THE SURVEY OF THE USE OF VR AND AR AT IMMOVABLE TANGIBLE CULTURAL HERITAGE TOURISM IN CHINA

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ABSTRACT:

This paper focuses on VR/AR applications in immovable tangible cultural heritage (ITCH) tourism by considering both academic research and cases in the XR industry. The goal is to understand how VR/AR can be used to present heritage information to the public. A framework is developed, including the purpose of using the technology, hardware, software, and user experience to have an overall understanding of VR/AR applications. Cases collected based on the framework are divided into four heritage types to answer the following questions: under a certain heritage context, what is the commonly used technology, is there a correlation between the purpose of using VR/AR, the enabling technology, and the user experience, and is there a difference in the concentration point between academia and the XR industry in China.

1. INTRODUCTION

Developments in information and communication technology (ICT) have played a crucial role in encouraging tourists to visit cultural heritage in person (Neuhofer et al., 2012), because the integration of technological infrastructures and end-user devices enriches and personalizes visitors' experiences (Buhalis and Amaranggana, 2014). Under this background, ICT is used in cultural heritage sites to attract more tourists. Among ICT, virtual reality (VR) and augmented reality (AR) have played a big role because of their significant advancements in software and hardware development.

We regard VR and AR as types of media or technology, which are not defined by the hardware devices such as the headset. Specifically, VR is defined as a system where people can be "surrounded by a three-dimensional computer-generated representation and can move around in the virtual world and see it from different angles" (Rheingold, 1991), which can be supported by VR headset, holography video, big screen, panorama, etc. AR is defined as a system that "supplements the real world with computer-generated objects that appear to coexist in the same space as the real world" (Azuma et al., 2001), and the devices can be AR glasses, handheld devices, and tablets. Previously, VR/AR was used in the gaming and entertainment industry due to its properties of education, entertainment, and interaction. Since these properties are also highly involved in cultural heritage tourism (CHT), VR/AR has had a revolutionary impact on CHT (Tussyadiah, 2014). Thus, the application of VR/AR on CHT has become a trend.

In this paper, we developed a framework to understand VR/AR applications in ITCH in both academia and in the XR industry in China, from technology to user experience for different types of ITCH. Based on the cases in four survey tables of collecting data and twelve figures of analyzing data, this paper is proposed to provide an understanding of the correlation between types of ITCH, technology, and user experience, and an insight into the different practices between VR/AR cases in academic research and those in the XR industry.

2. LITERATURE REVIEW

The papers that provide a systematic review of VR/AR applications in cultural heritage can be found. One paper summarizes the top trending applications of VR/AR in cultural heritage (Boboc et al., 2022). It focuses on the various applications of using VR/AR in the cultural heritage domain but does not distinguish between VR and AR and consider their technical differences in the applications. Another survey is about state-of-the-art projects using VR, AR, and MR in cultural heritage, providing a technical framework to compare different types of digital immersive technology and find appropriate technology for a given application (Bekele et al., 2017). As the comparison is mainly from a technical perspective, it does not consider tourists' experience of using VR/AR.

3. METHODOLOGY

One important method in this paper is to consider both academic and professional aspects of VR/AR applications in ITCH. The framework for understanding VR/AR applications in ITCH tourism is developed based on the systematic structure created by Mafkereseb Bekele et al. (2017) to understand VR/AR applications from a technical perspective. Bekele et al. (2017) organized and synthesized VR/AR applications in cultural heritage, including their purposes, tracking, display, interface, and setting. The framework in this paper absorbed the technical aspect of their structure and further developed it by combining user experience and different types of cultural heritage, to gain an understanding of the process of applying VR/AR in specific contexts.

Two main methods of collecting data are adopted. One method is a review of academic papers published after 2016 through the China National Knowledge Infrastructure (CNKI) database. As

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most of the cases and technological methods mentioned in Bekele's paper are before 2016, the selected papers mainly focus on VR/AR applications in ITCH in China from 2016 to 2022 to gain insight into the state-of-the-art technical development in digital heritage. Criteria for paper selection are established. First, the paper's subject needs to be immovable tangible cultural heritage, so papers about movable cultural heritage, intangible cultural heritage, and natural heritage are excluded. Second, the paper should focus on VR/AR applications in heritage tourism, so those with the purpose of historic preservation or heritage management for heritage practitioners are excluded. Third, the research process in the paper should include the process of developing VR/AR applications for the public, so papers addressing technical issues to produce the digital twin of heritage (eg. 3D scanning, computer graphics) are excluded.

