Digitizing the Past for the Future

A guideline for developing AR-CH applications in situ for urban heritage interpretation and management

Yueying Zhang
School of Architecture, Southeast University
220220136@seu.edu.cn

This research presents an extensive exploration of Augmented Reality (AR) in the context of cultural heritage (CH), particularly within the dynamic landscape of Smart Cities. It aims to offer a practical guide for the selection of advanced development tools for crafting AR-CH applications, starting with an assessment of the technical characteristics of mobile AR and moving on to a practical evaluation of core recognition methods. The study reveals the interplay between virtual augmentation and physical heritage elements that is critical for the enhancement of urban heritage sites. A proposed framework within the paper not only seeks to deepen the interpretive experience but also to facilitate public engagement and foster collaborative heritage management. By rigorously evaluating the functionalities of prominent AR Software Development Kits (SDKs) and conducting hands-on experiments, this research aims to provide an exhaustive resource for developers. It advocates for innovative, accessible, and cross-platform AR experiences that bridge the past with the future, enabling broader interaction and participation in heritage conservation and management.

Keywords: *Mobile Augmented Reality, Urban Heritage Preservation, Smart Cities, Stakeholder Engagement, Heritage Management.*

INTRODUCTION

The utilization of Augmented Reality (AR) in preserving and exhibiting cultural heritage (CH), hereafter referred to as 'AR-CH applications' in this paper, is increasingly becoming a focal point within the broader context of smart city frameworks. In detail, mobile AR can directly superimpose virtual contents of historical information on the in situ urban built heritages with dynamic interaction for integrated interpretation, engagement, and education instead of traditional physical restoration and static display. Furthermore, due to the digital nature that conveys and gathers data from different sources, it can not only work as a medium to exchange ideas and concepts of heritage preservation among various stakeholders through portable devices but also integrate other digital technologies applied in CH, from documentation to monitoring and management, while also fostering collaboration among different stakeholders.

Regarding practice, most AR applications are led by professionals who possess a deep understanding of heritage values and preservation technologies. However, their expertise in software development may not be as strong. Figure 1 illustrates the complex development process of AR-CH applications. These challenges are notably detected in the selection of appropriate technologies and development tools required to construct sophisticated AR applications.

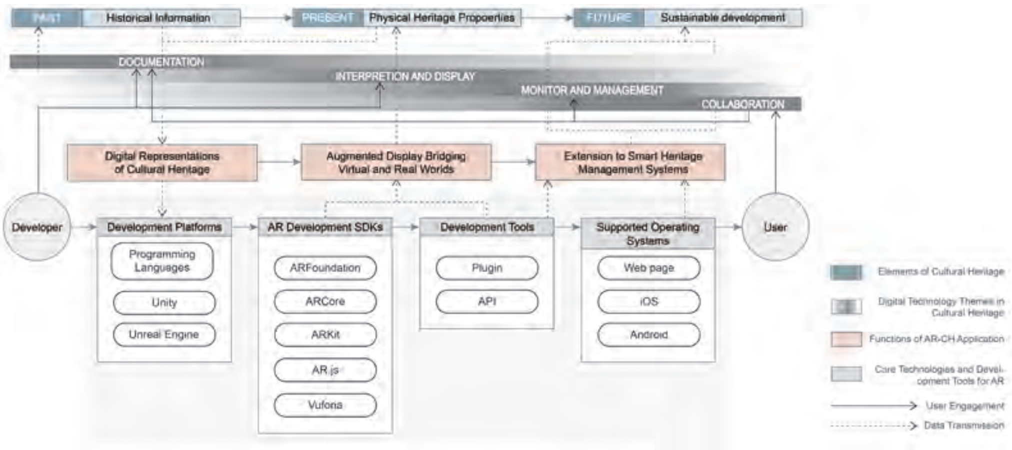

Figure 1
Technical Lifecycle of AR in CH from Documentation to Sustainable Management and Collaborative User Engagement

The situation becomes more complicated when CH is integrated into the broader concept of smart cities. The interests and requirements of diverse stakeholders, from the general public to government officials, ask for a more tailored AR application and add complexity to technical development. Consequently, it is crucial to bridge the gap between the rich knowledge of those professionals and the technical capacity required to bring their visions to life within the dynamic landscape of AR and Smart Cities.

