CaldanAugmenty – Augmented Reality and Serious Game App for Urban Cultural Heritage Learning

Irene Capecchi[1(✉)], Iacopo Bernetti[1], Tommaso Borghini[2], and Alessio Caporali[2]

[1] Department of Agriculture, Food, Environment and Forestry (DAGRI),
University of Florence, Piazzale delle Cascine 18, Florence, Italy
{irene.capecchi,iacopo.bernetti}@unifi.it

[2] Department of Architecture, University of Florence, via della Mattonaia 14, Florence, Italy
{tommaso.borghini,alessio.caporali}@unifi.it

Abstract. This research presents CaldanAugmenty, a GPS-enabled geolocalised augmented reality (AR) application. Applied to the historic village of Caldana, the application uses serious gaming elements to create an interactive treasure hunt that offers users an enriching journey through the local history and architecture of the region.

CaldanAugmenty features a unique collection of 3D animated historical characters that bring the village's heritage to life. In the treasure hunt, players must find these characters by exploring the physical landscape of Caldana; these characters appear within the AR interface at various points of interest. These characters delve into the local history and architectural heritage of the village and challenge users with intriguing questions that provide elements for localization of the treasures.

CaldanAugmenty incorporates the village's hidden treasures into the virtual gameplay. These treasures are located in four real underground passages that are physically inaccessible for security reasons. The application incorporates these dungeons into a 'virtual tour' function, complete with immersive photo spheres. As users discover treasures during their virtual exploration, these are manifested in AR at the entrances to the real dungeons.

The effectiveness of the application as an interactive educational tool was evaluated using a comprehensive questionnaire administered to 79 middle school students. The questionnaire was designed to assess the dimensions of intrinsic motivation, ease of use and intention to use the application in the future. Preliminary results suggest that CaldanAugmenty is a highly engaging tool to facilitate learning about local history and heritage, with the majority of students expressing a high intention to continue using the application.

Keywords: Augmented reality · GPS · Serious game · Urban cultural heritage

1 Introduction

Cultural heritage can be defined as the legacy of physical artifacts (cultural goods) and intangible attributes of a group or society inherited from the past. Culture can promote economic growth (cultural tourism, crafts, food, etc.) and environmental sustainability

(preservation of cultural and natural heritage). For this reason, it is essential to preserve cultural identities around the world because they can accelerate the transition to a more sustainable future. UNESCO [1] issued the Historic Urban Landscape Recommendation to recognize the living character of cities. This document expands the concept of cultural heritage; it takes into consideration the dynamic character of cities, recognizing them as living entities, not just expressions of their past. In short, cultural heritage is a permanent categorical construction that takes into account the past and the present.

There are already published works on the need to engage the public with cultural heritage using virtual reality (VR) or augmented reality (AR) experiences [2, 3]. There is also work [4, 5] examining how museums seek to engage and bridge the distance between the user and their cultural heritage, reinforcing the importance museums already place on building relationships between users, objects, and institutions.

At the time of this writing, there is enough literature examining how institutions are making use of AR, or the impact of experiences especially in museum visitation.

First, AR is enhancing the heritage and museum user experience by making it more engaging. This is based on articles in which immersive technologies seem to keep people's attention [6] and increase engagement. Second, AR allows the user to better remember the information conveyed. This is based on articles written on AR in teaching and learning [7] that conclude that AR improves users' retention of information. Therefore, this study aims to contribute to the field of museums and cultural heritage by analyzing the use, potential benefits, and constraints of AR outside the museum space.

Another important tool for the enhancement of cultural sites are serious games (SG), i.e., games designed for educational purposes; SG are applied in cultural sites through trivia, puzzles and mini-games for participation in interactive exhibitions, mobile applications and simulations of past events. The combination of Augmented Reality (AR) and digital cultural content has produced examples of cultural heritage recovery and revitalization around the world. Through AR, the user perceives the information of the visited place in a more real and interactive way [8]. Another interesting technological development for the revitalization of cultural sites is the combination of AR and Global Positioning System (GPS), which integrated have the ability to enhance the user's perception of reality by providing historical and architectural information related to specific places organized on a route [9].

