

Ronald Zamora-Musa*

Department of Computer Science
and Electronics

Universidad de la Costa

130012 Barranquilla, Colombia

and

Universidad Pontificia Bolivariana

Jeimy Vélez

Universidad de Cartagena and

Corporación para la ciencia

la investigación

la innovación y el

emprendimiento – CORCIEM

Heyder Paez-Logreira

Politécnico de la Costa Atlántica

Evaluating Learnability in a 3D Heritage Tour

Abstract

The implementation of 3D virtual reality (VR) environments to represent human culture and heritage has been growing during the last two decades as a result of information and communication technologies (ICT) development. Precisely, regarding virtual heritage development, some weaknesses have been detected such as "lifeless" environments lacking interaction, and research still under development on learning assessment. In this article, a VR environment is presented, through users taking a virtual tour visiting some elements of cultural heritage of the island of San Andrés, Colombia. In the tour, users participate in a 3D VR environment, answering questions and learning about the cultural heritage of the island. Also, the usability of the VR environment is assessed through SUMI (Software Usability Measurement Inventory) standard ISO9241-11 evaluating aspects such as usefulness and learnability. The results demonstrate that with the implementation of a VR environment about heritage, the users achieved optimum performance with an 80% average of correct answers and a high correlation between learning and the usability of the 3D VR environment.

I Introduction

The development of 3D VR environments fosters greater user participation and interaction in various topics, for example, education in culture and heritage. Some of the most representative environments in the international context are Second Life, OpenSim, and several others (Lorenzo, Sicilia, & Sánchez, 2012), which are 3D interactive virtual environments resembling the real world. In 3D VR or immersive environments, also called metaverse, users are graphically represented by an icon or avatar—virtual representation of a person—through which they can interact with other avatars. The main objective of doing so is to exchange knowledge or information (Kapp & O’Driscoll, 2010).

Currently, only partial virtual heritage is available for users (Champion, 2015; Bonfigli, Cabri, Leonardi, & Zambonelli, 2004), leading them to little element interaction and limited action feedback. Thus, VR environment interaction has to be supported with tools, such as OpenSim (OpenSimulator, 2017).

Besides the above, and although 3D VR is a potentially useful technology to allow novel interaction in learning human culture and heritage (Malegiannaki & Daradoumis, 2017; Carrozzino & Bergamasco, 2010), and despite the fact that ICT’s use has increased in the field of virtual heritage (Kabassi, 2017; Gombault, Allal-Chérif, & Décamps, 2016; Veltman, 2005), it is still not

enough for a full heritage appropriation or learning through virtuality (Ott & Pozzi, 2011; Chassagne, Bou-Saïd, Ceccotti, Jullien, & Togni, 2007; Twining, 2005). For that reason, this article presents a VR implementation about the cultural heritage of the island of San Andrés, Colombia, evaluating aspects such as usefulness and learnability.

Heritage learning bases its importance on being the channel to link people with their history. It embodies the symbolic value of cultural identities and is the key to understanding other peoples. However, the protection of some types of heritage is vulnerable (UNESCO, 2018), and that is why it is important to implement 3D VR to learn about heritage so that it remains a vital source of an identity deeply rooted in the history of the peoples.

This article is allocated as follows: the first section analyzes the context and background of virtual heritage implementation through immersive environment; next, in Materials and Methods, the evaluation of the immersive environment's usability is explained to gather the necessary outcomes to be implemented in related works; and finally, the last section outlines conclusions and future work.

2 Context and Background

There are several types of immersive environments such as Massively Multiplayer Online Games (MMOG), and synthetic immersive environments (SIEs), which are visually rendered spaces that combine aspects of open social virtualities with goal-driven activities (Dindar & Akbulut, 2015; Sykes, Oskoz, & Thorne, 2008; Stefan, 2012). When multi-user interaction ability is added to SIEs, they become MUVE (Multi-User Virtual Environment), which are 3D graphics representations accessed by the internet and allowing multiple users simultaneously (Chen et al., 2016; Bishop, 2009; Ahmad, Wan, & Jiang, 2011). Now, when heritage information is conveyed through MUVE, it is called MUVHE (Multi-User Virtual Heritage Environment) (Leavy, 2007). These surroundings comprise social learning elements that help to embrace new behaviors which can be used to represent a more realistic virtual heritage. Learning components promote the implementation of more dynamic

environments. Social and cognitive theories of motivation are also to be considered, especially for attitudinal responses likely to be manifested by users (Pallud, 2017; Nye & Silverman, 2013; Mayer & Alexander, 2011).