The other method is the expert interview, aimed to interview practitioners in the XR industry in China and focus on their products of applying VR/AR on cultural heritage sites. Experts are appropriately selected based on their positions within the companies and their involvement in the ITCH tourism. The interview process is rigorous and well-designed to ensure the reliability and validity of the collected data. The cultural heritage sites that are included are either listed under UNESCO or classified as AAAAA Tourist Attractions of China.

After collecting data in the tables, we compare the technology and user experience for different types of ITCH. This paper aims to answer the following questions: under a certain heritage context, what is the commonly-used technology? Is there a correlation between the purpose of using VR/AR, the enabling technology, and user experience? And what are the differences in the focus between academia and industry in China?

4. DATA COLLECTION

The survey conducted in this paper will be based on the complete process of making a VR/AR application, from technical development to user interaction, discussing state-of-the-art cases that apply VR/AR to ITCH. These cases will be classified into three types: Group of Buildings, Monuments, and Sites, according to UNESCO's classification of ITCH (Kurniawan, 2011). As many museums were established on ITCH, they are also included in VR/AR industry cases.

Because of the different technical methods between VR and AR, two tables for collecting data are developed. Both tables include the purpose, hardware, software, and user experience. Purpose includes: Education (emphasizing cultural information dissemination among the public, not necessarily in the traditional classroom), Exploration (emphasizing that tourists can freely walk in the virtual models, but interaction or additional cultural information are not necessarily provided), Exhibition Enhancement (emphasizing to enrich the content of an existing exhibition).

For VR, Hardware, focusing on which type of display device is used, includes Head-Mounted-Display, Handheld Display, Non-handheld Display, Cave Automatic Virtual Environment, and Front-projected Holographic Display. Software, focusing on how the information of the heritage is digitalized, includes Data Collection (Traditional Measurement, Historic Drawings, 3D Scanning & Photogrammetry, Panorama, and Others), Data Processing (Actual Construction (3D models are constructed by collecting the point cloud of the heritage), Mathematical Construction (3D models are constructed based on the measurement), Artificial Construction (3D models are constructed without measurement)). User Experience, focusing on how the content is presented and how users can interact with the virtual environment, includes Content (2D Image, Video Clips, 3D Models, Audio Clips), Degree of Freedom (0 DOF, 3 DOF, 6 DOF), Presentation Style (Non-immersive Fimication (users only watch the content in the virtual world without interaction), Non-immersive Gamification (users can interact with the virtual objects), Fully-immersive Filmication and Fully-immersive Gamification), and Interaction Style (Hand-held Controllers, Hand-tracking, Voice Commands, Gaze, Mouth and Keyboard, Touchscreen, and No Interaction).

For AR, the overall organization of the framework is similar, from hardware, software to user experience. But because of the technical differences between VR and AR, hardware and software in the framework are adjusted to a certain extent. Hardware includes two parts: Display (Head-mounted display, Spatial AR, Handheld Display) and See-through Technology (Video See-Through (VST) and Optical See-Through (OST)). As AR heavily relies on the physical context and the tracking technology, Software and Algorithms are included, which are divided into Mapping Data Collection (3D Scanning & Photogrammetry, Panorama, 2D Image) and Tracking and Registration (2D Image Recognition, Simultaneous Localization And Mapping (SLAM), Visual Positioning System (VPS)).

For data from academic research, the papers, which are searched from the CNKI database, are further selected according to the criteria mentioned above. Finally, 14 highly relevant papers were collected. More information is in the following tables (Table 1, Table 2). For cases in XR Industry, the methods of collecting data about cases in XR Industry are through interviewing VR/AR practitioners from four companies (MEIJING, ROKID, HIAR, and NREAL). The collected data is shown below (Table 3, Table 4).

5. DATA ANALYSIS AND DISCUSSION

Based on the collected data, this research aims to determine the technical methods for each type of ITCH, synthesize the conditions for applying VR and AR and compare the differences between academic and professional projects. The correlations between purpose, technical methods, and user experience for each type of ITCH in both academia and industry are visually presented (Figure 1- Figure 12).

