The Role of Haptic Feedback and gamification in virtual museum systems

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Haptic feedback and gamification in VM systems

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ABSTRACT

This paper reports the results of a research, aimed to evaluate the ability of a haptic interface to improve the user experience with virtual museum systems. In particular, two user studies have been carried out in order to: (1) determine similarities between visual and tactile experiences during manipulation of a 3D printed replica of an artefact with a pen like stylus and of a 3D reconstructed artefact using the considered haptic application and (2) compare the user's perceived usability and user experience during the interaction with the haptic application interface, both gamified and not gamified, and with a mouse-based 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 interface is suitable for use by people familiar with mouse-based computer interaction, but without previous experience with haptic systems, and provide some insights useful to better understand the role of haptic feedback and gamification in enhancing user experience with Virtual Museums (VM), and to guide the development of other similar applications in the future.

CCS CONCEPTS

• Human-centered computing • Human computer interaction (HCI) • Interaction devices • Haptic devices

KEYWORDS

Virtual Museum, Haptic Interface, User Experience, Virtual Reality.

1 Introduction

Before the middle of the nineteenth 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]. Nowadays, only in extreme cases, visitors are allowed to touch the exhibits [3]. Nevertheless, in recent years, the multisensory aspect of the museum, although neglected for many years, is undergoing a rebirth, which is leading to an increasing emphasis on widening access to museum collections, also for people visually impaired [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 currently available: the construction of 3D printing replicas or 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 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 actually 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 artefacts, many museum institutions have begun to equip themselves with virtual museum 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 the 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 to reproduce the haptic feedback but also to increase the engagement, in order 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 today 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.g., the act of discovery, excavation, digging). For example, to bring the visitor closer to the main act of archaeology, it is possible to use an haptic interface to simulate the explorer's act of finding an archaeological treasure.
Therefore, the key question that needs to be addressed before considering the introduction of haptic tools in a museum is whether the addition of haptic feedback and gamification to the virtual museum experience are worthwhile.

2 Research Aim

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

- Determine similarities between visual and tactile experiences during manipulation of a 3D printed replica of an artefact with a pen like stylus and of a 3D reconstructed artefact using a haptic interface.
- Compare the user's perceived usability and UX during the interaction with a haptic interface, both gamified and not gamified, and with a mouse-based 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.

3 Research Background

3.1 Haptic Technology

Interaction with the virtual environment is one of the biggest challenges to be faced 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 to interact with the virtual environment, but do not provide the sensation, which allows us to say "I touched an object!", like haptic devices (HD).
Haptic devices are tools that simulate the sense of touch in a virtual environment. In particular, they apply a force or vibration to the user, who in this way gets a tactile sensation when he or she virtually comes into contact with a virtual object [18]. Often, the virtual object is a polygonal mesh with a texture [19], [20], which can be manipulated and explored. Being electromechanical devices with manipulators, they allow movement in different degrees of freedom (DoF) 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 HD, 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].

3.2 Haptics in Museums

Within the world of cultural heritage, many people have long argued that the application of HD can lead to improvements from different points of view [18], [25], [26], [27]. In fact, visual perception alone lacks a lot of important information, which can provide tactile enjoyment, such as weight, roughness, etc. [10]. There are many advantages that could result from this. Just think of the breaking down of barriers for visitors with visual difficulties, the quantity of artefacts 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 in 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 that 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], or the 2D mouse implemented by the University of Glasgow [33], and finally "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 compared them with other virtual technologies that allows users to navigate and manipulate virtual reproduction of cultural heritage artefacts.

3.3 Gamification in Museum

Gamification is a communication tool to engage, attract and at the same time convey information to visitors [35], [36], [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], [40], [41].
As Döpker et al. say, "Gamification" describes the integration of traditional game elements into a non-game context - such as the virtual museum [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 realise the artefacts. Of particular interest is "Cycladic Sculpture Application", in which visitors are invited to try their hand at making a Cycladic figurine in which visitors are invited to try their hand at making Cycladic figurines, through a sort of Nonogram type puzzle game [42].