PRACTICAL RESEARCH INSIGHTS

There have been numerous practical trials of developing AR applications to showcase cultural heritages. Boboc et al. (2022) have made a comprehensive analysis of 1,201 pieces of research on AR for CH from 2012 to 2021 and concluded eight main trending topics. Despite the burgeoning growth and broader exploration of such digital practices, the full potential of AR in presenting historical information, while preserving the physical integrity of heritage sites, remains underexploited. Some CH subjects researched and designed are limited to simplistic representations like postcards (Nagakura and Sung, 2017), or can be displayed and interacted with anywhere without tight relation to their urban contexts (Niblock et al., 2022). However, AR applications that allow to visit heritage sites in situ are necessary, because it has been confirmed to enhance visitors' engagement with virtual information (Singh, Sharma and Daim, 2024), and thus contribute to public engagement in heritage-related matters (Varinlioglu and Halici, 2019). In addition, through this approach, AR can construct fundamental connections between real objects and digital data for heritage sites' planning and management in Smart Cities (Böhm et al., 2021).

From a technical perspective, current research tends to take a single heritage site as the subject for experimentation. However, many studies merely address the basic process of overlaying virtual contents on physical structures through abstract demos, lacking detailed and explicit exploration of appropriate technical roadmaps for complex components aligned with heritage's intrinsic values. Voinea et al. (2019) compared user perceptions of Google ARCore and ARKit applications in the 3D reconstruction project of the Prejmer fortified church. This study outlined technical requirements for CH in terms of the digitalization process, including data acquisition, registration, integration, and texture. However, while it concentrated on the spatial forms and material composition intrinsic to CH, it omitted considerations of the actual on-site experience.

Regarding real heritage properties as objects to be augmented, the AR-CH application should fully consider these physical materials and the methods used to detect and blend them with virtual content, adding complexity to the development process. Recently, Ramtohul and Khedo (2024) have conducted a systematic review of AR systems in CH domains, which included an examination of technical aspects like types of devices utilized, and the techniques and algorithms applied. Their work also introduced a preliminary category of CH and their specific displaying requirements. Furthermore, technical developers have made thorough comparisons of various developing tools. For example, Oscar Falmer (2021) released an online document comparing the features of nine mobile AR SDKs. Though these pieces of research have contributed to defining the research scope and subjects in AR-CH application development by examining all the factors, they have not established clear links between the technical dimensions and the attributes of CH for practical application.

METHODOLOGY

This research employs both theoretical analysis and technical experiments to examine AR's characteristics and its integration with CH preservation. To propose a practical technology roadmap for the development of AR-CH applications within the framework of Smart Cities, this research deconstructs the intricate technical process into three parts:

- The basic technical features of AR to realize the blend of real and virtual environments,
- The specific interpretative and display needs of CH, which involve recognizing physical heritage attributes and integrating digital archives,
- The advancement towards smart heritage management systems.

Based on the real experiences and obstacles that occurred during several previous AR-CH application development by the author, this research takes these trials as analysing materials to reveal the relevance between technical features and CH preservation. Then, the specialized requirements are incorporated and posited by smart city paradigms from the stakeholders' perspectives.

In the end, this paper conducted practical experiments by developing tools, especially established SDKs, and examined their specific technical aspects. By comparing the utilization of existing resources (Past), this paper provides practical references for CH developers (Present) and offers insights for SDK developers to innovate AR tools tailored to the needs of CH applications within Smart Cities (Future).

