

## Article

# Virtual Reality Usability and Accessibility for Cultural Heritage Practices: Challenges Mapping and Recommendations

Hwei Teeng Chong <sup>1</sup>, Chen Kim Lim <sup>1,\*</sup>, Minhaz Farid Ahmed <sup>1</sup> , Kian Lam Tan <sup>2</sup> and Mazlin Bin Mokhtar <sup>1</sup>

<sup>1</sup> Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia (UKM), Bangi 43600, Selangor, Malaysia; p109634@siswa.ukm.edu.my (H.T.C.); minhaz@ukm.edu.my (M.F.A.); mazlin@ukm.edu.my (M.B.M.)

<sup>2</sup> School of Digital Technology, Wawasan Open University (WOU), 54, Jalan Sultan Ahmad Shah, George Town 10050, Penang, Malaysia; andrewtan@wou.edu.my

\* Correspondence: kim@ukm.edu.my

**Abstract:** In recent years, virtual reality (VR) is at its maturity level for real practical exercises amongst many fields of studies, especially in the virtual walkthrough exploration system of cultural heritage (CH). However, this study remains scattered and limited. This work presents a systematic review that maps out the usability and accessibility issues that are challenging in using VR in CH. We identified 45 challenges that are mapped into five problem groups: system design, development process, technology, assessment process and knowledge transfer. This mapping is then used to propose 58 recommendations to improve the usability and accessibility of VR in CH that are categorized in three different recommendation groups namely, discovery and planning, design and development, and finally the assessment factors. This analysis identified the persistence in certain accessibility and usability problems such as there is a limit in navigating the view and space that constraint the users' free movement and the navigation control is not ideal with the keyboard arrow button. This work is important because it provides an overview of usability and accessibility based challenges that are faced in applying, developing, deploying and assessing VR in the usage of digitalizing CH and proposed a great number of constructive recommendations to guide future studies. The main contribution of this paper is the mapping of usability and accessibility challenges into categories and the development of recommendations based on the identified problems.

**Keywords:** usability (UB); accessibility; user experience (UX); virtual reality (VR); cultural heritage (CH)



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## 1. Introduction

In previous years, virtual reality (VR) technology gained worldwide acknowledgement and reached its dependable point for practical uses. Conversely, VR systems are still rarely utilized because of several issues in their design and development phases. The drawbacks can be derived from the cost, complexity, accessibility (AC) and maintainability of the application system. The drawbacks of this system application need to be reviewed and improved further because of rapid technological advancement. Given the rapid development of innovation, the VR system has evolved with mobile implementation that comes along with specially designed wearable technologies to enable users to experience immersive VR [1]. The evolution of mobile implementation (e.g., smartphones and tablets) into VR is influenced by the advancement state of mobile intelligence and performance specifications; moreover, it is highly influenced by different mass users because of its convenience to perform daily activities [1,2].

Mobile VR implementation with head-mounted device (HMD) comes in a wide range of devices. The rapid phase in the development and enhancement of novel technologies created new and retained old challenges that require further improvement. Ref. [1] stated that the occurrence of system issues is due to high prices and other problems that included

complexity in development, limited accessibility to content and unfamiliar features and functionality. Various technology system design and development may also affect new usability (UB) restrictions.

The use of VR system can be beneficial and practical in many other areas of studies such as medical [3–5], gaming [6] and education [7]. In the context of presenting CH in the traditional way is to simulate CH presence [8]. However, to be able to further immerse users, we need practice simulation of VR into CH [9]. Therefore, further investigation and providing researchers and developers with extensive overview of VR system within the digital heritage context of practices are significant for further improvisation and research directions.

## 2. Methodology

The study selection was searched through the systematic review method within the major area of VR, UB and VH. The main source of references search was performed with advance, command or expert mode with the generated keywords in the four libraries database particularly the Web of Science, Science Direct, IEEE Xplore and Scopus. The generated keywords or terms that were selected for search included words or terms that are closely related to the major area of studies. Terms that share similar notions were grouped with “OR” to retrieve a broader view of articles and “AND” was to further group another notion of words. The keywords used for all database is shown in Table 1. Besides, the restriction of articles was also refined in the scope of English languages and the document types (article and conference) were the year range of 2007 to January 2020. Next, the filtration process began from eliminating duplicated papers and unrelated papers with abstract scanning. Then, intensive review on full-text article was conducted to obtain the final selection of papers. The flowchart presented in Figure 1 describes the complete process of inclusion/exclusion of papers.

**Table 1.** Generated keywords.

Main Keywords	Close Related Keywords
User Experience	(“human computer interaction” OR HCI OR usability OR “user satisfaction” OR “user interaction” OR “user immersion”)
Culture Heritage	(“digital heritage” OR “digital cultural heritage” OR “cultural heritage”)
Virtual Reality	(“virtual reality” OR VR)

Based on Figure 1, the paper extraction process was carried out through the keyword search while the paper filtration process was done by filtering the duplicated articles, the title and abstract scan and eliminating the inaccessible articles. The selection process was done via full text reading and including the articles based on the listed inclusion criteria and eliminating the articles based on the listed exclusion criteria.

The documents included in this systematic review research found in year 2012 to January 2020 in the Web of Science was 11, ScienceDirect was 371, IEEE Xplore was 52 and Scopus was 1117, making the total numbers of articles retrieved 1551. There were 80 documents that were filtered out as they were duplications in the total numbers of documents. After the filtration process of the duplicated documents, 1470 articles were first filtered by the title and then the abstracts were scanned through. At this stage, the inclusion criteria and exclusion criteria played an important role because we were very strict with documents that did not address VR or address the VR but not in the domain of CH and even in the context of CH, but no usability and accessibility emphasized in the user experience were excluded. Besides, documents that mentioned about augmented reality and mixed reality were not considered too as the usability and accessibility for this paper was concentrated on the application of VR on CH. This left 383 documents and 19 of them were not accessible for full-text reading. Off all papers selected (364 papers), only 47 papers were included because the remaining 316 papers fell outside of the scope of this paper due to majority of the papers mentioned about the challenges faced but not recommending the improvements for accessibility and usability of the VR in CH.

