Evaluating Extended Reality Application for a Virtual Museum. Case Study: Remigio Crespo Museum

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***Abstract*—The COVID-19 pandemic was the main reason why many organisations decided to include information and communication technologies in their processes to allow them to continue with their activities, be it providing services to users (food, medicine, etc.), training/education or disseminating culture. In the field of culture, some museums incorporated technology into their operating environment, moving from face-to-face visits to virtual visits. However, in many museums, the lack of apps designed to solve the problem of virtual visits caused some to stop receiving visitors during the pandemic. In this context, this paper describes the development of an application with a user-centred design that incorporates extended reality to allow virtual visits to the Remigio Crespo Museum in the city of Cuenca (Ecuador). The evaluation carried out to verify the application's usability and learnability is also included. The results obtained indicate that users/visitors found the application usable and easy to learn.**

Keywords—* *Extended reality, virtual museum, user-centred design, usability

I. Introduction

During the COVID-19 pandemic, there was a need for companies and institutions around the world to continue serving the public, whether in the field of service provision (food, medicine, education, etc.), in the dissemination of culture (art academies, museums, etc.) and in tourism. Tourism is a key generator of foreign exchange all over the world and museums are an important source of income in many countries. However, due to the COVID-19 pandemic, museums stopped receiving visitors due to the restrictions to stop the advance of the pandemic, which severely affected the museums [1]. The solution to this problem was to revert to information and communication technologies, thus turning traditional museums into virtual museums. However, the concept of a virtual museum is not new but was revived to enable tourists to visit museums in times of travel restrictions [1]. Extended reality (XR) was used to include art collections (sculptures, paintings, etc.) in virtual visits by means of XR applications installed in mobile devices. This type of application is based on agile methods, although in some cases the developers have not defined a special method for this type of applications.

The present research work is related to an XR application for exhibition spaces which was developed for the requirements of the Remigio Crespo Museum in Cuenca (Ecuador). This application is multiplatform, i.e. users (tourists) can use it in a computer (desktop or notebook) or a mobile device with a user-centred design and an agile method.

To evaluate the usability and learnability of the application we used a SUS questionnaire (SUS - System Usability Scale), which is a widely used questionnaire that has proven to be a robust and reliable evaluation tool [2]. Effectiveness and efficiency are evaluated by means of a statistical process and validity threats are analysed. Finally, the results are analysed and discussed. The main contribution of this research work is twofold: (1) the XR application developed to permit virtual visits to the Remigio Crespo Museum and, (2) the evaluation of its usability and learnability.

The rest of this paper is organised as follows. In Section II we present the background to the work, including the related definitions and terms. Section III reviews the literature on similar studies to our research work. In Section IV we describe the development of the XR application. Section V describes the testing of the usability and learnability of the proposed XR application. Section VI contains the results and a discussion, while Section VII includes threats to validity. Finally, Section VIII gives our conclusions and outlines future work.

II. Background

This section includes some definitions and terms related to our research work.

XR is an emerging umbrella term for all the immersive technologies, for example, augmented reality (AR), virtual reality (VR), and mixed reality (MR). All immersive technologies extend the reality we experience by either blending the virtual and "real" worlds or by creating a fully immersive experience [3]. According to Rodríguez and Díaz [4] there are two types of VR technology, which are: (i) immersive VR: this uses 3D computer-generated (CG) environments in which the user is isolated from the real world. Special devices are used to manipulate these environments. (ii) non-immersive VR: this uses 3D CG environments, but the user is not isolated from the real world. The 360° virtual tour is a type of non-immersive VR which consists of applications that allow users to explore a real or fictional world virtually, giving them the sensation of actually being present in a certain place.

Agile is a wide umbrella term for software development beliefs consisting of a conceptual framework for software engineering that begins with an initial planning phase and follows the path to the deployment phase with iterative and

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incremental interactions throughout the life-cycle of the project [5].

User-centred design (UCD) is a design method and philosophy in which the needs, goals, and success of the end user are considered. The UCD process often includes analysis of the typical user's tasks, identifying different groups of users based on their needs, rapid prototyping using mock-ups and storyboards, and usability testing [6]. According to ISO, in its 9241-11:2018 standard, usability can be defined as: "the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [7].

III. Related Work

This section describes work related to the evaluation of the usability of extended reality applications in the context of exhibition spaces for which related works of the last four years (2018-2021) were reviewed.