Table 1
Classification and Comparison of Mobile AR Recognition and Tracking Methods

Technology Approach	Recognition Method	Description	Example	Preparation Effort	Tracking Accuracy	Adaptability to Various Environments
Vision Based	Marker-Based	Recognizes predefined visual markers to position virtual content.	Image, QR Code	Low	High	Low
	Marker-less	Detects natural features of the environment, such as surfaces or objects, for AR content placement.	Plane	Low	Low	High
	VPS	Uses a combination of sensor data and visual features to create a map of the environment and track the user's position within it.	Spatial navigation	High	High	High
LBS Location based	Sensor-Based	Employs other sensors (such as gyroscopes, accelerometers, and compasses) alongside GPS to improve the accuracy and stability of AR content placement in the user's environment.				
	GPS-Based	Utilizes GPS data to place AR content at specific latitude and longitude coordinates.	GPS data	Low	Variable	High

RECOGNITION METHODS OF MOBILE-AR

Space perception is the basic technology that facilitates AR effects through the recognition, understanding, and interaction with users' physical spaces. Mobile AR devices, particularly smartphones, are equipped with hardware such as cameras, GPS, accelerometers, and compass sensors to detect the environment in which the user is situated.

Thus, the recognition and tracking methods mostly used by Mobile-AR (Table 1), can be categorized into Vision-Based and LBS Location-based regarding the hardware used in the mobile devices. Then, these methods can be further subdivided into Marker-based and Marker-less, VPS, Sensor-Based, and Location-Based, regarding their recognition Methods. They require the identification of real objects' dimensions of CH ranging from images and planes to urban spaces or utilize geographic information to pinpoint users' locations.

Marker-based AR triggers effects by recognizing images, graphics, or designated 2D code markers. When an AR device's camera detects a preset image or marker, it generates and overlays the virtual content onto the live camera feed. This method is prevalent for scanning small-scale items like postcards or flat images. In real-world settings, it maintains a relatively precise registration, as demonstrated in Figure 2a. However, its application in real-world scenarios is restricted by the Field of View (FOV) and the required proximity to capture the marker accurately, ensuring the scene's recognizability. These constraints can be somewhat mitigated by employing an extensive database of image markers, though this results in a more complex development process for AR-CH applications.

As for marker-less AR, virtual content can be anchored to any flat surface recognized. Hence, this approach is less dependent on specific real-world contexts, as shown in Figure 2b. Once virtual objects are placed in reality, they can be observed and interacted with from various angles and positions.

Figure 2
Experiments with AR Visualizations Using Different Recognition Methods: Image-Based, Plane-Based, and GPS-Based

For GPS-based Location AR, the system overlays relevant digital information or virtual objects onto the real-world view. This method works without the need for markers or specific images, making it very suitable for outdoor and extensive application scenarios (Figure 2c). Nevertheless, issues such as jitter and offset may occur due to occasional inaccuracies in GPS data (Figure 3), compromising the precision of 3D registration.


Figure 3
Jitter and offset of virtual objects in position


Figure 4
VPS-based Augmented Reality Scene through TOOLYA SDK. This developing tool has been unavailable since 2023

Visual Positioning System (VPS), used in conjunction with sensors, can provide a much more accurate and flexible interaction with virtual contents. This technology typically necessitates the modelling of urban environments or relies on pre-modelled city databases to align the AR system with the recognized real-world scenes accurately. However, the development of such applications for large outdoor environments is often challenging and costly due to the extensive data collection and integration required for modelling. Moreover, although companies like Google utilize data from their Street View Maps, and TOOLYA has pre-modeled several urban spaces, the availability of such databases is limited to a few regions worldwide (Figure 4). The complexity of urban heritage contexts, some situated in narrow alleys or within complex building structures, may further limit the accessibility of this data.

WHAT TO AUGMENT AND HOW: ELEMENTS AND TECHNIQUES IN AR-CH

Physical Elements for Augmentation

For analysis of AR displays that are applied to CH, it is essential to recognize the varied scales and levels of such exhibitions. The displayed real elements of CH show a variety of dimensions and layers that AR must adeptly integrate to provide a comprehensive and enriching user experience.

Physical properties consisting of urban heritages are the tangible presentation of intangible culture and history (Mah et al, 2019). The physical composition of built heritage in situ varies greatly in scales and forms, including indoor sacrificial furniture, material decorations, architectural spaces and forms, and related urban environments, which are accurate to centimetres, meters, or larger respectively. The greater the scale of the physical components intended for augmentation, the more challenging the accuracy of these recognition methods becomes.

