The Role of Haptic Feedback and Gamification in Virtual Museum Systems

SILVIA CECCACCI, ANDREA GENEROSI, ALMA LEOPARDI, MAURA MENGONI (*), and FERRUCCIO MANDORLI

Università Politecnica delle Marche, via Brecce Bianche, 60131 Ancona

s.ceccacci@pm.univpm.it, a.generosi@pm.univpm.it, a.leopardi@pm.univpm.it, m.mengoni@univpm.it, f.mandorli@univpm.it

(*) Corresponding author: Maura Mengoni

This article reports the results of a research aimed to evaluate the ability of a haptic interface to improve the user experience (UX) with virtual museum systems. In particular, two user studies have been carried out to (1) compare the experience aroused during the manipulation of a 3D printed replica of an artifact with a pen-like stylus with that aroused during the interaction (visual and tactile) with a 3D rendering application using a haptic interface and PC monitor, and (2) compare the users' perceived usability and UX among a traditional mouse-based desktop interface, haptic interface, and haptic gamified interface based on the SUS scale and the AttrakDiff2 questionnaire. A total of 65 people were involved. The considered haptic application is based on the haptic device Omega 6 produced by Force Dimension, and it is a permanent attraction of the Museo Archeologico Nazionale delle Marche. Results suggest that the proposed haptic device interface is suitable for people who commonly use mouse-based computer interaction, but without previous experience with haptic devices systems, and provide some insights useful to better understand the role of haptic feedback and gamification in enhancing UX with virtual museums, and to guide the development of other similar applications in the future.

Keywords: • Virtual museum, haptic interface, user experience, virtual reality

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INTRODUCTION

Before the middle of the 19th century, the central feature that characterized the visit of the first museums was the possibility to touch and handle the exhibited archeological finds [1]. However, over time, increasingly stringent measures have been introduced to limit the physical interaction with objects within the museum in order to ensure their preservation for future generations [2]. Today, only in exceptional cases visitors are allowed to touch the exhibits [3]. Nevertheless, in recent years, the multisensory aspect of the museum is undergoing a rebirth, which is leading to an increasing attention on widening the accessibility of museum collections, especially for blind and visually impaired people [4]. Moreover, several studies have shown that allowing visitors to touch the exhibits is very important for educational purposes [5, 6]. To re-establish this great component of museum pedagogy, museum curators are therefore called upon to reconcile the need to allow interaction by touch, with the need to protect the artworks.

To achieve this goal, two possible solutions are available: the construction of 3D printing replicas and the use of haptic devices. For visitors, the first solution would certainly be more satisfactory than the second one, although some problems regarding the rendering of physical properties and authenticity still need to be addressed [7, 8]. In fact, the quantity and quality of the tactile sensations provided by the contact between the fingers and the 3D replica is much richer than those that can be experienced using a haptic device, which allows one to reproduce a single point contact with the surface [9]. Moreover, cutaneous feedback is very limited in most haptic devices, as they stimulate the sense of touch by applying force feedback and movement [10].

However, the use of 3D printed replicas has considerable practical limitations: building replicas of an entire exhibition would be extremely expensive and would require the availability of large exhibition spaces, which most museums do not have. In particular, the lack of adequate exhibition space represents a problem that many Italian museums, especially archaeological museums, have always had to face [11]. To overcome the problem of inaccessibility of artifacts, many museum institutions have begun to equip themselves with virtual museum (VM) systems [12]. The use of haptic feedback technology can be then considered as a good compromise in this case: it allows augmenting with tactile information an entire digital library of all artworks stored in the museum, including those that are normally left in storerooms, because of the lack of adequate exhibition space. However, the main goal should not only be to reproduce the haptic feedback but also to increase the engagement, to motivate the users to explore the digital archive. To this end, as observed in Hong et al. [13], the use of gamified interfaces can be a reliable solution to better convey meaningful experience to very young audiences (i.e., school students), who represent the main visitors of Italian archaeological museums [14, 15]. The conveyed experience should concern not only the purely cultural or historical sphere but also the peculiarities and attractive elements proper of archaeology (i.e., the act of discovery, excavation, digging). For example, to bring the visitor closer to the main act of archaeology, it is possible to use a haptic interface to simulate the explorer's act of finding an archaeological treasure.

