User Requirements for Virtual Reality in Architectural Heritage Leaning

Juliana Aida Abu Bakar, Puteri Shireen Jahnkassim, and Murni Mahmud

Abstract—Virtual reality has inherent characteristics such as spatial navigation and presence that makes it a good candidate for learning the past. However, little is known on what are required by the experts and the general public for virtual reality, particularly, in architectural heritage learning. This article attempts to discuss user requirements from the perspective of the experts. It describes the way requirements were gathered from sequential expert interview, expert review, and expert evaluation at different stages of development. Using interviews and focus group discussions coupled with cognitive walkthrough, at least five common attributes are identified: content, support, usability, and location. This article further discusses these common attributes on user requirements and subsequently recommends potential solutions to wherever applicable.

Index Terms—user requirements, virtual reality, architectural heritage learning, cognitive walkthrough.

1 INTRODUCTION

IN a critical review on virtual reality (VR) and history pedagogy, Allison asserts the technological wealth nowadays can bring history closer to us because "they are not only provide avenues to re-conceptualize the past, but also revive the debate about what exactly meant by the past" [1]. VR, as it is associated with the ability to simulate reality, is a good candidate to be used for the above purpose. To date, numerous virtual reality applications have been developed for cultural heritage but there still lack of evidence on whether there is any successful installation. While studies on formal education are heavily focused on the impact of V R and how it may fit in subjects curriculum, the use of VR in informal education such as in museums and other cultural institutions have been less studied. There, relatively more freedom to adopt VR due to its flexibility of learning methods and styles. The ambient of non-structured curricula and self-dependent learning in museums is more or less lighter than the formality of classrooms [2]. A visit to the museum may enlighten the theories or principles being taught in the classrooms Therefore, the existence of a museum is equally visible and important to support learning and in particular, architectural heritage leaning.

There are general guidelines for designing an interactive museum exhibit that emerged from previous studies. An interactive exhibit should be suitsble for learning where it contains different linked elements with appealing contents; enjoyable and engaging; easy to use where it must be intuitive and has clear affordances so that visitors can concentrate on its content and suitable for groups where it allows group exploration [3, 4]. These guidelines were derived from series of user interview after using multimedia and pre-rendered VR exhibits which were already installed in those cultural heritage settings However, little is known on what requirements are needed for VR to be used for architectural heritage learning from the perspective of expert and public users As requirements by public users particularly museum visitors have been discussed elsewhere [5], this article attempts to reveal those from experts This article discusses user requirements from the perspective of the experts.

This article begins with the overview of learning potentials of virtual reality based on empirical evidence in formal education as well as informal education particularly in museums. It describes how requirements were gathered from sequential expert interview, expert review, and expert evaluation at different stages of development. Using combination of data gathering techniques, at least four common requirements are identified: content, support, usability, and location. This article further explains these common requirements and subsequently recommends potential solutions.

2 BACKGROUND

There has been a steady increase in identifying the potentials of and providing empirical evidence of virtual reality (VR) for learning. Beginning with [6] who explored the educational potentials of VR for learning by reporting more than 60 educational projects, recent studies provide statistical evidence that school students performed better in the VR learning environment provided that they actively participated in the learning process [7][8]. Apart from academic performance, VR has produced positive learning experiences for students such as enjoyment, sense of reality, ease of understanding, and satisfaction [8]. In formal education, VR offers a handful

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unique experience such as hands-on learning, group projects and discussions, virtual field trips, simulations, and concept visualization to both teachers and students together with successful instructional strategies [9]. A recent study by [10] suggests that the use of desktop VR with high visual realism and high navigational freedom have provided positive learning gain.

In informal education particularly in museums, there are diverse learning theories of informal learning and mental models that constituted learning in museum context such as the contextual model of learning [11], the complex behavior of visitors [12], and the significance of such studies to be embodied in overall museum experience [4]. In museum context, the historical interpretation, storytelling, contextualizing objects, allowing artistic means of expression, and creating emotional response to visitors are keys to successful museum visits [12, 13]. The concept of 'Cultural Presence' to denote a feeling of different people with diverse culture being in a virtual place [14] has been argued to have impact towards learning cultural heritage whereby immersion, enjoyment, engagement, and interaction between visitors and exhibits were among the attributes [15]. As previous work emphasizes on museum learning and interactive exhibits, this study further expands the use of interactive digital media, particularly virtual reality, to learn architectural heritage. Thus, the need for user requirements particularly for virtual reality in learning architectural heritage is surfaced.

