

Received October 6, 2019, accepted November 6, 2019, date of publication November 11, 2019, date of current version November 20, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2953003

# Mobile Five Senses Augmented Reality System: Technology Acceptance Study

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This work was supported in part by the Portuguese Foundation for Science and Technology (FCT), Projects: Laboratory of Robotics and Engineering Systems, LARSyS (UID/EEA/50009/2019), Arts and Communication Research Center, CIAC (UID/Multi/04019/2019), Research Centre for Tourism, Sustainability and Well-Being, CinTurs (UID/SOC/04020/2019), Center for Advanced Studies in Management and Economics, CEFAGE (UID/ECO/04007/2019), and in part by Project M5SAR I&DT nr. 3322 financed by the CRESC ALGARVE2020, PORTUGAL2020 and FEDER.

**ABSTRACT** The application of the most recent technologies is fundamental to add value to tourism experiences, as well as in other economic sectors. Mobile Five Senses Augmented Reality (M5SAR) system is a mobile guide instrument for cultural, historical, and museum events. In order to realize the proclaimed five senses, the system has two main modules: a (i) mobile application which deals mainly with the senses of sight and hearing, using for that the mobile device camera to recognize and track on-the-fly (museum's) objects and give related information about them; and a (ii) portable device capable of enhancing the augmented reality (AR) experience to the full five senses through the stimulus of touch, taste, and smell, by associating itself to the users' smartphone or tablet. This paper briefly presents the system's architecture but, the main focus is on the analysis of the users' acceptance for this technology, namely the AR (software) application, and its integration with the (hardware) device to achieve the five senses AR. Results show that social influence, effort expectancy, and facilitating conditions are the key constructs that drive the users to accept and M5SAR's technology.

**INDEX TERMS** Augmented Reality, TAM, UTAUT, five senses.

## I. INTRODUCTION

Driven by mobile devices massification, augmented reality (AR) technologies have been gaining a huge amount of different applications and users [2]. AR empowers a higher level of interaction between the user and real world objects, extending the experience on how the user sees and feels those objects, by creating a new level of professional and edutainment applications that was not available before. The M5SAR: Mobile Five Senses Augmented Reality system for museums [36] aimed at the development of an AR system to be a guide in cultural, historical, and museum events. The novelty of this system is to extend AR in mobile devices to the 5 human senses: sight, hearing, touch, smell, and taste [36], [37].

Traditional AR systems yield sensorial feedback for only two senses – sight and hearing. Unlike those AR systems, multi-sensorial media focuses on providing a more

The associate editor coordinating the review of this manuscript and approving it for publication was Lei Wei<sup>1</sup>.

immersive communication, enhancing the user's quality of experience [46]. Existing multi-sensorial systems, related to augmented sensing experiences, are big hardware systems far from being portable (see Sec. II).

It is important to reinforce that, the main technological contribution of M5SAR is the implementation of a full mobile system that allows reality augmentation using five senses. The integration in a complete usable mobile system, based on a mobile device and a small hardware device [37], that integrates simultaneously smell, taste, and touch (i.e., heat, cold, and vibration), did not exist previously, to the best of our knowledge. Nevertheless, portable systems exist, but focus typically only in one sense [10], [14], or at most three when counting vision, hearing and an additional sense, for instance the smell.

To develop a portable device that explores all five human senses, three big challenges were addressed in the M5SAR's context: (a) how to integrate the visitor's smart device (tablet or smartphone) in a compact new device that allows the user to have an immersive five senses experience;

(b) how to fit the needed hardware in a small and ergonomic device; and (c) how to validate the integration between user's mobile/hardware device and the user's experience enhancement but, at the same time, in the present case, not removing the focus in the museum visit – the museum's objects. On other words, the goal is that the museum's visitors do not go for a "head down" visit ("smombie"), always looking at the mobile device, but instead appreciate the museum's objects which are accompanied by an AR experience, where the narrative about each object explores the five senses.

In more detail, the M5SAR's complete system consists of a mobile application (App) and a physical mobile device (PMD), to be integrated with the user's smartphone or tablet in order to explore the five human senses. The PMD is portable, light and small, but it adds touch, smell, and taste experiences to the sight and sound provided by the App, completing the augmented system. In short, the system has the following main features: (a) an App that can be installed in any mobile device (independent of the operating system); (b) the App can detect museum's objects using the rear camera of the device; (c) for each object of the museum (after being detected), the App reveals contents (text, audio, and/or video); (d) the App has an adaptive user interface, that can adapt to the user on-the-fly; (e) the App provides a smart route navigation and localization system; and (f) the system (App and PMD) gives five senses contents for the most important objects (masterpieces), i.e., text, audio, video, touch (cold, heat, vibration), smell, and taste.

The present papers refers to the M5SAR's system, being the proposed technology acceptance model and the system's analysis main contributions. In addition, the overall system's architecture is presented for the first time.

The paper is structured as follows: the present section made an introduction, which is followed by a more in-depth contextualization and state of the art analysis in Sec. II. Section III presents the system's architecture, describing the main modules and features, which will be in analysis by the proposed technology acceptance model presented in Sec. IV. The paper concludes with a final discussion and future work, Sec. V.

## II. CONTEXTUALIZATION AND STATE OF THE ART

The more informational channels we use the better the transmitted information will be perceived, being this a generally accepted fact in psychology [26]. Still, most modern multimedia systems are focused only on two senses (sight and hearing). The difficulty to digitally convey compelling sensations for the remaining senses justifies their absence on those systems. Even though, there has been a series of attempts to achieve a full senses system but, almost none were embraced by developers, product designers, manufacturers, or consumers.

As for the general multimedia systems, the same happens for the museum's mobile Apps, being the vast majority focused in 2 senses (vision and audition). However, a huge variety of Apps exist. For instance, the Wall Street Journal

presents an interesting article with their envisage of the best Apps for visiting museums [40]. The same kind of articles are presented by Information Week, with 10 (fantastic) Apps for museum visits [24], and by The Balance, with some of the fine art museum Apps [4].

There are several examples of AR in archaeological sites [15], and in museums, including applications that use historic building information modelling (HBIM) to model the museum's objects and or building [28], [31], the implementation of head-worn displays [41], and solutions that partially explore the five senses (nonexclusive for museums), being one example in the Science Museum - atmosphere gallery [38] (not a mobile application).

Typically indoor AR Apps are marker-based systems, also called image-based [11]. AR marker-based systems allow adding preset signals (e.g., paintings or statues) easily detectable in the environment and use computer vision techniques to sense them. There are many commercial AR toolkits and AR content management systems [9], [27], [44], including open source software development kits (SDKs), being ARToolKit(X) [1] probably the most well known. For a more in-depth analysis on this subject, e.g., see [35]. Nevertheless, none of these platforms explore the five senses, being the extension of the user's ordinary mobile device with an hardware gadget – PMD – a solution.