Therefore, a key question that needs to be addressed before considering the introduction of haptic tools in a museum is whether or not the addition of haptic feedback and gamification to the VM experience is worthwhile.

RESEARCH AIM

This work aims to evaluate the ability of a haptic instrument based on force feedback to faithfully reproduce the tactile sensation with a real object, and to investigate the role of haptic feedback and gamification in enhancing User eXperience (UX), during the interaction with virtual reality digital representations of archaeological finds. To this end, two studies have been carried out to:

1. Compare the experience aroused during the manipulation of a 3D printed replica of an artifact with a pen-like stylus with that aroused during the interaction (visual and tactile) with a 3D rendering application using a haptic interface and PC monitor.
2. Compare the users' perceived usability and UX among a traditional mouse-based desktop interface, haptic interface, and haptic gamified interface.

A particular haptic application has been considered, which is a permanent attraction of the Museo Archeologico Nazionale delle Marche. It is based on a haptic device with six degrees of freedom: the Omega 6 produced by Force Dimension. Several performance metrics have been considered, derived from the field of usability and UX.

RESEARCH BACKGROUND

Haptic Technology ~~Devices~~

Interaction with the virtual environment is one of the biggest challenges to face when building an application that includes several virtual technologies. In addition to visualization technologies, interaction can be rendered through X-Reality technologies that stimulate different sensory channels, providing different levels of immersion. Classic tools such as mouse and touch systems [16, 17] allow interaction with the virtual environment but do not provide the sensation, which allows us to say "I touched an object!," like haptic devices do.

Haptic devices are tools that simulate the sense of touch in a virtual environment. In particular, they apply a force or vibration to the users, who in this way get a tactile sensation when comes into contact with a virtual object

[18]. Often, the virtual object is a polygonal mesh with a texture [19, 20] that can be manipulated and explored. Being electromechanical devices with manipulators, they allow movement in different degrees of freedom depending on what is implemented in the tool. Combined with visualization technologies, they create a virtual environment characterized by a high degree of immersion and interaction. Precisely the high degree of interaction and haptic feedback that the operator can obtain thanks to haptic devices is one of the strengths of this technology, as demonstrated by recent studies [21, 22].

Their main use can be found in the medical field for the training of doctors for operating practices [23], or in the industrial field for the simulation of operations performed with the help of anthropomorphic robots and for personnel training [24].

Haptics in Museums

Within the world of cultural heritage, many people have long argued that the application of haptic devices can lead to improvements from different points of view [18, 25–27]. In fact, visual perception alone lacks a lot of important information, which can provide tactile enjoyment, such as weight and roughness [10]. Many advantages could result from this. Just think of the breaking down of barriers for visitors with visual difficulties, the quantity of artifacts that could be made available to a very wide audience, or overcoming one of the main barriers of a museum: being able to touch and interact actively with a work of art, which has been denied until now [18, 20, 28].

Therefore, it is of fundamental importance to carry out research to understand whether the sense of touch, and therefore the use of haptic devices, can actually lead to an improvement in the enjoyment of the exhibits. As stated by Asano et al. [29], there is no study that analyzes the applications already developed in tactile museums, where real and virtual coexist, involving visitors to test their perception. This lack is also due to the scarcity of large-scale applications, which are usually not realized, to focus more on very specialized situations [10]. In this regard, there are studies and applications that implement visualization and haptic technologies, such as the Museum of Pure Form [30, 31] or the application in the Gold Museum in Bogota [32]. Others mainly aim at breaking down the barrier between the visitor and the work of art, such as the application called *The Interactive Art Museum* of the University of Southern California [33], the 2D mouse implemented by the University of Glasgow [33], and the Probos Console Touch & Discover Systems developed by the Manchester Museum [34].

However, very few studies (e.g., [4, 28, 43]) analyze haptic devices and their relationship with the visitor. No study has compared them with other virtual technologies that allows users to navigate and manipulate virtual reproduction of cultural heritage artifacts.