Some work, like [8], [9], [10], [11], [12] and [13] use different techniques to develop AR applications for exhibition spaces and cover aspects of their design and development. [14] evaluates the interfaces of the AR application developed for the exploration of a museum. Another work carries out tests to confirm that the AR application facilitates the user experience, although it does not specify the procedure used for this evaluation [15].

Other authors, such as [16], [17] and [18] evaluate the application, user experience and the design and functionality of the XR applications through questionnaires.

Another study [19] evaluates the application with respect to user satisfaction and experience through questionnaires with the parameters proposed in [20]. [21] evaluates the ease of use, utility and enjoyment through a subjective assessment (by questionnaires) and an objective evaluation (using the Log method), while [22] evaluates the application by reference to four constructs proposed by [23].

[24], [25], [26] and [27] evaluate the usability of XR applications through a SUS questionnaire. However, none of these studies specifies the process used to perform the evaluations.

The review of the existing literature shows that there is no adequate methodological orientation for a usability evaluator to conduct a study on museum exhibition spaces. In the present work, we evaluated the usability of a virtual reality application. To the best of our knowledge, no articles on usability studies of virtual reality applications have been published to date for museum exhibition spaces.

IV. The XR Application Developed

This section describes the procedure used to develop the XR application, which was the method proposed by [28] comprising six steps (Fig. 1):

(1) understanding and specifying the context of use,
(2) specifying the user requirements,
(3) collecting data,
(4) designing the system architecture,
(5) the VDDE cycle, and
(6) closing the project.

Following this method, we developed the multiplatform XR application based on a 360° virtual tour.

The application architecture consists of three layers: data layer, service layer and presentation layer. In the data layer, Oracle XE is used as a database and stores the information on the museum's exhibits. The service layer allows access to data layer information, for which a REST API is implemented using Spring Boot as the framework. In the presentation layer we use React JS, which creates interactive graphic interfaces and interacts with different input and / or output devices.

The application was deployed in a case study on the Remigio Crespo Museum as a requirement during the Covid-19 pandemic, when visitors did not have access to the museum facilities due to mobility restrictions.

The purpose of the application was to allow access to the exhibits in the Elia Liut Room and archaeological reserve of the museum by means of 360° tours. These exhibits were selected because: (i) the Elia Liut Room is one of the most popular rooms in the museum and is also temporary exhibition, i.e. it is available only for a limited time; (ii) the archaeological reserve is a restricted area of the museum to which the general public does not have access.

The requirements were defined by means of a prototype. In this stage the participation of all interested parties was necessary, including the end users. The areas of interest in the museum were then defined through an expert's guided tour of the museum. Information was provided from the web and material provided by the museum expert. The most important exhibits on show were selected and data was collected from each exhibition area. The data collected by the application were found in different types of multimedia, such as: text, images and videos. During the data collection, the following devices were used: a 360 ° camera with 4K resolution, a high-resolution camera and a tripod. To cover all the user requirements, three iterations of the VDDE cycle of the method were performed, at the end of which the completed application was obtained [29].

The application consists of three user interfaces (UI), which are: the main page, which provides a description of the museum and allows access to more detailed information. It should be mentioned that the application is designed to include additional museums in the future. The second UI shows the most important museum photographs together with general information and a list of virtual tours to which the users have access (Fig. 2).

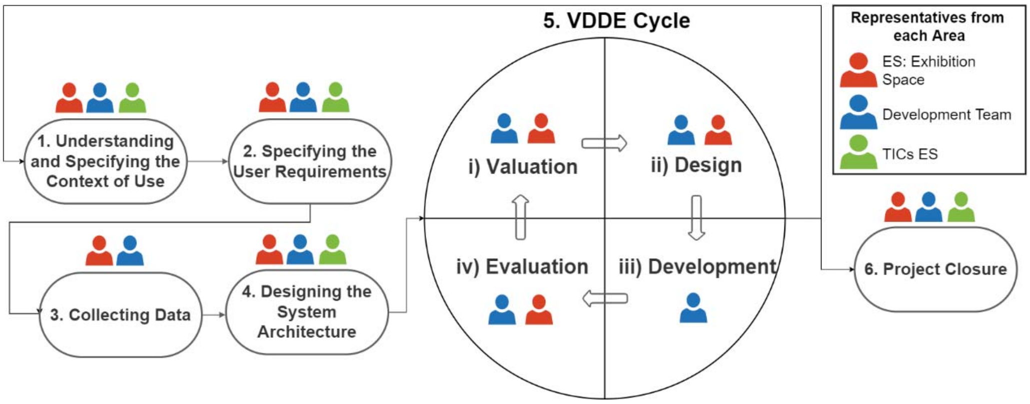

Fig. 1. Method used in the application development [28].