Although there are some systems that combine multiple senses to offer a more immersive sensorial experience, portable devices to extent AR to five senses are inexistent. The most similar devices are probably the ones used in 4D movie theaters or shows, which allow to experience physical effects synchronized with the movie, such as rain, wind, temperature changes, strobe lights, vibrations, smells, fog, and chair movements, among other things. In the virtual reality (VR) consumer market there has been some developments, as is the example of the FeelReal VR Mask [17]. The mask, compatible with the Oculus Rift [17] and some other existing VR headsets, is a multi-sensory gaming interface, which enables the user to experience different smells and simulated effects of wind, heat, water mist, and vibration. The Museum of Food and Drink (MOFAD) [29], in New York, also developed a very interesting odor interactive display, called The Smell Synthesizer. The interactive display allows visitors to press different buttons that release chemicals associated with the smell of certain elements. However, their multi-sensory approach was not exactly integrated into a single system, and the taste aspect of it was recreated separately using gumball machines (candy-like pellets with peculiar flavors such as tomatoes, porcini mushrooms, and parmesan cheese). For more details about multi-sensorial systems see [37], and for a recent survey with the state-of-the-art in augmented, virtual, and mixed reality systems for cultural heritage perspective see [5].

One huge gap in many of this innovative systems is the lack of analysis on how users come to accept and use the proposed technologies, namely on how AR applications interact with cultural and historical sites, and the purpose of improving

instructional design and use guidelines. Nevertheless, some examples exist, such as the one proposed in [22].

In this context, the technology acceptance model (TAM) was developed with the goal of explaining and predicting how users accept and use the proposed technologies [13]. TAM integrates the theory of reasoned action, developed by Fishbein and Ajzen [18] as a theoretical base to explain the human behavior in terms of the determinants of information and communication technology usage.

After a revision and consolidation of the theory, TAM was extended to the unified theory of acceptance and use of technology (UTAUT) model [42], which intends to investigate the user's intentions when facing a new technology. The UTAUT model considers four constructs [42]: (i) performance expectancy, (ii) effort expectancy, (iii) social influence, and (iv) facilitating conditions. For instance, this model has been applied to explore user's acceptance of mobile technologies [45], on-line purchasing tickets [16], security-related factors in mobile payment [25], and mobile technology in museum visits [30]. Despite the excellent model to analyze the acceptance and usage of technology provided by UTAUT, the standard presents some limitations to the consumer's environment, and the UTAUT2 model was developed. UTAUT2 explains approximately 70% of the variance in behavioral intention and 50% of the variance in technology use [43], being composed by seven constructs: (i) performance expectancy, (ii) effort expectancy, (iii) social influence, (iv) facilitating conditions, (v) hedonic motivation, (vi) price value, and (vii) habit.

The M5SAR system will be presented in the following section, including the description of its architecture, references to detailed architecture modules' reports made by the authors in previous publications, the UTAUT model proposed for the system, and the corresponding model's results analyzes.

### III. M5SAR ARCHITECTURE

Figure 1 presents the M5SAR's system which has three main modules. The (a) server, depicted on the left side of the figure, where the contents for the AR and bundles (museum's AR object markers – image descriptors) are stored, for more details see [35], [36]. The server communicates with the (b) mobile App, depicted on the middle of the figure, which *per se* is divided in three main sub-modules, namely: (b.i) the adaptive user interfaces (AUI) [36], (b.ii) the mobile image recognition based augmented reality (MIRAR) sub-module, which includes the object recognition unit (walls and human clothe AR contents superimposition) [3], [34], [35], and the (b.iii) localization and adaptive navigation unit [7], [8]. On the figure's right side, the (c) devices "connected" (via Bluetooth) with the mobile device are shown, namely: the (c.i) Beacons employed in the computation of the user's localization and the (c.ii) portable device for touch, taste and smell (PDTS, in the figure; in this paper mentioned as PMD) sensations used to enhance the five senses [37].

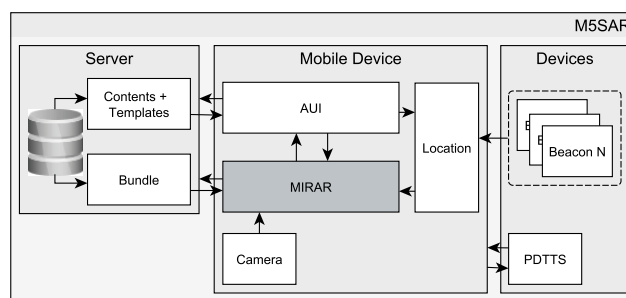


FIGURE 1. Simplified architecture of the M5SAR system.

To understand the TAM application it is necessary to explain in more detail the system's main features, modules (b) and (c). As mentioned, the (b) mobile App module has the (b.i) AUI sub-module which, at the limit, corresponds to the build of a different layout and content for each UI view and user, in order to achieve a full adaptive UI. Nevertheless, different users could have the same layout or at least partially similar layouts. The same layout and structure can also be used in multiple views (e.g., when showing information about different paintings to the same user). In this case, the thing that changes are the contents to be displayed to the user. Of course, contents could be different for different users, even when the layout is the same. In this context, and with the principle of adapting the UI on the fly, the UI view was separated in (A) structure/layouts and (B) contents. This means that, the application will no longer create views but will instead make "card-layouts" and place different contents on the (same) card-layout at different execution points, allowing the (different) layouts and structures to be used multiple times. For more details see [36]. Despite the system being prepared to create different UI layouts for each user, the App tests were done limiting the UI to 5 types of users: standard, senior, expert, child, and family. The TAM inquiries and results reflect only the standard user layout, presented in Figs. 2 and 3.

Also part of the (b) mobile App module, the (b.ii) MIRAR sub-module has four main features: (i) the detection and recognition of museum objects, triggering a card in the App [36]; (ii) the detection, recognition, and tracking of objects as the user moves along the museum, allowing to touch different areas of the objects displayed in the mobile screen and showing information about that region of the object [35]; (iii) the detection and modeling of the museum's walls, and subsequent projection of information/contents (e.g., images, movies, or text), related with the recognized objects' epochs, into the those detected walls [34]; and (iv) the detection of persons moving in the museum and, for instance, dressing them with clothes from the exhibition's epoch [3].

MIRAR's object recognition unit uses images from the museum's objects and the mobile device's camera to recognize and track on-the-fly, on the client-side, those objects. The environment detection and recognition unit is supported upon the same principles of the object's recognition, but uses images from the environment (e.g., walls) to recognize them.