Gamification in Museum

Gamification is a communication tool to engage, attract, and convey information to visitors [35–37]. Thanks to applications implementing gamification elements, it has been possible to attract a younger audience by giving them a motivation to return to the museum [38]. For these reasons, there are many gamification applications implemented in museums [35, 36, 39–41]. As Döpker et al. say, *gamification* describes the integration of traditional game elements into a non-game context, such as the VM [35], so it is very important to try to keep the parallel between real and game. In the literature, there are several examples where games are implemented that recall real gestures and procedures to realize the artifacts. Of particular interest is Cycladic Sculpture Application, in which visitors are invited to try their hand at making a Cycladic figurine through a sort of *nonogram-type* puzzle game [42].

Usability and UX

Usability and UX are considered as key quality determinants of any product, system, or service intended for human use, which in turn can be considered as product, system, or service success or failure indicators [44]. According to ISO 9241-11 [45], *usability* is "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." Based on this definition, several methods have been proposed to assess product usability [46]. Among them, satisfaction questionnaires represent very cost-effective methods. Examples of most widely adopted questionnaires include the SUMI [47], QUIS [48], and System Usability Scale (SUS) [49]. ISO 9241-201 [45] also defines UX as follows: "[a] person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service." This points out that UX "includes all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviors and accomplishments that occur before, during and after use." Conse- quently, as also reported by this standard, UX is a consequence of several factors: brand image, functionality, system performance, interactive behavior, and assistive capabilities of the interactive system; the user's internal and physical state resulting from prior experiences, attitudes, skills, and personality; and the context of use.

In general, two typologies of product attributes most determine UX: pragmatic and hedonic attributes [50]. Pragmatic quality (PQ) refers to the product's perceived ability to support the achievement of "do-goals," so it refers to product utility and usability in relation to potential tasks external to the user. Hedonic quality refers to the product's perceived ability to support the achievement of "be-goals," so it refers to the ability of the product to support users in achieving personal goals (i.e., being special, being competent).

The project "All About UX" (https://www.allaboutux.org/attrakdiff) provides a wide and complete overview on the principal methods and tools currently used to assess UX. One of the most used tools is the Attrakdiff2 questionnaire [51], which allows one to assess the user's feelings about the system considering both hedonic and pragmatic dimensions of UX.

MATERIALS AND METHODS

Experimental Design

Two studies have been carried out: a comparative and a parallel user testing. The first inspection method is aimed to compare the overall UX when handling a 3D printed replica of an archaeological artifact using a pen- like stylus and the 3D reconstructed artifact using virtual reality and haptic feedback. It involved a single user group, and each participant experimented with both the interaction with a 3D printed reconstruction by using a stylus pencil with a 1.45-mm fine-point tip, and with the virtual reality digital reproduction by using the haptic interface. The second study is aimed to compare, in terms of usability and UX, the quality perceived by users during the exploration of virtual finds with the haptic interface and with a traditional mouse-based desktop interface. Moreover, it aims to compare the quality of the experience perceived by users during the sculpture game with that experienced during the simple exploration of virtual replicas. The second experiment consists of a parallel user study. Participants were randomly assigned to three groups (A, B, and C). A specific interface was presented to each group: the traditional mouse-based desktop interface to group A, the haptic interface to group B, and the haptic gamified interface to group C.

Fig. 1. The “classic” 3D rendering application.

Development of Application

Three VM applications have been developed:

1. A “classic” 3D rendering application in which navigation and interaction with models are obtained by using a mouse. In particular, such an application allows the user to (1) rotate, (2) pan, and (3) zoom the digital object respectively by (1) clicking and dragging the left mouse button, (2) holding the mouse wheel and dragging, and (3) rolling the mouse wheel (Figure 1).
2. A haptic VM application with the possibility to interact with models and virtual space through a haptic device with six degrees of freedom: the Omega 6 produced by Force Dimension. When the user grabs the end effector, as if it is a pen, a small sphere that represents the virtual cursor with which the user can navigate is displayed on the screen. This cursor, similar to a mouse pointer, allows the user to have a controllable reference point to navigate and interact with the digital environment (Figure 2). Once ~~one~~ it comes into contact with the virtual historical find, the Omega 6 returns a force feedback to the user simulating the "collision" of the pen with the surface of the virtual object and the "resistance" that the virtual material itself opposes, based on the action-reaction principle. Another feature of the Omega 6 is the possibility to grasp the virtual object through a special button at the base of the end effector: keeping it pressed, it is possible to move the object inside the virtual scene and at the same time to simulate its weight, by means of a force proportional, approximately, to the mass of the real object, applied downward.
3. A gamification sculpturing application that implements a sort of puzzle game. Acting on the Omega 6 end effector, it is possible to sculpt a block of stone that hides an object inside it. Once the find is discovered, user can interact with it as well as in the navigation version using a haptic device. The choice of the nomogram puzzle is motivated by the fact that the artifacts in the application are objects that derive from sculpturing processes, and therefore this game is the most suitable to arouse curiosity and discovery motivation.

All of the applications allow one to visualize and navigate digital reproductions of three archaeological finds preserved at the Museo Archeologico Nazionale delle Marche in Ancona: the Venus of Frasassi (Venere di Frasassi), the Augusto Capite Velato, and the Pyx (Pisside) (Figure 3). For each of these finds, a digital model has been created using a Konica Minolta Range 7 laser scanner in combination with photogrammetric techniques, according to the procedure described by Mengoni and Leopardi [52]. The models are displayed and navigated through the same graphic visualization software. A 50-inch screen is placed in front of the haptic device (or mouse) to allow the visitors to observe the artifact while they are virtually interacting with it.

Fig. 2. The proposed haptic interface, based on the Omega 6 produced by Force Dimension.

Fig. 3. The considered archaeological finds virtual replicas (left) and an example of a gamified interface (right).

Through the X3D markup language (based on the XML language and developed by the Web 3D Consortium), it was possible to parameterize the physical characteristics of the rendered models and their surfaces, such as static and dynamic friction, rigidity, and magnetic attraction. Magnetic attraction in particular is a feature that has made it possible to simulate the force of gravity (simplifying it as a magnetic force coming from below and activated only when the user grasps the virtual object), which is not present among the default features that can be set. To develop the applications, the open source platform H3DAPI was used, which provides APIs to program the haptic characteristics of the rendered models and simultaneously take care of the graphic component, making primarily use of the X3D and OpenGL standards. The strength of the H3DAPI platform is the ability to integrate scripting languages such as Python, to introduce the possibility to operate with flow control structures, such as conditional statements (if then else).

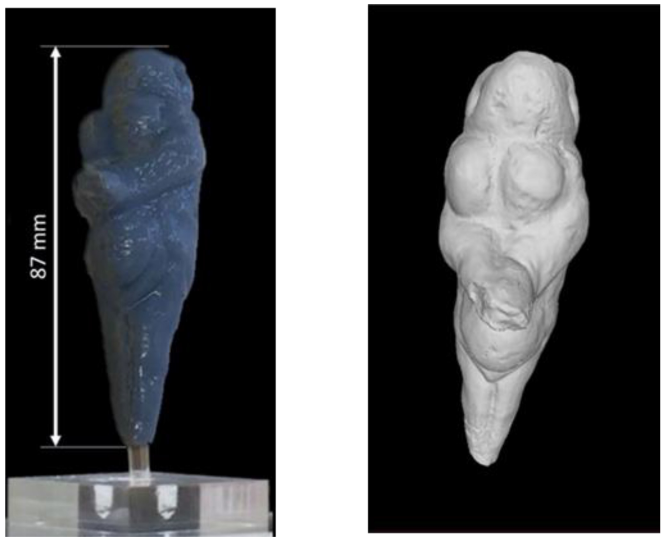

Fig. 4. 3D printed replicas of the Venus of Frasassi (left) and a virtual reality model without textures (right).

The use of Python in particular has been fundamental to implement the gamification application. Another strong point of H3DAPI is the possibility to interact with the most common operating systems and with a wide range of haptic devices available on the market.

H3DAPI also provides a 3D and haptic rendering software called *H3DViewer*, defined by the developers themselves as an "X3D browser" (https://h3dapi.org/) and that has been used to start and run the source code of all developed applications.