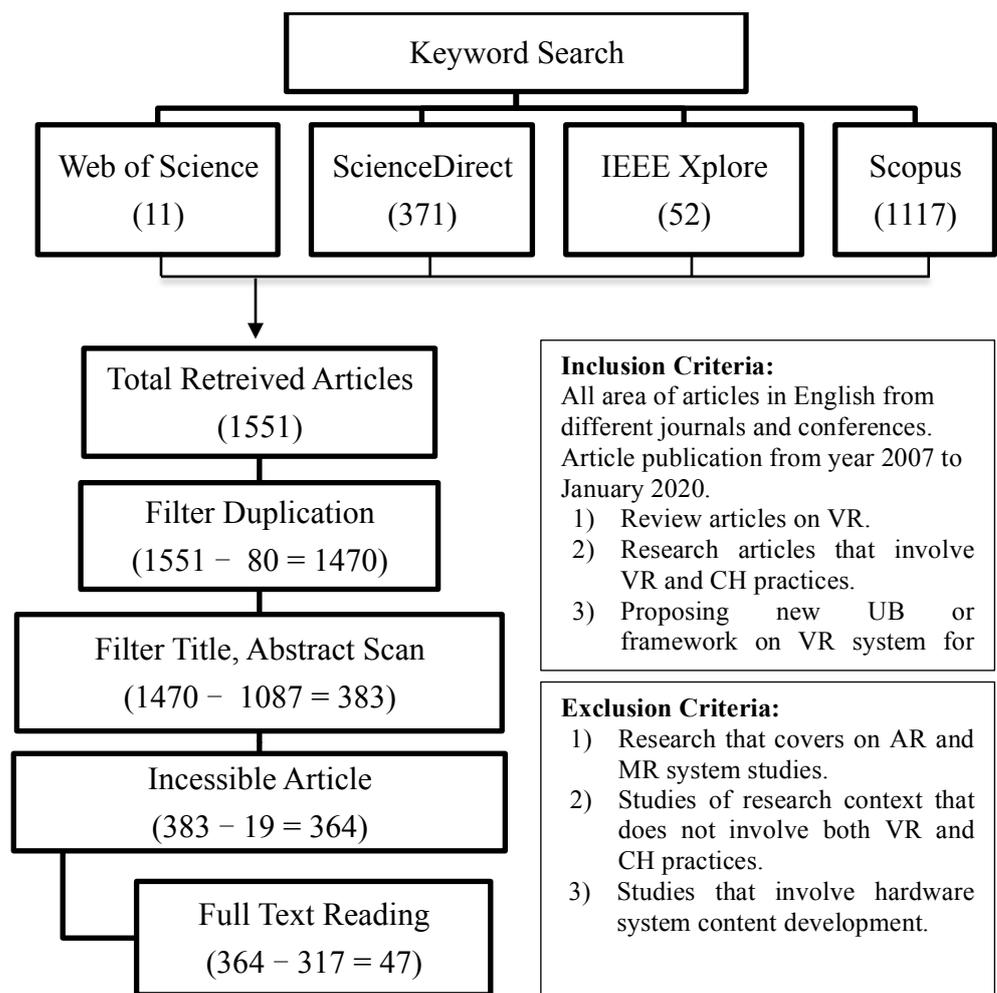


Figure 1. Flowchart of the complete process of inclusion/exclusion of papers found.

### 3. Descriptive Analysis of the Documents

This section presents a descriptive analysis of the 47 documents selected in the systematic review. The analysis included the number of publications by year. Figure 2 shows the distribution of 47 published papers in a yearly manner. There is a notable increase in the number of documents through the time series especially in 2018 and 2019. The difference in the year 2020 can be explained by the fact that we were conducting the systematic review early in the year and thus only January 2020 articles were included.

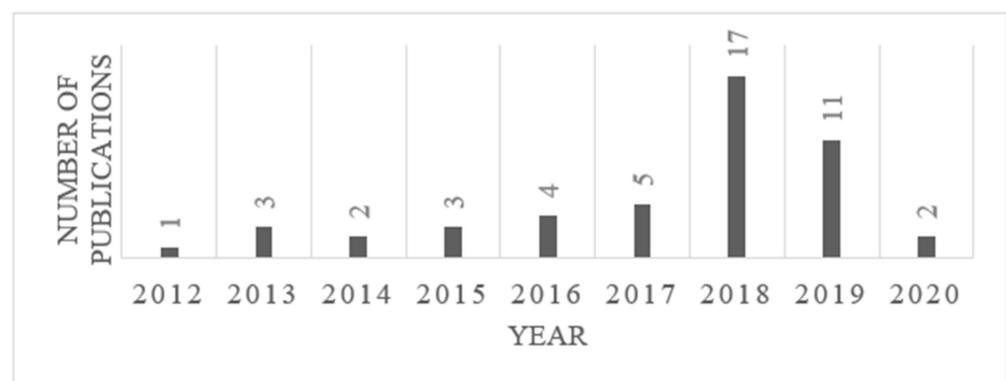
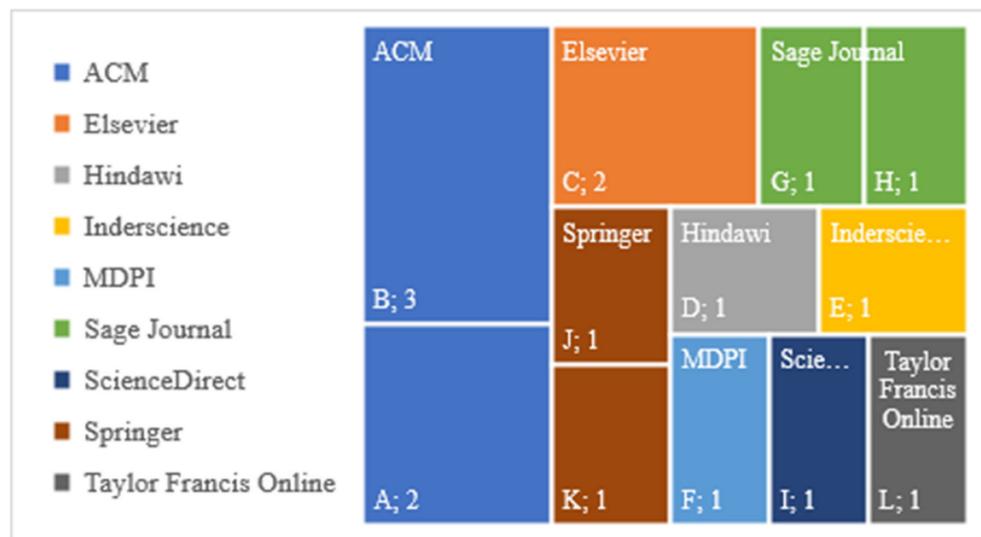