5.1 Group of Buildings: VR applications

For "Group of Buildings" in academia, two purposes of using VR are education and exploration. When the projects aim for education, the hardware usually adopted is head-mounted displays and hand-held displays, combined with historical drawings and traditional measurements for mathematical construction or with 3D scanning for actual construction. As for user experience, more than three types of content are included in one educational project to provide multimedia information. All of the educational projects develop 6 DOF fully immersive gamification experiences so that users can freely move around in the virtual world and interact with virtual objects with hand-held controllers. When the projects aim for exploration, the common method is virtual roaming. Usually, desktop devices are used, and 3D virtual models are either reconstructed based on traditional measurement and historic drawings or artificially constructed. In the XR industry, groups of buildings are often used in ITCH scenes for educational purposes. Experiencers can access panorama contents from handheld displays and head-mounted displays to enjoy 2D images, video clips, and audio

clips, which are used to improve the touring experience and information conveyance efficiency. The fully-immersive or non-immersive filmication can be viewed in a 3 DOF environment. Users can manage their touring progress using hand-held controllers, touchscreen, or mouth and keyboard.

Comparing the VR application in groups of buildings in academia with that in the XR industry, we notice different technical methods of producing contents and different approaches to interaction. Many researchers would like to reconstruct 3D models of heritage based on precise measurements and produce a 6 DOF environment where users can roam freely. However, in a commercial VR product, a more efficient method of obtaining the physical context, panorama, is adopted, and only 3 DOF simulation is available. The difference may be caused by profit issues that a VR company needs to consider. However, a commercial VR product involves more types of interaction to attract potential users as much as possible.

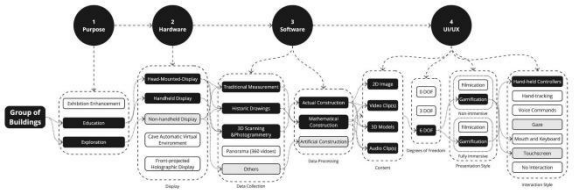

Figure 1. How VR is used in a group of buildings in academia

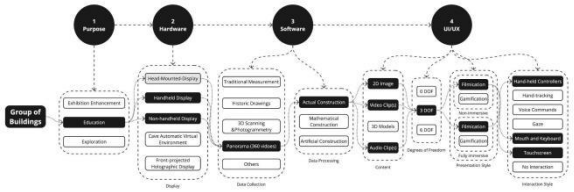

Figure 2. How VR is used in a group of building in the XR industry

5.2 Group of Buildings: AR applications

Academic cases of applying AR in groups of buildings aim to enhance education and exploration. For educational purposes, head-mounted displays and optical see-through technology are adopted to provide a more immersive environment. 3D scanning and SLAM are used for tracking and registration, which is then used to produce multimedia content in the 6 DOF gamification environment. Interaction is achieved through hand-tracking, voice commands, and gaze, to make the user's interaction with virtual objects more natural. For exploration purposes, hand-held displays and video see-through technology are common, with 2D image recognition. Although the 6 DOF environment is adopted, the content is presented with non-immersive filmication and gamification with touchscreen for interaction or no interaction. No AR cases used for the Group of Buildings have been found in the XR industry.

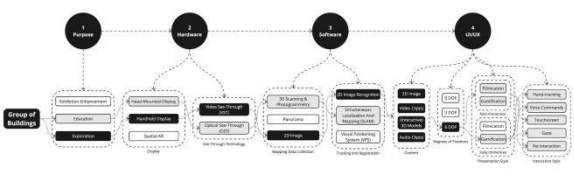

Figure 3. How AR is used in a group of buildings in academia

This phenomenon may be caused by operational factors when it comes to a practical AR project. Many groups of buildings, such as historic districts, are open and do not have fixed entrances and exits, which makes it difficult to manage AR devices rented to tourists. Additionally, in China, historic districts are often crowded with tourists. Under such a situation, tourists wearing AR glasses may get injured in the crowd.

5.3 Monuments: VR applications

For "Monuments", in academia, the main purpose is exploration, with devices such as head-mounted displays and non-handheld displays. Either panorama is used for actual construction to present images and video clips, or measurement and historic drawings are used to construct 3D models and present images and audio clips. The environment is usually 6 DOF, non-immersive gamification or fully immersive gamification. In the XR industry, Monuments use exactly the same technical approach as that mentioned in the Group of Buildings.

