Australia.

[76] Xuansheng Xia, Yue Li, and Hai-Ning Liang. 2024. CovisitVM: Cross-Reality Virtual Museum Visiting. In *Proceedings of the 2024 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW '24)*, 1074–1075. DOI: https://doi.org/10.1109/VRW62533.2024.00333

[77] Lesley Xie, Alissa N. Antle, and Nima Motamedi. 2008. Are Tangibles More Fun? Comparing Children's Enjoyment and Engagement Using Physical, Graphical and Tangible User Interfaces. In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction (TEI '08)*. ACM, New York, NY, 191–198. DOI: https://doi.org/10.1145/1347390.1347433

[78] Ningning Xu, Yue Li, Xingbo Wei, Letian Xie, Lingyun Yu, and Hai-ning Liang. 2023. CubeMuseum AR: A Tangible Augmented Reality Interface for Cultural Heritage Learning and Museum Gifting. *Int. J. Hum. Comput. Int.* 40, 6 (2023), 1409–1437. DOI: https://doi.org/10.1080/10447318.2023.2171350

[79] Ningning Xu, Yu Liu, Zhichao Zhang, and Lingyun Yu. 2023. TimeQuestAR: Unfolding Cultural Narratives via Situated Visualizations. In *Proceedings of the 2023 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct '23)*. IEEE, 86–91. DOI: https://doi.org/10.1109/ISMAR-Adjunct60411.2023.00026

[80] Daniel Zilio, Nicola Orio, and Luca Zamparo. 2021. FakeMuse: A Serious Game on Authentication for Cultural Heritage. *J. Comput. Cult. Herit.* 14, 2, Article 17 (2021), 22 pages. DOI: https://doi.org/10.1145/3441627

[81] Michael. Zyda. 2005. From Visual Simulation to Virtual Reality to Games. *Computer* 38, 9 (2005), 25–32. DOI: https://doi.org/10.1109/MC.2005.297

Appendix A
Survey Questions

I. Demographics

1. What is your age? _____

2. What is your gender?
○ Female
○ Male
○ Prefer not to say

3. What is your occupation?
○ Student
○ Clerical Support Worker
○ Professional
○ Business people
○ Freelancer
○ Other _____

4. Have you lived in or visited Suzhou, Jiangsu province?
○ Yes
○ No

5. Have you been to the *Shuangta* site?
○ Yes
○ No

6. Please evaluate your knowledge about *Shuangta* site.
○ Not at all knowledgeable
○ Slightly knowledgeable
○ Somewhat knowledgeable
○ Moderately knowledgeable
○ Extremely knowledgeable

II. Advanced Technology Experience

7. Please evaluate your experience with AR applications (e.g., Alipay AR scan, Pokemon Go, AR digital artifacts, AR virtual try-on, AR makeup).
○ Not at all familiar
○ Slightly familiar
○ Somewhat familiar
○ Moderately familiar
○ Extremely familiar

8. Please evaluate your experience with exploration game.
○ Not at all familiar
○ Slightly familiar
○ Somewhat familiar
○ Moderately familiar
○ Extremely familiar

9. How willing are you to experience new technologies?
○ Very unwilling
○ Unwilling
○ Neutral
○ Willing
○ Very willing

10. How willing are you to invest time in learning via new technologies?
○ Very unwilling
○ Unwilling
○ Neutral
○ Willing
○ Very willing

III. Culture Heritage Experience

11. Please evaluate your frequency of cultural heritage visits (e.g., museums, cultural exhibits, ancient calligraphy exhibitions, historic sites, historic buildings, ancient towns, and historical art exhibitions).
○ Never
○ Once a year or less than once a year
○ Once a half year
○ A couple of times a year
○ Once a month or more than once a month

12. Which of the following are you willing to do while visiting cultural heritage? [Multiple-choice]
□ Communicate and interact with others
□ Acquire knowledge
□ Collect items (e.g., cards, tickets)
□ Photo-taking
□ Share experiences with friends and family
□ Other _____

13. How willing are you to visit the cultural heritage onsite?
○ Very unwilling
○ Unwilling
○ Neutral
○ Willing
○ Very willing

14. Compared with the traditional way of visiting cultural heritage (audio guide or tour guide service), how willing are you to choose AR exploration game?
○ Very unwilling
○ Unwilling
○ Neutral
○ Willing
○ Very willing

IV. Culture Heritage Learning

15. How willing are you to learn while visiting the cultural heritage?
○ Very unwilling
○ Unwilling
○ Neutral
○ Willing
○ Very willing

16. Which of the following are you willing to know about while visiting cultural heritage? [Multiple-choice]
□ Basic information
□ Architectural structure
□ The restoration of the artifacts
□ Legend stories
□ History
□ Other _____

17. Which ways do you prefer to learn about cultural heritage? [Multiple-choice]
□ Read relative text materials and pictures
□ Watch promotional videos containing history and culture
□ Purchase cultural and creative products
□ Experience narratives based on historical and cultural scripts
□ Experience the interactive game with the cultural characteristics
□ Other _____

18. Which content would you like the cultural heritage AR exploration game to have? [Multiple-choice]
□ Interactive tasks
□ Detailed knowledge exploration
□ Immersive storytelling
□ Logical thinking
□ Game reward mechanics
□ Other _____

Received 15 September 2023; revised 8 August 2024; accepted 4 October 2024