Figure 2. Number of publications distributed by year.

The analysis also presents the distribution of the 47 documents according to the type of publication and conference papers according to different regions. Concerning the publication type, there were 16 out of 47 documents that were journal papers while there were 31 conference papers. Figure 3 shows the 16 articles mapping to the journal databases. ACM is the highest numbers where the journals are in ( $n = 3$ ). Other journals including Elsevier, Hindawi, Inderscience, MDPI, Sage Journal, ScienceDirect, Springer and Taylor Francis Online. Figure 4 presents the remaining 31 documents that were mapped into its conference region and name. Europe is the region with the highest number of publications for the conference papers ( $n = 26$ ) and VSMM had the highest number of documents in that region ( $n = 4$ ) all in year 2018.



A	Presence: Teleoperators and Virtual Environments ( $n = 1$ ; 2018) ( $n = 1$ ; 2019)
B	Journal on Computing and Cultural Heritage (JOCCH) ( $n = 1$ ; 2015) ( $n = 2$ ; 2018)
C	Digital Applications in Archaeology and Cultural Heritage ( $n = 1$ ; 2019) ( $n = 1$ ; 2019)
D	Advances in Multimedia ( $n = 1$ ; 2019)
E	International Journal of Simulation and Process Modelling ( $n = 1$ ; 2017)
F	Computers ( $n = 1$ ; 2019)
G	Journal of educational computing research ( $n = 1$ ; 2018)
H	The International Journal of Research into New Media Technologies ( $n = 1$ ; 2020)
I	Journal of Cultural Heritage ( $n = 1$ ; 2017)
J	Multimedia Tools and Applications ( $n = 1$ ; 2018)
K	On Transactions on Edutainment IX ( $n = 1$ ; 2013)
L	Interactive Learning Environments ( $n = 1$ ; 2019)

Figure 3. 16/47 articles mapping to journal database.

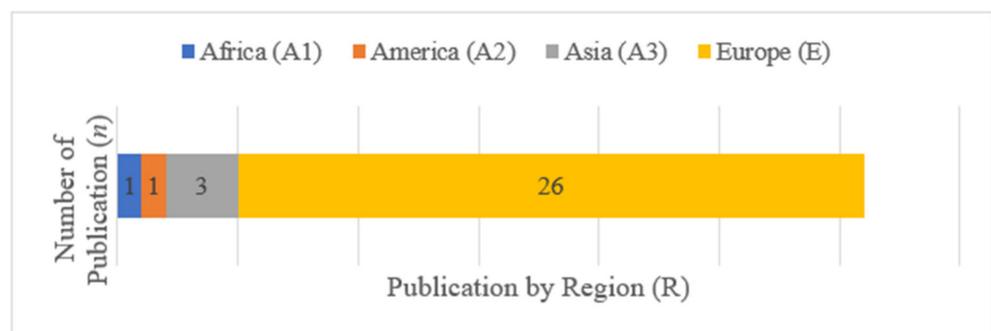


Figure 4. Cont.

R	Conference Name	Year	n
A1	In Proceedings of the Second African Conference for Human Computer Interaction: Thriving Communities	2018	1
A2	In Symposium on Virtual and Augmented Reality (SVR)	2018	1
A3	In Digital Information and Communication Technology and Its Applications (DICTAP)	2014	1
	In 16th International Symposium on Distributed Computing and Applications to Business, Engineering and Science (DCABES)	2017	1
	In Proceedings of the International Conference on Artificial Intelligence and Virtual Reality	2018	1
E	In Euro-Mediterranean Conference	2014	1
	In Digital Heritage	2015	1
	In Information, Intelligence, Systems and Applications (IISA), 2015 6th International Conference	2015	1
	In Multimedia & Expo Workshops (ICMEW), 2016 IEEE International Conference	2016	1
	In AVI* CH	2016	1
	In Computational Intelligence for Multimedia Understanding (IWCIM), 2016 International Workshop	2016	1
	In International Conference on Augmented Reality, Virtual Reality and Computer Graphics	2016	1
	In 2018 7th European Workshop on Visual Information Processing (EUVIP)	2018	1
	In Proceedings of the 13th Biannual Conference of the Italian SIGCHI Chapter: Designing the next interaction	2019	1
	In Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia	2019	1
	In World Conference on Information Systems and Technologies	2019	1
	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 2019, XLII-2/W10	2019	1
	In International Conference on VR Technologies in Cultural Heritage	2018	2
	In Proceedings of the CHI Conference on Human Factors in Computing Systems	2018	1
		2019	1
	In International Conference on Virtual System & Multimedia (VSMM)	2012	1
		2017	3
	In Digital Heritage International Congress (DigitalHeritage)	2013	2
	In Digital Heritage International Congress (DigitalHERITAGE) held jointly with International Conference on Virtual Systems & Multimedia (VSMM)	2018	4

Figure 4. A total of 31/47 articles mapping to the conference region and name.

#### 4. Challenges Mapping

VR technology practices show many advantages for CH practices, this technology also identified other challenges and limitations for implementation [10,11]. Reviews are categorized on the basis of the practices in this subject matter. The results are mapped into five categories: system design, development process, technology, assessment process and knowledge transfer (Figure 5).