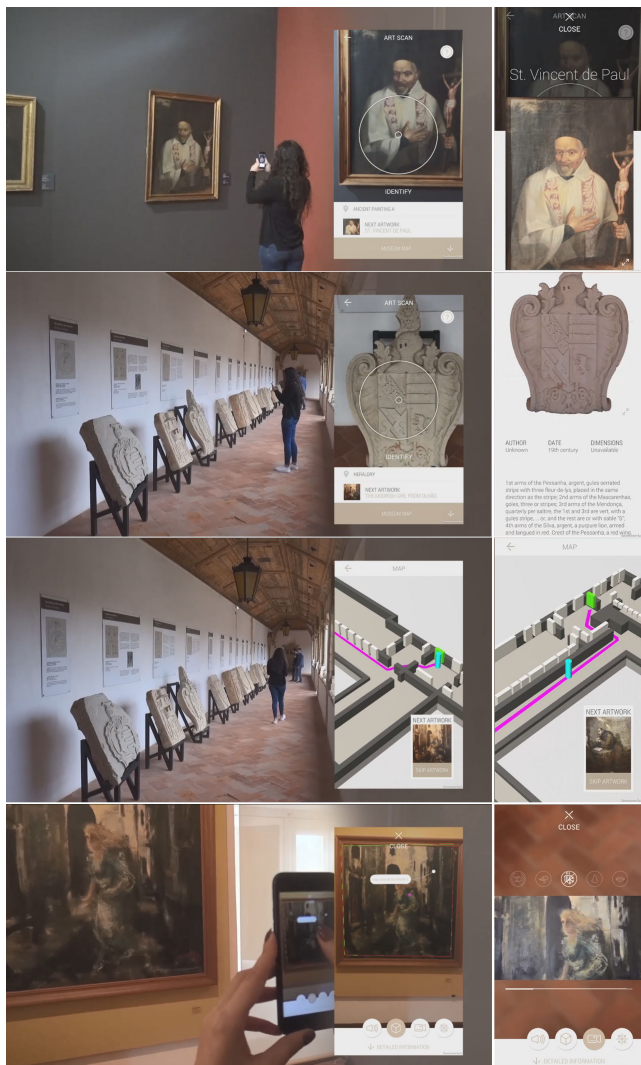


FIGURE 2. Examples of the App in stand-alone mode.

Finally, the human detection and segmentation unit uses convolutional neural networks for the detection of persons and 3D volumes to overlap the clothes over those detected persons. It is also important to stress that, since the sensor used to acquire the images from the environment is the mobile devices’s camera, in order to save battery, the camera is only activated when the AR option is selected in the UI. When the activation occurs, the user can see the environment in the mobile device’s screen and execute the previously mentioned actions.

Sub-modules (b.i) and (b.ii) need to communicate with the server to obtain operating information. The required information filtering is done as MIRAR module (b.iii) estimates the user’s position, based on the previous object detections and the localization given by the beacon’s signals (there is a beacon *per* museum room), and sends it to the server. From the server, the MIRAR module receives a group of object markers (image descriptors), here called bundles [35], that contain information about the objects available in the located



FIGURE 3. Examples of the App and PMD working.

room or museum section. In a way to minimize communications, the App stores locally the bundles from the previous room(s) or museum section(s) (limited to each device’s memory size) and as soon as it detects a new beacon signal it

downloads the new bundle. Older bundles are discarded in a FIFO (first in, first out) manner.

In terms of adaptive navigation (b.iii) [8], the first approach was to adapt a recommender system, supported on rule-based machine learning, to do the planning of the visits. Later, in [7], an implicit recommender system was used to propose points of interest to be explored in the cultural heritage places. In both cases, the overall system uses data acquired by a mobile application to feed the recommender system in a non-intrusive way, i.e., suggestions of artworks or artists are supported on the mobile application usage. The recommenders aggregate information of the objects typically visited by users with the same profile, the path proposed by the museum's experts, objects the user is seeing with the AR functionalities, etc. Figure 2 shows examples of detected objects and a map for the recommended navigation.

Also noteworthy, the App allows to track groups (e.g., families or other visiting groups), informing where the other elements are, by showing the last object visited and/or beacon position. For instance, this feature might be important when kids and parents want to explore different parts of the museum.

Figure 2 shows examples of the App working on a stand-alone mode in Faro Municipal Museum. In the left, from top to bottom, the detection of a museum object (picture), the detection of a family crest, user navigation, and detailed information about pressed object regions. The figure's right side shows more details about the objects obtained when scrolling or pressing the application options.

Relatively to the (c) devices module, this paper will only focus the (c.ii) PMD, since the beacon communication and localization sub-module is quite trivial. As mentioned, the PMD is capable of realizing a complete five senses experience when used in conjunction with the mobile device running the App. This means that the PMD should be light, small, and flexible enough to adapt to different mobile devices. In this sense, the hardware module was limited to a size of  $7 \times 7 \times 25$  cm, although the apparatus could be composed of one or two of those parts. The two parts case implies the positioning of one part on each side of the mobile device. Figure 3 shows the one side configuration, being the TAM applied to this version. Albeit the two sides configuration allows to have twice the amount of smells and tastes, the one side is more comfortably carried by a person during a typical museum visit, maintaining the capacity to reproduce compelling stimulus for the three senses (i.e., touch, taste, and smell) at the appropriate time, i.e., when instructed by the application. It is important to stress that all hygiene precautions are taken into account, including the use of disposable components ("straw") in case of taste sense.

A microcontroller is the core unit of the PMD. The microcontroller receives instructions from the mobile application and acts accordingly, controlling the remaining hardware. The device communicates with the mobile application via a Bluetooth interface and uses a wired communication for the remaining physical output interfaces/hardware. The physical

output interfaces will be responsible for reproducing the sensorial stimulus for the mentioned three senses. The left and right hardware parts (if two parts are used) are very similar to each other, and they have the same modules, components and connections, with one main difference: the part with Bluetooth (left) will have the master microcontroller and a slave microcontroller will be on the other side (right). For development details see [37].

Exemplifying the system's usage with a practical example is important to better understand the collaboration between App and PMD which, as already was mentioned, communicate using Bluetooth. When App and PMD are connected and a masterpiece is detected by the App (the museum defines which objects are masterpieces), the overall system activates the 5 senses functionalities [37].

