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Virtual museum system evaluation through user studies

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Abstract

Virtual Museum (VM) systems are a very effective solution for the communication of cultural contents, thanks to their playful and educational approach. In fact, these appealing technological systems have demonstrated their usefulness and value in science centres and traditional museums all over the world, thanks to the fact that visitors can view digitized artworks and explore reconstructed historical places by means of VM-hosted installations.

This paper presents a methodology, based on user studies, for the comparative evaluation of different design alternatives related to the user interaction with VM systems. The methodology has been validated by means of a testbed related to a VM system hosted at the “Museum of the Bruttians and the Sea” of Cetraro (Italy).

The results of the user study demonstrate that this methodology can be effectively adopted in the development process of VM systems to optimize its outcomes in terms of usability and potential for entertainment and education.

Keywords: virtual museum systems; virtual reality; user-centered design; user study.

1. Introduction

In recent years, Virtual Museum (VM) systems have gradually become popular thanks to a growing trend in museums, i.e. to enhance traditional collections and exhibits with modern technological systems such as virtual museum exhibitions, which are able to provide educational and funny experiences to their visitors.

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These systems stand as an effective response to the need to combine the educational mission of museums with the ability to emotionally involve their visitors, so that audiences may discover new contents in a playful manner. This approach was investigated since the 80s with the advent of the New Museology movement [1] that broke the old schema of traditional museology and brought to an evolved concept of 'museum' thanks to the adoption of emerging technologies, such as Virtual Reality, Augmented Reality, Web technologies, and new communication languages. And, more recently, with the large and incessant spreading of edutainment and the birth of the 'economy of experiences' [2]. In particular, the former focuses on 'compensating the strains' of the visit with playful and educational activities, while the latter claims that it is necessary to offer experiences able to involve physically, psychologically, and emotionally any kind of consumer.

Modern technologies have been very helpful for combining educational purposes with the capability to emotionally involve visitors [3, 4, 5, 6]. Thanks to these technologies, in the last two decades different VM systems have been developed: each one is characterized by a given type of devices, a peculiar user workspace, and different levels of immersion, interaction, and presence [7]. Currently, many of these systems present some limitations due to their expensive installation and maintenance costs, or to a poor user-system interaction caused by an incomplete maturity of a specific technology for museum applications.

Starting from these considerations, and taking into account that 90% of museums are small-sized and relying on a low budget, we focused our research on the most commonly adopted architecture of VM systems, which consists in a monitor or projector for the visualization of contents, and a desktop device controller for the interaction. The success of this kind of architecture is due to its maturity gained in the last decades, as there were several applications in the field of VR, and also to its low cost that represents, for many museum directors, the only cost-effective and therefore feasible access to VM systems.

2. Research aim

This paper presents a methodology, based on user studies, for the comparative evaluation of different design alternatives related to the user interaction with VM systems. In particular, the evaluation approach adopts a combination of traditional and alternative metrics for performing usability studies with a deeper insight into the subjective notion of the perceived enjoyment and knowledge transmission after experiencing interactive virtual environments.

The methodology has been validated by means of a testbed related to a VM system hosted at the "Museum of the Bruttians and the Sea" of Cetraro (Italy). The testbed has been of fundamental importance in order to illustrate and validate the proposed methodology but, furthermore, to exemplify and distinguish between the cases, that usually arise in the development of VM systems, in which the technical issues can be resolved by

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means of consolidated previous experience or budget constraints and those in which the evaluation approach is necessary in order to take into account user's perspective.

The results of the user study demonstrate that the proposed methodology can be generalized and efficiently adopted in the development process of VM systems to optimize its outcomes in terms of usability and potential for entertainment and education.

3. Methodology

The proposed methodology for the evaluation of the VM design alternatives consists in the following step:

- **Definition of the metrics.** Starting from the assumption that the VM systems are holders of digital contents that can be accessed by a large variety of visitors it is possible to approach the problem of its usability evaluation according to traditional methods and instruments developed in the user-centered design (UCD) fields. But, since these systems occur to provide an educational and pleasant experience too in a very limited amount of time it is necessary to take into account also non-traditional metrics in order to evaluate both usability performances and factors related to visitor's feelings and emotions.
- **Recruiting participants**. The participants have to be recruited among representative, and not expert, users and separated in homogenous (visual acuity, age and gender) groups.
- **Evaluation phase.** The experimental procedure consists of two tests: a comparative and a parallel user testing. While the first inspection method aimed to finding usability problems only, the second study allows to evaluate also cognitive aspects related to users enjoyment and attention.
- **Data analyses.** At the end of the user testing quantitative and qualitative data are analyzed with the support of statistical methods and techniques.

All the above-mentioned steps are deeply illustrated and detailed in section 5.