A 3D printed copy of the Venus of Frasassi (Figure 4) has been realized with a 3D printer (3D Fortus 250mc) by Stratasys starting from a digital model. The original of this archaeological find, which has the stylistic characteristics typical of the female statues of the Upper Paleolithic, is currently preserved in the Museo Archeologico Nazionale delle Marche.

Experimental Procedure

Tests have been carried out in the Virtual Reality Lab of the Università Politecnica delle Marche. Participants in the experiment received informed consent prior to accessing the lab to take part in the test.

In the first study, participants were trained first on how to interact with the physical object using the stylus. Then, participants were presented with the haptic VM application, and they were trained on how to navigate the virtual reconstructed model using the haptic interface. Afterward, participants were left free to interact both with the 3D printed object and the digital model, visualized without textures on a PC monitor, to gather information about the artifact using sight and touch: they could switch multiple times between the two interaction modes to analyze in detail the differences in tactile sensations and visual appearance. During both the interaction with physical and virtual models, participants were asked to concentrate their attention on the physical properties of the artifacts' surface (i.e., texture, stiffness, and friction). Finally, participants were asked to rate the similarity between the experience (visual and haptics) with the physical reproduction and its digital representation on a 7-point Likert scale from strongly agree (perfectly matching the experience with the real artifact) to strongly disagree.

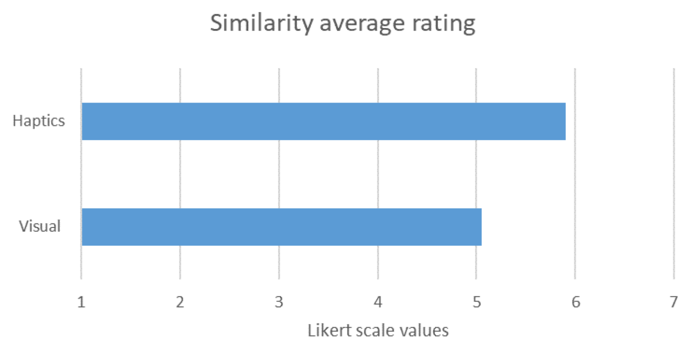

Fig. 5. Average values of similarity rating.

In the second study, first of all, participants in groups A, B, and C were respectively trained on how to use the VM "classic," the VM haptic, and the gamified VM applications. Then the experiment began, and they were asked to use the proposed interface to freely explore (or play with) digital reproduction of the archeological finds, currently preserved in the Museo Archeologico Nazionale delle Marche (i.e., the Augusto Capite Velato, the Pisside, and the Venus of Frasassi), without any time limit. The total time spent by each participant interacting with the device was recorded and used as a measure of users' engagement with the proposed interaction devices. Then they were asked to answer two questionnaires: the SUS questionnaire and the AttrakDiff2 questionnaire. The SUS questionnaire consists of 10 items that are answered using a 5-point Likert scale ranging from strongly agree to strongly disagree. It is a reliable and widely valid measure of overall perceived usability [53]. It was chosen because it is widely applied, it allows for a comparison with existing results and products [54], and it is particularly relevant for comparing two versions of an application that are based on different technologies [55]. The AttrakDiff2 questionnaire consists of 28 7-point items with bipolar verbal anchors (i.e., semantic differential). The seven response options for AttrakDiff2 range from –3 to +3, with 0 at the center of the scale. It allows to determine PQ, hedonic quality (stimulation) (HQ-S), hedonic quality (identity) (HQ-I), and attractiveness (ATT) of the UX provided by the considered interaction devices. It has been chosen because it demonstrates a high reliability and internal consistency in several studies (e.g., [56, 57]). In addition, user comments have been registered.

Participants

Participants have been recruited among students of the Carlo Rinaldini High School of Ancona and undergraduate students of Building Engineering-Architecture of the Università Politecnica delle Marche. All participants were involved in the experiments only on a voluntary basis. They were all familiar with the mouse-based PC interaction, but they did not have any previous experience with haptic devices. A total of 20 subjects (9 females and 11 males, aged between 16 and 24 years, mean age 18 years) were involved in the comparative experiment. A total of 45 subjects (24 males and 21 females, aged between 16 and 23 years, mean age 19 years) were recruited and separated into three age and sex matching groups (A, B, C), for the parallel user study.