Previously, the museum's experts prepared a 5 senses narrative for each masterpiece, i.e., a narrative/story is prepared using image (video) and sound to highlight the object (masterpiece), as traditionally is done in many museums. But, in our case, along with the narrative, the experts analyze specific points in the timeline where they introduce the remaining 3 senses. In the case presented in Fig. 3, the object is a painting of a Portuguese – Algarvian legend, which can be told in a few words. Once upon a time, a Nordic princess married a Moorish prince that ruled the Algarve. The princess grew sad because she missed seeing the snow so was she so used to it in her country. Decided to alleviate the princess sadness, the prince ordered the massive planting of almond trees, so that when they were in bloom she would look to a landscape covered in white flowers, looking like fresh snow.

Knowing the narrative and which points should and could be enhanced, the museum's experts define in a timeline when the user should feel the different senses, for how long, and with which intensity (3 to 4 levels of intensity are allowed, depending on the sense). In the Algarvian legend's narrative, the user should feel cold with the highest level of intensity during some second, e.g, when in the timeline he/she is being told about the white flowers that look like fresh snow. Each sense can be stimulated several times in the same narrative, with different intensities and durations. Again in the exemplified narrative, different vibrations were used to show the sadness of the princess, among other events. The "smell of the castle" was used in the beginning of the narrative, heat was used to simulate the temperature of Algarve, and the smell of the almonds was also used along with two different tastes of the epoch, introduced in specific point of the timeline. Finally, it is important to stress that all senses can be stimulated alone or combined with others (the only exception is the simultaneous stimulation by heat and cold). The heat/cold is implemented using a Peltier thermoelectric module in the back of the PMD [37], which in many cases is used in conjunction with wind, produced by the fan placed in the front of the PMD.

The museum's experts have a back office tools to insert the events they intend in the timeline, that is stored in the system's database.

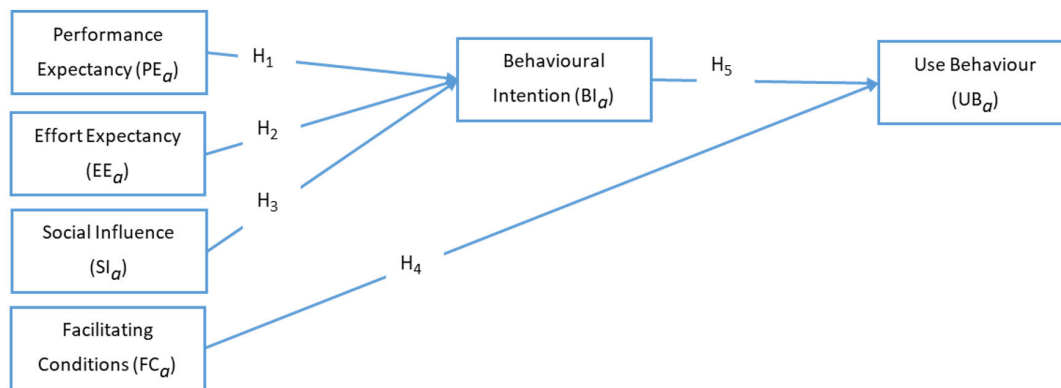


FIGURE 4. M5SAR's UTAUT research model.

Examples of the App and PMD working together are shown in Fig. 3, being the active senses displayed in the bottom of each image. In the next section the proposed TAM model is presented.

IV. TECHNOLOGY ACCEPTANCE MODEL

The M5SAR system (App + PMD), due to its specifications, needs to be evaluated before it can be made available to the public. In accordance with the UTAUT model [42], in the present context two constructs will not be analyzed: the hedonic motivation (considering purchases is related to hedonic impulses) and price value. This decision is justified by the fact that both modules (App and PMD) are not yet commercially available, and mostly because PMD is expected to be rent (in the museum space) by a symbolic value. The business model is out of the focus of this paper, but it is related with the increase selling of associated merchandising. With the withdraw of the UTAUT's referred constructs, the base model is the one proposed in Fig. 4 and detailed next.

The performance expectancy (PE) is the degree to which a user believes that using M5SAR's system will provide benefits in visiting a museum [42], i.e., the indicator gives the idea of improving the performance of the visit if you use the features of the system. Therefore, it was hypothesized:

H1. The impact of PE on behavioral intention (BI) will be positive.

The effort expectancy (EE) is the degree of ease associated to the use of the M5SAR's system [42]. Regardless of the museum visitor's technological abilities, the EE allows to evaluate if the users expect to find difficulties in the use of the system. If the system is easy then it will potentiate its future use. Therefore, it was hypothesized:

H2. The impact of EE on BI will be positive.

Social influence (SI) is the extent to which users perceive that family and friends believe they should use the M5SAR's system when visiting the museum [42]. Therefore, it was hypothesized:

H3. The impact of SI on BI will be positive.

Facilitating conditions (FC) refers to how users believe that the technological infrastructure exists to help them use the M5SAR's system whenever necessary [42]. For instance,

the mobile technologies usage requires some skills, e.g., connecting to the internet or navigating in the functionalities. The access to an application characterized by a set of facilitating conditions will influence a greater intention of usage. Therefore, it was hypothesized:

H4. The impact of FC in use behavior (UB) will be positive.

Individual behavior is predictable and influenced by individual intention. UTAUT also supports the belief that behavioral intention has a substantial influence on the use of technology, i.e., BI reflects the relationship between behavioral intention and substantial influence on the use of technology [42]. Therefore, it was hypothesized:

H5. The impact of BI in UB will be positive.

A. METHODOLOGY

Following the adapted UTAUT model, a survey in Portuguese and English was developed and a group of information systems experts reviewed and tested it. The survey was composed by two main sections: (i) the UTAUT data constructs expressed in a five-point Likert scale, from "strongly disagree" (1) to "strongly agree" (5); and (ii) the demographic characteristics of the respondent. The technology acceptance questionnaire associated to the M5SAR's system was designed and hosted on a popular web service for collecting the data. Then, the questionnaire was presented to a group of museum visitors who were invited to test the application and agreed to answer the survey's questions.

The survey was developed to evaluate the M5SAR-App (stand-alone mode) and the M5SAR-PMD, with different questions adapted according with the functionalities of each of the components. The App survey and the PMD survey were applied in different moments so the respondents could clearly distinguish what they were evaluating. Nevertheless, it is important to stress that the PMD is completely integrated with the App, so in the case of the M5SAR-PMD's survey the results represent the PMD and its integration with the App.

After collecting surveys' data, responses were codified to make possible the usage of descriptive statistics to characterize the sample and the structural equation model (SEM) to evaluate the research model. SEM was considered since



it is indicated to overcome the need to measure multidimensional and not-directly-observable concepts, also called constructs or latent variables [6]. According to Gefen [20], the SEM “has become the rigneur in validating instruments and testing linkages between constructs. The SEM considered is based on variance-based SEM or partial least squares path SEM [32], which permits the construction of the model in an exploratory phase, with a (little) portion of the sample which is not normally distributed [33].