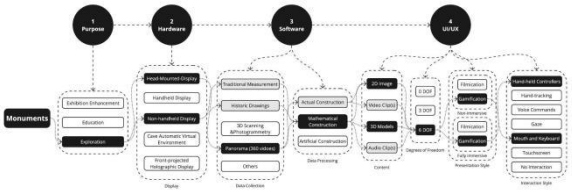

Figure 4. How VR is used in monuments in academia

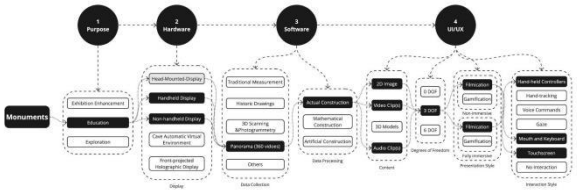

Figure 5. How VR is used in monuments in the XR industry

Cases in Academia and those in the XR industry both use panorama to collect data and use similar types of content in their VR applications in Monuments. However, researchers prefer 6 DOF gamification for users to freely explore the simulated environment, while practitioners opt for 3 DOF filmication for users to receive more information.

5.4 Monuments: AR applications

When it comes to AR application in Monuments, only cases in the XR industry are available. Such projects, designed for education or exploration, involve AR glasses with OST. They are supported by 3D scanning and photogrammetry for data collection in small cave spaces, SLAM for tracking and registration and a 6 DOF environment for content viewing. Voice commands and touchscreens are added for the immersive experience.

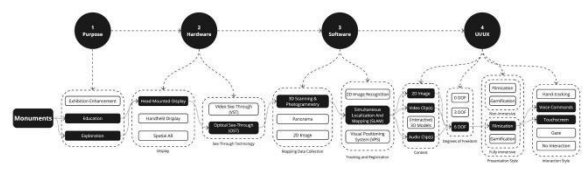

Figure 6. How AR is used in monuments in the XR industry

5.5 Sites: VR applications

For "Sites" in academia, one main purpose of using VR is education. With head-mounted displays, models of artifacts are reconstructed through 3D scanning, and the site is artificially constructed based on historical drawings. As a result, 3D models are presented in a 6 DOF fully immersive gamification environment, where users can interact with these models using hand-held controllers. In the XR industry, the exact same technical approach used in the Group of Buildings and Monuments is also adopted in Sites.

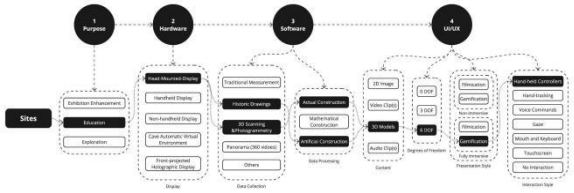

Figure 7. How VR is used in sites in academia

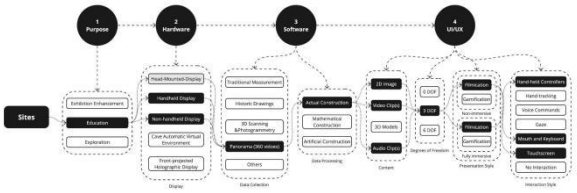

Figure 8. How VR is used in sites in the XR industry

Academic VR projects on Sites and practical VR projects on Sites share the same goal, education, but different approaches are taken. Researchers in academia use high-end technology to create a highly interactive 6 DOF virtual world that allows for hands-on learning. In the XR industry, low-cost methods are used to reproduce the physical world, but also use multimedia contents and various types of interaction to create an immersive learning experience.

5.6 Sites: AR applications

Academic cases of applying AR in Sites also aim for education. Although data on mapping, data collection, tracking, and registration methods are not available, it is known that the device used is usually a handheld display with VST, in order to present video clips, 3D models, and audio clips in a 6 DOF non-immersive gamification environment. Users can interact with 3D models by touching the screen. In the XR industry, AR is also suitable to be used in Sites to disseminate information for educational purposes or to encourage tourists to explore. Tourists can wear AR glasses equipped with OST technology. To collect mapping data, 3D scanning and photogrammetry are used, along with some 2D images for subsequent 2D image recognition. VPS is also required at this stage. When tourists wear AR glasses, they can experience content in a 6 DOF environment containing images, video clips, and audio clips. Through voice commands and touchscreen interaction, tourists can enjoy fully immersive content and see the once architectural heritage reconstructed in 3D.