4 Materials and Methods

4.1 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 archeological artifact using a pen like stylus and the 3D reconstructed artifact using VR and haptic feedback. It involved a single user group and each participant experimented in two consecutive sessions both the interaction with a 3D printed reconstruction by using a stylus pencil with a 1.45 mm fine point tip, and with the VR 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, the haptic gamified interface to group C.

4.2 Development of Application

Three VM applications have been developed:

- 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) by holding the mouse wheel and dragging and (3) by rolling the mouse wheel (Figure 1).
- An 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, similarly to the mouse pointers, allows the user to have a controllable reference point to navigate and interact with the digital environment (Figure 2). Once the cursor comes into contact with the virtual representation of a historical find, so with one of the rendered models, the Omega 6 returns a force feedback to the user who is holding the pen through the mechanical actuators of the device, thus 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 in fact 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 downwards.
- A Gamification sculpturing application that implements a sort of Nonogram type 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, you can interact with it as well as in the navigation version using a haptic device. The choice of the Nonogram 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 the applications allow 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 [44]. The models are displayed and navigated through the same graphic visualization software. A 50” screen was placed in front of the haptic device (or mouse) to allow the visitor to observe the artifact while she or he’s virtually interacting with it.

Figure 1: The "classic" 3D rendering application

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

Figure 3: The considered archaeological finds virtual replicas (on the left). An example of gamified interface (on the 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, magnetic attraction and so on. 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), 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).

The use of Python in particular, has been fundamental in order 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" [45] and that has been used to start and run the source code of all the developed applications.

A 3D printed copy of the Venus of Frasassi (Figure 4) has been realized with a 3D printer “3D Fortus 250mc” of 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”.

Figure 4: The 3D printed replicas of the Venus of Frasassi (on the left). The VR model without textures (on the right).

4.3 Experimental Procedure

Tests have been carried out in the Virtual Reality Lab of the Univeristà Politecnica delle Marche. The participants to the experiment received informed consent previous to accessing the lab.

In the first study, participants were trained at 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 with the digital model, visualized without textures on a pc monitor, to gather information about the artifact using sight and touch. 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.

In the second study, first of all, participants of group A, B and C have been respectively trained on how to use the VM "classic", the VM haptic and the gamified VM applications. Then the experiment starts 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 Software Usability Scale (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 [46]. It was chosen because it is widely applied, it allows for a comparison with existing results and products [47], and it is particularly relevant for comparing two versions of an application that are based on different technologies [48]. 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 "pragmatic quality" (PQ), "hedonic quality (stimulation)" (HQ-S), "hedonic quality (identity)" (HQ-I) and "attractiveness" (ATT) of the UX provided by the considered interaction devices. It had been chosen because it demonstrates a high reliability and internal consistency in several studies (e.g., [49], [50]). Also, free user comments have been registered.

4.4 Participant

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 the 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, mean age 18) were involved in the comparative experiment. A total of 45 subjects (24 males and 21 females, aged between 16 and 23, mean age 19) were recruited and separated in three age and sex matching groups (A, B, C), for the parallel user study.

5 Results and Discussion

The graph in Figure 5 reports the results of the comparative study. As it 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, while thanks to the haptic display system, you can zoom in on every single detail.
This result suggests that the proposed haptic system would enable museum visitors with computer skills to enjoy satisfactory digital reproductions of archaeological finds.

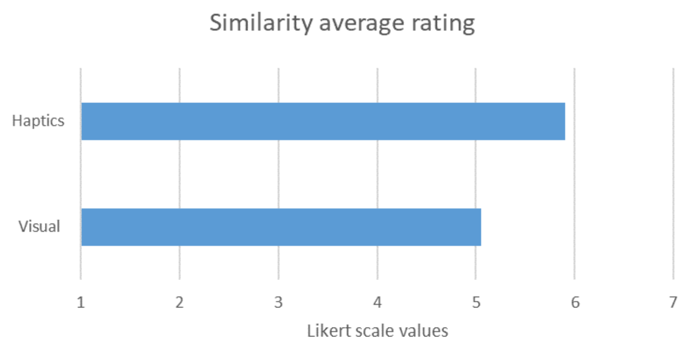

Figure 5: Average values of similarity rating.