Fig. 2. The Elia Liut Room and the museum's archaeological reserve.

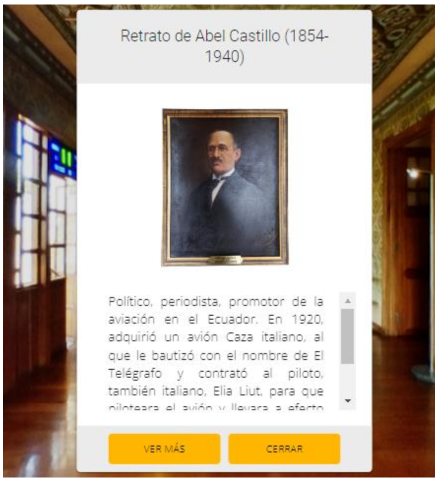

Fig. 3. A partial view of the virtual tour.

The third UI (Fig. 3) consists of a virtual tour that allows access to information on the exhibition pieces through infographic cards.

A meeting was held with all interested parties to conclude the project in which the fulfilment of all requirements was verified, after which the application's user and technical manuals were complied.

V. Usability and Learnability Testing

To evaluate the XR application developed, we used SUS [2] to test its usability and learnability and tested effectiveness and efficiency by a statistical process. This test of the virtual museum was conducted after the development phase of the XR application. The subjects (end users) were asked to fill in a form from Google Forms containing an informed consent, demographic questions, SUS items and an additional comment section on the virtual museum. They were also asked to state whether they had prior experience of XR applications (yes=expert, no=novice). Also, a 5-point Likert scale was used to collect their ratings of the virtual museum's perceived usability. The time required to complete the proposed tasks was registered with the aim of calculating the effectiveness and efficiency of the XR application.

A. Goal

The approach we used in our evaluation was the Goal, Question, Metric (GQM) method [30] using the GQM template. The purpose of this process was to evaluate the XR application with respect to its usability and learnability by end users from the researchers' point view in a virtual visit to the Remigio Crespo museum in Cuenca (Ecuador).

B. Planning

1) Subjects: A convenience sampling technique was used to recruit 74 subjects aged 18 to 28 years old, with varied backgrounds (academic level: 52.7% high-school and 47.3% university education) to participate in this evaluation. They were asked if they would like to participate voluntarily in the study and were not offered any monetary or other reward for their contribution.

2) Research questions: the following research question was derived from our goal (see Table I).

Table I. Research Questions

RQ	Question: When the subjects use the XR application …
1	… is their usability affected by their experience level?
2	… is their learnability impacted by their experience level?

3) Hyphotheses: the following null hypotheses were established:

- H_{10}: The subject's experience level does not influence the perceived usability of the developed XR application (RQ1).
- H_{20}: The subject's experience level does not influence the effectiveness in using the developed XR application (RQ1).

- H_{30}: The subject's experience level does not influence the efficiency in using the developed XR application (RQ1).
- H_{40}: The subject's experience level does not influence the perceived learnability of the developed XR application (RQ2).

4) Variables and metrics. The independent variable, which is expected to be influenced to some extent by the independent variable is:

- Experience level: expert (subject had prior experience using XR applications) and novice (subject had no experience of this type of application)

The dependent variables are:

- Usability: extents to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use [31].

  Effectiveness: the ratio between the number of tasks correctly completed and the total number of tasks during the experiment.

$$effectiveness = \frac{number\ of\ tasks\ completed}{\text{number of proposed tasks}} \quad (1)$$

- Efficiency: this was assessed by recording the time taken to do the tasks during the experiment. We recorded efficiency in minutes.

$$efficiency = \frac{number\ of\ tasks\ completed/time\ invested}{\text{number of proposed tasks/expected time}} \quad (2)$$

  The result was a value that allowed the subjects to be evaluated comparatively, considering that the higher values presented greater efficiency and the lower values a deficiency. The expected time was calculated as the average value of the times obtained by expert evaluators doing the tasks proposed in the experiment.