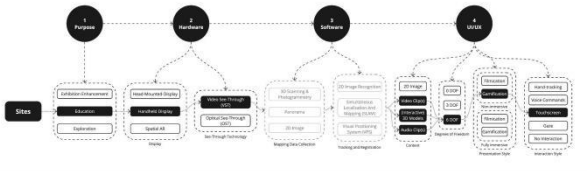

Figure 9. How AR is used in sites in academia

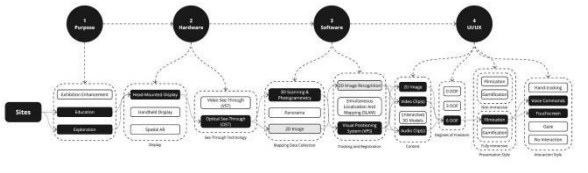

Figure 10. How AR is used in sites in the XR industry

Unlike researchers who use handheld display devices and design 6 DOF gamification AR applications on Sites, AR practitioners in the XR industry prefer head-mounted display devices with 6 DOF filmcation on sites. The underlying reason why practitioners are reluctant to develop games with their head-mounted display might be that sites are usually outdoors with strong light, and AR game applications can hardly provide a comfortable experience for users in such a context.

5.7 ITCH Relevant Museums: VR applications

For “ITCH Relevant Museums", only cases in the XR industry are found. For the VR applications, the main purpose is education. Handheld and non-handheld displays are more often used by users than head-mounted displays. Panoramas are often captured for actual constructions. 2D images, video clips, and audio clips can be found in the user interface. 3 DOF content provides non-immersive or fully immersive filmic experiences. Users can choose to interact with the content using hand-held controllers, touchscreens, or mouth and keyboards.

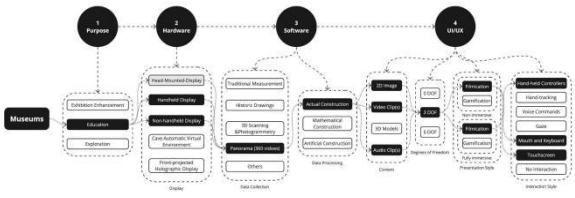

Figure 11. How VR is used in ITCH relevant museums in the XR industry

5.8 ITCH Relevant Museums: AR applications

For the AR projects, all of them share the same goal of exhibition enhancement or education. The project either uses AR glasses for touring or uses handheld displays. AR glasses normally use OST, while phones and tablets use VST. 3D scanning and photogrammetry could be used to capture point cloud information of the exhibition hall in the museum, which delivers a more interactive AR experience to visitors. At the same time, 2D image recognition can also be used for display enhancement. SLAM and VPS technology enable fully immersive styles for AR glasses and mobile terminals. In museums, touchscreens, voice commands, and gaze interaction are used.

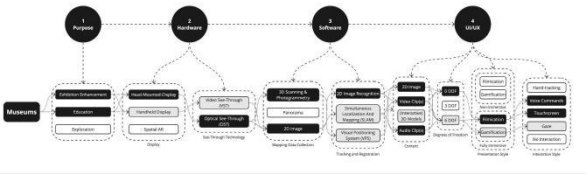

Figure 12. How AR is used in ITCH relevant museums in the XR industry

AR is commonly used in museums in practical projects for several reasons: First, museums provide indoor environments with simple and stable lighting conditions, making it convenient to use technologies such as hand-tracking and gaze. Second, museum operations are relatively simple, with determined visiting routes, which makes it easier for museum staff to manage the rental of AR devices. Third, museums have lower requirements for tracking and registration accuracy, mainly using 2D image recognition technology and 0 DOF video clips. Additionally, museum scenes are suitable for setting up gaming functions, since much information about exhibitions can be expressed through gamification. Finally, there is currently a surge in demand for the related market in China, and thus the industry has many practical opportunities.