Figure 6 shows the SUS scores assessed for the three interfaces through the parallel study. As it can be observed, the perceived usability level was high for all the 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 evidenced in Bangor et al. [51] there is a close relationship between SUS score and adjectives such as "good", "poor" or "excellent", so that 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 results 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 ($F(2,42) = 1.347$, $p = .271$).

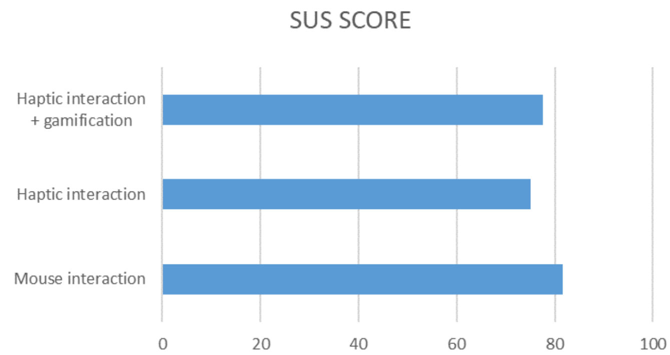

Figure 6: SUS scores related to the three interaction modalities considered.

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 [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.

As determined by one-way ANOVA, there was a significant effect of the interface on the time (sec) 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 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 artefacts, 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 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.

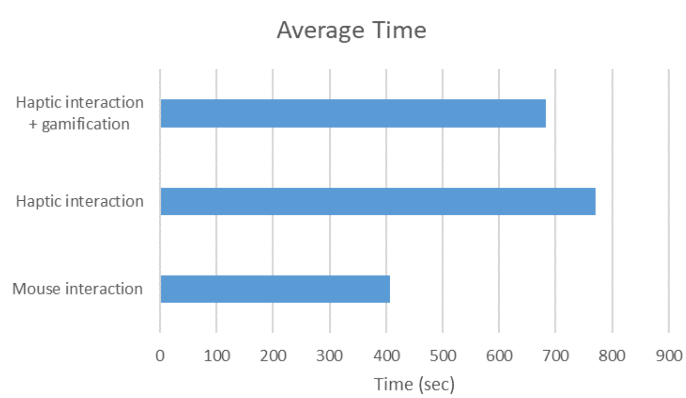

Figure 7: Average time spent by users in interacting with the three considered interaction modalities.

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 in Hassenzahl [52] and in

Isleifsdottir & Larusdottir [53], PQ attributes are primarily associated with how the users find the proposed system ease to use, so that a high PQ score primarily implies high usability. HQ-I attributes are primarily social, so that 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, 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.

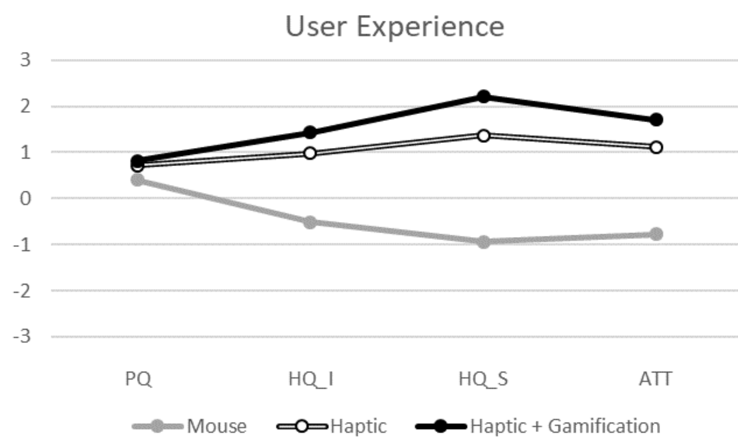

Figure 8: Mean scores for each scale of AttrakDiff 2 related to the three interaction modalities considered