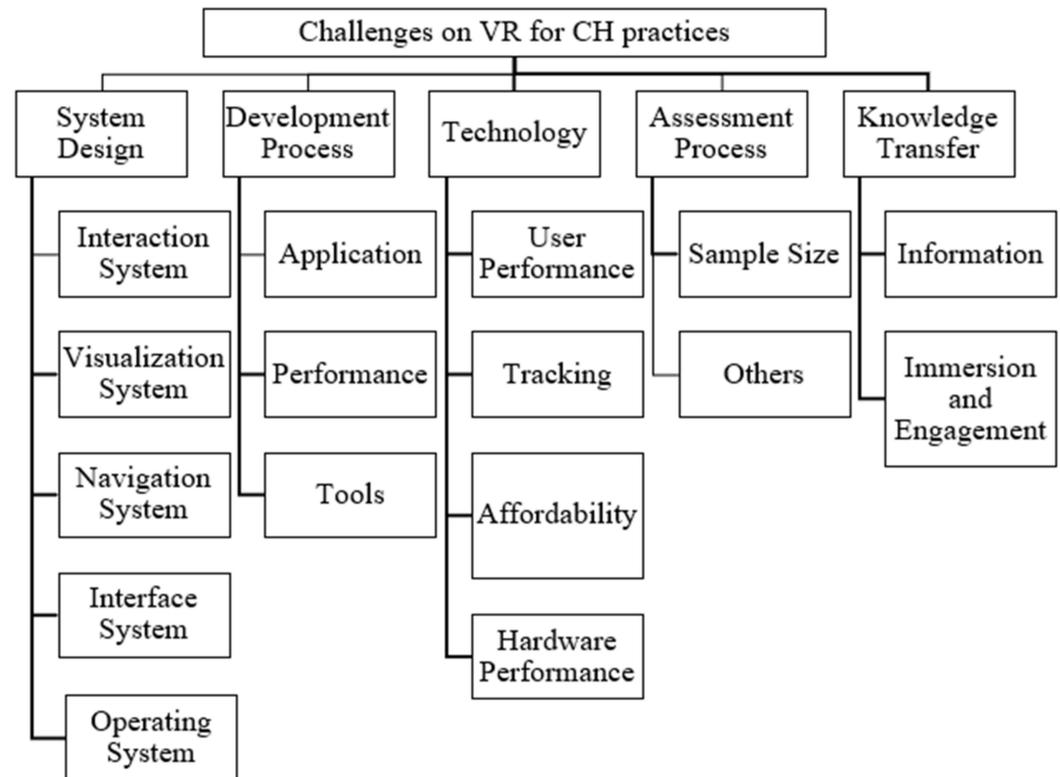


Figure 5. Categories of challenges mapped.

##### 4.1. System Design

The concerns within the VR system design in practices are divided into subcategories. VR technology is a complex system that allows various types of interactivity. Consequently, various research scope in terms of interactivity for UX involve the interaction system, visualization system, navigation system, interface system and not forgetting, the operating system [12,13]. Reviews on challenges are also concerned on technology tracking accuracy to spacing setups, the reliability of input techniques design for specific tasks, information transfer method to teach users to operate such technology within the application and the need for widespread the technology practices.

**Interaction System:** The VR interaction system aimed to meet the term ‘naturalness’ during interaction activities to achieve high level of immersion. Meeting ‘natural’ interactions are similar to how users interact with objects in a real-world environment seamlessly. However, various challenges are reported within the system whereby the requirement of long practices is emphasized to interact with the system. The challenges including various users’ interaction behavior especially hand interaction style actually conflicts in the real environment [14]. A lack of standardized gesture mechanisms such as body movement restriction and variation range of postures is also another challenge. Some user needs an assistant to guide them as being unfamiliar with system controls and requires some time to acquire [15,16]. These subsequently affect the tracking accuracy fail to recognize fast hand gesture movement or large blockage area mainly due to interaction malfunction [17,18]. For example, grasping big objects is difficult due to physical impact. The delay issues in VR are usually caused by needing ample time of loading on interactive input due to interaction

feedback that may be misled by other combined settings and multiple interaction devices or continuous interaction input to perform complex tasks by the user.

**Visualization system:** The VR system operates in rendering interactive 360-degree views where users can interact in real-time to visualize and experience the built VE surrounding [19]. With such an advantage, many concerns on the visual system design, development and implementation practices still need to be addressed. Generally, the practices included the orientation of visual defect such as discomfort with camera visual perception and rendering delay in achieving visual rendering with system performance. Multi-users' collision causes visual disappearance while limited field of view causes rendering constrain on image resolution [18]. Moreover, visual pixilation such as flickers and glitches effects during continual movement influenced personal UX subjected to 3D image quality presentation [20]. Concerns are highlighted in the area of UX space (e.g., physical and virtual) and system application performance to cater for specific tasks. These components influence and determine UX results. Other rendering concerns include:

- Multiple aerial views and distorted virtual view;
- Low luminance on screen affects difficulty to identify objects;
- Parallel rendering algorithm are still unavailable within the development tool;
- Only achievable with light 3D visual medium in room;
- Capturing realistic 3D graphics still present countless limitations.

**Navigation system:** Navigation system is a system that requires interactive inputs that allows users to navigate themselves interactively within the 3D VE or a 3D virtual world. The advantage of navigating in VE with VR system is limitless regardless of virtual space and time besides the constraint on designed and developed VE space. The visibility issue of the teleportation system on user sense of presence is one of the biggest concerns and thus the way-making and trace pathway feature is deficient [21]. Yet, there are still other concerns such as:

- Difficulty in understanding space and distance in relation to VE;
- Lacking on user's location indication in VE.

These concerns highlighted on space design in operating the system despite the knowledge needed on how to navigate within the system.