2.1 Virtual Reality for Architectural Heritage Learning

Cultural heritage sites may include architectural significance of monuments and structures that possess unique features and represent cultural identity of the nation. This is critical at this juncture not only to preserve and conserve these structures in the name of cultural heritage but also to disseminate cultural information behind these standing structures which normally intangible and not available on site. There perhaps restrictions on people or in this case tourists, to get physically on site. Furthermore, dramatic erosion and pollution by tourists may do more harm than good towards the cultural heritage sites which were already combating their existence against time and nature [16]. Therefore, it is crucial to devise a '3D documentation' as a complement method of disseminating cultural information to the general public. Virtual reality, due to its inherent characteristics, deems fit to take this role besides many other techniques such as laser scanning and photogrammetry.

In the last decade, notable VR systems have been developed for cultural heritage sites or cultural objects. These projects have utilised either VR software such as X-VRML [17] or VR devices such as CAVE and ImmersaDesk [18] and/or head-tracking and haptic devices [19]. Virtual Malacca performs a technique to accelerate real-time navigation in a large heritage site [20]. Among all, Virtual Hagia Sophia is targeted to perform realistic visualization of Hagia Sophia with real-time rendering [20][21]. Current development in this project shows animated avatars with their clothes representing those dedicated years were added. However, the end result has limited user interaction with their systems.

At least two projects listed are involved with game-like activity. One is Ancient Olympic Games [18] which involves Olympic pottery puzzle as well as walkthrough the Olympia and another is MediaEvo [23] which includes a didactic game about the history of the Middle Ages. Recent development as discussed by [24] shows the use of Wiimote and Balance Board for user navigation. These projects clearly provide user interaction with the systems but there is little user evaluation or user requirements being addressed in these articles. User evaluation is expected to take place at the very end of project development or after installation while user requirements are typically gathered from project stakeholders.

In a laboratory setting,[14] evaluated the effects of certain modes of interaction that are observation, instruction, and game-style instruction on cultural presence. Using within-subjects experimental design, three groups of archeology students, virtual heritage designers, and IT-experienced people were asked to experience three virtual environments with different modes of interaction. The evaluation metrics are task performance, cultural understanding, presence survey, environmental recall, and subjective experience of time passing. In addition to the statistical results, observation is also used to provide discussions on some unexpected findings. Champion found that though least interaction mode is used, that particular virtual environment is ranked first and second for most interesting world. His findings suggest that engagement relates to how appropriate the interactivity is to the environment rather than what type of interactivity it is, hence the environment that people are experiencing is an important factor. This initial work in evaluating cultural learning requires extensive research to support its defining measures [16].

In a nutshell, the development of virtual reality for architectural heritage may require beyond visual realism and interactivity in order to support architectural heritage learning. The need for experts' opinion on user requirements is critical in order to design and develop a virtual reality application in architectural heritage for a real-world use and to determine evaluation metrics suitable for virtual reality in architectural heritage learning.

2.2 Gathering Requirements from the Experts

In practice, the user centered design and evaluation approach, if incorporated inside the development cycle, requires longer development time, involve human capital and hence higher budget expenditure [25]. Thus, it is essential to carefully plan any user involvement during any stage of the development and choose affordable methods to be applicable in the duration of the development project and inclusive of the budget. It is then typical, for the case of VR system development, to

find literature that supports user evaluation only at the design stage, particularly in evaluating interaction techniques, such as mentioned in [26] and [27], or literature that supports user evaluation only towards the final stage of development particularly when the VR prototype is partially or fully functional as reported by many [28][29][30][31][32][33][34].

The earlier work by [35] and subsequent work by [36] extensively describe how the VE usability engineering methods was implemented on the development of Dragon, a battlefield visualization project. The early design of Dragon was based on user task analysis (on which the procedure was not clearly described) and was followed by iterative expert guidelines-based evaluation and four iterative formative evaluations that covers usability aspects to navigation techniques.

The work by [38] is relatively closer to the context of this study. Working closely with architects, designers, and decision makers, they informed the design of the Tramway project by collecting user requirements by series of discussions. This technique, although the term is not mentioned anywhere in the article, is perhaps similar to focus group discussions as mentioned in [39] and [25]. The experimental approach was done by controlled experiment to identify the effect of realism as well as usability of their system. In [38], observation was used in field deployment where the VR system was presented in the City Hall meetings and public events. In the case of urban planning, it is found that realism is desirable and important and the capability of VR to provide multiple views were considered very useful by users, both in controlled experiment and various field deployment [38]. Users in their case have absolute interest in that particular VR system as the urban planning project would affect their living directly.