Augmenting Virtual Content in AR-CH Applications

For the virtual contents digitalized in the previous research process, AR-CH applications should deal with multi-dimensional historical sources for exhibiting various heritage values. For example, antiquarian text tells through words, while historical images or videos capture the conditions of heritage sites at specific moments. Creating digital twins of heritage sites to present three-dimensional information about forms and spaces has also become more accessible. Furthermore, animations and films transcend temporal limitations, enabling visitors to revisit historical events. What is more, the display is not limited to a simple showcase of existing historical resources. Beyond merely presenting historical resources, augmented displays can offer interactive experiences. By manipulating these prefabricated sources through gestures and movements, visitors can engage with different historical layers, uncovering narratives and details often obscured in a non-augmented context.

Therefore, the developing platform is responsible for integrating these multifaceted historical sources. It should also allow the visitors to experience them through interactions in an active approach. Regarding registration methods, texts, images, and videos typically require viewing from a singular perspective, whereas models should be accessible from all angles surrounding the virtual objects. Additionally, interactive capabilities such as rotating, scaling, or moving can compensate for the limitations of exploring virtual content in situ.

Display Requirements and Technical Precision in AR-CH Applications

To effectively convey heritage values, different kinds of virtual information, ask for varying levels of display precision, depending on the physical objects they augment. Therefore, each display approach can correspond with different AR's technical features. Figure 5 established the relationship between real CH elements, forms of digital information displayed, and specific AR recognition technology utilized.

Interpretation. Overlaying annotations upon the backdrop of heritage through AR is a common practice. Such information, comprising text, images, or videos, should be intricately linked to specific elements of the heritage site. The accuracy of this alignment varies with the size of the components. In detail, precise registration is critical for small-scale augmentations and can be achieved using marker-based recognition methods. Conversely, broader contextual information need not adhere as strictly to specific points, allowing for some spatial discrepancy.

Disclosure. Heritage buildings that are famous for inner structures or details present unique challenges for AR applications, which are not immediately visible and deeply hidden under the surface. To reveal these elements, digital modelling of 3D structures or architectural intricacies is employed, which must integrate smoothly with the actual environment. Given the widespread distribution of such details within a heritage building, the ability to move and view freely is crucial in an AR-CH application. Therefore, setting a series of image markers at strategic locations, or indoor VPS can improve the user experience, the former is easy to develop while the latter is more accurate and flexible.

Recreation. Over time, some elements of CH inevitably fade or vanish. The selection of recognition and display methods for them should be tailored to the scale and current state of the physical sites. For archaeological sites that require a complete reconstruction of original structures, location-based AR proves fitting, especially when physical remnants are scarce, providing little to no direct mapping. Additionally, urban heritage sites may suffer functional losses, rendering the intangible aspects of heritage, such as the routine use of spaces for rituals crucial for preservation and exhibition. Such intangible features can be represented within a defined spatial context, employing either location-based AR or marker-less technology that recognizes planes in the relevant areas. In addition, marker-based AR is suitable for the disappeared parts of heritages like peeling murals, damaged structures or envelopes which need precise correspondence with original building elements. Besides, marker-less AR can be applied in reappearing sacrificial vessels on communion tables, which asks for low accuracy with specific real objects while needing high flexibility to view virtual contents.