**Interface system:** Interface design for VR system can be very challenging in terms of implementing it in 3D virtual interactive space to be able to create effective communication between users and the system. The paper discussed concerns mainly on interface interference leads to challenges in selecting objects as the settings are different depending on technology applications [22] and insufficient knowledge perception on cross object interface causing limited studies on radial menu as structure menu [23]. Other challenges for interface system include:

- Complexity in multigestures interface design that is connected between all features;
- Large interface or widget display may not suit towards enormous environment and obstruct UX;
- Deficiency on 3D user interface design as interface design lack of naturalness.

Interface design plays an important role to inform users on how to navigate and operate the system. The appropriateness on implementation method determine the UB of system for UX.

**Operating system:** This section reviews concerns on the VR system practice for CH content studies. To summarize, educating the public is always difficult but still physical assisted instruction is required during the initial try-outs as not all the users understand the only visuals information presented. Motion sickness is noticeable with increased age group and the restriction to access the system leads to restricted usage duration [24]. Other concerns include issues between real and virtual space.

- Application is still in its prototype stage and inadequate maintenance [25,26];
- Content is only for individual appreciation, which may not serve other regions;
- Multiple UB issues and multi-UX is missing;

- Security breach;
- Internet platform reduces rendering polygon and connectivity dependency;
- Operate on different device performance leads to different details of content accuracy presentation and 3D reconstruction development [27];
- Spatial audio features constricted to presenting stereo panning and not full 360-degree;
- Influenced by technology effects instead of focus on content experience;
- Limited practical area for other application;
- No resolution is provided to all issues with walkthrough application [21].

These review findings highlighted that operating applications are wide, and many considerations are needed for implementations.

#### 4.2. Development Process

Various areas of development for VR system practices are available. Review concerns are subcategorized into the application system, performance and development tools. Developing a VR system for implementation practices requires complex process to output the application for UX. As a result, many concerns are highlighted within the development practices.

**Application:** This section describes challenges in developing application system practice. Some of the main challenges include development that is still in progress or attempted for the first time [28], poor definition of virtual content design purposes due to missing design, having a set of standard rules and lack of clarity on information presentation [29], and applications that operate on different devices that lead to different 3D reconstruction development processes [27]. Incompatibility between applications and devices for examples are web development is yet to integrate with VR glasses and complexity in authoring VR environment. Other problems in application system development include the following:

- Insufficient digitized remote-based virtual content and scenario;
- A 3D graphic construction is time consuming;
- File format underdetermined;
- Trial-and-error approach;
- Lack of originality in content and simplifying information transfer;
- Modeling inaccuracy of large area due to site modernization or restoration are observed.

This summary is within the application contents and the resources needed for the development of practices and devices are considered for implementation.

**Performance:** Reviews highlighted their concerns on the needs of high resources whilst dealing with graphics development for VR system. Optimizing graphic details to achieve responsive system is the focus of system performance within the development process. Bad performances are system that consumes longer time to load image texture and consume high data processor calculation for search or scanning feature [20]. The concerns also deal with:

- A 3D model mapping resolution difference caused by lighting source and algorithm of relief mapping restriction [15];
- Uploading large amount of 3D datasets into game engine requires ample of time [30].

**Tools:** Development process that emphasized on the tools to develop applications. The challenges faced by the tools used are highlights as follows:

- Accuracy and precision systems include tasks that are difficult to perform [31];
- Lack capability to integrate events into objects and execute events in runtime;
- Requires high cost, skilled programmer and advanced user knowledge [32].

The number of studies within development tools are limited for CH content development practices. Therefore, studies can expand towards this area to determine or create a more advance tool that can ease development practices and utilized lower resources to output a usable and effective CH application.

### 4.3. Technology

VR technologies come in range of design and specifications. Consequently, various challenges are due to the number of design variation where each of the technology presents their own advantage and disadvantages. This section reviews the technology performance and the affordance of implementation practicability.

**User performance:** VR technology is designed to enable high level of immersion within users during their experiences that create sense of presence within the virtual world [33]. However, there are still several challenges identified within research documents. Users tend to get exhausted easily in trying to familiarize the control and after all, not all individuals can experience the immersion. Basically, personal experience differences depending on familiarity with technology and for the new users, they are generally observed to be more over overwhelmed with technology instead of content. Other challenges are summarized as follows:

- Being a first-time user who utilize such technologies is unfamiliar with multiple ways of input to experience VE [34];
- Unfamiliarity requires a lot of learning and remembering [17];
- Noticeable motion sickness is observed especially on senior citizens as discomfort and UB issues are observed after long operating time [35].

Most reviews concerned on multiple types of distractions that breaks or lower down the level of immersion whilst users are experiencing the system. These reviews are also concerned on one's wellbeing and familiarity whilst using the technology.

**Tracking:** Aside from the traditional technology of computing that enables interactivity between human and machines, the technology of VR system also supports ranges of tracking devices that can track either the user's whole-body movement or specific parts of the body movement, which allows user to interact with the system. Imitating users' physical movement can enhance the level of immersion and sense of presence during UX [16]. Yet, the technicality of the system presented various challenges [30]:

- Misoperated feedback;
- Distraction from wearing cloth and accessories;
- Tracking accuracy results high concentration in performing gestures combination;
- Marker-less motion capture cannot determine depth values;
- Limited number of users that are allowed due to the environmental effects and limited space at a time;
- Delay effects;
- Limitations in the low-cost hardware system.

With the current state of technology innovation, most researchers are concerned on implementing with higher-end machines to work more intelligently.

**Affordability:** VR system can be presented in various manners. However, challenges are presented within the affordability to implement such technology to practices. The difference in costing resulted in different user's movement and interaction freedom, limited accessible VR devices for practical and limited impact factors offered by various platforms. The concerns are:

- Resources in terms of requiring huge area, expensive, complexity in maintenance and installation, mastering, belief in exercise the technology and settings requirements to allow users learning [18,35];
- Additional instruction on installation to avoid device faultiness [36];
- Limitation on hardware specification to output virtual exhibition [29];
- Still presenting prototype version or its early stage of implementation [26];
- Needed proper exhibition presentation design for specific scenario [24];
- No applicable generic design properties are available for implementation [21];
- Lack promoting VR in public space for UX [25];
- Various complication obstructs technology acceptance and widespread of technology for practice [37].