4. VM system development

Prior to proceed with the design stages, it is fundamental to take into account the requirements specified by museum directors that are generally related to budget reasons but could affect also the overall dimensions and the aesthetics of the VM system. In particular, as requested by the director of the "Museum of the Bruttians and the Sea", the VM system should allow its visitors to experience two different virtual scenarios reproducing in a realistic fashion archaeological finds preserved in the museum itself:

- a tomb belonging to the necropolis of Treselle discovered in the area of Cetraro. The visitors should be able to visit the virtual tomb, with its Bruttian burials, and visualize and manipulate its contents, such as

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bronze and iron weapons (bronze belts, spearheads, javelins), pottery, drinking cups (skyphoi, kylikes, bowls, cups), and dishes (plates, paterae);

- an underwater archaeological deposit, located 20 km away from Cetraro, a few meters from the shore and only 2-4 meters deep. The residual deposit consists of some remains and fragments of amphorae of the MGS V and VI types, dating back to the middle of the III century BC.

The development process of VM systems follows different progressive stages, in which each decision contributes to the definition of the final design and also affects and limits the alternative solutions that could be taken into account in the next stage. In particular, the main stages focus on: user interface (UI) design; selection of the visualization and interaction devices; software framework implementation; user studies.

4.1. UIs design

Since the VM system will be used by a variety of audiences, its interfaces should communicate its purpose in a clear way, in order to allow even the technologically naïve visitors to understand immediately what they should do. For this reason, a Cognitive Walkthrough (CW) [8,9] inspection method has been adopted for the evaluation and refinement of the first version of the UI prototypes, before proceeding with the development of the final UI design.

The CW evaluation has been preferred to other inspection methods because of its ability to generate results in a quick and cost-effective way. In particular, the CW inspection has been conducted by a group of 6 evaluators (2 user interface designers, 2 software developers, 1 archaeologist, and 1 museum curator) who evaluated the understandability and ease of learning of the UIs by going through a set of tasks. According to Wharton's [8] recommendations, we started with simple tasks and moved to more complex ones. Standard questions [8] have been adopted during the action sequences that have to be performed for each task, in order to verify that visitors are able to easily understand the controls of the UI and never get lost.

The following figure (fig.1) depicts the final UIs derived from the CW analyses, which allows visitors to interact with the VM system. In particular, the VM exhibition is composed of three levels.

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Figure 1: first (a) and second levels (b, c) of the virtual exhibit.

In the first level, the visitor (fig.1a) can choose the preferred language, but most importantly, he/she can select among the various experiences. In fact, in the second level there are two virtual 3D scenarios, the tomb of Treselle (fig.1b) and a submerged area (fig.1c), which occupy most of the screen for their visualization. The rest of the screen is organized to provide information to the user, i.e. how to use the input device to interact with the system and what he/she is going to experience. When the user selects one of the virtual archaeological finds, he/she enters in the third level (fig.2) in which it is possible to manipulate, zoom-in, and get specific information about the virtual objects.

Figure 2: 3D digital artefacts accessible through the third UI level.

4.2. Criteria for hardware selection

Once the definition of the UIs has been completed, the development process focused on the selection of the hardware to be used for the design of the VM system. The hardware selection has been carried out according

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to the budget constraints that, as mentioned in section 1, limit the choice to monitors and projectors for the visualization and desktop device controllers for the interaction.

Among the various off-the-shelf projectors and Full High Definition (HD) monitors, we opted for monitors due to their better visualization quality in terms of contrast and brightness, their lower maintenance costs in comparison with projectors, and their robustness that allows for a continuous use without experiencing heating problems. Full HD monitors allow for considering two possible solutions for visualization and user interaction: collocated and non-collocated devices. In fact, it is possible to interact with the VM exhibition directly on the display by means of a touch-screen monitor (fig.3a) or to deploy user interaction far apart from the monitor by incorporating a controller (fig.3b).