In architectural heritage learning, however, the focus is typically on the structural significance such as those that answer on how and why one structure is built at the first place. Apart from that, users may want to learn historical and cultural perspectives of a particular place. As the focus is very much dependant on not only technically but also on that subject matter, it is decided to include experts throughout the development process. Hence, expert evaluation techniques which are widely used in usability valuation are adapted in order to gather requirements from the experts.

3 RESEARCH APPROACH

Expert evaluation may be considered for assessing early design and then user evaluation is done to study the actual use of the system by using a working prototype. [25] covers a substantial overview of expert evaluation techniques such as cognitive walkthrough, guidelines review, consistency inspection, metaphors of human thinking, and formal usability inspection. This study, at times, adapts cognitive walkthrough in which experts would experience the prototype with the existence of the designers and stakeholders and voice out their perspectives.

In this study, user requirements were gathered during focus group discussions at intervals throughout the virtual reality application development stages. Fig. 1 depicts these stages which include expert interview, expert review, and expert evaluation. Before any development took place, interview was conducted with museum director, architect, and historian on possible user requirements and specific content. Throughout the development stages, two focus group discussions were conducted to assess the content of the application and also the design of the interface. Finally, the evaluation by experts was conducted on fully functional prototype.

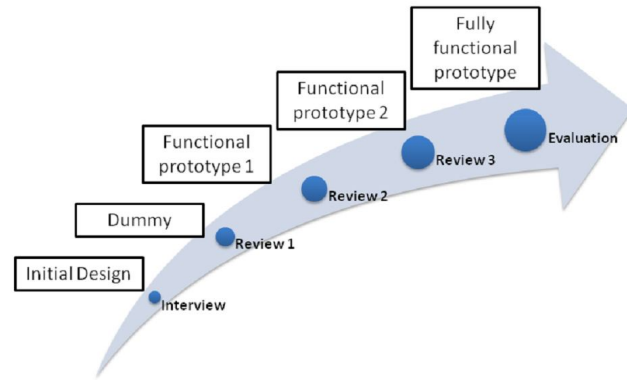


Fig. 1. Focus group discussions with experts at intervals during development process.

During the face-to-face interview, a brief presentation on the project and its technical features was done where the experts voiced out their opinions and initial requirements throughout the presentation. These items serve as the basis for developing a dummy prototype.

The first review was conducted using the dummy prototype at the second week of the development process. Using storyboard, the developers' team described the storyline of the application and explained the overall content of the subject matter (see Fig. 2). The experts would then comment and adjust the storyline accordingly.

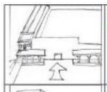
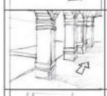
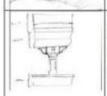
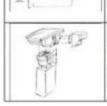
	Some details of Diwan-I Am should be shown here. Indicating approach of general public, seat of the emperor and how the Emperor used to arrive and take his seat along with his ministers.	3	CAMERA: Dolly towards the Diwani Am SHOT: Long shot AUDIO: DES: Heading towards Diwani Am complex.
	Description of the seat of emperor and decorative motifs.	2	CAMERA: Dolly into the complex SHOT: Medium shot AUDIO: DES: Entering into the complex
	Description of columns, their bas, shaft and capital; type of columns, total number of columns.	11	CAMERA: Dolly through Diwani Am corridor. SHOT: Medium shot AUDIO: DES: Walk through the corridor.
	Every column at Diwān-i Ām has the same construction method. The brackets are jointed by interlocking joints to merge the dual unit of bracket with the single unit bracket. These brackets are then connected to the capital using the similar jointing. However, dovetail construction are used to assemble the column construction especially at the shaft and base. This is good.	10	CAMERA: Still SHOT: Medium shot AUDIO: DES: Motion graphic explaining the structure of the pillar at Diwani Am.
	The bracket is one of the dominating features of the column unit as it represents the identity of the Mughal architecture of Akbar's period. Monolithic (massive) struts or serpentine (curved) brackets were used not only along the porticos but also used at the verandah of the throne pavilion. Although, the column and beam structure of Diwani Am is classified as simple structure compared to other building of Fatehpur	8	CAMERA: Still SHOT: Medium shot AUDIO: DES: Motion graphic animating the separate structure of the pillar at

Fig. 2. Screen shot of a storyboard that partially explains the storyline.