To the authors' knowledge, there are currently few applications that combine GPS AR and SG for urban heritage revitalization, and these are generally aimed toward adult tourists [9] rather than young people.

The present research focused on evaluating the impact of a GPS and AR-based application for the promotion of visits to small historic villages aimed specifically at the alpha generation (AG) (those born after 2010). Visiting scientific, cultural and natural heritage tourist sites, such as museums, is an integral part of most Western childhood education [10], and AG represents a culturally and racially diverse demographic group of technology-savvy children. Therefore, the aim of this work is to test the hypothesis of whether the use of AR applications can increase the motivation of the AG to visit urban heritage centers by changing the way a technological present relates to the historical and architectural evidence of the past.

The rest of the paper has been divided into the following sections. Section 2 describes the study area and the design of the GPS+AR+SG application. Section 3 presents the questionnaire that is employed in the evaluation; finally, Sect. 4 presents the concluding remarks.

Learning methods can be distinguished between student-centered and teacher-centered methods [11]. Constructivism is a learning paradigm that is part of the student-centered methods and is based on the assumption that the subject constructs knowledge from his or her own experiences; knowledge is thus a dynamic quality built around discovery [12].

The use of games is the most natural way to achieve high levels of interactivity. Games are activities designed to engage users in an environment where they can learn with a learner-centered approach to education. The use of games in learning is widely demonstrated in the literature because they influence and increase learner engagement and motivation to learn in a more conscious and lifelong way [13].

2 Materials and Methods

The SG GPS-AR implementation process is divided into the following phases

1. Selection of the study area. The characteristics of the study area should be: (i) allow the implementation of appropriate storytelling; (ii) facilitate the use of the application by younger generations; (iii) allow transferability to other urban heritage sites.
2. Definition of the storyboard. In this phase, the cultural information to be provided, the village locations that will make up the route and the historical characters that will interact with the children were identified. The information was then organised into a series of screens that made up the SG storyboard.
3. Application design and development. In these stages of the application we create the 3D model and then develop the interactions.
4. Evaluation. Structuring and carrying out the questionnaire to determine the effectiveness of the application.

2.1 Study Area

The study area is the renaissance village of Caldana in Tuscany, Italy (Fig. 1). We have been chosen a small village for the development of this GPS-AR application compared to a big city, in order to understand if new technologies can help to make the educational offer of a lesser known artistic, urban and architectural heritage more attractive. In particular, the Caldana neighborhood was chosen because of its small and protected size that allows for safe experimentation and on the entire urban context.

The Renaissance village of Caldana in the province of Grosseto is an outstanding choice for an augmented reality (AR) application aimed at promoting urban cultural heritage. This stems from its rich cultural and architectural heritage, intricate urban design, compelling history, and potential for educational engagement. Caldana's unique urban organization, historical structures, and detailed design provide an ample educational material and engaging physical context. This can be enhanced by AR, offering an immersive way to narrate the town's history and architectural evolution. Moreover,

AR can be a powerful educational tool, especially for younger audiences, to kindle interest in history, architecture, and urban planning, demonstrating the importance of cultural preservation. Lastly, the accessibility provided by an AR application can expose this somewhat remote village to a global audience, fostering awareness of its cultural significance and making its rich heritage more accessible.