6. CONCLUSION

In conclusion, this research synthesizes VR/AR applications in four types of ITCH and discusses their purpose, technology, and user experience to provide an overall insight into VR/AR applications in different types of heritage contexts. It also bridges academia and the XR industry by comparing the differences between cases from researchers and practitioners.

One limitation of this research is that the number of cases and papers collected may not be large enough to reach a more general conclusion about which technology is more suitable for each type of ITCH. More cases from the XR industry and more papers from other databases need to be collected. Another limitation is that the scope of cases is defined in China, but relevant practices in other countries may differ from those in China. Therefore, research and practices from around the world need to be included in further research. Although there are some limitations, the outcomes may help researchers further investigate how to apply VR or AR under a certain context of immovable tangible cultural heritage and help managers of heritage sites decide which type of technology is worthwhile to invest in to attract more tourists. The tourists will be the beneficiaries, as they can gain richer information and more engaging experiences if the appropriate immersive technology is used.

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APPENDIX

VR (Academia)											
Development Process	**Detailed Information**		**Goup of Buildings (GB)**	**GB**	**GB**	**GB**	**GB**	**Monuments (MO)**	**MO**	**MO**	**MO**	**Sites**
			Guangfu Local Architecture (Tan, 2021)	**Tengwang Tower (Jia, 2016)**	**Dongnuange Pavilion (Liu, 2020)**	**Shijia Tower (Tong, 2017)**	**Fenghuang County (Li et al., 2021)**	**Ya'an Gaoyi Watchtower (Liu, 2018)**	**Jiaoshan Stele Forest (Zhou, 2021)**	**Jiayuguan Fortress (Lin et al., 2019)**	**Watchtower of Ming Great Wall (Xv, 2021)**	**Qinling Mausoleum (Luo, 2019)**
1 Purpose	Exhibition Enhancement		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Education		☐	☐	☑	☑	☑	☐	☐	☐	☐	☑
	Exploration		☑	☑	☐	☐	☐	☑	☑	☑	☑	☐
2 Hardware	Display	Head-Mounted-Display	☐	☐	☑	☑	☑	☐	☑	☐	☑	☑
		Handheld Display	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐
		Non-handheld Display	☑	☑	☐	☐	☐	☑	☐	☑	☐	☐
		Cave Automatic Virtual Environment	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		Front-projected Holographic Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3 Software	Data Collection	Traditional Measurement	☐	☑	☐	☑	☐	☐	☐	☑	☐	☐
		Historic Drawings	☐	☑	☐	☑	☐	☑	☐	☐	☐	☑
		3D Scanning&Photogrammetry	☐	☐	☑	☐	☑	☐	☐	☐	☐	☑
		Panorama	☐	☐	☐	☐	☐	☐	☑	☐	☑	☐
		Others	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
	Data Processing	Actual Construction	☐	☑	☑	☐	☑	☐	☑	☐	☐	☑
		Mathematical Consturction	☐	☐	☐	☑	☐	☑	☐	☑	☑	☐
		Artificial Construction	☑	☐	☐	☐	☐	☐	☐	☐	☐	☑
4 User Interface & User Experience	Content	2D Image	☑	☐	☑	☐	☑	☑	☑	☐	☐	☐
		Video Clip(s)	☑	☐	☐	☑	☑	☐	☑	☐	☐	☐
		3D Models	☑	☑	☑	☑	☑	☑	☐	☑	☑	☑
		Audio Clip(s)	☑	☐	☑	☑	☑	☑	☐	☐	☐	☐
	Degrees of Freedom	0 DOF	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		3 DOF	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		6 DOF	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
	Presentation Style	Non-immersive: Filmication	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		Non-immersive: Gamification	☑	☑	☐	☐	☑	☑	☐	☑	☐	☐
		Fully immersive: Filmication	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		Fully immersive: Gamification	☐	☐	☑	☑	☑	☐	☑	☐	☑	☑
	Interaction Style	Hand-held Controllers	☐	☐	☑	☑	☑	☐	☑	☐	☑	☑
		Hand-tracking	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		Voice Commands	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		Gaze	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
		Mouth and Keyboard	☑	☑	☐	☐	☐	☑	☐	☑	☐	☐
		Touchscreen	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐
		No Interaction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Table 1. VR application in ITCH from academia