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), with the haptic interface was 0.71 (SD = 1.05), and with the gamified haptic interface was 0.82 (SD = 0.62). This confirms results of 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 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, $F(2, 42) = 40.217$, $p < .001$. Tukey HSD test revealed that there are significant differences between HQ-S perceived with 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, Tukey HSD test evidenced that the mouse interface (M = -0.77; SD = 0.77) is perceived in a significantly different way that haptic interfaces, both gamified (M = 1.70; SD = 0.94) and not gamified (M = 1.11; SD = 1.40), while 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 is no correlation between Time and PQ.

6 Conclusion and Future Works

This paper 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 VR 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. Morevore, 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 SUS score. As has been observed by many participants, the haptic system allows you to "feel" all the details that characterize the shape of the object, even the smallest ones, which could not be easily observed interacting with the real object.

The role of tactile feedback in influencing engagement and UX resulted 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 UX score based on Attrakdiff2 questionnaire.

On the other hand, 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 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 towards 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.

In conclusion, it can be stated that haptic devices can represent valid tools for both communication and user involvement within virtual museums, 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. Moreover, several studies should be carried out to better understand how specific gamification features can contribute to the users' engagement with haptic VM applications.

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REFERENCES

[1] Classen, Constance, and David Howes. "The museum as sensescape: Western sensibilities and indigenous artifacts." Sensible objects: Colonialism, museums and material culture 5 (2006): 199.

[2] Candlin, Fiona. "Museums, modernity and the class politics of touching objects." Touch in museums: Policy and practice in object handling (2008): 9-20.

[3] Kyriakou, Panayiotis, and Sorin Hermon. "Can I touch this? using natural interaction in a museum augmented reality system." Digital Applications in Archaeology and Cultural Heritage 12 (2019): e00088.