- Learnability: enables new users to be effective, efficient and satisfied when learning to use a new system [31].

C. Instrumentation

1) Questionnaire: We implemented a Web-based survey using Google Forms, which was composed of three sets of questions regarding:

- *Demographic data*: we asked about gender, range of age, educational background, experience level using XR applications, quality of Internet connection.
- *Task Description Document*: this describes the tasks to be performed in the experiment using the XR application and contains empty spaces to be filled in by the subjects with the start and end times of each task of the experiment. This document contains guidelines to guide the subject through the experiment.
- *SUS questionnaire*: In this case, we used the SUS, which is a widely used instrument to measure the perceived usability of products and systems [2]. According to [32] it is a valid and reliable questionnaire (see Table II) for measuring usability, containing 10 questions with alternating positive and negative statements to avoid response biases, with a five-point Likert score ranging from strongly disagree to strongly agree. These questions will be further analysed and calculated for the final score (0–100) and graded from A to F or using adjective ratings (see Fig. 4). According to Lewis and Sauro [33], SUS is a bi-dimensional measurement: usability (all questions except 4 and 10) and learnability (questions 4 and 10) sub-scales. In our research work we conducted a bi-dimensional analysis of the SUS scale.
- *Experimental feedback*: A post-test questionnaire that includes open questions about feedback to improve the XR application.

TABLE II. SUS QUESTIONNAIRE

ID	SUS questions
q1	I think that I would like to use this system frequently
q2	I found the system unnecessarily complex
q3	I thought the system was easy to use
q4	I think that I would need the support of a technical person to be able to use this system
q5	I found the various functions in this system were well integrated
q6	I thought there was too much inconsistency in this system
q7	I would imagine that most people would learn to use this system very quickly
q8	I found the system very cumbersome to use
q9	I felt very confident using the system
q10	I needed to learn a lot of things before I could get going with this system

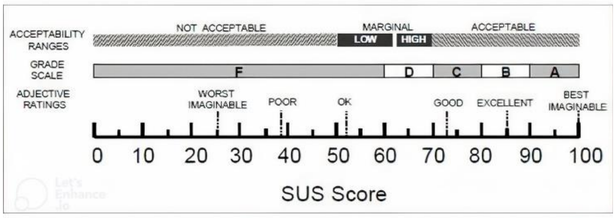

Fig. 4. SUS Score rating

D. Experimental Procedure

The procedure of this study is divided into three stages (Fig. 5):

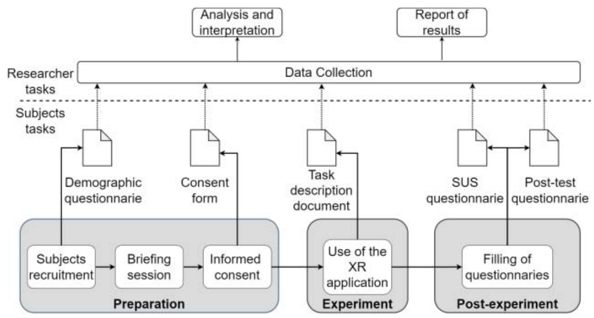

Fig. 5. Experimental Procedure

Stage 1: Preparation

- *Subject recruitment:* 74 subjects were recruited to participate in the study, who filled in the demographic questionnaire.

- *Briefing session*: Subjects were briefed about the purpose of the study and the evaluation procedures and given a demonstration on how to use the XR application.
- *Informed consent:* Subjects were asked to sign the consent form on Google Forms. They were told that they could withdraw from the test at any time without any type of penalty.

Stage 2: Experiment

- *Use of the XR application:* The next step was the use of the XR application to make a virtual tour of the museum. Subjects were told to use the XR application for as long as possible to get familiar with the application by fulfilling certain tasks. described in the Task Description Document.

Stage 3: Post-experiment

- *Questionnaires:* After using the XR application, the subjects were required to complete the forms (SUS and post-test questionnaires) on Google Forms to evaluate the XR application.

VI. Results and Discussion

The statistical analysis was carried out on the SPSS v.23 statistical tool. The result of the SUS evaluation of the XR museum application is given in detail in Table III. The evaluation was conducted on the experience level in using XR applications. We used Shapiro-Wilk tests to evaluate the samples' normality as it is appropriate for small sample sizes (<50 samples).