Avatar use is important in immersive environment development; in these settings, immersion is the clue to promoting efficacy and differentiation, therefore creating positive effects in the usage of 3D environments such as virtual tours (Zhang, Dang, Brown, & Chen, 2017; Bredl, Groß, Hünninger, & Fleischer, 2012; Michel, Helmick, & Mayron, 2011; Levesque & Lelievre, 2011).

In the last two decades, recent computing enhancements have made possible the use of various technologies and environments, allowing the creation of different kinds of virtual heritage (Barbieri, Bruno, & Muzzupappa, 2017; Champion, 2016; Bustillo, Alaguero, Miguel, Saiz, & Iglesias, 2015; Nicolas et al., 2015; Bergamasco, Frisoli, & Barbagli, 2002).

The first approaches were based on fixed photographs of heritage with a progressive design toward more dynamic settings (Sylaiou, Liarokapis, Kotsakis, & Patias, 2009). Later approaches include serious games (Anderson et al., 2010), virtual museums (Carmo & Cláudio, 2013), 3D models with render applications (Jiménez Fernández-Palacios, Nex, Rizzi, & Remondino, 2014), and 3D printing of architectural heritage (Esmacili, Woods, & Thwaites, 2014). Nowadays, researchers are working on the application of enhanced virtual environments, including, for example, multi-user virtual heritage and virtual heritage agents.

To represent heritage virtually some 3D programming and visualization technologies were created to provide tools to help the user feel really present (Ch'ng, Gaffney, & Chapman, 2013; Lee, 2004). In this case, the San Andrés Island heritage tour uses an immersive environment that complements the feeling of "being there" by being accompanied by, accessible, and available for others, avatars (Nowak, 2001). Suitable software for this kind of virtual tour experience is OpenSimulator, also called OpenSim (OS). It is a tool that consents to build and to simulate 3D virtual settings with features such as working with open coding and multi-user capacity, that is, different users embodied by avatars interacting simultaneously in the virtual environment and enabling col-



Figure 1. Example of four places represented in a virtual heritage: Venice, Statue of Liberty, Stonehenge, UK, and Champs-Élysées.

laboration. For this reason, OpenSimulator is used to implement the virtual tour.

Besides the latter, SecondLife, created by Linden Research Inc., is another platform used for the same purpose (SecondLife, 2017). Some examples of these platforms for virtual heritage contexts, where landmarks from around the world have been implemented using immersive environment technology, are shown in Figure 1. A chart with four of these places is shown: Venice, the Statue of Liberty, Stonehenge, and the Champs-Élysées.

Many places around the world have been incorporated into the World Heritage List, administered by the United Nations Educational, Scientific and Cultural Organization (UNESCO) through the World Heritage Convention. San Andrés Island was proposed as Seaflower Marine Protected Area (MPA); it is the first MPA in Colombia, the largest in the Caribbean region, and it is among the largest in the world (UNESCO, 2017). The MPA is a program developed by UNESCO.

Regarding the evaluation of learning about heritage in 3D virtual environments, we can say there are still developing studies that are not mature enough; in fact, previous studies have focused on the design and architecture of these environments (Vosinakis, Koutsabasis, Makris, & Sagia, 2016). The abovementioned can be verified

with the search string: “learning” AND “heritage” AND “virtual reality,” using specialized databases such as Scopus and Web Of Science and with analysis of a bibliometric map using normalization of co-occurrence of data through VOSviewer® software (Comas-Gonzalez et al., 2017; Waltman, van Eck, & Noyons, 2010). Figure 2 shows the map resulting from the analysis.

Figure 2 allows us to analyze that the keywords design, architecture, and research are the most frequent occurrence in specialized databases with search string: “learning” AND “heritage” AND “virtual reality.” In the map, the bigger size of circles denotes more occurrence. The keyword “design” is the one with the highest occurrence, which indicates most VR environments presently on heritage have focused on design. In the same way, keywords like “learning process,” “effectiveness,” and “e-learning” have a minimal occurrence. Additionally, keywords like “learning process” (purple cluster) and “cultural heritage” (red cluster) are in different clusters, indicating they are terms with probably little connection in previous articles.