In addition, Caldana has urbanistic peculiarities: it is a Renaissance fortified village that is built above the walls, has a unified urban structure, and more has a labyrinth dungeon that cover much of the outer village. The dungeons for security reasons are not accessible, but they remain an immense heritage of the village that can be discovered and enjoyed thanks to these technologies. All these features, both functional and aesthetic, have made it the village of choice.
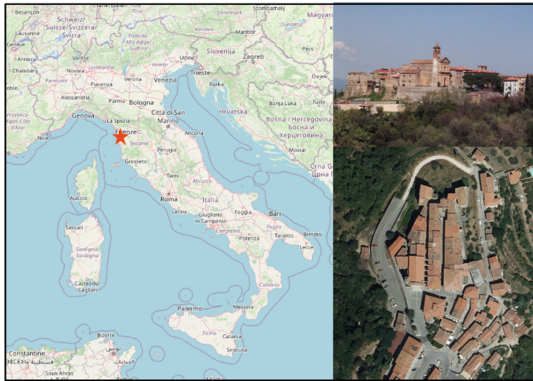

Fig. 1. Study area.

2.2 Storyboard Definition

The storyboard of the SG is based on the history of the three characters who built the village: marquis Marcello Agostini, who was commissioned by Cosimo I de Medici Grand Duke of Tuscany to build the village, his son Ippolito and his architect Lorenzo Pomarelli. The game is structured as a treasure hunt divided into the following steps (Fig. 2).

1. An introductory phase, where students find the initial game menu with 7 items, start game, continue game, characters, treasure map, locations, final prize, thanks. Items number 3, 4, 5 and 6 in the menu are locked because they will be unlocked upon completion of the related steps (Fig. 2.1a). On the second game screen (Fig. 2.1b) the participant must choose his or her virtual assistant, from two archaeological explorers: Maya and Jack. In the third game screen (Fig. 2.1c) explains or purpose of the game: "*Caldana is an ancient fortified village, within it are hidden treasures that few people know about. You will have to go on a real treasure hunt! If you find all the clues and solve the riddles, the entrances to Caldana's dungeons will be revealed. Now your phone is a time machine and you can talk to the ghosts of Marcello Agostini, his*

son Ippolito and architect Lorenzo Pomarelli. Look for them in the village and they will tell you the story of Caldana. Listen to them well, because their clues will be invaluable. You must also have patience and perseverance; ghosts are hard to find and tend to disappear suddenly to reappear not far away."

2. A Tutorial phase, where students can learn how to use app during the 3 historical characters (Marcello Agostini, Ippolito Agostini, and Lorenzo Pomarelli) introduce themselves in AR summarizing their role in the history of the village of Caldana (Fig. 2.2.)

3. Game phase, the first map displayed is the clues map, which through lens-shaped icons indicates points of historical interest (Fig. 2.3a). Participants by clicking on one of the lenses can, thanks to their virtual assistant, know the name of the place where they have to go to view the character in AR with GPS target; once the character is found (Fig. 2.3b), it tells historical information about the place and asks a simple question that the student has to answer (Fig. 2.3c). For each correct answer the user receives a reward a door or key randomly. The doors are displayed in the second map the treasure map (Fig. 2.3d) The user can through a swipe interaction change maps and decide whether to continue with the clues map, and continue looking for the lenses, or to start opening the entrances to the dungeons, assuming they have enough keys. The dungeons are actually not accessible to the public for security reasons; by virtually opening the door they are reproduced on the smartphone through 360-degree images that form non-immersive virtual tours (Fig. 2.3e). Hidden within each dungeon is a hotspot that activates the display of virtual treasures in AR in front of the entrance door (Fig. 2.3f). The virtual treasures are also related to the history of Caldana village and the use of the cellars in the past.

4. The final phase, completed the game the student has access to the entire menu unlocked (Fig. 2.4a). Within the "*Premio Finale*" final prize item, the students can scan the virtual identity card (Fig. 2.4b) to have the final prize, the Agostini family medal (Fig. 2.4c), appear in augmented reality. In addition, the user can take home all the information collected. In the "*Personaggi*" that is the characters section, the biography of the historical characters is given via a short textual description, and it is also possible to make the characters appear in AR any place thanks to floor recognition (Fig. 2.4f). In the "*Luoghi*", although place item, it has a map summary (Fig. 2.4d) of the places visited with a textual description and a slideshow of images for each place (Fig. 2.4e). In "*Mappa del Tesoro*" that is the treasure map section (Fig. 2.4g), users can visit the dungeons at any time and view the prizes in floor recognition.