**B. RESULTS**

The results for the stand-alone App and PMD analysis were divided in 4 strands: (a) sample characterization, (b) measurement model, (c) structural model, and (d) discussion.

(a) *Sample characterization*: in the case of the App there were 72 respondents, being the sample characterized by a majority of males (66.7%), over 35 years (44.4%), in possession of an university degree (66.7%), and dependently employed (77.8%). For the PMD, the sample had 84 respondents and is defined by a majority of males (57.1%), over 35 years (50.0%), in possession of an university degree (85.7%), and dependently employed (85.7%).

(b) *Evaluation of the measurement model*: the adjustment quality of the model analyzes comprehends three steps: (i) evaluation of the measurement model to guarantee the convergent validity, by the average variance extracted (AVE) (ii) observation of internal consistency values, through the values of Cronbach’s alpha (CA) and composite reliability (CR), and (iii) discrimination quality assessment, where the square roots of AVEs should be larger than Pearson’s correlations between those of latent variables. Tab. 1 presents the average variance extracted (AVE), composite reliability (CR), and Cronbach’s alpha (CA) values.

To differentiate between App and PMD, constructs and other variables will have an *a* subscripted in the case of the App (e.g., BI<sub>a</sub>) or a *d* subscripted in the case of the PMD (e.g., BI<sub>d</sub>).

Since AVE values are greater than 0.5, as summarized in the Tab. 1, it is assumed that the model converges to a satisfactory result [19], i.e., it is concluded that the model has convergent validity. Observation of internal consistency values takes into consideration the values of CA and CR, expressed by the  $\rho$  of Dillon-Goldstein. The values of CA should be higher than 0.6, being values of 0.7 considered adequate. In similar fashion, CR values should be higher than 0.7, being values of 0.9 considered satisfactory [21]. Therefore, according with the work of Hair et al. [21], the model has internal consistency.

In the measurement model’s third step, the discriminant validity assessment permits to investigate the independence between latent variables and other variables. This analysis can be done by the criterion of Fornell and Larcker [19], which compares the square roots of the AVE values of each latent variable with the Pearson’s correlations between the latent variables. The square roots of AVEs should be larger than the correlations between those of latent variables, as presented

**TABLE 1. Quality criteria: construct reliability and validity. App in the top rows and PMD in the bottom rows.**

App Construct	AVE <sub>a</sub>	CR <sub>a</sub>	CA <sub>a</sub>
BI <sub>a</sub>	0.927	0.974	0.961
EE <sub>a</sub>	0.876	0.966	0.952
FC <sub>a</sub>	0.858	0.948	0.919
PE <sub>a</sub>	0.654	0.948	0.779
SI <sub>a</sub>	0.844	0.956	0.938
UB <sub>a</sub>	0.852	0.920	0.835
PMD Construct	AVE <sub>d</sub>	CR <sub>d</sub>	CA <sub>d</sub>
BI <sub>d</sub>	0.584	0.846	0.760
EE <sub>d</sub>	0.817	0.947	0.925
FC <sub>d</sub>	0.649	0.847	0.751
PE <sub>d</sub>	0.610	0.860	0.809
SI <sub>d</sub>	0.721	0.886	0.817
UB <sub>d</sub>	0.533	0.886	0.851

**TABLE 2. Values of the correlations between the latent variables and the square roots of the AVE values - on the main diagonal. App in the top rows and PMD in the bottom rows.**

App	BI <sub>a</sub>	EE <sub>a</sub>	FC <sub>a</sub>	PE <sub>a</sub>	SI <sub>a</sub>	UB <sub>a</sub>
BI <sub>a</sub>	<b>0.963</b>					
EE <sub>a</sub>	0.866	<b>0.936</b>				
FC <sub>a</sub>	0.298	0.682	<b>0.926</b>			
PE <sub>a</sub>	0.668	0.682	0.397	<b>0.809</b>		
SI <sub>a</sub>	0.850	0.686	0.069	0.393	<b>0.919</b>	
UB <sub>a</sub>	0.405	0.669	0.530	0.202	0.412	<b>0.923</b>
PMD	BI <sub>d</sub>	EE <sub>d</sub>	FC <sub>d</sub>	PE <sub>d</sub>	SI <sub>d</sub>	UB <sub>d</sub>
BI <sub>d</sub>	<b>0.764</b>					
EE <sub>d</sub>	0.664	<b>0.904</b>				
FC <sub>d</sub>	0.534	0.401	<b>0.806</b>			
PE <sub>d</sub>	0.568	0.792	0.382	<b>0.781</b>		
SI <sub>d</sub>	0.312	0.173	0.324	0.323	<b>0.849</b>	
UB <sub>d</sub>	0.473	0.433	0.516	0.496	0.104	<b>0.730</b>

in Tab. 2. Therefore, it is possible to guarantee the quality of the discriminant validity. Another way to evaluate the discriminant quality of the model is through the cross-loading criterion. The cross-loading criterion refers that each item should present a higher loading on its corresponding factor than the cross-loading on other factors [12]. Furthermore, the cross-loading values are presented in Appendix A for the App and Appendix B for the PMD. After guaranteeing discriminant validity in the evaluation of the measurement model, for App and PMD, the evaluation of the structural model is made in the next step.

(c) *Structural model*: the evaluation of the structural model is performed using Pearson’s correlations coefficient ( $R^2$ ) of the endogenous latent variables. The App model explains 89.9% of variation in behavior intention and 34.8% in use behavior, as presented in Fig. 5 – top. In the case of the PMD model, 48.1% of variation in behavior intention and 32.1% in use behavior are explained, as presented in Fig. 5 – bottom.

Another aspect to analyze is the model’s capacity to predict, which requires the calculation of the Stone-Geisser indicator ( $Q^2$ ) and the Cohen indicator ( $f^2$ ) associated to the effect size [21]. The Stone-Geisser indicator evaluates how close the model is to what was expected; the Cohen indicator evaluates how useful each construct is for the model. Results