Then, during the second review, a functional prototype was presented to the experts where they were then expressed their opinions on the interface design of the prototype. The functional prototype has a concept design of a kiosk whereby a graphical user interface was designed as the main page which includes links to various sections on historical and architectural information about the subject matter. A menu button to trigger the virtual reality application is also included at the end of the list as we assumed the application would be the last thing to see as to save the best for last.

Fig. 3. The initial graphical user interface of a functional prototype. Selecting menu on the left will trigger virtual reality application in a new window.

The third review was conducted using another functional prototype of the virtual environment. Fig. 4 depicts a screen shot inside the virtual reality application during user navigation. This prototype has covered more than half of the overall content and interface design as recommended during the initial design. Visual realism of certain structure is relatively preserved. With this decision, another round of content selection was conducted among the team members to make consensus on the strategy of developing the virtual reality application.

Fig. 4. A screen shot during navigation inside the virtual environment. The textured cube is in fact rotating which reveals information on architectural significance upon user selection.

The fully functional prototype was finally evaluated by experts in the real-world setting that is either museum or classroom. The prototype is projected onto a large screen and experts are invited to navigate the virtual reality application themselves.

4 Results and Discussion

There were eight experts involved in this study as listed in Table 1. Their expertise is related to the domain of architectural heritage and/or museum. Three experts were participated in the initial design, four experts in series of review and three were participated in the evaluation stage.

TABLE 1. List Of Experts And Their Expertise

Expert	*Expertise*	*Affiliation*	*Involvement Stage(s)*
S	History	Professor	Initial Design, Review 1
T	History	Professor	Initial Design
U	Museology	Associate Professor	Initial Design, Review 1, Review 2, Review 3
V	History	Assistant Professor	Review 2
W	Museology	Museum Director	Review 3
X	Archeology	Museum Assistant Director	Prototype Evaluation
Y	History	Professor	Prototype Evaluation
Z	Architecture	Assistant Professor	Prototype Evaluation

Based on the opinions and recommendations from the experts, similar items were grouped into common attributes as listed in Table 2. It is anticipated that these experts would give recommendations that are related to their expertise. For example, most content-related items are those mentioned by experts in history and architecture and experience-related items be mentioned by those in museology.

TABLE 2. ATTRIBUTES MENTIONED BY EXPERTS

Expert	*Content-related*	*Experience-related*	*Setting*	*Support*	*Interface*
S	/				
T	/	/			
U		/		/	
V	/				
W			/		/
X		/			
Y	/				
Z	/				
Total	5	3	1	1	1

Attributes that were less mentioned not necessarily less important. Significance of VR setting may have affect user experience to unfavorable. The following subsections have details on the rest of the findings.

4.1 Content-related Items

During interview while determining the initial design, selection on the content subject matter is purposely asked to the experts in order to focus only relevant details about the subject matter. Among suggestion are the inclusions of space and building functions and structural significance, the philosophy and planning on the heritage site, reconstruction of the past during the majestic era or replication of what it is now (such as with ruins, damaged structure, and eroded paintings), water elements which are normally associated with past architecture such as the drainage system, the rainwater harvesting system, and attached garden and landscape. There is also suggestion which needs an extensive research that is to focus on visual details of the building such as original colors of materials. During the second review, the expert expressed concern on the contextual setting of the subject matter where she insisted that users should know the overview of the building such as its builder and the significance of the building location.

During the third expert review, a functional VR application was presented upon the same expert. At this point, the expert expressed his satisfaction on the level of realism of the virtual environment. On the other hand, he contended that the content of information should tackle as much as possible the level of audience. Museum visitors may have or may have not prior knowledge on the subject matter of the content thus the content should fulfill the expectation of both.

During the evaluation, the authenticity of the digital reconstruction was being questioned by the expert as he noticed delicate carvings have been simplified and few beams are missing. It is required that there should be a disclaimer if any simplification or changes have been made in the digital reconstruction. A holistic context and accurate content of a cultural heritage site are required in order to be exhibited to the general public.