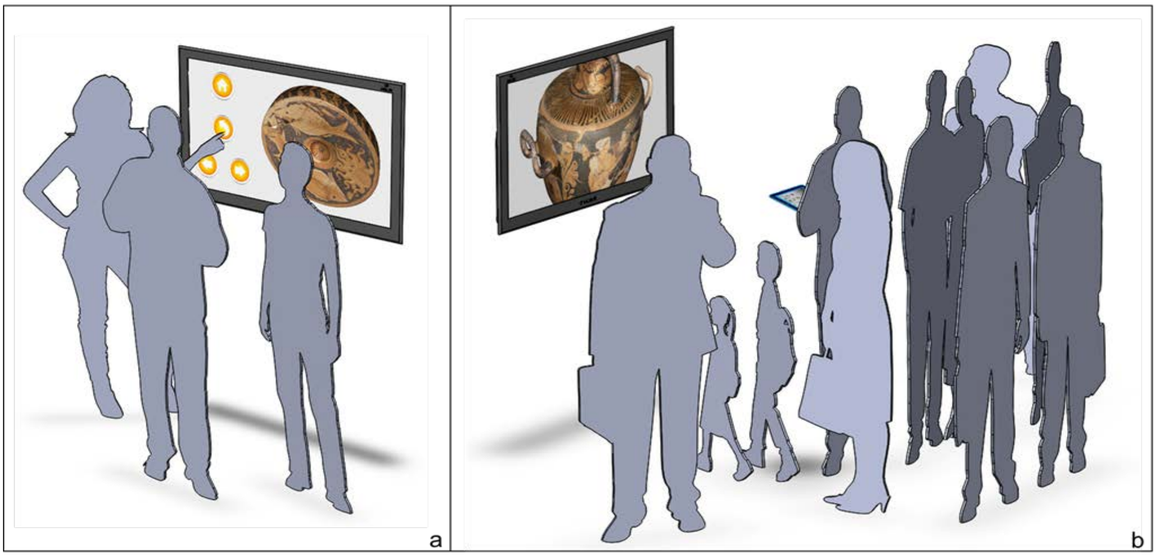

Figure 3: touch-screen monitor for user interaction and visualization of 3D contents (a) and displacement of the controls by means of a remote device controller (b).

A touch screen device, intended to be used for a collocated visualization and user-system interaction (fig.3a), doesn't allow users to get an optimum immersive visual experience, as recommended by THX and SMTPE standards, and furthermore it has limitations in terms of visual obtrusion. On the basis of these considerations, the first solution has been rejected in favour of the second one, that is, the splitting of visualization and interaction in two different places (fig.3b), thanks to the adoption of a device controller.

The final stage, related to the hardware selection, concerns the selection of the interaction device. Among the most common human interface devices, trackballs, touch-screen consoles, and gesture recognition devices (i.e., MS Kinect or Leap Motion) have been taken into account. Since the goal was the development of an easy-to-use and inexpensive system, the choice was limited to the most popular and cost effective devices such as trackballs and touch-screen consoles. Furthermore, Kinect and Leap Motion systems provide a kind of interaction known

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only by a restricted audience (i.e., younger people and videogame lovers) that shows its limitations when more than one person are in front of the screen. For which concerns trackballs, these devices have been efficiently adopted in last decades for many applications in different fields, included VM exhibition systems, but the current trend is the switching to more modern devices (from indirect action to more direct action, such as touching and moving buttons and icons directly on the screen). On the other side, when the monitor is controlled by a touchscreen remote control, the users may get confused due to the information being arranged between the two screens.

On the basis of these considerations, the interaction device has been defined by means of user studies, detailed in section 5, to objectively find the best solution for satisfying users' needs in terms of system usability, enjoyment, and attention.

4.3. VM system framework

The system framework, depicted in figure 4, has been implemented in accordance to the choices done in the previous stages and their outcomes. In particular, the hardware consists of few common components that can be obtained with a very low budget. A 3D HDTV monitor, specifically a 50LB671V LG 50", is used for the visualization of the digitized artworks, while a Kensington trackball or a multi-touch screen of 23 inches, model T232HL Acer, can be adopted for user interaction.

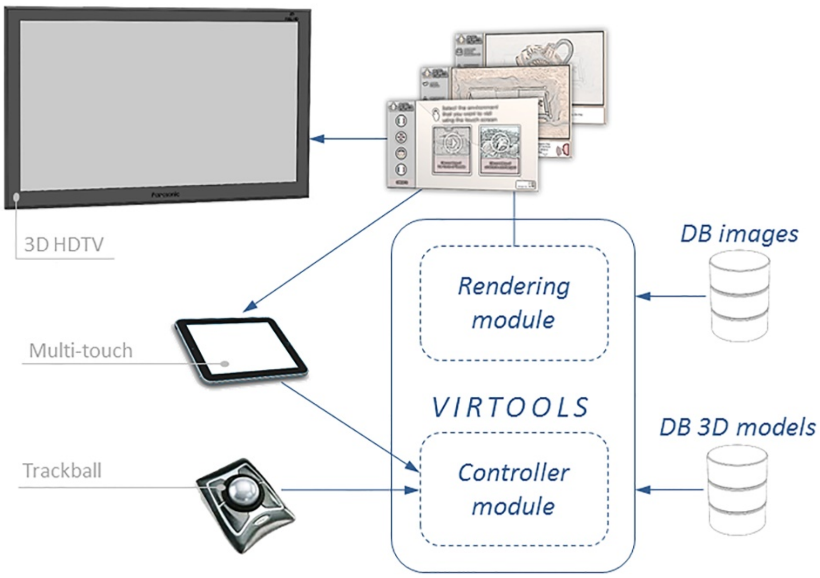

Figure 4: VM system framework, hardware (left) and software (right).

The core of the framework is a flexible software, programmed in Virtools Dev 4.0, which can be easily readapted and tailored for the desired controller, i.e, trackball or touch-screen. The software consists of two main modules.

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In particular, a Controller module has been programmed according to the event-driven paradigm, in order to detect the actions of a user and send these inputs to the algorithm that, thanks to a Graphical Rendering module, creates the final scene for the visualization on the display devices. The Graphical Rendering module composes the final scene by accessing to the DB images and create menus and textual information, while the 3D models database is queried for the generation of the virtual environment area designed for the manipulation of 3D artworks. The 3D models of the archaeological finds have been realized by means of reconstruction techniques based on 3D scanning and high definition cameras [10,11] which ensures a photorealistic reconstruction of every detail of shapes and decorations of an object.