3 Evaluation

3.1 The Questionnaire

The evaluation of the AR application was aimed at measuring children's motivation to visit urban cultural heritage. The learning motivation scale was originated from the two dimensions of the Intrinsic Motivation Inventory (IMI), namely interest/fun and value/utility. Part of the content was modified from the measure proposed by the Museum Play Motivation Questionnaire of Bossavits [14] and Li Ye et al. [15]. Using a five-point
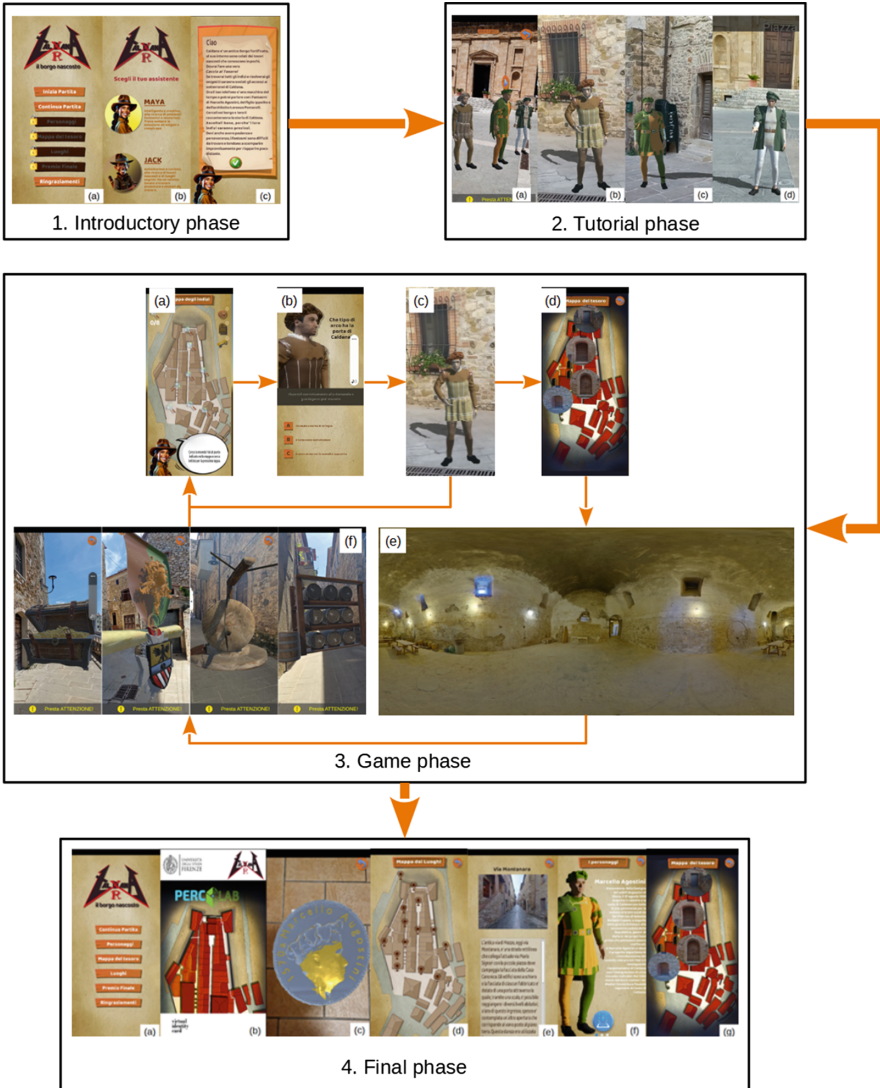
Fig. 2. Storyboard.