In museums, the authenticity of displayed exhibits is critical whereby information should be derived from only reliable and valid sources. The authenticity of the content is an utmost important for a museum application and must be taken care of by VR developers and any interactive exhibit designers. To comply with such, the prototype storyline was derived from various historical books and articles, salient architectural features were carefully selected, and finally these were vetted by an architectural expert. The 3D models were then accurately reconstructed from 2D architectural drawings which were drawn after measurements from the site by undergraduate students during their heritage studies. Reviewing process was made iteratively with the museum expert to ensure this requirement was met.

The developed VR application attempts to disseminate architectural heritage and historical knowledge of a cultural heritage site. Given that the selected site has many salient architectural features and ornamentation, it is decided to be selective on what should be in the virtual environment and what should not in order to balance on the real-time navigation performance with visual realism. This selection, on the other hand, has affected the quality of representation towards a handful of heavily ornamented structural elements. To an art historian, this reduction of quality has made the application less authentic and not accurate.

The issues of authenticity in any digital reconstruction are also discussed elsewhere [40][41][16][42]. Another school of thought believes that hyperrealism in digital reconstruction is claimed to be counter-productive for learning [42] and can bore visitors if no interactivity is performed [40]. It naturally comes to a consensus that digital reconstruction including VR must be somewhat authentic but to what extent? The answer to this probably lies in the eyes of the beholder. It is then up to the individual to interpret and critic the digital reconstruction upon knowledge as recommended a history educator [1].

Fig. 5. Gigantic pillar (left) is used by the Majesty of the past during His sermon to officials. Users may feel such majestic event while looking up this pillar in the virtual reality application.

To these experts, the capability of VR in representing

cultural heritage site is expected to go beyond visual and auditory senses. Using VR characteristics of real-time navigation, visitors may feel two extreme conditions due to space and scale: superior (as if a Majesty to his citizens) when looking down to ground from the upper platform of the gigantic pillar, for example, and inferior (as if a citizen to the Majesty) when looking up from the ground to the upper platform of that pillar as in Fig. 5.

Besides authenticity, scale is another concern of the expert in order to reflect the size of building structure. This can be fulfilled by adding in figurative elements such as crowd.

In a nutshell, experts welcome the use of VR in architectural heritage learning with substantial care. Their main concern relates to the accuracy and authenticity of the digital reconstruction and the depth and breadth of architectural heritage knowledge.

4.2 Experience-related Items

Experience-related items include the need of allowing users walking through the past building as if they were there (or known as presence) and to revive the scent of old abandoned building in its digital reconstruction. By using tactile input devices such data glove using force sensor by [43], visitors may have a sense of touch on a rough surface or feel the curve of a carved bracket.

When a functional prototype with an interface of a kiosk was presented during the second review, the expert commented that virtual reality is preferred than the kiosk metaphor because it is newer. Hence, it should be the major part of the application. This is related to the term 'wow' experience that may attract users even though the content is not changing over the years [44].

During the evaluation, the expert highlighted that the walkthrough ability of virtual reality might help disabled people go through the museum collection without having to go upstairs. This perhaps explains the necessity of having a virtual museum to replicate physical museum such as the one developed by [31].

4.3 Setting-related Items

The third review was conducted prior to the user evaluation using a fully functional prototype. The museum director suggested that the prototype should be performed in a closed room to have impact on visitors hence he offered the use of auditorium in the upper level. The audio sound was very good and should be functional with an appropriate level of volume. He also advised that should visitors were to allow contact with input devices; close monitoring must be done to avoid behavior misconduct.

Expert recommends that any application that has audible embedded must be confined in a closed room setting. Be it a stand-alone VR application that has no seamless integration with other exhibits, it then should be able to be independent from the rest of exhibits. As permanent exhibits normally have stories to link each other, a stand-alone VR application is an ideal for temporary exhibition if the content is not connected with other exhibits.

4.4 Support-related Items

The virtual reality application in this study is developed with an assumption that potential users are novice. However, during the third review, it is recommended that the virtual reality application covers both novice and expert users. Expert users were referred to those who working in the domain to better educate them on a particular architectural heritage. Based on this comment, it is decided to expand the information to details such as the material of a structure and types of carvings. This information is hidden at default and only appears upon user selection.

4.5 Interface-related Items

At the early design stage, it is targeted that users should be able to appreciate the architectural heritage and at the same time, to learn some historical information on the cultural heritage site using the proposed application. Hence, the designated tasks were simply navigating through the virtual environment, clicking upon icons to reveal historical information, and appreciating the cultural significance of the building.

During the third review, it is recommended that the input device may only be limited to one device only. However, at the moment it is decided to use mouse and keyboard as its input device due to constraints of resources.