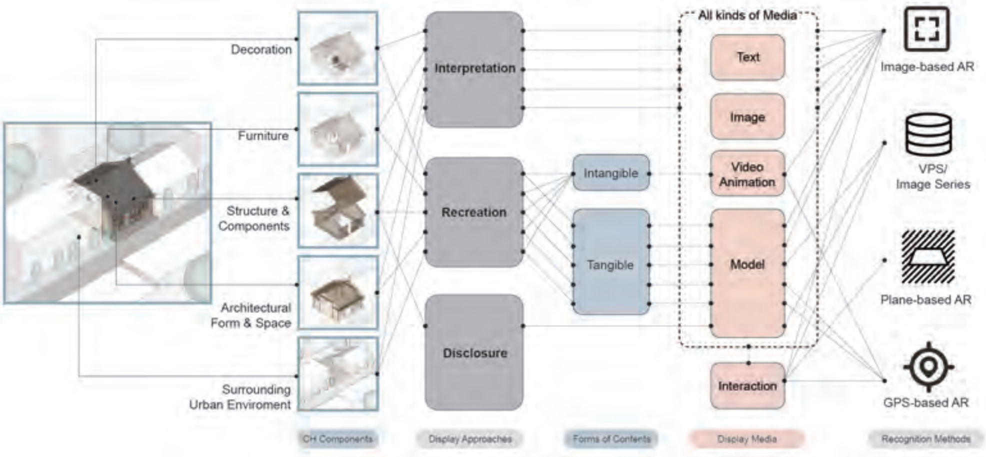

Figure 5
Relationship between AR features and CH elements

In short, the choice of recognition technology approach is influenced by three fundamental factors. First is the level of accuracy required for recognition. Second is the scale of the objects to be augmented within the heritage context, which impacts both development costs and recognition precision. Thirdly, there is the need for spatially flexible experiences in the real environment and the ability to interact meaningfully with virtual content. Identifying strategies for developing scalable and accessible AR solutions is crucial for developers working with limited budgets or focusing on less prominent heritage sites. Such guidelines on creating scalable AR solutions that can be adapted to different scales and complexities of heritage sites will empower developers to broaden the reach of their applications.

EXTENSION TO HERITAGE MANAGEMENT

Accessible user platform to ensure public engagement

An accessible user platform is significant in stimulating public engagement with AR-CH applications. Such platforms should be intuitive, removing barriers to entry for users regardless of their technical proficiency or familiarity with AR technology. Therefore, the devices, hardware and software they use daily should prioritize ease of use. These AR-CH platforms can not only invite wider participation but also enhance the educational and experiential value of heritage sites.

Collaborative Management Capacity

Within the framework of Smart Cities, AR-CH applications also play a pivotal role in fostering integrated and collaborative management of CH. These applications offer tools for urban planning and maintenance that respect heritage integrity. City planners and conservationists can use AR to visualize changes to heritage sites before any physical work begins, ensuring that any addition or alteration harmonizes with the original structures. This pre-emptive visualization aids in making informed decisions that balance modernization with preservation, a critical aspect of managing urban heritage in dynamic cityscapes. In addition, the role of AR in engaging communities with their CH cannot be overstated. By making historical knowledge accessible and engaging, AR helps build a sense of identity and community among residents. Additionally, communities residing near urban heritage sites can often monitor these locations more regularly than professionals. By uploading images or videos of the heritage sites' daily conditions, not only can immediate risks to these heritages be identified, but the documentation of ongoing cultural practices, such as rituals performed in situ, also serves to enrich the historical archive.

To achieve this objective, a critical technology is the transmission of real-time information among multiple stakeholders, contributing to a comprehensive database. In this context, collaborative APIs like ARKit's Collaborative Session and ARCore's Cloud Anchor, which enables shared AR experiences, become crucial. This capability lays the foundation for a cooperative and inclusive approach to heritage management within the Smart City framework.

RESULTS AND DISCUSSION

When it comes to the practical development period, AR SDKs are crucial to understanding and selecting the most suitable tools for developing AR applications. Each SDK offers different features, tools, and interfaces that enable developers to create virtual content that interacts with the real world. Choosing the right SDK is essential to ensure application performance, compatibility, and user experience, especially for CH within Smart Cities, where accuracy and immersion are key to user engagement and collaboration. By comparing various AR SDKs, researchers and developers can make informed technological choices based on their project needs, leading to richer and more captivating AR experiences.

Therefore, based on previous analysis of the technical characteristics and display contents of AR-CH applications, Table 2 further examines the varied capabilities of five popular AR SDKs through two perspectives, aiming to provide comprehensive and practical guidance for CH professionals and other developers to create AR-CH applications under the concept of smart heritage management. The first is the technical capacity for blending virtual elements with real-world scenes, further divided into five recognition methods that depend on the nature of the real objects and their urban contexts recognized. The second evaluates their potential to integrate into smart urban heritage management systems, encompassing functionalities such as Cloud Anchor for collaborative efforts, and the compatibility with various development platforms and operating systems to accommodate the needs of different stakeholders.