Implementation and widespread of VR technology can be challenging in terms of handling a complex technology that requires ample of resources.

**Hardware performance:** Despite having the ability to practice VR technology in various platforms and hardware specifications, the different specifications of hardware lead to varying levels of performance that may influence UX. Firstly, devices cannot be generalized as an effective solution, i.e., VR glasses have their specific point of view for each multiuser during experience. Secondly, the head gear can only cater for one user and internet dependency for wireless feature and therefore, there is a need of high-end camera to visualize in-depth details beyond explorable panorama. Other highlighted challenges are as follows:

- Lack or limited processor powers for application inputs or development [30];
- Issues involve 3D space inputs: lack stability leads to motion sickness [38];
- PC platforms lack mobility for users to experience outdoor and level of immersion is lower for desktop and mobile platform [39];
- External environment factor cannot be easily manipulated Internet connection, battery consumption and overheating of device is dependent for each user [40].

#### 4.4. Assessment Process

The technology should be assessed to further suggest enhancement for continuous practices or assessment method process, which could assist researchers and developers to conduct their studies. A major assessment trend is yet to meet the standards for practice especially with the issues of immersion and sense of presence that is the most important factor when it comes to evaluating the VR application. The reviews presented major variation concerns amongst the participants. Besides, some secondary concerns categorized others details in the assessment trend studies.

**Sample size:** Many study reviews have limited participants involved in their research scope. For example, the sample size is derived from older samples due to a challenge to attain authority on younger samples [41] and is constrained to a selective group of population [42]. Respondents from different backgrounds and different age groups differ from how much they feel being immersed and generally also feel being present physically in the virtual world. The reason why the samples have various variables are as follows:

- Lack control-group based studies;
- Insufficient number and involve different races;
- Performed with convenient samples;
- Serves only experts and scholars;
- Unequal gender number;
- Based on voluntarily instead of considering gender bias;
- Focus on adolescent that may be challenging for elderly;
- Focus group and may not be representable for world populace.

The main issue is to consider the appropriate samples of users involved for the right research studies in order to generalize results that cater for that specific population sample of users.

**Others:** Besides the concerns on users' samples, the assessment trends highlighted various concerns in terms of the evaluation process and the variety of assessment variables within VR system studies. Majority of the challenges here are due to goals that are not properly defined as only the present consequence with only short-term experience were focused on. Other challenges are:

- Lack of significant assessments parameter of studies [1,14,43,44];
- Lack of a validation test due to a lot of time, money and human resources needed for testing [18,45];
- Variables for studies are manipulated and derived only from users' opinion and hearing where results are being influenced by many aspects [18];
- Limited and lack appropriate approach on data collection [46];

- Did not consider user prior experience and users' understanding towards technology [41];
- Younger kid samples turned out to be more interesting compared to older samples [41].

#### 4.5. Knowledge Transfer

The section concerns about transferring knowledge of the VR system that can be challenging where the users need to be self-involved into numbers of interactivity to experience and learn from the system. The concerns can solely be derived from application or technology or both outputs.

**Information:** Information transfer with the VR system can be effective when the content is complex to access any other mediums. Many studies involved the use of the VR system in teaching and learning practices. However, some of the concerns are misled information and a lack of accuracy or incomplete content due to the direct assumption method in interrelating and transmitting knowledge [25,47], a lack of investigation on learning memory and fantasy elements that have shown no influence on learning the VR system. The accuracy of information transfer depends on the quality of rendering and is mostly based on developers' or authors' design perception for knowledge transfer. Therefore, it is essential to involve the right authority to validate the information to transfer accurate and reliable information.

**Immersion and engagement:** This section presents the usage of VR technology to enhance user immersion and engagement into learning information. The concerns derived are within the existing learning facility that is still at its initial stages of application development, the children's learning ability is much slower compared with older participants and no grades awarded for learning output. This is because the user mainly focused on technology rather than VR for learning and also users' prior knowledge and experiences hinder the immersion and engagement because of the expectations between the real and virtual spaces. Vice versa, there is no absolute solution to curb learning distraction due to its implementation, especially for new users without prior experience. The disadvantage of distraction would be just as a benefit to motivate learners in active participants. Thus, it can also be utilized for knowledge transfer purposes.

### 5. Recommendations

The implementation of VR practice has gained extensive interest amongst research as it can be advantageous to use and practical in many other fields too. Exercising the system in CH practice is beneficial and can overcome various obstacles in presenting CH content. However, due to the range of VR system implementation and application, there are many challenges that need to be resolved. Therefore, this section compiles the recommendation from the reviewed papers in three categories: discovery and planning, design and development and finally the assessment factors.

#### 5.1. Guidelines on Discovery and Planning

Implementing the VR system is complex in terms of setting up, installation of applications and application system itself. This synthesis is beneficial towards practitioners and researchers who practice VR technology for CH content presentation. The application system covers on the application studies on the contents of the VR system that allows users to experience the designed and developed application in various platforms and recommendations of future works focused on various research matters. There are also recommendations on enhancing application by adding or improving presented contents within the system. This section also recommends on extending technology practices as VR technology comes in a range of devices and setups that can be beneficial for accessibility depending on practitioners or users' ability. Educating the user in the real world can be challenging, especially when presenting complex content learning environments that cannot be afforded in real-world or contents that are non-existent. Therefore, the use of VR system is practical in assisting in the presentation of complex contents in a virtual world with additional interactive features to engage users. The recommendations towards

all the enhancement on implementation the aforementioned features are divided into six categories: visual system, audio system, multiuser features, content, HDM and finally user support (See Table 2).