Likert to investigate students' motivational changes after play. In addition to the two scales of primary motivation and motivational change, the usability of the AR application was also assessed based on the dimensions proposed by Sang Min Ko et al. [16].

The items are distributed in the three dimensions of primary motivation (10 items), usability (15 items) and motivational change (5 items). Among them, the primary motivation theme was used to assess participants' attitudes toward cultural heritage and visits to historic cities before the experiment. The usability theme was used to assess the AR application experience of using the serious games in terms of User-informations,

User-Cognitive and User-interaction. The theme of change in motivation was used to re-evaluate participants' attitudes toward their willingness to visit urban cultural heritage after the experiment. The contents of the scale are shown in Table 1. All questions in the scale have been accurately translated into Italian to ensure that participants can understand and answer them correctly.

Table 1. Scales and items used to evaluate AR application.

Dimension	Sub-dimension	
Usability	User information	1. The app was easy to use (Default) 2. The initial screens and menus of the App were understandable (Language familiarity) 3. The map of Caldana was easy to understand (Spatial familiarity) 4. The screens of the App were aesthetically beautiful (2D Enjoyment) 5. The assistants (Jack and Maya) were pleasant (2D Enjoyment) 6. The 3D characters of Caldana were aesthetically beautiful (3D Enjoyment)
	User cognitive	7. It was easy to Fig. out what I needed to do to continue the game (Predictability) 8. It was easy to answer questions (Learnability) 9. The information given by the characters was helpful in answering the questions (Consistency) 10. The rewards were fun and satisfying (Award consistency)
	User interaction	11. It was easy to find the characters in different places around the country (Spatial Interaction) 12. App buttons were easy to use (2D interaction) 13. The voice and movements of the 3D characters were realistic and engaging (Human interaction) 14. The screen of my smartphone/tablet was adequate to use augmented reality (Device efficiency) 15. Audio was easy to hear (Audio efficiency)
Primary motivation		1. I like historical countries and like to have information about them 2. I often visit countries and cities of art 3. I liked Caldana 4. When I am on vacation, I am happy if my parents take me to visit countries and art cities 5. It is nice to visit countries and art cities on school trips 6. When I visit a country or an art city, I don't want to have explanations 7. I like to visit a country or an art city by listening to explanations from a tour guide 8. I like to visit a country or an art city by listening to explanations from my school teacher 9. I like to watch documentaries about countries and art cities on television 10. I like to read books about countries and art cities

<div align="right">(continued)</div>

Table 1. (*continued*)

Dimension	Sub-dimension	
Motivation change		1. Augmented reality helped me understand the history of Caldana 2. I would like to find augmented reality applications in other cities 3. I would recommend the augmented reality experience in Caldana to my friends who were not here today 4. I would like to have more augmented reality experiences similar to this one at school 5. I would like to have more augmented reality experiences similar to this one with my parents and/or friends

3.2 Results

We recruited experimental subjects from the second- and third-year courses of a middle school. A total of 79 middle school students participated in the study: 50.6% female and 49.4% male, with an age range of 12 to 16 years and a mean of 13.08 years and a standard deviation of 0.01.

Figure 3 displays the frequency distributions of the Likert scales used to assess the questionnaire items. The items concerning the usability of the GPS-AR-SG application received consistently positive evaluations, with over 70% overall positive ratings. Evaluations of the motivation for alpha generation towards urban heritage varied. The items related to the motivation to visit cities of art (items 16 to 20) received the highest evaluations, ranging from 71% (item 17: I enjoy visiting cities of art) to 81% (item 19: I like it when my parents take me to visit countries and cities of art). Conversely, the items related to the motivation to acquire knowledge from traditional sources of information (items 21 to 25) garnered limited interest, with generally low ratings throughout. The highest positive response rate was only 60% for item 22 (I enjoy visiting a country or art city while listening to a tour guide), while the lowest positive response rate was 38% for item 25 (I enjoy reading books about countries and art cities).