More recently, literature has emerged that offers greater connection between “learning process” and VR on heritage, for example, related published works such as Ijaz, Bogdanovych, and Trescak (2016), where the authors compare the learning in books and videos versus VR on heritage, and the results show better understanding of the study material with the use of VR. Bruno et al. (2017) designed primarily for entertainment but provides a game-based learning experience. Vosinakis, Koutsabasis, Makris, and Sagia (2016) developed an application for learning using a kinesthetic sensor, with a positive evaluation of the application. The authors write “The majority of cultural heritage applications today place more emphasis on the content presentation rather than the user interaction and experience.”

There are other related published works such as Zhou, Zhou, Kobashi, and Sugihara (2016), who developed a VR system to enhance motivation and support learning of history and heritage in Japan. Fabola and Miller (2016) use VR as a tool for heritage learning on St Andrews Cathedral, Scotland, where *outcomes* refers to user experiences with the system. Several others, such as



Figure 4. Avatar choosing correctly an answer in the questionnaire.

Figure 5 illustrates three remote visitors interacting among themselves to agree on an answer to the questionnaire regarding the virtual tour.

Comparing the features described by Ch'ng (2009) to the progress achieved in the virtual tour of San Andrés Island, Colombia, it can be said that selective and participatory subfeatures have been employed. These refer to the possibility to choose suggested options and the fact that the user can establish communication with other avatars. The causative subfeature is partially accomplished since feedback is achieved just when the user answers questions about the virtual tour. Lastly, multi-user capacity is achieved using the connection of different remote visitors through a computer network (Comas-Gonzalez et al., 2017; Zamora-Musa & Villa, 2013).

4 Experiment

To assess the immersive environment usability in the virtual tour, a previous meeting took place to explain the platform's usage. After this, participants remotely logged into a server with software like WampServer to get on the tour's immersive environment. Each participant from different locations used computers with internet access and viewer software capable of displaying 3D environments like Singularity (2017) or Firestorm (2017) to interact through the 3D VR, which included answering some questions about the heritage of San Andrés Island. Finally, users completed an environment usability evaluation through SUMI's platform.



Figure 5. Avatars interacting to select a response about the virtual heritage tour.

4.1 Method

4.1.1 Participants. To calculate the number of participants, the sample size is determined by Equation 1:

$$n = \frac{N\sigma^2 z_\alpha^2}{e^2(N-1) + \sigma^2 z_\alpha^2}, \quad (1)$$

where n = sample size (number of participants); N = population size; σ = standard deviation of the population, usually 0.5; Z_α = confidence level, usually 95%; and e = acceptable limit of sample error, usually 5%.

In this case, the number of participants (sample size) is 52 remote visitors (28 men and 24 women); the resulting number from an average population of visitors in a heritage tour is 60 (population size); there is a 95% confidence level, and a 5% sample error. The participant's mean age was 23.4 years ($SD = 4.3$), and all of them were novice users concerning 3D VR environments that represent human culture and heritage.

4.1.2 Materials. To test learnability in a 3D heritage tour, we conducted two studies. In the first one, questions were asked about the heritage of San Andrés Island, specifically of subjects related to the 3D VR. Topics covered were Caribbean houses, including the evolution of island houses and surroundings of the house; traditional architecture, including the permanence of buildings and balloon frame (assembled wood structure); and other topics like pedestrian walkway Spratt Bay, Baptist Church, and Morgan's Cave.

Users answered questions about the heritage of San Andrés Island, interacting with the 3D VR environment, which shows the rating divided by themes and the average reached by each user. The rating has a range of 0.0 to 5.0 and is also shown in percentage. In the second study, we used the SUMI's method (Software Usability Measurement Inventory), which measures or assesses the quality and usability of software or environment from the end user's stance. This method has been rigorously tested and proven in different works (Sumi, 2017; Mansor, Kasirun, Yahya, & Arshad, 2012; Arh & Blazic, 2008), also in history teaching and virtual heritage (Karahoca, 2013), and it comprises the following six aspects:

- Efficiency: Measures the degree to which the user can achieve goals during direct interaction with the environment, and at the same time, assess its performance.
- Affect (likeability): It is the user's emotional response when interacting with the software or environment.
- Helpfulness: It evaluates how useful is the software or environment.
- Control: Measures the extent to which the user feels in control and comfortable during the use of the software.
- Learnability: Measures the facility and speed with which the user can learn about the environment's usage and acquire knowledge through its use.
- Global: It is a global summary of the five previous aspects.