[4] Levent, N., & Pascual-Leone, A. (Eds.). (2014). The multisensory museum: Cross-disciplinary perspectives on touch, sound, smell, memory, and space. Rowman & Littlefield.
[5] Willcocks, Judy. "The Power of Concrete Experience: museum collections, touch and meaning-making in art and design pedagogy." Engaging the senses: object-based learning in higher education. Farnham: Routledge (2015): 43-56.
[6] Pye, Elizabeth, ed. The power of touch: handling objects in museum and heritage context. Routledge, 2016.
[7] Wilson, Paul F., et al. "Evaluation of touchable 3D ‐ printed replicas in museums." Curator: The Museum Journal 60.4 (2017): 445-465.
[8] Carrozzino, Marcello, and Massimo Bergamasco. "Beyond virtual museums: Experiencing immersive virtual reality in real museums." Journal of Cultural Heritage 11.4 (2010): 452-458.
[9] Dima, Mariza, Linda Hurcombe, and Mark Wright. "Touching the past: haptic augmented reality for museum artefacts." International Conference on Virtual, Augmented and Mixed Reality. Springer, Cham, 2014.
[10] Brewster, Stephen A. "Impact of haptic 'touching' technology on cultural applications." (2005): 273-284.
[11] Zampieri, Girolamo, and Beniamino Lavarone. Bronzi antichi del Museo archeologico di Padova. Vol. 28. L'erma di Bretschneider, 2000.
[12] Mafkereseb Kassahun Bekele, Roberto Pierdicca, Emanuele Frontoni, Eva Savina Malinverni, and James Gain. 2018. A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. J. Comput. Cult. Herit. 11, 2, Article 7 (June 2018), 36 pages. DOI: https://doi.org/10.1145/3145534
[13] Hong, Jon-Chao, et al. "Using the saliency-based model to design a digital archaeological game to motivate players' intention to visit the digital archives of Taiwan's natural science museum." *Computers & Education* 66 (2013): 74-82.
[14] ISTAT, Annuario Statistico Italiano 2019
[15] Eslam Nofal, Georgia Panagiotidou, Rabee M. Reffat, Hendrik Hameeuw, Vanessa Boschloos, and Andrew Vande Moere. 2020. Situated Tangible Gamification of Heritage for Supporting Collaborative Learning of Young Museum Visitors. J. Comput. Cult. Herit. 13, 1, Article 3 (February 2020), 24 pages. DOI: https://doi.org/10.1145/3350427
[16] Barbieri, Loris, Fabio Bruno, and Maurizio Muzzupappa. "Virtual museum system evaluation through user studies." Journal of Cultural Heritage 26 (2017): 101-108.
[17] Sundén, Erik, Ingemar Lundgren, and Anders Ynnerman. "Hybrid Virtual Reality Touch Table: An immersive collaborative platform for public explanatory use of cultural objects and sites." 15th Eurographics Workshop on Graphics and Cultural Heritage, Graz, Austria, September 27-29, 2017. Eurographics-European Association for Computer Graphics, 2017.
[18] Butler, Matthew, and Peter Neave. "Object appreciation through haptic interaction." Hello! Where are you in the landscape of educational technology? Proceedings ascilite Melbourne 2008 (2008): 133-141.
[19] Bergamasco, Massimo, Antonio Frisoli, and Federico Barbagli. "Haptics technologies and cultural heritage applications." Proceedings Of Computer Animation 2002 (CA 2002). IEEE, 2002.
[20] Comes, Radu. "Haptic devices and tactile experiences in museum exhibitions." Journal of Ancient History and Archaeology 3.4 (2016).
[21] Mohammadi, Mostafa, et al. "Cooperative aerial tele-manipulation with haptic feedback." 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2016.
[22] Gioioso, Guido, et al. "A force-based bilateral teleoperation framework for aerial robots in contact with the environment." 2015 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2015.
[23] Hoshyarmanesh, Hamidreza, et al. "Evaluation of haptic devices and end-users: Novel performance metrics in tele-robotic microsurgery." The International Journal of Medical Robotics and Computer Assisted Surgery (2020): e2101.
[24] Javaid, Ahmad, Hammad Munawar, and Mohammad Armughan Mohyuddin. "A Low Cost 1-DoF Encounter Type Haptic Device for Use in Education." 2019 International Conference on Robotics and Automation in Industry (ICRAI). IEEE, 2019.
[25] Brogni, B. A., et al. "Technological approach for cultural heritage: augmented reality." 8th IEEE International Workshop on Robot and Human Interaction. RO-MAN'99 (Cat. No. 99TH8483). IEEE, 1999.