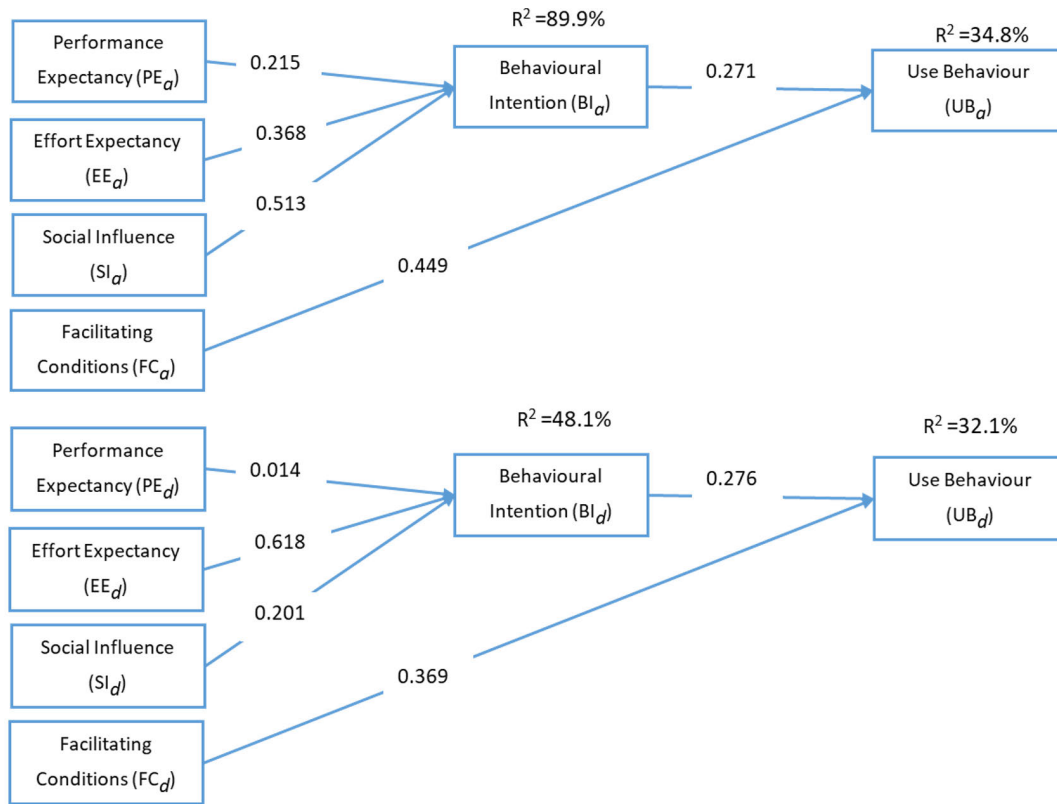


FIGURE 5. The App structural model (top) and the PMD structural model (bottom) results.

TABLE 3. Indicators values of the predictive validity and effect size. App in the top rows and PMD in the bottom rows.

App		$Q_a^2$	$f_a^2$
BI <sub>a</sub>	ENLV	0.773	0.723
EE <sub>a</sub>	EXLV		0.718
FC <sub>a</sub>	EXLV		0.621
PE <sub>a</sub>	EXLV		0.331
SI <sub>a</sub>	EXLV		0.673
UB <sub>a</sub>	ENLV	0.239	0.438
PMD		$Q_d^2$	$f_d^2$
BI <sub>d</sub>	ENLV	0.226	0.297
EE <sub>d</sub>	EXLV		0.510
FC <sub>d</sub>	EXLV		0.257
PE <sub>d</sub>	EXLV		0.300
SI <sub>d</sub>	EXLV		0.365
UB <sub>d</sub>	ENLV	0.142	0.234

are presented in Tab. 3, being EXLV the exogeneous latent variable and ENLV the endogeneous latent variable.

The  $Q^2$  value associated with the exogenous latent variables presents a value higher than zero (Tab. 3), which means that both endogenous variables have predictive power, and the structural model has predictive relevance. The  $f^2$  indicators associated with all the latent variables are higher than 0.15 for the App and PMD, which shows how useful each construct is for the model. In this case, all variables have a medium impact in the App and in the PMD on the structural model.

The structural model analyses ends with the individual analysis of the coefficients of the respective model (path coefficients), as presented in Fig. 5 and Tab. 4 (being  $\sigma$  the standard deviation). In this case, it is necessary to analyze the sign, the value and the  $t$  statistical significance, which should be more than 1.96 (bilateral and with a 5% significance level) [23]. In the case of the App, taking in considerations the  $t$ -values, which are all higher than 1.96, and  $p$ -values, which are all less than 0.05, the null hypothesis from H1 to H5 should all be rejected and the direct coefficients should be different from zero, once coefficients are significant. For the case of the PMD, taking into consideration again the  $t$ -values, only H1 is lower than 1.96, and the  $p$ -value is higher than 0.05. Therefore, the null hypothesis should be accepted and the structural coefficients should be equal to zero, once coefficient is non significant.

(d) Discussion: Table 4 presents the direct effect which indicates, by the  $t$ -test values and  $p$ -values. By analyzing Fig. 5 and Tab. 4, which present the structural coefficients and how significative they are, we can conclude which constructs have most impact to explain the App and the PMD acceptance. In the App case, all constructs have positive effects on both behavioral intention and use behavior. Furthermore, effort expectancy, social influence, facilitating conditions have a great impact as they have structural coefficients greater than 0.3. On the other hand, performance expectancy and



**TABLE 4.** Direct effects in the structural relationships between the latent variables. App in the top rows and PMD in the bottom rows.

App	Structural coefficient	$\sigma$	$t$ -value	$p$ -value
$BI_a \rightarrow UB_a$	0.271	0.077	3.523	0.000
$EE_a \rightarrow BI_a$	0.368	0.057	6.414	0.000
$FC_a \rightarrow UB_a$	0.449	0.111	4.033	0.000
$PE_a \rightarrow BI_a$	0.215	0.035	6.192	0.000
$SI_a \rightarrow BI_a$	0.513	0.055	9.411	0.000
PMD	Structural coefficient	$\sigma$	$t$ -value	$p$ -value
$BI_d \rightarrow UB_d$	0.276	0.135	2.041	0.042
$EE_d \rightarrow BI_d$	0.618	0.187	3.304	0.001
$FC_d \rightarrow UB_d$	0.369	0.139	2.655	0.008
$PE_d \rightarrow BI_d$	0.014	0.200	0.070	0.944
$SI_d \rightarrow BI_d$	0.201	0.097	2.062	0.040

behavioral intention yield moderate effect once their structural coefficient is less than 0.3. This means that increasing the value by 1.0 in the facilitating conditions construct will increase the value of the use behavior construct by 0.449.

Taking in consideration the Tab. 4 and Appendix A (App), it is possible to identify the detailed motivations associated to the App acceptance. In terms of behavior intention, friends, family, and influencer opinions contribute to use the App. The effort expectancy, defined by the way as the user interacts with the App, which is considered easy to use and to learn, contributes the sensation that he/she can be skillful in using it. In general, all of these contribute to the acceptance of the M5SAR's App. In summary, the App was considered useful, permitting to accomplish tasks more quickly and faster, which contributes to the behavior intention to use the App.