RESULTS AND DISCUSSION

The graph in Figure 5 reports the qualitative results of the comparative study. As can be observed, the average score related to the similarity perceived by users between the visual experience with the 3D printed replica and that with digital reproduction is equal to 5.05 (SD = 1.15). Regarding the haptic experience, the average score related to the similarity perceived by users is equal to 5.90 (SD = 0.97). Many participants commented that the digital model allows to visualize and "feel" the details that characterize the shape of the object even better than the real model. In fact, since the real object is very small, it is difficult to fully appreciate the details with a stylus, whereas thanks to the haptic display system, one can zoom in on every single detail.

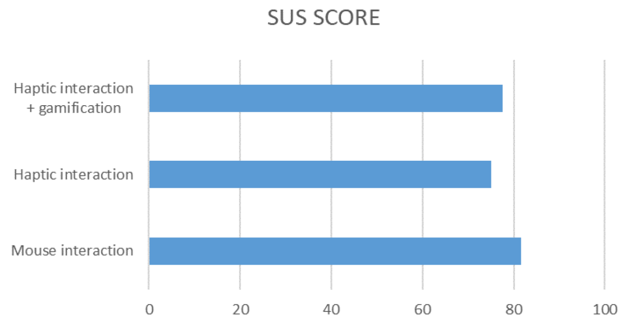

Fig. 6. SUS scores related to the three interaction modalities considered.

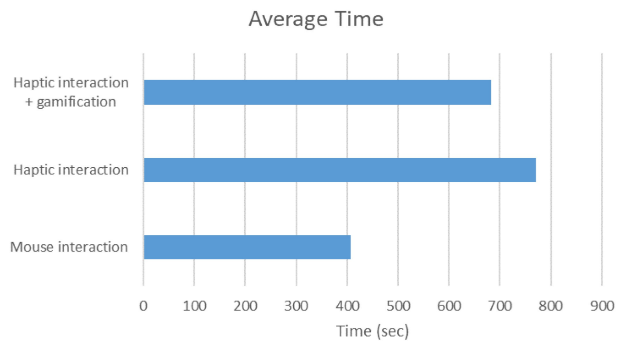

Fig. 7. Average time spent by users in interacting with the three considered interaction modalities.

This result, even if in a purely qualitative way, suggests that the proposed haptic system would enable museum visitors with computer skills to enjoy satisfactory digital reproductions of archaeological finds.

Figure 6 shows the SUS scores assessed for the three interfaces through the parallel study. As observed, the perceived usability level was high for all considered interfaces. In particular, the average SUS score resulted respectively equal to 81.67 (SD = 13.18) for the traditional mouse-based interface, equal to 75.17 (SD = 8.04) for the haptic interface, and to 77.67 (SD = 10.02) for the haptic gamified interface. As is evidenced by the work of Bangor et al. [58], there is a close relationship between the SUS score and adjectives such as "good," "poor," and "excellent," so it is possible to use the SUS score to determine a grading score for a particular product. Based on these results, it is then possible to state that all the proposed system interfaces resulted in a very good rating. As a consequence, the proposed haptic interfaces seem to be highly suitable for use by people familiar with mouse-based computer interaction but without previous experience with haptic systems: the level of usability experienced by users during their use is similar to that experienced when using interaction systems familiar to them, such as mouse-based interfaces. There are no significant differences between the considered systems in terms of perceived usability, as determined by one-way ANOVA ($F(2,42) = 1.347$, $p = .271$).

By analyzing the data in Figure 7, it is possible to observe that users on average spent more time interacting with haptic interfaces than with the mouse-based interface. This confirms what is observed also in the work of Butler and Neave [18]: more time is spent by visitors viewing artifacts while using the haptic device. This suggests that using the haptic interface may increase user engagement.