AR (Academia)								
Development Process	**Detailed Information**		**Goup of Buildings (GB)**	**GB**	**GB**	**Monuments (MO)**	**Sites (S)**	**Musuems (M)**
			Five Avenues (Zou, 2017)	**Chengde Historical District (Su and Li, 2021)**	**Baoguo Temple (Yao, 2020)**		**Weiyang Palace (Nie, 2020)**	
1 Purpose	Exhibition enhancement		☐	☐	☐		☐	
	Education		☐	☐	☑		☑	
	Exploration		☑	☑	☐		☐	
2 Hardware	Display	Head-Mounted-Display	☐	☐	☑		☐	
		Spatial AR	☐	☐	☐		☐	
		Handheld Display (phone, tablet)	☑	☑	☐		☑	
	See-Through Technology	Video See-Through (VST)	☑	☑	☐		☑	
		Optical See-Through (OST)	☐	☐	☑		☐	
3 Software & Algorithms	Mapping Data Collection	3D Scanning & Photogrammetry	☐	☐	☑		☐	
		Panorama	☐	☐	☐		☐	
		2D Image	☑	☑	☐		☐	
	Tracking and Registration	2D Image Recognition	☑	☑	☐		☐	
		Simultaneous Localization And Mapping (SLAM)	☐	☐	☑		☐	
		Visual Positioning System (VPS)	☐	☐	☐		☐	
4 User Interface & User Experience	Content	Image	☑	☐	☑		☐	
		Video Clip(s)	☑	☐	☑		☑	
		(Interactive) 3D Content	☐	☑	☑		☑	
		Audio Clip(s)	☑	☐	☑		☑	
	Degrees of Freedom	0 DOF	☐	☐	☐		☐	
		3 DOF	☐	☐	☐		☐	
		6 DOF	☑	☑	☑		☑	
	Presentation Style – Non-immersive	Filmication	☑	☐	☐		☐	
		Gamification	☐	☑	☐		☑	
	Presentation Style – Fully immersive	Filmication	☐	☐	☐		☐	
		Gamification	☐	☐	☑		☐	
	Interaction Style	Hand-tracking	☐	☐	☑		☐	
		Voice Commands	☐	☐	☑		☐	
		Touchscreens	☐	☑	☐		☑	
		Gaze	☐	☐	☑		☐	
		No Interaction	☑	☐	☐		☐	

Table 2. AR application in ITCH from academia

VR (XR Industry)									
Development Process	**Detailed Information**		**Goup of Buildings (GB)**	**GB**	**GB**	**Monuments (MO)**	**MO**	**Sites (S)**	**ITC related Musuems (M)**
			Classical Gardens of Suzhou (MEIJING)	**Ancient City of Ping Yao (MEIJING)**	**Summer Palace(MEIJING)**	**Mogao Caves (MEIJING)**	**The Great Wall (MEIJING)**	**Archaeological Ruins of Liangzhu City (MEIJING)**	**Museum of Archaeological Ruins of Liangzhu City (MEIJING)**
1 Purpose	Exhibition enhancement		☐	☐	☐	☐	☐	☐	☑
	Education		☑	☑	☑	☑	☑	☑	☑
	Exploration		☐	☐	☐	☐	☐	☐	☐
3 Hardware	Display	Head-Mounted-Display	☑	☑	☑	☑	☑	☑	☑
		Handheld Display (phone, tablet)	☑	☑	☑	☑	☑	☑	☑
		Non-handheld Display (desktop)	☑	☑	☑	☑	☑	☑	☑
		Cave Automatic Virtual Environment	☐	☐	☐	☐	☐	☐	☐
		Front-projected Holographic Display	☐	☐	☐	☐	☐	☐	☐
2 Software	Data Collection	Traditional Measurement	☐	☐	☐	☐	☐	☐	☐
		3D Scanning&Photogrammetry	☐	☐	☐	☐	☐	☐	☐
		Panorama	☑	☑	☑	☑	☑	☑	☑
		Historic Drawings	☐	☐	☐	☐	☐	☐	☐
		Others	☐	☐	☐	☐	☐	☐	☐
	Data Processing	Actual Construction	☑	☑	☑	☑	☑	☑	☑
		Mathematical Construction	☐	☐	☐	☐	☐	☐	☐
		Artificial Construction	☐	☐	☐	☐	☐	☐	☐
4 User Interface & User Experience	Content	2D Image	☑	☑	☑	☑	☑	☑	☑
		Video Clip(s)	☑	☑	☑	☑	☑	☑	☑
		3D Models	☐	☐	☐	☐	☐	☐	☐
		Audio Clip(s)	☑	☑	☑	☑	☑	☑	☑
	Degrees of Freedom	0 DOF	☐	☐	☐	☐	☐	☐	☐
		3 DOF	☑	☑	☑	☑	☑	☑	☑
		6 DOF	☐	☐	☐	☐	☐	☐	☐
	Presentation Style – Non-immersive	Filmication	☑	☑	☑	☑	☐	☐	☐
		Gamification	☐	☐	☐	☐	☐	☐	☐
	Presentation Style – Fully immersive	Filmication	☑	☑	☑	☑	☑	☑	☑
		Gamification	☐	☐	☐	☐	☐	☐	☐
	Interaction Style	Hand-held Controllers	☑	☑	☑	☑	☑	☑	☑
		Hand-tracking	☐	☐	☐	☐	☐	☐	☐
		Voice Commands	☐	☐	☐	☐	☐	☐	☐
		Gaze	☐	☐	☐	☐	☐	☐	☐
		Mouth and Keyboard	☑	☑	☑	☑	☑	☑	☑
		Touchscreen	☑	☑	☑	☑	☑	☑	☑
		No Interaction	☐	☐	☐	☐	☐	☐	☐