In terms of use behavior, the facilitating conditions is the construct that has more impact, followed by the behavior intentions, where the users considers that he/she has the resources and the knowledge necessary to use the App. Also, the App being compatible with others technologies that the user employs contributes to its acceptance and usage, e.g., to search for additional information about museum's objects and about auxiliary services. The impact of the behavior intention contributes to accept the App, once the users intend to use it in the future, whenever it is possible, and considers it as a good idea when visiting the museum.

In the case of PMD, all constructs have positive effects on both behavioral intention and use behavior. However, the performance expectancy construct is not significant for behavioral intention. The effort expectancy and facilitating conditions have the greatest impact as they have structural coefficients greater than 0.3. This means that increasing the value of 1.0 in the effort expectancy variable will increase 0.618 in the value of the behavior intention variable and increasing the value of 1.0 in the facilitating conditions variable will increase 0.369 in the value of the use behavior. The structural coefficient of social influence in behavioral intention and behavioral intention in use behavioral have a positive, significant but moderate effect.

Taking in consideration Tab. 4 and Appendix B, the detailed motivations associated to the PMD acceptance

can be explained. The opinion of the family, friends, and museum influencers contributes to the intention to use the PMD, aided by fact that users consider the interaction with the device clear and understandable. The PMD was considered easy to use and to learn, while contributes to the user feeling of being skillful when using it. The last contributes to define the behavior intention in the acceptance and use of the PMD.

In terms of the use behavior, the facilitating conditions is the construct that has more impact, followed by the behavior intentions, where the users considers that he/she has the resources and the knowledge necessary to use the PMD. The possibility to get help from others when having difficulties using the PMD, for example, a specific person is available for assistance with the PMD difficulties in the museum contributes for its acceptance and usage. The impact of the behavior intention contributes to the acceptance of the PMD, once the user intends to use it in the future in the museum, whenever it is possible. In other words, the PMD is a good idea when visiting the museum, making the visit more interesting, namely when used with the application and with the several "senses" integrated (cold/heat feeling, wind, smell, taste, and vibrations sensation).

## V. CONCLUSION

This paper briefly presents the M5SAR's system (App and PMD), followed by the application of the UTAUT technology acceptance model to it. Results shows that the M5SAR App and M5SAR PMD have an enormous potential to develop and apply in a real context. In summary, social influence (family, friends, and influencers) has a great impact in the intention of usage; the expectations associated to the effort, which means the degree of ease associated to the M5SAR App and M5SAR PMD usage, also contributes to intention of using the system; and the degree associated to the user's believes that the App provide benefits in visiting the museum also contributes to the intention to use and accept the M5SAR App.

Results demonstrated the intention and the facilitating condition to use the M5SAR App and M5SAR PMD contributing to the user behavior. Mainly, the use of the M5SAR App to find additional information about museum's objects and auxiliary services, and the use of the M5SAR PMD, integrated with the application and senses activated, contribute to create a more interesting visit to the museum.

Future work will go in four complementary/parallel strands: (a) improve the initial existing model to harvest human features [39] in a way to change the AUI in function of each user and integrate the concept of user experience in the interface; (b) optimize the walls and human detection modules [3], [34] so they can work more smoothly on mobile devices, to achieve on-the-fly environment and clothe AR contents superimposition; and (c) apply the TAM to the 5 different types of users (standard, senior, expert, child, and family), instead of only the standard, analyzing the differences (if exists) and adapting M5SAR in consonance. (d) Last but not least, integrate in the TAM questions that shows that

**TABLE 5. App cross-loadings.**

App	BI <sub>a</sub>	EE <sub>a</sub>	FC <sub>a</sub>	PE <sub>a</sub>	SI <sub>a</sub>	UB <sub>a</sub>
BI1 <sub>a</sub>	<b>0.935</b>	0.661	0.048	0.595	0.828	0.158
BI2 <sub>a</sub>	<b>0.977</b>	0.904	0.427	0.705	0.761	0.379
BI3 <sub>a</sub>	<b>0.975</b>	0.905	0.343	0.626	0.866	0.576
EE1 <sub>a</sub>	0.801	<b>0.867</b>	0.667	0.568	0.670	0.329
EE2 <sub>a</sub>	0.823	<b>0.985</b>	0.660	0.618	0.655	0.691
EE3 <sub>a</sub>	0.900	<b>0.981</b>	0.591	0.670	0.728	0.703
EE4 <sub>a</sub>	0.700	<b>0.905</b>	0.647	0.708	0.488	0.794
FC1 <sub>a</sub>	0.097	0.481	<b>0.929</b>	0.243	-0.124	0.455
FC2 <sub>a</sub>	0.342	0.706	<b>0.919</b>	0.380	0.120	0.590
FC3 <sub>a</sub>	0.389	0.694	<b>0.931</b>	0.498	0.201	0.378
PE1 <sub>a</sub>	0.778	0.749	0.345	<b>0.965</b>	0.496	0.268
PE2 <sub>a</sub>	0.210	0.331	0.449	<b>0.585</b>	0.111	0.061
PE3 <sub>a</sub>	0.175	0.247	0.238	<b>0.829</b>	-0.049	-0.090
SI1 <sub>a</sub>	0.782	0.573	-0.104	0.260	<b>0.975</b>	0.378
SI2 <sub>a</sub>	0.835	0.715	0.164	0.549	<b>0.961</b>	0.440
SI3 <sub>a</sub>	0.585	0.337	-0.208	0.338	<b>0.863</b>	0.153
SI4 <sub>a</sub>	0.865	0.802	0.299	0.289	<b>0.870</b>	0.474
UB1 <sub>a</sub>	0.142	0.414	0.441	0.044	0.223	<b>0.887</b>
UB2 <sub>a</sub>	0.524	0.752	0.526	0.278	0.483	<b>0.957</b>

the technology is in line with the United Nations Sustainable Development Goals.

**APPENDIX A  
APP CROSS-LOADINGS**

Table 5 presents the list of the latent variables and their constructs (in bold), being:

**BI<sub>a</sub>: Behavioral Intention**

- BI1<sub>a</sub>: I intend to continue to use the APP in the future;
- BI2<sub>a</sub>: I plan to continue to use the App whenever possible;
- BI3<sub>a</sub>: I intend to use the App because it is a good idea.

**EE<sub>a</sub>: Effort expectancy**

- EE1<sub>a</sub>: My interaction with the App is clear and understandable;
- EE2<sub>a</sub>: I find the App easy to use;
- EE3<sub>a</sub>: Learning how to use the App is easy for me;
- EE4<sub>a</sub>: It is easy for me to become skillful at using the App.

**FC<sub>a</sub>: Facilitating Conditions**

- FC1<sub>a</sub>: I have the resources necessary to use the App;
- FC2<sub>a</sub>: I have the knowledge necessary to use the App;
- FC3<sub>a</sub>: The App is compatible with other technologies I use.