Basic recognition approaches including marker-based, markerless, and location-based are universally supported by all SDKs, highlighting their fundamental importance in crafting AR experiences that blend real and virtual elements. For more advanced recognition methods, such as indoor and outdoor VPS offering precise tracking and enhanced AR experiences, only the ARKit SDK provides these capabilities. Although ARCore does not include direct tools for indoor VPS recognition, it facilitates the creation of similar AR effects through the use of extensive image marker databases, incorporating predefined routes or positions. Moreover, the ability to support collaborative features like data sharing among users plays a crucial role in smart heritage preservation and management. This functionality, however, is primarily available in ARKit and ARCore, utilizing Collaborative Session and Cloud Anchor features, respectively.

Functions of SDKs		AR.js	ARCore	ARKit	ARFoundation (Unity Package)	Vuforia
Recognition Methods	Plane-based AR	√	√	√	√	√
	Marker-Based AR	√	√	√	√	√
	Indoor VPS	×	○	√	○	×
	Outdoor VPS	×	√	√	√	×
	GPS	√	√	√	√	√
Collaboration API		×	√	√	√	○
Interaction With Virtual Objects		√	√	√	√	√
Developing Platform		Java Script	Unity/Unreal	Unity	Unity	Unity
Users' operating systems		Web	Android	iOS	Android/ iOS	Android/ iOS

Table 2
Comparison of AR SDKs Under Smart Heritage Interpretation and Management

When considering the public accessibility of AR-CH applications, those developed with ARKit or ARCore are limited to iOS and Android systems separately. Despite the popularity of these SDKs among professional developers, their platform-specific nature restricts simultaneous access for the global audience of both iOS and Android users. As a result, ARFoundation emerges as a superior choice due to its capability to enable developers to craft AR applications compatible with both iOS and Android platforms. This cross-platform functionality ensures that a single development effort can cater to a broader audience, effectively bridging the gap between the two leading mobile ecosystems and enhancing the accessibility of AR experiences worldwide, regardless of the users' device preferences. Additionally, ARFoundation is capable of supporting the full range of functionalities offered by both SDKs.

While WebAR like AR.js, may not support the full spectrum of features available in native applications due to browser constraints, it provides unmatched ease of access. Users can directly interact with AR content through their web browsers, eliminating the need to download and install specific apps from app stores. Also, Unity possesses the capability to create WebAR experiences via the WebXR plugin. Future research should focus on applications that use Unity's comprehensive development environment for crafting AR experiences that are web-accessible under Unity's advanced graphics and interactivity features while ensuring broad accessibility through web browsers.

CONCLUSIONS

This study investigates the technical roadmap that can fully exploit mobile AR's capabilities to improve public understanding and interpretation of urban cultural monuments. This research discovers a contemporary strategy for seeing and comprehending historical sites by analysing mobile AR's technical features and determining suitable techniques for superimposing digital content onto actual heritage sites. Although this research is grounded in the real-world development of AR-CH applications, the proposed framework and guidelines are mostly theoretical. Hence, to evaluate this research's practical applicability, the technical roadmap will be further applied in a specific CH site. This site may feature components of various scales and a diverse range of information to be displayed to test the effectiveness of the framework.

In essence, this study outlines a framework for AR applications that could bridge the past with the present, inviting a more inclusive and participatory approach to CH in an increasingly digital era. It provides a practical insight for CH professionals to utilize AR technologies. A comparison of different AR SDKs highlights ARFoundation and the relative developing tools in serving both iOS and Android platforms, suggesting a broader reach and inclusivity in public accessibility to AR experiences. The paper also highlights the critical role of AR in collaborative heritage management, which asks for accessible user platforms that can enable wider public involvement in heritage conservation. Finally, the research suggests that merging advanced graphical tools with the ease of web access could also democratize the experience of CH, ensuring its preservation and engagement for future generations.