The SUMI method is validated through the International Standard ISO 9241-11, and it consists of 50 multiple-choice questions, rated on a 3-point Likert scale in which the participant selects one out of three possible options: *Agree*, *Disagree*, or *Don't Know* (Sumi, 2017; Debevc, Stjepanovic, & Holzinger, 2014). (The survey can be retrieved from: <http://sumi.uxp.ie/en/>.) After the remote visitor takes the virtual tour, the participant completes the survey through a standard database that spawns a table with the results. If the mean score for such results is greater than or equal to 50, it can be said that this aspect has an above average value (Sumi, 2017;



Figure 6. VR environment showing results to users.

Tanja & Borka, 2008). Once the values are generated, the corresponding statistical analyses are carried out through a design of experiments.

Finally, after carrying out the two studies, a correlation between both is made to determine relations between learning and usability in the VR environment.

4.2 Results and Discussion

In the first study, after the users answered questions about the patrimony of San Andrés Island, the environment showed the results to the users, as illustrated in Figure 6.

The overall results for the 52 users are summarized as follows: the overall average was 4.08, that is, greater than 80% of correct answers, indicating good performance. Table 1 shows a statistical summary.

Table 1 shows summary statistics for Results. The standardized kurtosis and standardized skewness can be used to determine whether the sample comes from a normal distribution. Values of these statistics outside the range of -2 to $+2$ indicate significant departures from normality. In this case, both values are within the range expected for data from a normal distribution.

The user with the lowest score had 3.2 (64%), and the user with the highest score had 5.0 (100%). The number of users with a rating lower than 4.0 (below 80% of performance) is equal to 16 users (equivalent to 30.76%), and the number of users with a rating greater than or

Table 1. *Statistics Summary for the First Study Results*

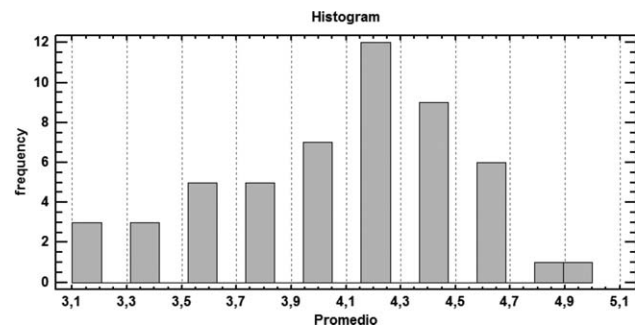
Count	52
Average	4.08077
Standard deviation	0.428878
Minimum	3.2
Maximum	5.0
Range	1.8
Std. skewness	-1.03834
Std. kurtosis	-0.598284

equal to 4.0 (above 80%) is equal to 36 users (equivalent to 69.24%). This means that 69.2% (the majority) of users achieved optimum performance. In Figure 7, the histogram of the ratings is illustrated, where it can be verified that the majority of the users reached a rating higher than 4.0.

For the second study, usability for the VR environment is shown in Table 2, with statistics summary using SUMI software like median values, superior and inferior confidence levels, asymmetry, and standardized kurtosis.

Table 2 shows a statistical summary for each one of the six variables: Global, Efficiency, Affect, Helpfulness, Control, and Learnability. Of particular interest is the presence of standardized skewness and standardized kurtosis, which can be used to determine if the sample comes from normal distribution. Values outside the range of -2 to $+2$ indicate a significant deviation from normality, which would tend to avoid many of the statistical procedures commonly applied. The statistical analyses were performed with the Statgraphics software (Statgraphics Plus 5.1, StatgraphicsTM net).

Table 2 indicates that the six variables present standardized skewness and standardized kurtosis values within the expected range (-2 to $+2$). For example, for Efficiency the standardized skewness is (-0.427) , that is, within the expected range (-2 to $+2$), and for Learnability the standardized kurtosis is (0.270) , that is, within the expected range (-2 to $+2$); hence, the sample comes from normal distribution, validating in this way the statistic procedures applied to data entries from the virtual heritage tour.