The Rendering module generates two skewed images of the same scene that are superimposed onto the 3D HD monitor, in order to allow viewers to experience a stereoscopic immersion after having worn a pair of polarized glasses.

Even if the active 3D technology allows for enjoying the full HD resolution, we have preferred passive technology because of its low priced glasses and low maintenance costs.

5. VM system testing and evaluation

Starting from the assumption that VM systems are holders of digital contents that can be accessed by their visitors by means of user interfaces, it is possible to evaluate their usability according to the UCD methods.

According to the outcomes of section 4, user studies have been carried out to test and compare two VM systems, depicted in figure 5, which differ only for the interaction device. In particular, system A adopts a trackball to navigate through the menus, manage and manipulate images and virtual objects. System B uses the HD monitor only for displaying multimedia contents, e.g., pictures, videos, 3D objects, while all the menus and controls can be found on the touch-screen console.

The user studies have been conducted in the laboratories of the Department of Mechanical, Energy and Industrial Engineering (DIMEG) of the University of Calabria.

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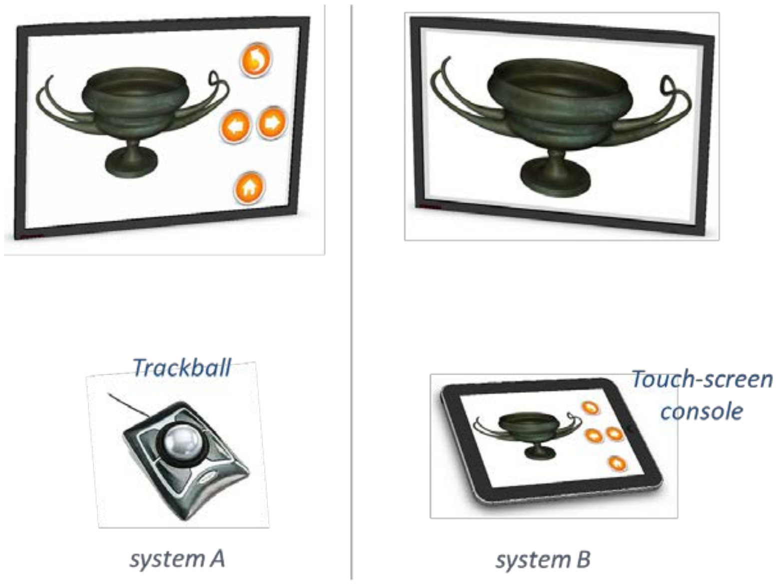

Figure 5: VM systems submitted to the user testing.

5.1. Metrics

A deeper insight into the interaction that occurs between VM systems and its visitors reveals clearly the capability of this kind of systems to provide their users a meaningful and pleasant experience in a very limited amount of time. Consequently, a VM system should serve a threefold purpose: easy to use, enjoyable, and educative.

About the first purpose, it is possible to exploit traditional UCD methods that allow for evaluating the usability of the system by performing user studies that analyse human behaviours in target acquisition tasks. In particular, we have used traditional metrics that are related to the functioning, such as time and number of errors [12], and a questionnaire that, as an alternative to the think-aloud protocol, allows for catching cognitive aspects related to user satisfaction. The questionnaire has been developed using standard satisfaction surveys as a foundation, whose definition is based on psychometric methods [13]. The questionnaire is composed of 6 items that are 7-point graphic scales (Likert scale), anchored at the end points with the terms “Strongly disagree” = 1, “Strongly agree” = 7.

In order to evaluate the other two purposes, it is necessary to explore the subjective notion of the perceived enjoyment and knowledge transmission of users after experiencing the virtual exhibit. In particular, for the evaluation of the user enjoyment, we have adopted a questionnaire, based on the Likert scale, with the addition of other two questions that are the adaptation of the Smileyometer and the Again-Again table [14] for adult users. Instead, the overall user attention and the system’s capability to transfer knowledge have been evaluated

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by means of a user questionnaire and the measurement of the time (holding time) spent by the user for his/her free exploration.

5.2. Experimental procedure

The experimental procedure, depicted in figure 6, consists of two main tests, i.e., a comparative and a parallel user testing. While the first inspection method is aimed to detect usability problems, the second study allows for evaluating cognitive aspects related to users' enjoyment and attention.