**PE<sub>a</sub>: Performance Expectancy**

- PE1<sub>a</sub>: I find the App useful;
- PE2<sub>a</sub>: Using the App enables me to accomplish tasks: more quickly.
- PE3<sub>a</sub>: Using the App allows me to be faster in executing activities, for example: searching the exit.

**SI<sub>a</sub>: Social Influence**

- SI1<sub>a</sub>: People who are important to me think that I should use the App (friends, family);
- SI2<sub>a</sub>: People who influence my behavior think that I should use the App;

**TABLE 6. PMD cross-loadings.**

PMD	BI <sub>d</sub>	EE <sub>d</sub>	FC <sub>d</sub>	PE <sub>d</sub>	SI <sub>d</sub>	UB <sub>d</sub>
BI1 <sub>d</sub>	<b>0.591</b>	0.160	0.561	0.257	0.469	0.405
BI2 <sub>d</sub>	<b>0.856</b>	0.310	0.292	0.335	0.188	0.244
BI3 <sub>d</sub>	<b>0.824</b>	0.574	0.355	0.720	0.128	0.436
BI4 <sub>d</sub>	<b>0.758</b>	0.749	0.423	0.366	0.238	0.327
EE1 <sub>d</sub>	0.737	<b>0.927</b>	0.363	0.795	0.234	0.281
EE2 <sub>d</sub>	0.499	<b>0.892</b>	0.430	0.792	0.142	0.491
EE3 <sub>d</sub>	0.577	<b>0.957</b>	0.333	0.746	0.148	0.478
EE4 <sub>d</sub>	0.537	<b>0.835</b>	0.332	0.510	0.073	0.359
FC1 <sub>d</sub>	0.418	0.289	<b>0.769</b>	-0.009	0.014	0.359
FC2 <sub>d</sub>	0.133	0.378	<b>0.776</b>	0.299	0.157	0.230
FC3 <sub>d</sub>	0.576	0.332	<b>0.868</b>	0.529	0.476	0.545
PE1 <sub>d</sub>	0.240	0.371	0.143	<b>0.769</b>	0.388	0.166
PE2 <sub>d</sub>	0.495	0.677	0.204	<b>0.893</b>	0.350	0.479
PE3 <sub>d</sub>	0.602	0.790	0.551	<b>0.815</b>	0.203	0.465
PE4 <sub>d</sub>	0.139	0.384	-0.052	<b>0.622</b>	-0.001	0.290
SI1 <sub>d</sub>	0.145	0.203	0.140	0.397	<b>0.813</b>	0.198
SI2 <sub>d</sub>	0.279	0.053	0.242	0.174	<b>0.883</b>	0.081
SI3 <sub>d</sub>	0.313	0.207	0.373	0.310	<b>0.850</b>	0.046
UB1 <sub>d</sub>	0.358	0.521	0.615	0.445	0.113	<b>0.846</b>
UB2 <sub>d</sub>	0.421	0.302	0.039	0.377	-0.118	<b>0.629</b>
UB3 <sub>d</sub>	0.486	0.253	0.299	0.402	0.090	<b>0.818</b>
UB4 <sub>d</sub>	0.310	0.145	0.356	0.151	-0.223	<b>0.829</b>
UB5 <sub>d</sub>	0.150	-0.066	0.485	0.195	0.068	<b>0.735</b>
UB6 <sub>d</sub>	0.252	0.211	0.192	0.220	0.349	<b>0.500</b>
UB7 <sub>d</sub>	0.444	0.677	0.396	0.645	0.229	<b>0.686</b>

- SI3<sub>a</sub>: People whose opinions I value, say that I should use the App;
- SI4<sub>a</sub>: The museum suggest the use of the App.

**UB<sub>a</sub>: Use Behavior**

- UB1<sub>a</sub>: Search for additional information about statues;
- UB2<sub>a</sub>: Search for additional information about auxiliary service.

**APPENDIX B  
PMD CROSS-LOADINGS**

Table 6 presents the list of the latent variables and their constructs (in bold), being:

**BI<sub>d</sub>: Behavioral Intention**

- BI1<sub>d</sub>: I intend to continue to use the PMD in the future;
- BI2<sub>d</sub>: I plan to continue use the PMD whenever possible;
- BI3<sub>d</sub>: I intend to use the PMD because it is a good idea;
- BI4<sub>d</sub>: I intend to use the PMD because it makes the visit more interesting.

**EE<sub>d</sub>: Effort Expectancy**

- EE1<sub>d</sub>: My interaction with the PMD is clear and understandable;
- EE2<sub>d</sub>: I find the PMD easy to use;
- EE3<sub>d</sub>: Learning how to use the PMD was easy for me;
- EE4<sub>d</sub>: It is easy for me to become skillful at using the PMD.

**FC<sub>d</sub>: Facilitating Conditions**

- FC1<sub>d</sub>: I have the resources necessary to use the PMD.
- FC2<sub>d</sub>: I have the knowledge necessary to use the PMD.
- FC3<sub>d</sub>: I can get help from others when I have difficulties using the PMD (a specific person is available for assistance with the app difficulties in the museum).

**PE<sub>d</sub>: Performance Expectancy**

- PE1<sub>d</sub>: I find the PMD useful;
- PE2<sub>d</sub>: Using PMD allows me to have a faster immersive experience;
- PE3<sub>d</sub>: Using the PMD increases my chances of getting more knowledge acquisition;
- PE4<sub>d</sub>: Using the PMD increases my chances of getting more acquisition knowledge.

**SI<sub>d</sub>: Social Influence**

- SI1<sub>d</sub>: People who are important to me think that I should use the PMD (friends, family);
- SI2<sub>d</sub>: People who influence my behavior think I should use PMD;
- SI3<sub>d</sub>: The museum suggest the use of the PMD.

**UB<sub>d</sub>: Use Behaviour**

- UB1<sub>d</sub>: I intend to use PMD integrated with the application;
- UB2<sub>d</sub>: I intend to use the cold feeling PMD - Interface;
- UB3<sub>d</sub>: I intend to use the heat feeling PMD - Interface;
- UB4<sub>d</sub>: I intend to use the wind feeling PMD - Interface;
- UB5<sub>d</sub>: I intend to use the smell sense PMD - Interface;
- UB6<sub>d</sub>: I intend to use the taste sense PMD - Interface;
- UB7<sub>d</sub>: I intend to use the vibration sensation PMD - Interface.

**ACKNOWLEDGMENT**

The authors would like to thank Faro Municipal Museum and SPIC - Creative Solutions [www.spic.pt].

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