[26] Dettori, Andrea, et al. "Art Touch with CREATE haptic interface." 2003. ICAR Proceedings. IEEE International Conference on Advanced Robotics.
[27] Patrick Reuter, Guillaume Riviere, Nadine Couture, Stephanie Mahut, and Loic Espinasse. 2010. ArcheoTUI—Driving virtual reassemblies with tangible 3D interaction. J. Comput. Cult. Herit. 3, 2, Article 4 (September 2010), 13 pages. DOI: https://doi.org/10.1145/1841317.1841319.
[28] Arnab, Sylvester, et al. "Touching artefacts in an ancient world on a browser-based platform." (2010): 478-482.
[29] Asano, Toshio, et al. "Surveys of exhibition planners and visitors about a distributed haptic museum." Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology. 2005.
[30] Grow, David I., Lawton N. Verner, and Allison M. Okamura. "Educational Haptics." AAAI Spring Symposium: Semantic Scientific Knowledge Integration. 2007.
[31] Tecchia, Franco, et al. "Multimodal interaction for the web." Museums and the Web 2007: Proceedings (2007).
[32] Figueroa, Pablo, et al. "Multi-modal exploration of small artifacts: an exhibition at the Gold Museum in Bogota." Proceedings of the 16th ACM Symposium on Virtual Reality Software and Technology. 2009.
[33] Brewster, S. A. "The Impact of Haptic 'Touching' Technology on Cultural Applications In Proceedings of EVA 2001." Glasgow, UK), Vasari UK, s28 pp1-14, also available on line: http://www. dcs. gla. ac. uk/~ stephen/papers/EVA2001. pdf (2001).
[34] Reichinger, Andreas, et al. "Spaghetti, sink and sarcophagus: design explorations of tactile artworks for visually impaired people." Proceedings of the 9th Nordic Conference on Human-Computer Interaction. 2016.
[35] Döpker, Andreas, Tobias Brockmann, and Stefan Stieglitz. "Use cases for gamification in virtual museums." INFORMATIK 2013–Informatik angepasst an Mensch, Organisation und Umwelt (2013).
[36] Hammady, Ramy, Minhua Ma, and Nicholas Temple. "Augmented reality and gamification in heritage museums." Joint International Conference on Serious Games. Springer, Cham, 2016.
[37] Huaman, Evelyn Marilyn Riveros, Roni Guillermo Apaza Aceituno, and Olha Sharhorodska. "Application of Virtual Reality and Gamification in the Teaching of Art History." International Conference on Human-Computer Interaction. Springer, Cham, 2019.
[38] Liu, Shunli, and Muhammad Zaffwan Idris. "Constructing a framework of user experience for museum based on gamification and service design." MATEC web of conferences. Vol. 176. EDP Sciences, 2018.
[39] Liarokapis, Fotis, et al. "Multimodal serious games technologies for cultural heritage." Mixed reality and gamification for cultural heritage. Springer, Cham, 2017. 371-392.
[40] Mortara, Michela, et al. "Learning cultural heritage by serious games." Journal of Cultural Heritage 15.3 (2014): 318-325.
[41] Mccarthy, J., et al. "Open workflows for polychromatic reconstruction of historical sculptural monuments in 3D." Journal on Computing and Cultural Heritage (JOCCH) 13.3 (2020): 1-16.
[42] Vosinakis, Spyros, et al. "A kinesthetic approach to digital heritage using leap motion: the Cycladic sculpture application." 2016 8th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES). IEEE, 2016.
[43] Jamil, Muhammad Hassan, et al. "The Role of Haptics in Digital Archaeology and Heritage Recording Processes." 2018 IEEE International Symposium on Haptic, Audio and Visual Environments and Games (HAVE). IEEE, 2018.
[44] Mengoni, Maura, and Alma Leopardi. "An Exploratory Study on the Application of Reverse Engineering in the Field of Small Archaeological Artefacts." Computer-Aided Design and Applications 16.6 (2019): 1209-1226.
[45] H3DAPI. Retrieved from https://h3dapi.org/
[46] Bangor, Aaron, Philip T. Kortum, and James T. Miller. "An empirical evaluation of the system usability scale." Intl. Journal of Human–Computer Interaction 24.6 (2008): 574-594.
[47] Wetzlinger, Werner, Andreas Auinger, and Michael Dörflinger. "Comparing effectiveness, efficiency, ease of use, usability and user experience when using tablets and laptops." International Conference of Design, User Experience, and Usability. Springer, Cham, 2014.
[48] Brooke, John. "SUS: a retrospective." Journal of usability studies 8.2 (2013): 29-40.

[49] Hassenzahl, Marc, Michael Burmester, and Franz Koller. "AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität." Mensch & computer 2003. Vieweg+ Teubner Verlag, 2003. 187-196.
[50] Christou, Georgios. "The interplay between immersion and appeal in video games." Computers in human behavior 32 (2014): 92-100.
[51] Bangor, Aaron, Philip Kortum, and James Miller. "Determining what individual SUS scores mean: Adding an adjective rating scale." Journal of usability studies 4.3 (2009): 114-123.
[52] Hassenzahl, Marc. "The interplay of beauty, goodness, and usability in interactive products." Human–Computer Interaction 19.4 (2004): 319-349.
[53] Isleifsdottir, Jonheidur, and Marta Larusdottir. "Measuring the user experience of a task oriented software." Proceedings of the international workshop on meaningful measures: valid useful user experience measurement. Vol. 8. 2008.