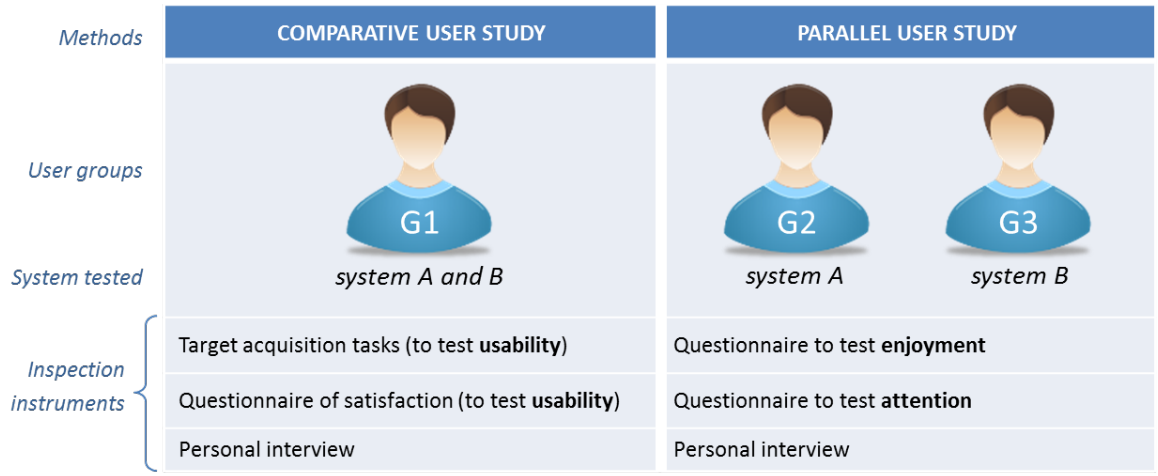

Figure 6: experimental procedure for VM system evaluation and comparison.

In the comparative study, three steps were undertaken with the adoption of a single user group (G1). In the first step, users were informed of the tasks to be accomplished and they started to interact with the system in order to select the most appropriate actions for accomplishing the tasks. Each participant tested system A and B (fig.5) in two consecutive sessions. In order to minimize skill transfer between the sessions, two preventive measures have been taken: the sessions were at least 15 minutes apart; the order of sessions was counterbalanced over the participants. Once the first step was completed, users were invited to compile a satisfaction questionnaire and to perform a one-on-one personal interview aimed to collect all their possible personal judgements to better understand and interpret the objective and subjective data gathered in the previous steps.

Since usability tends to undervalue what people experience and report [12], the comparative study is coupled with a parallel user study that allows for evaluating other hedonic (non-utilitarian) systems requirements, such as users' enjoyment and attention. The parallel study is performed on the basis of subjective measurements that require the adoption of two homogeneous groups (G2 and G3): a specific VM system was associated to each one. The study starts with a free exploration of the system, without any time limit, and ends with two questionnaires that allow for evaluating users' fun and how much and in which terms the system interaction influenced their attention. Both questionnaires required about 5 minutes to be completed.

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5.3. Participants

All the participants were undergraduate and graduate students from the Department of Mechanical, Energy and Industrial Engineering (DIMEG) and the Department of Humanistic Studies of the University of Calabria. Participants in all conditions were naive to the purpose of the experiment.

A group (G1) of 10 volunteers (age group from 19 to 28 and age ratio of 25) has been recruited for the comparative user study. The number of participants has been chosen according to the following formula $1-(1-\rho)^n$, where n is the number of subjects and ρ is the mean problem discovery rate computed across subjects. Normally the values of ρ are around 0.30, but there are studies [15,16] that consider this value overly optimistic, furthermore the rate of ρ could vary depending on several factors (e.g., specific tasks selected, match between the test and the context of real world usage, skill of the evaluator [12]). In order to overcome this problem, an adjustment and normalization procedure [17] has been carried out on the initial estimate of ρ. We found the following adjusted values of $\rho_A=0.22$ and $\rho_B=0.18$ respectively for the system A and B. The lowest value has been adopted as reference resulting in a problem discovery goal of 86% with 10 participants as sample size.

For which concerns the parallel user study, 40 subjects have been recruited and separated in two homogenous (visual acuity, age and gender) groups (G2 and G3) with age ranged from 19 to 27 and age ratio of 24.

5.4. Results and discussions

The following graph (fig. 7) shows the results of the satisfaction questionnaire fulfilled by users after performing tasks in the virtual environment by means of the system A (with trackball) and the system B (with touch-screen console). The questionnaire items have been gathered in three groups addressing very important components of user satisfaction related to the usability of the VM systems: learnability, device efficacy, and system efficacy. The graph shows little differences in subjective opinions about the usability of the two systems. Despite of the greater values achieved for the system B, paired sample t-tests reveals that there is insufficient evidence to conclude that the system B is more usable than system A. In fact, t-test results are: $t(9)=-0.82$, $p=0.43$ for the learnability; $t(9)=-1.13$, $p=0.28$ for device efficacy; $t(9)=-1.86$, $p=0.09$ for system efficacy.