The Cronbach's alpha coefficient for the entire questionnaire was determined to be 0.93, indicating a high level of reliability. The coefficient alphas for the four dimensions ranged from 0.71 to 0.87 (user information: 0.87, user cognitive: 0.71, user interaction: 0.79, motivation: 0.76, and intention to use: 0.80), which suggests acceptable reliability for research purposes.
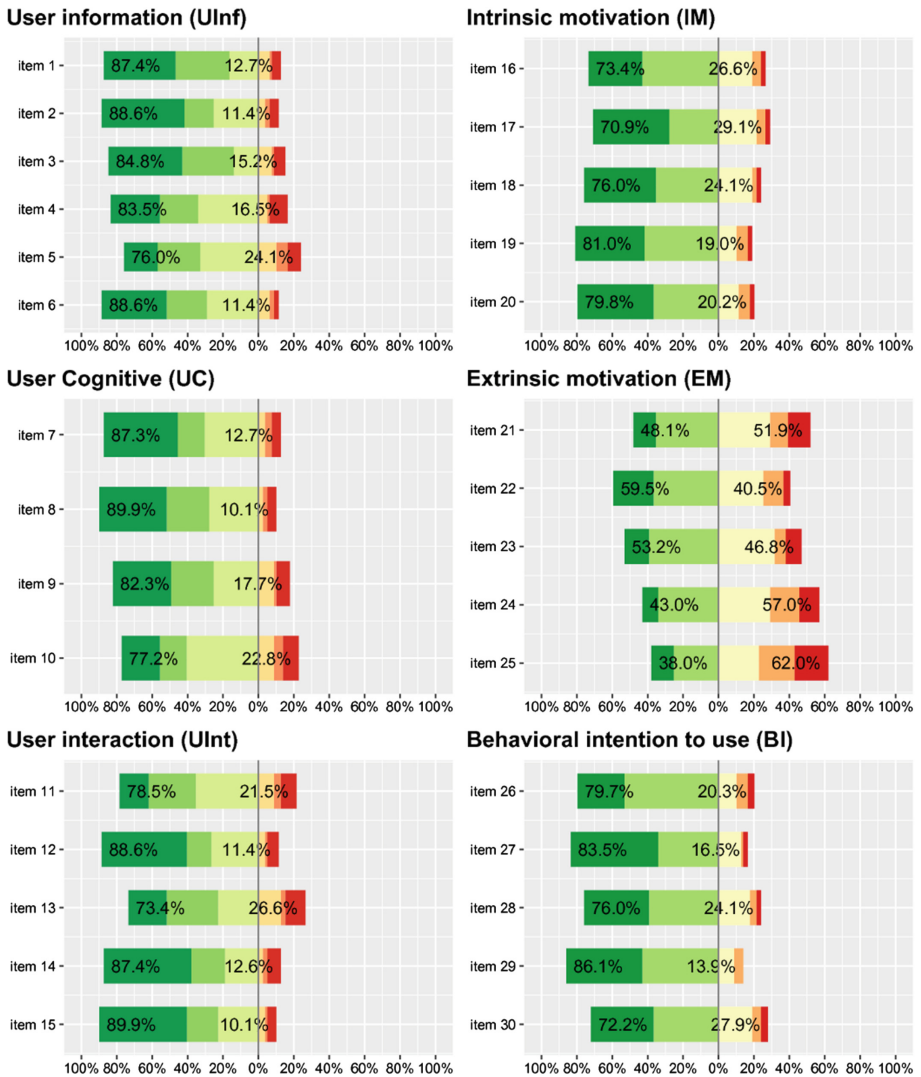
User information (UInf)

item 1 – 87.4% | 12.7%
item 2 – 88.6% | 11.4%
item 3 – 84.8% | 15.2%
item 4 – 83.5% | 16.5%
item 5 – 76.0% | 24.1%
item 6 – 88.6% | 11.4%