TABLE III. Comparison of mean scores according to experience level

Group	Statistic	Usability Rating	Effectiveness	Efficiency	Learnability
Novice	Mean	75.60	92.97	1.08	79.73
	SD	14.64	12.22	.45	21.72
Expert	Mean	66.40	92.16	0.99	81.42
	SD	20.01	12.05	.51	20.75
Overall	Mean	71.00	92.57	1.03	80.57
	SD	18.01	12.06	0.48	21.11

A. Usability Scores for experience level (RQ1).

The values of the Shapiro-Wilk tests (see Table IV) for usability, which was measured by SUS questionnaire followed a normal distribution (>0.05).

TABLE IV. Normality tests

Variable	Group	Shapiro-Wilk		
		Statistic	***df***	***Sig.***
Usability	Novice	.970	37	.421
	Expert	.972		.477
Effectiveness	Novice	.628		.000
	Expert	.702		.000
Efficiency	Novice	.967		.333
	Expert	.946		.073
Learnability	Novice	.847		.000
	Expert	.839		.000

A T-test was performed to evaluate if it was possible to differentiate usability between experience levels. Table V shows the results of the t-student test, in which we found a statistically significant difference for usability between the novice (mean=75.60, SD=14.64) and expert subjects (mean=66.40; SD=20.01), t(66)=2.258, p=.027, d= 0.52476. We therefore rejected the null hypothesis H_{10}.

The proposed XR application needs a certain degree of interaction between the user and the application to achieve the virtual tour and review the information of the different objects exhibited. But this degree of interaction affects the usability of the application which is on average a "good" index for novice and "high" index for expert users, according to the SUS score rating. These results suggest that, this being the first experience for novice users, the XR application had a positive impact on them compared to the experts, who had already used similar applications.

B. Effectiveness Scores for experience level (RQ1)

The values of the Shapiro-Wilk tests (see Table IV) for effectiveness were <0.05, which means that these variables did not have a normal distribution. We considered both groups as independent. The non-parametric Mann-Whitney U test was then selected to evaluate the second null hypothesis (H_{20}). Table VI gives the results of the Mann-Whitney U test. Given that we did not find any statistically significant difference for effectiveness between novice (Mdn=100.00; range=40) and expert subjects (Mdn=100.00; range=50), U=647.000, p=.640, g Hedges=0.066747. We therefore did not reject the null hypothesis H_{20}. In other words, with 95% confidence we can say the median values of effectiveness are similar for both subject experience levels. This means that effectiveness is independent of the subjects' experience level when they are using the XR application.

C. Efficiency Scores for experience level (RQ1)

The results obtained by applying Shapiro-Wilk tests (see Table IV) for efficiency were .333 for novice subjects and .073 for expert subjects, so that the values have a normal distribution. Table V gives the results of the t-Student test, in which we did not find any statistically significant difference for efficiency between novice (Mean=1.08; SD=.45) and expert subjects (Mean=.99; SD=.51), t(72)=.859, p=.393, d =0.187135. We therefore did not reject the null hypothesis H_{30}. In other words, with 95% confidence we can say the median values of efficiency are similar for both subject experience levels. This means that efficiency is independent of their experience level when they are using the XR application.

D. Learnability Scores for experience level (RQ1)

The non-parametric Mann-Whitney U test was selected to evaluate the fourth null hypothesis (H_{40}). Table VI gives the results of the Mann-Whitney U test. Given that, we did not find any statistically significant difference for learnability where the values for novice (Mdn=85.5; range=75) and expert subjects (Mdn=85.5; range=75) were equal, U=659.500, p=.778, g Hedges=0.079565. We therefore did not reject the null hypothesis H_{40}. In other words, with 95% confidence we can say the median values of learnability are similar for both subject experience levels. This means that learnability is independent of the subjects' experience level when they are using the developed XR application. The learnability of the application is on average a "good" index for novice and expert users according to the SUS score rating.