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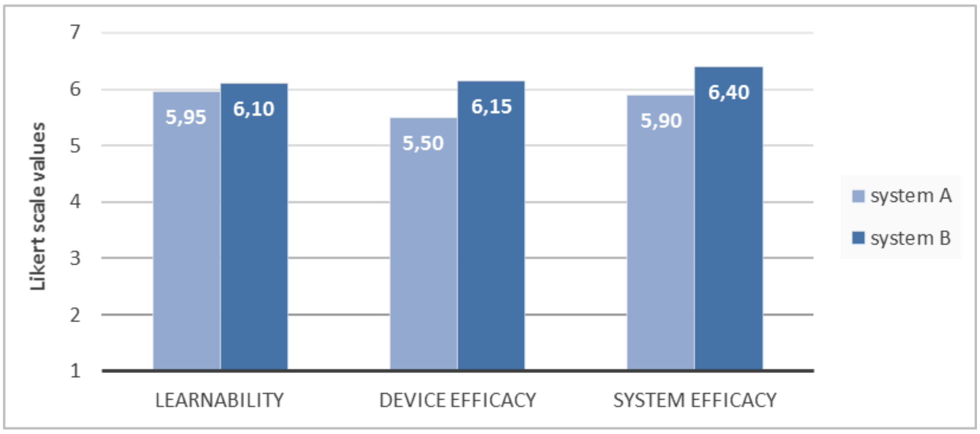

Figure 7: usability satisfaction questionnaire results.

We observed that the use of the trackball increases the time to perform tasks. In fact, the average time that it takes to complete the test has risen from 190±60 seconds for the system B, to 215±45 seconds for the system A. But a paired t-test analysis ($t(9)=1.28$, $p=0.23$) indicates that there is not a statistically significant difference to confirm this growth of 13% in time. So we can conclude that there isn't a difference in the usability of the two systems in terms of time required to perform a specific task. The above-mentioned 13% growth in time could be justified by intrinsic factors related to the functioning of the two different device systems. Indeed, if on one side the adoption of a touch-screen console allows users to select the desired option directly with their fingers, on the other side, trackballs forces their users to move through menus and buttons by means of relative movements which require their "travel time".

The number of errors found per person decreases from 2.1±1.2 for the system A to 1.1±1.3 for the system B. But the result of t-test $t(9)=1.94$, $p=0.08$ showed that there was not a statistically significant difference in the number of errors. Despite this evidence, the following graph (fig.8) shows the occurrence of the types of errors committed by users while experiencing with the VM system A and B. The results of an independent t-test analysis indicates that $t(8)=1.9$ and $p=0.09$, then for a confidence interval of 90%, there is a statistical significant difference between the two systems due to the adoption of different controller devices. In particular, by comparing the occurrences of the different errors, it appears clearly that when subjects use the trackball, they are not comfortable with operating the zoom and back/forward commands but, most of all, they have problems in selecting 3D objects. In fact, the 70% of users that had interacted with the VM system A had difficulty in selecting 3D artworks, especially the small sized ones, and some of them got frustrated after a few failed attempts.

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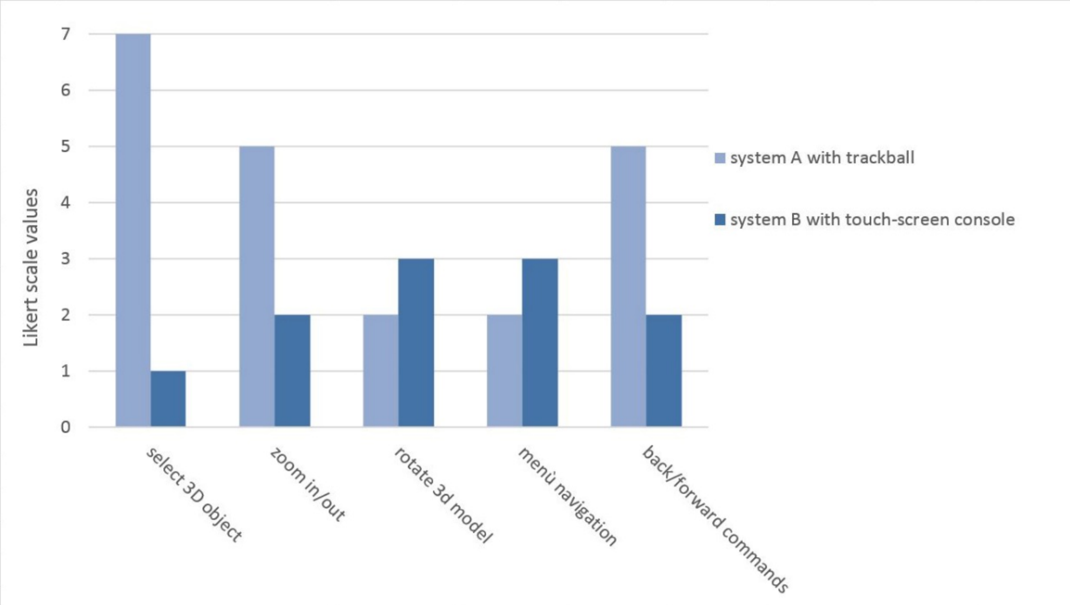

Figure 8: occurrence of the typology of error.

To sum up, even if from an objective point of view, the usability of the systems A and B are almost similar, on the contrary, from a subjective point of view, as reported in the following figure (fig.9), all the subjects clearly express their preference for the system B.