Based on experts' opinion, allowing public to interact with not only VR but all electronic devices is another concern of museums. Without supervision, it is hardly feasible to allow any interaction as most of these interfaces is fragile and easily damaged. In previous installation, museums normally spare a curator or human mediator to guide or even replace this interaction with electronic devices which is certainly against the intention of having the inherent interactivity in VR [44][45].

The idea of having visitors interact physically with exhibits probably is not feasible in museums with less maintenance allowance. As most museums in Malaysia are mainly non-profit organizations, technology that comes with high cost in acquisition and maintenance would be the least choice. This would be a major hindrance of getting virtual reality technology into the museums. Nonetheless, this can be encountered with the assignment of a dedicated curator who can play the role as facilitator to visitors. The effect of such setting would also motivate visitors to both use the technology and learn the subject matter [44, 46]. Thus, a concrete strategy has to be devised in order to reap the most benefit of this technology.

5 Conclusion and Future Work

This article attempts to gather user requirements for virtual reality in architectural heritage learning from the perspective of the experts. Experts came from various backgrounds namely historian, archeology, museology, and architecture that expertise is relevant to the content and context of the VR prototype. The overview of learning potentials of virtual reality based on empirical

evidence in formal education as well as informal education particularly in museums is discussed. User requirements were gathered from sequential expert interview, expert reviews, and expert evaluation at different stages of development.

Using cognitive walkthrough and focus group discussions, at least five common attributes are identified: content, experience, setting, support, and interface. Content refers to those related to the subject matter that users have to learn about such as the historical background, structural significance, and functions of the architectural heritage site or building. Experience includes presence where users feel being there and feel as well the aura of that place. Setting of a VR application should be restricted into a closed room with large projector at the least to offer users the VR experience. VR is also required to support both novice and expert users in not only technical but also the depth and breadth of related knowledge. Thus, the interface not only must be intuitive but also the information should cover a broad spectrum of architectural heritage.

These requirements would then serve as guidelines for later development of a virtual reality for architectural heritage learning in museums or education institutions. Some requirements are not met by the developed VR application such as those to revive the scent of an old building; hence further research may want to focus on the area of olfactory feedback. On another note, issues on the public use of such application mentioned by experts in this article are critical in ensuring a successful installation and implementation of VR applications in museums or for any usage by the general public. However, further research is needed to assess whether these issues are significantly contributing as critical success factors for VR installation and implementation in museums.

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REFERENCES

[1] J. J. Allison, "History educators and the challenge of immersive pasts: a critical review of virtual reality tools and history pedagogy," Learning, Media, and Technology, vol. 33, no. 4, pp. 343–352, 2008.

[2] J. Sefton-Green, "Literature review in informal learning with technology outside school," Futurelab UK, Report 7, 2004, retrieved February 10, 2010 from http://halshs.archives-ouvertes.fr/hal-00190222/.

[3] M. Economou and L. Pujol-Tost, "Educational tool or expensive toy? Evaluating VR evaluation and its relevance for virtual heritage," in New Heritage: beyond verosimilitude. Conference on Cultural Heritage and New Media., T. Kvan and Y. Kalay, Eds. Faculty of Architecture, University of Hong Kong, March 13-14 2006, pp. 284–302.

[4] L. Pujol-Tost and M. Economou, "Worth a thousand words? The usefulness of immersive virtual reality for learning in cultural heritage settings," in Proceedings: International Symposium on Information and Communications Technologies in Cultural Heritage, T. A. Mikropoulos and N. M. Papachristos, Eds., October 16-18 2008, pp. 73–90.

[5] Juliana Aida Abu Bakar, "Architectural Heritage Learning through Virtual Reality in Museums, Doctoral Thesis, International Islamic University, 2012.

[6] C. Youngblut, "Education uses of virtual reality technology," Institute for Defense Analyses, Alexandria, VA, Document Report D2128, 1998.

[7] L. Elinda Ai-Lim, W. Kok Wai, and F. Chun Che, "Learning effectiveness in a desktop virtual reality-based learning environment," in Proceedings of the 17th International Conference on Computers in Education [CDROM], S. Kong, H. Ogata, H. Arnseth, C. Chan, T. Hirashima, F. Klett, J. Lee, C. Liu, C. Looi, M. Milrad, A. Mitrovic, K. Nakabayashi, S. Wong, and S. Yang, Eds., 2009, pp. 832–839.