**Figure 7.** *Histogram of grades in VR.*

Using the statistical data of the median of each variable (Table 2), the median of the six variables with a value above 50, that is, all of them, are superior to the average (Sumi, 2017; Tanja & Borka, 2008). Therefore, the immersive environment of the virtual tour can be compared to any successful system already in force. The variable with the highest mean scores is Affect (63), which means that the aspect with the greatest positive impact is that associated with user feeling or the participant's emotional response when interacting with the 3D VR environment. The variable with the lowest mean score is Control (57.8), which is the condition that the participants are novice users in this type of environment; therefore, the aspect of control of the environment is the lowest. Another important aspect to discuss are the variables Learnability and Efficiency, which have an average of 62.1 and 60.4, respectively, which shows that users can achieve goals during direct interaction with the environment about heritage and acquire knowledge through its use.

Additionally, to statistically validate the data obtained, Table 3 shows the results of several tests carried out to determine whether the six variables can be correctly modeled through normal distribution. The chi-square test divides the range of the six variables into equally likely classes and studies the number of observations. The Shapiro-Wilk test is based on the comparison of the normal distribution quartiles to the data quartiles. The standardized skewness test identifies the lack of symmetry in the data.

Table 3 displays the lowest p -values for: Global (0.617), Efficiency (0.145), Affect (0.109), Helpfulness

Table 2. Statistics Summary for Usability

Summary Statistics	Global	Efficiency	Affect	Helpfulness	Control	Learnability
Median	63.2	60.4	63	59.1	57.8	62.1
Min.	57	53	49	50	49	52
Max.	70	67	70	66	66	68
Standardized Skewness	0.196	-0.427	-1.662	-0.572	-0.361	-1.438
Standardized Kurtosis	-0.723	-0.814	1.059	-0.778	-0.917	0.270

Table 3. Normality Test

Normality Test	Global	Efficiency	Affect	Helpfulness	Control	Learnability
Chi-square Test	6.266	12.133	12.133	7.733	12.133	9.2
<i>p</i> -value	0.617	0.145	0.145	0.459	0.145	0.325
Shapiro–Wilk Test	0.970	0.950	0.903	0.939	0.942	0.931
<i>p</i> -value	0.822	0.513	0.109	0.369	0.396	0.285
Asymmetry z	0.159	0.347	1.277	0.462	0.294	1.120
<i>p</i> -value	0.872	0.728	0.201	0.643	0.768	0.262
Comparison <i>p</i>-value	0.617 > 0.1	0.145 > 0.1	0.109 > 0.1	0.369 > 0.1	0.145 > 0.1	0.262 > 0.1

(0.369), Control (0.145), and Learnability (0.262), which means all *p*-values are equal or superior to 0.10; therefore, all the variables come from normal distribution.

Finally, in the correlation between the variable of the first study Results, which is obtained from the users' answers to questions concerning the heritage of San Andrés Island studied through a 3D VR, and the six variables of usability (Global, Efficiency, Affect, Helpfulness, Control, and Learnability), we obtain the data in Table 4.

Table 4 shows Spearman rank correlations between each pair of variables (Karahoca, 2013). These correlation coefficients range between -1 and +1 and measure the strength of the association between the variables. Also shown in parentheses is the number of pairs of data values used to compute each coefficient. The third number in each location of the table is a *p*-value, which tests the statistical significance of the estimated correlations. *p*-values below 0.05 indicate statistically significant non-zero correlations at the 95.0% confidence level.

Of particular interest is the correlation between variable Results (first study) and the other six variables (second study), where the following pairs of variables

have *p*-values below 0.05: Results and Global (*p*-value: 0.0002 and correlation: 0.9892), Results and Efficiency (*p*-value: 0.00421 and correlation: 0.5290), and Results and Helpfulness (*p*-value: 0.0449 and correlation: 0.5361).

Correlation is a quantitative value of the relationship between two or more variables, and can vary from -1.00 to 1.00. The correlation of direct or positive proportionality is established with the positive values and the correlation of inverse or negative proportionality with the negative values. Then the Results and Global variables have a high direct or positive proportionality (0.9892), which means that the implementation of good usability characteristics (interactivity, feedback, ease of use) of a 3D VR environment on heritage will enable optimal learning outcomes.

In the same way, the variables Results and Efficiency have a high direct or positive proportionality (0.5290), which means that in a 3D environment VR with a good level of efficiency (ability to achieve objectives during the direct interaction), users will get good results.