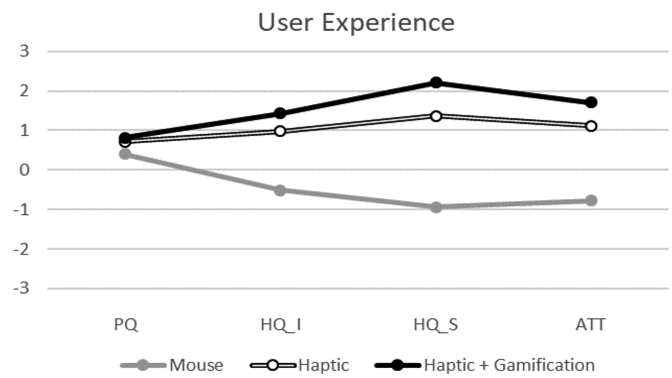

Fig. 8. Mean scores for each scale of ANrakDiff2 related to the three interaction modalities considered.

As determined by one-way ANOVA, there was a significant effect of the interface on the time (seconds) spent by users exploring (or playing with) the digital reproductions, $F(2, 42) = 39.921$, $p < .001$. Post hoc comparisons using the Tukey HSD test indicated that time spent with mouse interface (M = 407.40, SD = 82.90) was significantly different than time spent with the haptic interface (M = 771.07, SD = 115.15) and with the gamified haptic interface (M = 683.07, SD = 142.99). There are no significant differences between times respectively spent with haptic gamified and not gamified interfaces. However, it should be underlined that users who have used the simple haptic interface have spent a lot of time interacting with the virtual artifacts, manipulating and weighing them, so that they demonstrate the curiosity to observe even the smallest details.

Otherwise, users who have used the gamified application have only completed the games. Only two users, once the game was finished, spent time exploring the surface of the digital artifacts. As a result, it can be said that the gamified application seems to divert the users' attention from the artifact, even though it improves their enjoyment. However, in both of these cases, the longer time spent with the applications compared with that based on mouse interaction could also be partly motivated by the great curiosity and novelty aroused by the haptic device in the participants.

Scores related to PR, HQ-I, HQ-S, and ATT were calculated by averaging the respective item values per participant. Internal consistency of all the scores was high (Cronbach's alpha on the pooled values: PR, $\alpha = .83$; HQ-I, $\alpha = .79$; HQ-S, $\alpha = .93$; ATT, $\alpha = .94$). For each considered interaction modality, mean scores related to each scale of AttrakDiff2 are reported in Figure 8. As observed by Hassenzahl [51] and Isleifsdottir and Larusdottir [59], PQ attributes are primarily associated with how the users find the proposed system easy to use, so a high PQ score primarily implies high usability. HQ-I attributes are primarily social, so a high HQ-I score implies a high perceived capability of communicating identity to others. HQ-S is related to product attributes that allows users to develop further skills and knowledge, and consequently a high HQ-S score implies a high degree of perceived novelty, stimulation, and challenge. ATT can be viewed as an overall measure of the global appeal of the proposed system.

A one-way ANOVA evidenced that there were no significant differences between the PQ perceived by users during the interaction with the different proposed system interfaces. The mean score of PQ with the mouse- based interface was equal to 0.40 (SD = 1.17), the haptic interface was 0.71 (SD = 1.05), and the gamified haptic interface was 0.82 (SD = 0.62). This confirms results of the SUS scale: the haptic interface is perceived as usable as the mouse-based interface.