[8] C. J. Chen, "Are spatial visualization abilities relevant to virtual reality?" E-Journal of Instructional Science and Technology, vol. 9, no. 2, p. 16, September 2006.

[9] Y. Inoue, "Concepts, applications, and research of virtual reality learning environments," International Journal of Human and Social Sciences, vol. 2, no. 1, pp. 1–7, 2007.

[10] C. R. Harrington, Maria, "The virtual trillium trail and the empiricaleffects of freedom and fidelity on discovery-based learning," Virtual Reality, 2011.

[11] J. H. Falk and L. D. Dierking, Learning from museums: Visitor experience and the making of meaning. AltaMira Press, 2000.

[12] L. Pujol-Tost and M. Economou, "Evaluating the social context of ICT applications in museum exhibitions," in The e-volution of Information Technology in Cultural Heritage. Where Hi-Tech Touches the Past:Risks and Challenges for the 21st century. Proceedings of the 7th International Symposium on Virtual reality, Archaeology and Cultural Heritage, VAST2006. Eurographics, 2006, pp. 219–228.

[13] M. Roussou, "Learning by doing and learning through play: An exploration of interactivity in virtual environments for children," ACM Computers in Entertainment, vol. 2, no. 1, pp. 1–23, January 2004.

[14] E. M. Champion, "Evaluating cultural learning in virtual environments," Ph.D. dissertation, Faculty of Engineering and Faculty of Architecture, The University of Melbourne, January 2006.

[15] L. Pujol-Tost and M. Economou, "Worth a thousand words? The usefulness of immersive virtual reality for learning in cultural heritage settings." International Journal of Architectural Computing, vol. 7, no. 1, pp. 157–176, 2009.

[16] E. Champion, Playing with the Past. Springer-Verlag, 2011.

[17] R. Wojciechowski, c. Walczak, M. White, and W. Cellary, "Building virtual and augmented reality museums exhibitions," in Proceedings of the ninth international conference on 3D Web technology. ACM, 2004, pp. 135–144.

[18] A. Gaitatzes, D. Christopolous, and G. Papaioannou, "Virtual reality systems and applications: The ancient olympic games," in Lecture Notes in Computer Science, P. Bozanis and E. Houstis, Eds. Springer-Verlag, 2005.

[19] C. Christou, C. Angus, C. Loscos, A. Dettori, and M. Roussou, "A versatile large-scale multimodal VR system for cultural heritage visualisation," in VRST '06: Proceedings of the ACM Symposium on Virtual Reality software and technology. Limassol, Cyprus: ACM, November 1-3 2006, pp. 133–140.

[20] Mohd Shahrizal Sunar, Daut Daman, Abdullah Bade, Norhaida Mohd Suaib, Hasnul Hadi Shamsuddin, and Nor Azhar Mohd Arif, "The development of real-time rendering for large scale 3d virtual heritage," Universiti Teknologi Malaysia, Malaysia, Research Report 79097, 2008.

[21] A. E. Foni, G. Papagiannakis, N. Cadi-Yazli, and N. Magnenat-Thalmann, "Time-dependant illumination and animation of Virtual Hagia-Sophia," International Journal of Architectural Computing, 2007.

[22] A. E. Foni, G. Papagiannakis, and N. Magnenat-Thalmann, "Virtual Hagia Sophia: Restitution, visualization and virtual life simulation," UNESCO World Heritage Congress, 2002.

[23] L. T. DePaolis, G. Aloisio, M. G. Celentano, L. Oliva, and P. Vecchio,"Design and development of a virtual reality application for edutainment in cultural heritage," in 15th International Conference on Virtual Systems and Multimedia. IEEE, 2009, pp. 80–84.

[24] L. T. DePaolis, G. Aloisio, and M. Manco, "Navigation and interaction in the virtual reconstruction of the town of Otranto in the middle ages," in ACHI 2011: The Fourth International Conference on Advances in Computer-Human Interactions. IARIA, 2011, pp. 120–125.

[25] B. Shneiderman, andC. Plaisant, Designing the User Interface: Strategies for Effective Human-Computer Interaction, Pearson, 2010.

[26] A. Steed, "Defining Interaction within Immersive Virtual Environments", PhD thesis, University of London, Department of Computer Science, 1996.

[27] D. A. Bowman, D. B. Johnson, and L. F. Hodges, "Testbed evaluation of virtual environment interaction techniques," Presence: Teleoperators and Virtual Environments, 10(1), 75–95, 2001.