From another perspective, the technical requirements of CH preservation for AR application development revealed in this research can offer new insights for technical professionals, guiding them in creating specialized tools as well. It hopes to facilitate effective collaboration between AR experts and CH specialists in the end.

ACKNOWLEDGEMENT

This research is funded by the Postgraduate Research & Practice Innovation Program of Jiangsu Province (Grant No. SJCX23_0033).

The author would also like to thank Yiyi Chen, Peilin Li, and Haoran Wang for their support during the experimental development of AR-CH application demos.

REFERENCES

Azuma, R.T. (1997) 'A Survey of Augmented Reality', *Presence: Teleoperators and Virtual Environments*, 6(4), pp. 355–385.

Bademosi, F. and Issa, R.R.A. (2019) 'Implementation of Augmented Reality Throughout the Lifecycle of Construction Projects', in *Advances in Informatics and Computing in Civil and Construction Engineering*. Cham: Springer International Publishing, pp. 307–313.

Batchelor, D. and Schnabel, M.A. (2021) 'Opportunities and Recommendations for Local Governments Delivering Smart Heritage', in. *CAADRIA 2021: Projections*, Hong Kong, pp. 749–758.

Boboc, R.G. *et al.* (2022) 'Augmented Reality in Cultural Heritage: An Overview of the Last Decade of Applications', *Applied Sciences*, 12(19), p. 9859.

Böhm, F. *et al.* (2021) 'Augmented Reality and the Digital Twin: State-of-the-Art and Perspectives for Cybersecurity', *Journal of Cybersecurity and Privacy*, 1(3), pp. 519–538.

Gleue, T. and Dähne, P. (2001) 'Design and implementation of a mobile device for outdoor augmented reality in the archeoguide project', in *Proceedings of the 2001 conference on Virtual reality, archaeology, and cultural heritage - VAST '01. the 2001 conference*, Glyfada, Greece: ACM Press, p. 161.

Mah, O.B.P. *et al.* (2019) 'Generating a virtual tour for the preservation of the (in)tangible cultural heritage of Tampines Chinese Temple in Singapore', *Journal of Cultural Heritage*, 39, pp. 202–211.

Nagakura, T. and Sung, W. (2017) 'AR mail from Harbin', in *ACM SIGGRAPH 2017 VR Village. SIGGRAPH '17: Special Interest Group on Computer Graphics and Interactive Techniques Conference*, Los Angeles California: ACM, pp. 1–2.

Niblock, C. *et al.* (2022) 'An augmented and interactive exhibition of an archived model for Frederick Kiesler's Endless House, 1959', *Frontiers of Architectural Research*, 11(6), pp. 993–1006.

Oscar Falmer (2021) *Mobile AR Features Landscape*, *Google Docs*. Available at: https://docs.google.com/spreadsheets/d/1S1qEyDRCqH_UkcSS4xVQLgcMSEplu_mPtfHjsN02GNw/edit?usp=sharing&usp=embed_facebook (Accessed: 3 September 2023).

Ramtohul, A. and Khedo, K.K. (2024) 'Augmented reality systems in the cultural heritage domains: A systematic review', *Digital Applications in Archaeology and Cultural Heritage*, 32, p. e00317.

Singh, P., Sharma, M. and Daim, T. (2024) 'Envisaging AR travel revolution for visiting heritage sites: A mixed-method approach', *Technology in Society*, 76, p. 102439.

Varinlioglu, G. and Halici, S.M. (2019) 'Gamification of Heritage through Augmented Reality', in *Blucher Design Proceedings. 37 Education and Research in Computer Aided Architectural Design in Europe and XXIII Iberoamerican Society of Digital Graphics, Joint Conference (N. 1)*, Porto, Portugal: Editora Blucher, pp. 513–518.

Voinea, G.-D. *et al.* (2019) 'Exploring Cultural Heritage Using Augmented Reality Through Google's Project Tango and ARCore', in M. Duguleană et al. (eds) *VR Technologies in Cultural Heritage*. Cham: Springer International Publishing (Communications in Computer and Information Science), pp. 93–106.