100% 80% 60% 40% 20% 0% 20% 40% 60% 80% 100%

Intrinsic motivation (IM)

item 16 – 73.4% | 26.6%
item 17 – 70.9% | 29.1%
item 18 – 76.0% | 24.1%
item 19 – 81.0% | 19.0%
item 20 – 79.8% | 20.2%

100% 80% 60% 40% 20% 0% 20% 40% 60% 80% 100%

User Cognitive (UC)

item 7 – 87.3% | 12.7%
item 8 – 89.9% | 10.1%
item 9 – 82.3% | 17.7%
item 10 – 77.2% | 22.8%

100% 80% 60% 40% 20% 0% 20% 40% 60% 80% 100%

Extrinsic motivation (EM)

item 21 – 48.1% | 51.9%
item 22 – 59.5% | 40.5%
item 23 – 53.2% | 46.8%
item 24 – 43.0% | 57.0%
item 25 – 38.0% | 62.0%

100% 80% 60% 40% 20% 0% 20% 40% 60% 80% 100%

User interaction (UInt)

item 11 – 78.5% | 21.5%
item 12 – 88.6% | 11.4%
item 13 – 73.4% | 26.6%
item 14 – 87.4% | 12.6%
item 15 – 89.9% | 10.1%

100% 80% 60% 40% 20% 0% 20% 40% 60% 80% 100%

Behavioral intention to use (BI)

item 26 – 79.7% | 20.3%
item 27 – 83.5% | 16.5%
item 28 – 76.0% | 24.1%
item 29 – 86.1% | 13.9%
item 30 – 72.2% | 27.9%

100% 80% 60% 40% 20% 0% 20% 40% 60% 80% 100%

Fig. 3. Results

4 Conclusion and Future Developments

The findings obtained from the experimental study conducted with secondary school students, utilizing the Serious Game-Augmented reality application in the village of Caldana, have provided substantial evidence to support our approach. Specifically, our hypothesis has been validated, demonstrating that the utilization of these emerging technologies within the dynamic and lived spaces of a historical city extends beyond being mere tools for documentation, intervention, representation, and transmission of urban

heritage. Instead, they have the potential to bring about transformative shifts in our personal connection with the past in relation to the present.

In essence, the selection of certain physical remnants as cultural heritage, when coupled with virtual and augmented representations and educational games, has the capacity to foster novel connections among the realms of the past, present, and future within the urban landscape. This implies that the integration of these innovative technologies not only enriches our understanding and appreciation of historical contexts but also reshapes our engagement and perception of the urban environment on a deeply personal level.

By embracing these digital tools, we open up avenues for reimagining the significance and value of heritage, transcending traditional boundaries and facilitating dynamic interactions between individuals and their urban surroundings. This transformative potential offers exciting prospects for the preservation, interpretation, and revitalization of urban heritage, encouraging a more immersive and participatory experience for both present and future generations.

These findings offer valuable insights into the utilization of augmented reality (AR) applications for urban heritage among the younger generation. However, there are still several areas that warrant further investigation. The study has certain limitations that need to be addressed through future research. Firstly, the application was developed for a small historical city, allowing for an augmented reality experience that could be completed within half a day. It is crucial to explore the design and implementation of storyboards in larger and more intricate cities, where serious game (SG) experiences may require longer visits spanning multiple days.

Due to privacy concerns, the software responses of the participants could not be recorded as they interacted with the app on their mobile phones. Consequently, it becomes necessary to investigate the learning aspect of the application and its impact. Additionally, broadening the demographic scope of the research to include older generations and individuals from diverse geographical locations would enhance our understanding of how AR technology influences engagement with urban heritage.

Moreover, conducting a comparative analysis of various design elements and user interface features would yield more specific insights, aiding the development of future AR applications. By evaluating the effectiveness of different design choices, we can refine and optimize the user experience, thereby improving the overall quality and impact of AR applications in the realm of urban heritage.

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