**Table 2.** Synthesis of recommendations on discovery and planning as identified in the studies examined.

Category	Recommendation	References
(A) Visual System	A1 Improve interface design and include instruction visually	Fonseca et al. [48]
	A2 Involve storytelling features with less technical application but maintaining the rendering quality	Koebel et al. [25]; Doležal et al. [40]
(B) Audio System	B1 Include adaptive voice recognition and gestures input	Zamora-Musa et al. [49]
	B2 Incorporate mute and visual response during speaking features	Kuták et al. [50]
(C) Multi-user Features	C1 Perform system management improvement on users account, validation and profile details	Katsouri et al. [43]
	C2 Substitute the traditional hardware control with gesture control	Loizides et al. [35]
	C3 enhance virtual-physical collaboration that incorporate realism avatar and ease users to identify another participant with name tag	Zamora-Musa et al. [49]; Kuták et al. [50]
	C4 Serious sensibility should be adopted to contextualize the exhibition	Parker & Saker [51]
(D) Content	D1 Provide greater access and entertainment introductory	Loureio et al. [52]; Minucciani and Garnero [53]; Maiwald et al. [54]
	D2 Incorporate on destination presentation with various and advance modes	Choi et al. [55]
(E) HDM	E1 Custom-made facility and accessibility with the use of HMDs to prolong UX	Rizvic et al. [56]; Koebel et al. [25]
	E2 Mobile design medium should be considered to suit in real-life social and political environment	Harley et al. [57]
	E3 Utilize available sensors to ease navigation system	Sinnott et al. [58]
(F) User Support	F1 VR learning as part topics of the school curriculum in teaching and learning	Taranilla et al. [46]
	F2 implementing edutainment and expanding other learning possibilities	Checa et al. [38]; Longo et al. [39]
	F3 Instant application can boost users' learning participation	Yang et al. [59]

## 5.2. Guidelines on Design and Development

Design and development approaches are crucial in outputting an effective and efficient application. The system requires multiple experts, such as content expert, graphic developers and programmers, to work together in the processes despite the need for other external resources. Interactivity and interfaces play a vital role in assisting users to obtain information and navigate within the system whilst presenting the interface design can be complex in 3D space. Recommendations on enhancing the user interface design implementation could assist in boosting the UB and widen the level of user acceptance to self-practice with the VR system. The recommendations of navigation system design depend on the required application tasks, activities and methods of system installation output. Consequently, various considerations are observed on the navigation design system to achieve seamless and continuous experience. Developing and rendering 3D visuals are complex and require great processor performance. This section also recommends various design development approaches towards improving visualization and implementation studies as comprehending the visual rendering system implementation can divert users' presence into the application, which enhance the level of immersion and achieve close gaps within the real and virtual world. Moreover, application

development approaches elicited considerable attention and finally, studies on development tool performance plays a role to enable a developer to output an operative application. The challenge lay upon how optimization tools can help in achieving a high level of effectiveness and efficiency within the development process. Thus, these recommendations can be beneficial to developers to exercise VR system towards CH practices. We categorized the recommendations on design and development into five categories: interaction system, interface design, navigation system, visualization system and approaches (development and optimization) as shown in Table 3.

**Table 3.** Summary of recommendations on design and development to enhance the usability and accessibility of VR in CH practices.

Category	Recommendations	References
(A) Interaction System	A1 Adding numbers of interactivity	Malomo et al. [1]; Hürst et al. [42]; Duguleana and Postelnicu [60]
	A2 Improvement of interactive techniques to enable users to gain information, enhance UX, increase accessibility, boost wider audience acceptance, cater for specific designed tasks and cater for public settings	Vishwanath et al. [24]; Longo et al. [39]; See et al. [20]; Häkkinen et al. [61]
	A3 Incorporate customization with more flexible interaction	Li et al. [18]
	A4 Utilize potentials of collaborative interactivity such as voice-activated interface to promote hands-free interaction	Kulik et al. [62]; Erickson et al. [63]
	A5 Provide short tutorials on interaction	Oliver et al. [64]
	A6 Integrate realistic tactile response through haptic devices and physical movement	Sinnott et al. [58]; Battisti and Di Stefano [65]
(B) Interface Design	B1 Resolve issues of interface and latency for improved interactivity	Kuták et al. [50]
	B2 Investigation with cross-object user interface with various application environment	Sun et al. [23]
	B3 Develop an appropriate design for collaborative operations	Adão et al. [66]
(C) Navigation System	C1 Integrate novelty with recognized research methods and workflows in CH	Kulik et al. [62]
	C2 Sustain exploration of big CH scale of content with teleportation mechanism	Kulik et al. [62]
	C3 Navigation must be enhanced within the main view screen, feedback, cue visibility, documentation and support options along with language localization	JG et al. [67]
	C4 Discover a simpler method to enhance access towards preferred information and provide guide with orientation on VR display	Lee et al. [68]; Erickson et al. [63]
(D) Visualization System	D1 Apply appropriate visual design approaches aside from the aesthetic visual to communicate in-depth information	Koebel et al. [25]
	D2 Incorporate triangulation of scanning data to enhance rendering efficiency	Kulik et al. [62]
	D3 Discover proper approach to communicate perceptions and visual aesthetics intuitively	Koebel et al. [25]
	D4 Examine on solution to resolve rendering performance issues with ‘anti-aliasing’	See et al. [20]

Table 3. Cont.

Category	Recommendations	References
(E) Approaches	E1 The expansion of user navigation with additional animation, contents and interaction application	Giloth and Tanant [27]
	E2 The involvement of a user-centered design and advanced interactive visual realism to create exciting experiences to meet personal preferences	Skovfoged et al. [69]
	E4 Extend similar development on the previous culture and reconstruct a multiculture manner towards other geographic sites	Younes et al. [47]
	E5 Integrating editable, optimization and automation modelling system	Kalarat [15]; Adão et al. [66]
	E6 Construct a method of practice and prototype development with regards to the development time frame and technology constraint to achieve management capability	Fernandez-Palacios et al. [30]
	E7 Build free application that is available on the mobile market store for download	Duguleana and Postelnicu [60]

### 5.3. Guidelines on Assessment

Assessment is essential in contributing improvement feedback for researchers, practitioners and developers to enhance innovation implementation and development process. On one hand selecting and gathering samples for assessment can sometimes be challenging because various users' demography have different technology skills and knowledge. Furthermore, the availability of participants and obtaining their consent is another challenge. Therefore, results from participants involved in the studies can be limited. The rich multiculture and demography of sample users leads to different findings. The user's region culture, demography and features towards VR system practices must be understood. On the other hand, assessment variables can vary for specific findings and may be influenced by other application factors. Thus, selecting a suitable assessment factors can be challenging because of the diversity of technology especially in CH practices. The recommendations were divided into two categories, namely samples and conducts (see Table 4).