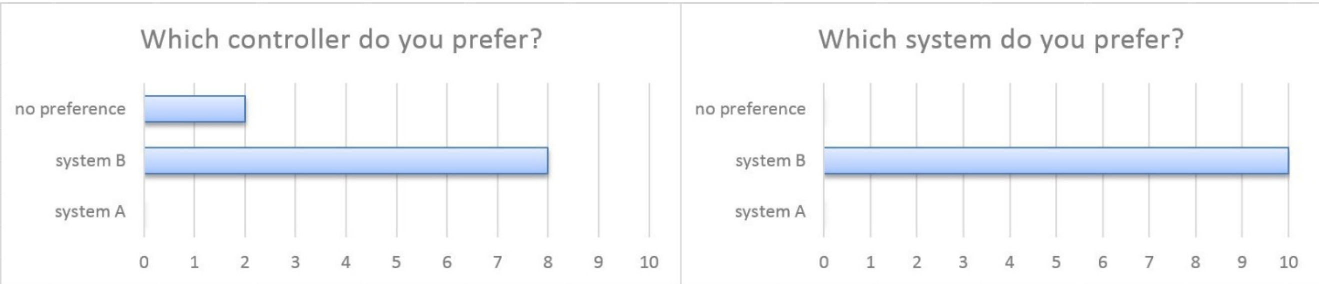

Figure 9: usability satisfaction questionnaire results.

This result was unexpected for us, because even if all users were confident in the use of the trackball, 8 out of 10 prefer to interact with the VM system by means of the touch-screen console and, furthermore, no one has expressed his/her preference for the trackball. In the one-to-one interview the subjects justified their preference asserting that “the 3D experience is less immersive when I have to use the trackball” while when “you use the touch-screen it is like to have the 3D object right in your hand”.

About the “fun of use”, from the questionnaire comes out that both the systems provide high levels of enjoyment. In fact, the following graph (fig.10) shows that the average values of user enjoyment for the system A and B are respectively 6.6±0.52 and 6.7±0.48. An independent samples t-test analysis $t(18)=0.44$, $p=0.66$ shows that there is not a statistically significant improvement of user enjoyment from the system A to the system B.

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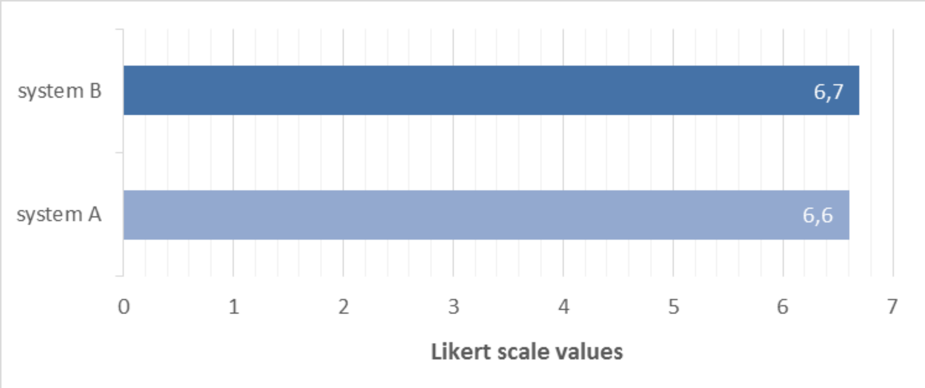

Figure 10: results of the questionnaire to test user enjoyment.

Also the Smileyometer and the Again-Again questions come up with the same results. In particular, the Smileyometer shows a result of 6.20 for both the systems on a Likert scale ranged from 1 to 7, where 7 represents the highest level of enjoyment. By means of the Again-Again question all the participants, of both the G2 and G3 groups, have expressed their desire to repeat the same experience in the near future.

On the basis of these investigations, we can conclude that the systems offer to their users high equivalent levels of enjoyment.

The levels of user attention have been verified by means of a user questionnaire, where the results attest the percentage of successful responses. An independent t-test was run on these data and it was found that there is not a statistically significant difference ($t(17.9)=0.25$, $p=0.84$) between the level of attention of the G2 group (system A) and the G3 group (system B) whose percentage are respectively of 33% and 36%. Furthermore, the average time spent by the participants experiencing the two systems is almost equivalent, in fact, the average time for the G2 group on the system A was of 6’41”±51.4”, while for the G3 group was of 6’38”±45.3”.

So it is possible to attest that, to the detriment of the statistical results that show no significant differences between the two systems, users expressed their subjective preference for the system B. Probably this preference is related to the results about the typology of errors (fig.8), which demonstrate that the system B is more usable thanks to the adoption of the touch-screen console. In fact, we noticed that after a first period (few seconds) in which the visitor shows an initial attraction and enthusiasm for the virtual exhibit primarily due to his/her curiosity, the following period denotes a bigger effort by the user in order to take a complete control of the system. In this phase it is possible to notice the first signs of stress and agitation, therefore the ease of usage and control of the UIs by means of the controller device is the main characteristic that could have a positive or a negative effect on visitor’s satisfaction about the system. Lastly, the visitor continues in the exploration of resources as a consequence of his/her satisfaction coming from the processing of information that are novel, interesting, and personally relevant [18].