Instead, there was a significant effect of the interface on the perceived HQ-I, $F(2, 42) = 31.659$, $p < .001$. Post hoc comparisons using the Tukey HSD test indicated that HQ-I perceived with the mouse (M = –0.52; SD = 0.67) is significantly different to both HQ-I perceived with the haptic interface (M = 0.98; SD = 0,86) and the gamified haptic interface (M = 1.43; SD = 0.58). There are no significant differences between HQ-I perceived with gamified or not gamified haptic interfaces. Moreover, there is a significant effect of the interface on HQ-S, $F(2, 42) = 40.217$, $p < .001$. The Tukey HSD test revealed that there are significant differences between HQ-S perceived with the mouse (M = –0.93; SD = 0.96) and those perceived with haptic interfaces, both gamified (M = 2.21; SD = 0.40) and not gamified (M = 1.37; SD = 1.37). There are no significant differences between HQ-S perceived with gamified or not gamified haptic interfaces. In the same way, there is a significant effect of the interface on ATT, $F(2, 42) = 21.871$, $p < .001$. Also in this case, the Tukey HSD test evidenced that the mouse interface (M = –0.77; SD = 0.77) is perceived in a significantly different way than haptic interfaces, both gamified (M = 1.70; SD = 0.94) and not gamified (M = 1.11; SD = 1.40), whereas there are no significant differences between gamified or not gamified haptic interfaces. These results can be explained considering the difference in user behavior when using the interfaces considered. In general, users, while appreciating the graphical quality of the digital reproductions, considered the mouse-based interface uninteresting and boring. This statement is also supported by the results of a correlation analysis across the considered interfaces, which evidenced a strong positive correlation between Time and HQ-I ($r = .518$, $n = 45$, $p < .001$), Time and HQ-S ($r = .557$, $n = 45$, $p < .001$), and Time and ATT ($r = .539$, $n = 45$, $p < .001$). Instead, there was no correlation between Time and PQ.

CONCLUSION AND FUTURE WORKS

This article focused on a haptic application, based on the haptic device Omega 6 produced by Force Dimension, which is a permanent attraction of the Museo Archeologico Nazionale delle Marche.

It reported a comparative study and a parallel study, respectively carried out to:

- Evaluate the ability of the considered haptic device to faithfully reproduce the tactile sensation with the real object.
- Compare usability between haptic and mouse-based interfaces, and to investigate the role of haptic feedback and gamification in enhancing UX, during the interaction with virtual reality digital representations of archaeological finds.

Results, although in a qualitative manner, suggest that the Omega 6 system is able to effectively provide realistic haptic sensation. However, further quantitative studies will be necessary to confirm this preliminary result. Moreover, the proposed system would enable museum visitors, familiar with mouse-based computer interaction, to enjoy digital reproductions of archaeological finds in a more satisfactory way: the haptic device usability resulted in a very good rating, based on the SUS score. As observed by many participants, the haptic system allows one to "feel" all of the details that characterize the shape of the object, even the smallest ones, which could not be easily observed when interacting with the real object. The role of tactile feedback in influencing engagement and UX is found to be very strong based on the results of the parallel study, considering both the interaction time, which is greater in the case of the haptic device, and the UX score based on the Attrakdiff2 questionnaire. However, the validity of these results can be partially limited due to several issues related to the adopted experimental procedure: this study does not consider many other effects, such as curiosity, difficulties, misunderstandings, confusions, and tiredness, which also may have affected the time spent by users with the applications. Further studies will be necessary to better investigate the role of these factors in determining user engagement. However, gamification does not seem to bring a significant increase in engagement and perceived UX quality compared to the haptic device per se. This may be due to the strong innovative character of the technology itself in the application context considered, as demonstrated by the high HQ-S score. In fact, haptic technology is a very different technology from that of classic interaction systems, such as the mouse or joystick, which are more widespread and common to be found also in the context of cultural heritage. This may affect the attitude toward haptic technology, which so far has been limited to very specific areas, such as research laboratories or in the medical sector, and can influence the perception of visitors, making them unfamiliar and thus preventing them from being completely involved in the game. Future studies should be carried out to better investigate these aspects. Another factor that can reduce the effect of gamification could be due to the fact that the considered game application was very poor in game elements. In fact, based on the taxonomy defined by Toda et al. [60], the considered application involved only the personal game dimension: it is only based on an "objective" element, as the unique player purpose relates to the completion of the nomogram puzzle. Several studies should be carried out to better understand how other gamification features can contribute to the users' engagement with haptic VM applications. It can be stated that haptic devices can represent valid tools for both communication and user involvement within VMs, thus allowing to increase the number of exhibits that can be made available to visitors. However, this study has some limitations. Only young people with experience in using the mouse-based PC interface have been involved in the experiences. Other studies are needed to understand whether the considered haptic application is suitable also for older people who are unfamiliar with the PC interface.

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