These results are significant because in previous research it has been mentioned that examples of mean-

Table 4. Spearman Rank Correlations

Sample Size = 52	Global	Efficiency	Affect	Helpfulness	Control	Learnability	Results
Global		0.5136	0.0444	0.5883	0.5338*	0.1746	0.9892*
<i>p</i> -value		0.0547	0.8681	0.0277	0.0458	0.5135	0.0002
Efficiency	0.5136		-0.1885	0.2835	0.4896	0.4941	0.5290*
<i>p</i> -value	0.0547		0.4806	0.2888	0.0670	0.0645	0.0421
Affect	0.0444	-0.1885		0.0390	-0.0481	0.3355	0.0309
<i>p</i> -value	0.8681	0.4806		0.8839	0.8573	0.2094	0.9081
Helpfulness	0.5883*	0.2835	0.0390		0.6772*	0.0207	0.5361*
<i>p</i> -value	0.0277	0.2888	0.8839		0.0113	0.9381	0.0449
Control	0.5338*	0.4896	-0.0481	0.6772*		0.2270	0.5122
<i>p</i> -value	0.0458	0.0670	0.8573	0.0113		0.3956	0.0553
Learnability	0.1746	0.4941	0.3355	0.0207	0.2270		0.1803
<i>p</i> -value	0.5135	0.0645	0.2094	0.9381	0.3956		0.4998
Results	0.9892*	0.5290*	0.0309	0.5361*	0.5122	0.1803	
<i>p</i> -value	0.0002	0.0421	0.9081	0.0449	0.0553	0.4998	

*: Data with *p*-values below 0.05 means a high correlation of positive proportionality between each pair of variables.

ingful interaction in 3D VR heritage environments are still too undeveloped (Champion, 2016; Rodriguez-Echavarría et al., 2007; Pujol Tost & Economou 2006; Roussou, 2005).

Also, other research shows that feedback and interactivity are necessary to provide adequate evidence of effectiveness so that learning gain ceases to be a barrier to the adoption of 3D VR (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Mortara et al., 2014).

Then, comparing the results of previous investigations with our results, significant advances are observed because there is a high direct or positive proportionality between the variables Results and Efficiency, which means the ability to achieve objectives during the direct interaction and use of usability characteristics such as feedback and ease of use.

5 Conclusions and Future Work

The implementation of a VR heritage tour through immersive featured environments made it possible for remote visitors—besides taking the tour—to learn about San Andrés culture and heritage. It equally helped visitors to feel they were immersed in a dynamic and inter-

active environment, in which they were also able to interact with other remote users.

Taking as reference the research carried out in the background section, which includes related works, we can conclude that previous research on heritage in 3D environments has had a greater emphasis on architecture, design, and presentation of themes and that the evaluation of learning in this type of environment is currently developing. In this research, we obtained excellent results regarding the evaluation in a 3D VR environment for heritage.

Concerning the evaluation of learning in a 3D VR environment on heritage, optimum performance of users was obtained, with an average of 80% correct answers for the total population. It is important to mention that 69.2% (the majority) of users achieved optimum performance because their correct answers were above 4.0 (80%).

In the study of usability, the variable with the highest average value obtained was Affect with a value of 63, which means that the aspect with the greatest positive impact is associated with users' feeling or the participant's emotional response when interacting with the 3D VR environment.

It was also observed that the variables Learnability and Efficiency obtained high values of usability, which shows that users can achieve goals during direct interaction with the environment about heritage and acquire knowledge through its use. With a statistical correlation of the six usability variables (Global, Efficiency, Affect, Helpfulness, Control, and Learnability) concerning the variable Results (related to the users' responses to the specific themes visited in the 3D heritage tour), we can conclude that characteristics like interactivity, feedback, and ease of use (topics associated with the Global variable) are highly related to the results that users can achieve. In the same way, the variable Results has a high correlation with the variables Efficiency and Helpfulness, which indicates that a direct interaction with an environment that contains user aids, feedback of processes (like answers to questions asked), and the ability to achieve objectives, will provide users optimal results in learning, with which some limitations of previous results are solved concerning the evidence of effectiveness and evaluation of learning in a 3D VR environment on heritage.

After analyzing some aspects by way of conclusion, it is necessary to mention some topics as a future research subject for 3D environments about heritage, such as the variable Control with the lowest average in usability. This result is following the condition that the participants are novice users in this type of environment. This aspect and how to improve the virtual tour to increase learnability can be enhanced by implementing adaptive behavior and using modeling of multiple-agent systems, voice recognition, and gestures, participant's study as a possible frustration, and generation of new models for deeper learning.

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