**Table 4.** Summary of recommendations on assessment approaches for VR improvements in CH practices.

Category	Recommendation	References
(A) Samples	A1 Expansion of research samples especially participant numbers	Checa et al. [38]; Li et al. [18]; Taranilla et al. [46]
	A2 Include experts' group with a referenced group that have no VR experience	Checa and Bustillo [70]; Hürst et al. [42]; Vishwanath et al. [24]
(B) Conducts	B1 Involve users and UB issues in field testing and user acceptance towards UX feedback	Bruno et al. [34]
	B2 Investigating second generation application in search for potential issues	Younes et al. [47]
	B3 UX assessment before and after major application	Koebel et al. [25]; Esmaeili et al. [28]
	B4 Validating results with repeated samples in single or full populated form and special users	Fonseca et al. [48]
	B5 Investigating with series of UB for verification, readability and educational capability	Wei et al. [71]; [33]
	B6 Performing a comparison on shorter and longer experience study user's behavior pattern and examine designers' perceptive performance	Checa and Bustillo [70]
	B7 adding investigation on creators' identity, background and nations	Vishwanath et al. [24]

## 6. Discussion

Although the research on VR is endless, therefore, related explanations and limitations are adequate for the aspects of CH in VR in this study. Some common challenges and guidelines occur within the VR technology such as motion sickness, rendering speed and underestimated depth feel caused by hardware, software and human physical or perceptual limitations. However, in this study, the challenges and the guidelines recommended on VR are uniquely mapped for CH practices. The main difference between the VR application in other sectors and VR in CH is the complexity levels in interactive input. For instance, VR application, for CH compared to the military or medical application, requires different prior training set on the use of VR before having to fully enable for public use because the users from the military or medical domains are mainly at their professional levels. In CH the users, who utilize the VR applications, usually have little to no prior knowledge about the use of VR. Moreover, the users are coming from diverse backgrounds. In addition, most of the time, the users are distracted by the use of VR instead of focusing on the CH content learning. In contrast to professional use, VR is highly concentrated on content learning after prior understanding of the use of the technology.

Therefore, VR in CH has proposed to output a simple interactive input simulation walkthrough with adequate quality of graphics that operates on mobile. The focus should be concentrated on users capturing the information accurately with the main concern of enhancing users' public awareness of the CH context. Besides, it is proposed to deploy CH on a mobile-based VR application due to the familiar use of a smartphone in people's daily activities. Hence, any users who are interested in CH can also use their smartphone to access the CH content rather than setting up a high-cost VR technology on site. Moreover, there is a need for an assistant to overlook when its technology is set up during exhibition as discussed earlier. Other sectors have moderators to look after, for example, VR education has teachers being present when students are learning the VR technology, but for the museum, if an assistant is required, it means the extra cost of human resources.

The demand for VR increases each day to the extent that the VR technology applications setup is for short-term use rather than for long-term use due to compulsory maintenance and advancement to meet the demand of its technology. Furthermore, through the literature reviews, the majority of the articles on CH digital preservation usually is for short-term implementation and completed in a small coverage of CH content or rather still in progress for the expansion of the same project. This is to minimize the challenges faced in terms of immersion and sense of presence, unfamiliarity on the technical inputs and inadequate graphics presentation of content that can lead to users' distraction. Diverse users' capability to use VR technology is different. Some have very high motion sickness that contributed to low/high accessibility to the content. Consequently, VR in CH is constantly proposed with the use of familiar technology such as a smartphone where users can choose to view on the mobile screen or the additional VR box based on this systematic review.

## 7. Conclusions and Future Directions

CH is an area where VR systems are exercised in presenting and preserving the contents for users to immerse within the virtual world to within the designed and developed VE. The studies of the VR system for CH practices that involves various platform settings, devices and application designs, including the assessment on the UX of VR system to achieve a high level of UB and sense of immersion, were systematically reviewed. A comprehensive analysis was conducted to observe the current studies towards identifying and defining issues, limitations of studies, benefits and recommendations related to VR system for CH practices. This study identified and mapped the issues and provided recommendations that can be beneficial for developers, practitioners and researchers. In addition, recommendations were defined and made on the basis of the suggested reviews from different papers published almost a decade ago. Considerable insights into the integration of the VR system, design and development approaches and assessment methods are considered for CH practices. These studies can cater

for future research references and continuous progress after mapping the challenges and acknowledging the recommendations from the papers reviewed.

Nevertheless, the results of this research, which were based on the current study, were limited to the reliable number and identity of database sources. Next, the rapid advancement of this field restricts the correctness of identifying the scope and boundary of the research. The reviews only signify the overviews of the research community towards current research trends to meet this research objective. In addition, researchers can investigate on the innovation and evolution trends of the VR system for CH practices in the future. In conjunction with VR technology application, other future directions on promoting the technology itself such as innovating technology for widespread use to boost acceptance towards common practices. Besides, having adequate technology resources for next generation and expert human resources for practices can achieve comparable outcomes with a lower budget. In terms of VR performance for CH, the future direction could be examining inclusive HMD-based tool based on affordability or consider higher cost implementation for better UX such as advancing sensor tracking technologies and gestures-based approaches. For challenges in the low processor power to render and visualize complex graphics, VR in CH would certainly need supports of faster and higher image resolution rendering with interactivity range of functions and build in progress that focus on flexible integration of HMDs.

As a conclusion, the challenges and recommendations of/for the latest available VR technology devices must be understood for CH practice besides users' ability to experience such complex machine. In addition, practitioners should consider environmental factor for technology setups and installation that caters different CH context scenario presentation. Furthermore, as rapid innovation takes place, it is crucial towards continuous studies with new technology implementation in the future.

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