Table 3. VR cases in ITCH from the XR industry

AR								
Development Process	**Detailed Information**		**Goup of Buildings (GB)**	**Monuments (MO)**	**Sites (S)**	**ITC related Musuems (M)**	**M**	**M**
				Mogao Caves (ROKID)	**Archaeological Ruins of Liangzhu City (ROKID)**	**Museum of Archaeological Ruins of Liangzhu City (ROKID)**	**Museum of Archaeological Ruins of Sanxingdui (NREAL)**	**Xibaipo Memorial (HIAR)**
1 Purpose	Exhibition enhancement			☐	☐	☑	☑	☑
	Education			☑	☑	☑	☑	☑
	Exploration			☑	☑	☐	☐	☐
2 Hardware	Display	Head-Mounted-Display		☑	☑	☑	☑	☐
		Spatial AR		☐	☐	☐	☐	☐
		Handheld Display (phone, tablet)		☐	☐	☐	☐	☑
	See-Through Technology	Video See-Through (VST)		☐	☐	☐	☐	☑
		Optical See-Through (OST)		☑	☑	☑	☑	☐
3 Software & Algorithms	Mapping Data Collection	3D Scanning & Photogrammetry		☑	☑	☐	☑	☐
		Panorama		☐	☐	☐	☐	☐
		2D Image		☐	☑	☑	☐	☑
	Tracking and Registration	2D Image Recognition		☐	☑	☑	☐	☑
		Global Positioning System (GPS)		☐	☐	☐	☐	☐
		Simultaneous Localization And Mapping (SLAM)		☑	☐	☐	☐	☑
		Visual Positioning System (VPS)		☐	☑	☐	☑	☐
4 User Interface & User Experience	Content	Image		☑	☑	☑	☑	☑
		Video Clip(s)		☑	☑	☑	☑	☑
		(Interactive) 3D Content		☐	☐	☐	☑	☐
		Audio Clip(s)		☑	☑	☑	☑	☑
	Degrees of Freedom	0 DOF		☐	☐	☑	☐	☐
		3 DOF		☐	☐	☐	☐	☐
		6 DOF		☑	☑	☐	☑	☑
	Presentation Style: Non-immersive	Filmication		☐	☐	☐	☐	☑
		Gamification		☐	☐	☐	☐	☐
	Presentation Style: Fully immersive	Filmication		☑	☑	☑	☐	☐
		Gamification		☐	☐	☐	☑	☐
	Interaction Style	Hand-tracking		☐	☐	☐	☐	☐
		Voice Commands		☑	☑	☑	☐	☐
		Touchscreens		☑	☑	☑	☐	☑
		Gaze		☐	☐	☐	☑	☐
		No Interaction		☐	☐	☐	☐	☐

Table 4. AR cases in ITCH from the XR industry