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6. Conclusions

This paper has presented a methodology for the comparative evaluation of different design alternatives related to the user interaction with VM systems. Thanks to the combination of traditional and alternative metrics, this method allows for performing comparative studies and evaluating both usability performances and factors related to visitor's feelings and emotions.

The methodology has been validated by means of a testbed related to a VM system hosted at the "Museum of the Bruttians and the Sea" of Cetraro (Italy). The description of the testbed puts in evidence that some technical issues can be solved by means of previous experience or budget constraints, while other aspects, like the choice of the interaction device, need to be evaluated on the basis of user studies.

The results demonstrate that the proposed methodology is effective and it could be generalized and applied to any VM system that requires three key qualities: easy to use, enjoyable, and educative.

7. References

[1] P. Vergo, New Museology. Reaktion books. London, 1989.

[2] B.J. Pine II, J.H. Gilmore, The Experience Economy: Work is Theatre & Every Business a Stage. Harvard, 2000.

[3] S.G. Barsanti, G. Caruso, L.L. Micoli, M.C. Rodriguez, G. Guidi, 3D Visualization of Cultural Heritage Artefacts with Virtual Reality devices. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40.5, (2015) 165.

[4] C. Terlikkas, C. Poullis, Towards a more effective way of presenting Virtual Reality museums exhibits. In Computer Vision Theory and Applications (VISAPP), 2014 International Conference on Vol. 3, (2014) 237-241.

[5] F. Fatta, Communication, Technology, and Digital Culture for the Conservation and Enhancement of the Architectural Heritage. Handbook of Research on Emerging Digital Tools for Architectural Surveying, Modeling, and Representation, (2015) 446.

[6] F. Bruno, A. Angilica, F. Cosco, L. Barbieri, M. Muzzupappa. Comparing Different Visuo-Haptic Environments for Virtual Prototyping Applications. In ASME 2011 World Conference on Innovative Virtual Reality, (2001) 183-191.

[7] M. Carrozzino, M. Bergamasco, Beyond virtual museums: Experiencing immersive virtual reality in real museums. Journal of Cultural Heritage, 11(4), (2010) 452-458.

Barbieri, L., Bruno, F., & Muzzupappa, M. (2017). Virtual museum system evaluation through user studies. Journal of Cultural Heritage, 26, 101-108. ISSN 1296-2074, https://doi.org/10.1016/j.culher.2017.02.005

[8] F. Bruno, S. Bruno, G. De Sensi, M.L. Luchi, S. Mancuso, M. Muzzupappa, From 3D reconstruction to virtual reality: A complete methodology for digital archaeological exhibition. Journal of Cultural Heritage, 11(1), (2010) 42-49.

[9] D. Skarlatos, S. Kiparissi, Comparison of laser scanning, photogrammetry and SFMMVS pipeline applied in structures and artificial surfaces. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume I-3, (2012) 299-304.

[10] C. Wharton, J. Rieman, C. Lewis, P. Polson, The cognitive walkthrough method: A practitioner's guide. In Nielsen, J., Mack, R.L. (Eds.), Usability Inspection Methods, John Wiley & Sons, New York, (1994) 79-104.

[11] C. Lewis, P. Polson, C. Wharton, J. Rieman, Testing a walkthrough methodology for theory-based design of walk-up-and-use interfaces. In Proceedings of the SIGCHI conference on Human factors in computing systems, (1990) 235-242.

[12] J. Nielsen, Usability Engineering. San Diego: Academic Press., Boston, 1993.

[13] J.C. Read, Validating the Fun Toolkit: an instrument for measuring children's opinions of technology. Cognition, Technology & Work, 10(2), (2008) 119-128.

[14] J.R. Lewis, Usability testing, in: G. Salvendy (Ed.), Handbook of Human Factors and Ergonomics, John Wiley, New York, NY, (2006) 1275–1316.

[15] A. Woolrych, G. Cockton, Why and when five test users aren't enough, in: J. Vanderdonckt, A. Blandford, A. Derycke (Eds.), Proceedings of IHM-HCI 2001 Conference, (2001) 105–108.

[16] J.R. Lewis, Sample sizes for usability studies: additional considerations. Human Factors: The Journal of the Human Factors and Ergonomics Society, 36(2), (1994) 368-378.

[17] C.W. Turner, J.R. Lewis, J. Nielsen, Determining usability test sample size, International encyclopedia of ergonomics and human factors, 3, (2006) 3084-3088.

[18] M. Csikszentmihalyi, K. Hermanson, Intrinsic motivation in museums: Why does one want to learn? In Falk, J.H. & Dierking, L.D. (Eds.), Public institutions for personal learning: Establishing a research agenda, (1995) 67–77.