[28] Z. Hendricks, J. Tangkumpien, and K. Malan, "Virtual galleries: Is 3D better?" In Proceedings of the 2nd ACM International Conference on Computer Graphics, Virtual Reality, Visualization and Interaction, 2003, pp. 17–24. South Africa: ACM Press.

[29] A. Alzua-Sorzabal, M. Linaza, M. Abad, L. Arretxea, and A. Susperregui, "Interface evaluation for cultural heritage applications: the case of FERRUM exhibition," in The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage, M. Mudge, N. Ryan, and R. Scopigno, Eds., 2005, pp. 121–128.

[30] Juliana Aida Abu Bakar, "An Evaluation on the Effectiveness of Virtual Tour Interfaces," Technical Report 11064, Universiti Utara Malaysia, Faculty of Information Technology, 2003.

[31] M. Forte, S. Pescarin, and L. Pujol-Tost, "VR applications, new devices and museums: visitor's feedback and learning. a preliminary report." In The e-volution of information technology in Cultural Heritage. Where Hi-Tech touches the Past: risks and challenges for the 21st century. Eurographics, 2006, pp. 64–69.

[32] Norazimah Awang, "Integrating virtual reality in ViSeum and end user acceptance," Master's thesis, Faculty of Technology Management, 2007.

[33] D. Fitzgerald, N. Trakarnratanakul, L. Dunne, B. Smyth, and B. Caulfield, "Development and user evaluation of a virtual rehabilitation system for wobble board balance training," In 30th Annual International IEEE EMBS Conference 2008, pp. 4194 – 4198. Canada: IEEE.

[34] L. Elinda Ai-Lim, W. Kok Wai, and F. Chun Che, "How does desktop virtual reality enhance learning outcomes? A structural equation modeling approach," Computer & Education, 55, pp. 1424–1442, 2010.

[35] M. C. R. Harrington, "The virtual trillium trail and the empirical effects of freedom and fidelity on discovery-based learning," Virtual Reality, 6(2), pp. 105-120, 2011.

[36] J. L. Gabbard, D. Hix, and J. E. Swan, "User-centered design and evaluation of virtual environments," IEEE Computer Graphics and Application, 19(6), 51–59, 1999.

[37] D. Hix, and J. L. Gabbard, "Usability engineering of virtual environments," In K. Stanney (Ed.), Handbook of Virtual Environments: Design, Implementation, and Application, Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers, 2002, pp. 681-699.

[38] G. Drettakis, M. Roussou, A. Reche, and N. Tsingos, "Design and evaluation of a real-world virtual environment for architecture and urban planning," Presence: Teleoperators and Virtual Environments, 16(3), 2007, pp. 318–332.

[39] J. Lazar, J. H. Feng, and H. Hochheiser, Research Methods in Human-Computer Interaction, United Kingdom: Wiley, 2010.

[40] L. Mosaker, "Visualising historical knowledge using virtual reality technology," Digital Creativity, 12(1), 15–25, 2001.

[41] B. K. Tan, and H. Rahaman, "Virtual heritage: Reality and criticsm," In T. Tidafi & T. Dorta (Eds.), Joining Languages, Cultures and Visions: CAAD Futures 2009.

[42] L. Pujol-Tost, "Realism in cultural heritage," International Journal of Virtual Reality, 10(3), 2011, pp. 41–49.

[43] N. H. Adnan, K. Wan, and Shahriman AB, "Accurate measurement of the force sensor for intermediate and proximal phalanges of index finger," International Journal of Computer Applications, vol. 45, pp. 59–65, 2012.

[44] M. Roussou, "Immersive interactive virtual reality in the museum," in Proc.of TiLE (Trends in Leisure Entertainment), June 2001.

[45] Juliana Aida Abu Bakar, Murni Mahmud, and Puteri Shireen Jahn Kassim, "The level of information communication and technology use by museums in Malaysia," in Proceedings of 4th International Symposium of Information Technology (ITSim), A. K. Mahmood, H. Badioze Zaman, P. Robinson, S. Elliot, P. Haddawy, S. Olariu, and Z. Awang, Eds., vol. 3, Kuala Lumpur, June 15-17 2010, pp. 1462–1467.

[46] J. Podgorny, "Studying visitor engagement in virtual reality based children's science museum exhibits," Master's thesis, University of Chicago, June 2004.

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