TABLE V. RESULTS OF HYPHOTESES TESTS

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	***Sig.***	***t***	***df***	***Sig. (2-tailed)***	***Mean Difference***	***Std. Error Difference***	***95% Confidence Interval of the Difference***	
									Lower	***Upper***
Usability by Experience Level	Equal variances not assumed	4.716	.033	2.258	66	.027	9.2027	4.075	1.065	17.339
Efficiency	Equal variances assumed	.0427	.516	.859	72	.393	.09541	.11111	-.12609	.31690

TABLE VI. RESULTS OF HYPHOTESES TESTS WITH U-MANN WHITNEY

	Novice	**Expert**	**U**	**P**	**g de Hedges**
	Mdn (Rango)	**Mdn (Rango)**			
Learnability	87.50 (75)	87.50 (75)	659.500	.778	0.079565
Effectiveness	100.00 (40)	100.00 (50)	647.000	.640	0.066747

The survey results revealed that the overall average usability (71.00) and learnability (80.57) are acceptable, so that it can be concluded that the developed XR application has at least a "good" subjective rating according to the SUS score rating.

Two open questions were included in the post-test questionnaire: (1) "Do you have any suggestions to make the application easier to use?" and (2) "Do you intend to use the application in the future? Why?". The intention of these two questions was to elicit feedback from the subjects about their assessment.

The subjects responded as follows:

To the first open question:

- It is necessary to optimize the browsing speed to improve the experience of the virtual visit.
- It is recommended that a map of the museum be included with a better map of the layout of the museum.

This feedback will be considered to improve new versions of the XR application.

To the second question:

- Some subjects indicated that they would like to continue using this type of applications in the future to visit other interesting exhibition spaces available on the Internet.
- Some subjects indicated that they would like to continue using this type of application since it helps them to discover other sites that they currently cannot visit for various reasons.

VII. VALIDITY THREATS

There are several threats that potentially affect the validity of our study, including threats to the statistical conclusions, internal validity, threats to the construct validity and to external validity.

A. Validity of the statistical conclusions

This validity can be affected by the statistical methods selected for the analysis. To deal with this, the Shapiro-Wilk's test was used to determine whether the sample had a normal distribution. The T-Student test and the non-parametric Mann-Whitney U test were then used to determine whether or not the null hypotheses should be rejected.

B. Internal validity

This can be affected by the participants' prior experience. In this case, none of the participants had used the XR application before. To balance these factors for all the participants, the briefing session was held before the evaluation was carried out.

C. Construct validity

The threat identified for this type of validity refers to the reliability of the questionnaire used to assess user perceptions. In this regard, the widely applied SUS questionnaire was used that has proven to be a robust and reliable evaluation tool.

D. External validity

This validity refers to the ability to generalise the results of the evaluation to the entire population. Despite the fact that the experiment was performed in an academic context, the results could be representative for novice users with little or no experience in XR applications. With respect to students as experimental subjects, several authors suggest that the results can be generalised to real contexts [34].

VIII. CONCLUSIONS AND FUTURE WORK

The digitalisation of museum collections is an innovation that provides a new experience through the use of technologies such as XR and also contributes to the preservation of cultural artefacts. This paper reports on the development of an XR application for exhibition museum spaces and evaluates it by applying the SUS questionnaire to evaluate its usability and learnability.

The overall average scores for usability (71.00), effectiveness (92.57), efficiency (1.03) and learnability (80.57) mean the XR application developed for the Remigio Crespo museum is "acceptable" to users, according to the SUS score rating.

The application usability was evaluated using measurements of its effectiveness and efficiency, for which various testing scenarios were performed. The results (effectiveness score: 92.97 for novices and 92.16 for experts; efficiency score: 1.08 for novices and .99 for experts) showed that the XR application can run its designed functionality with acceptable response times. The application's usability was also evaluated by the SUS method. The SUS score for novices was 75.60 and for experts 66.40, which means that it is "acceptable", according to the SUS score rating. Based on the hypotheses' tests, there was a significant difference in usability between novice and expert subjects.

The learnability of the XR application was evaluated by the same SUS method (79.73 for novices and 81.42 for experts). These values are considered as "good" based on the SUS score rating. Using the hypotheses' tests for effectiveness, efficiency, and learnability values, no difference was found between novice and expert subjects in using the XR application.

These results suggest that the XR application will help tourists in the virtual tour when they are visiting the museum. It is therefore expected to encourage tourists to visit the museum through virtual tours when the real museum is closed to the public.

In future work we plan to extend the evaluation and consider other factors (e.g. quality of the virtual tour according to the quality of the end users' Internet connection and its impact on the performance of the XR application) to see whether the results of this study can be generalised. Regarding the answers to the open questions, the feedback showed that it is necessary to include a map to make it easier for users to move around in the virtual tour as an improvement.

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