Virtual dives into the underwater archaeological treasures of South Italy

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Abstract – The paper presents a virtual diving system based on a Virtual Reality (VR) application for the exploitation of the Underwater Cultural Heritage (UCH). The virtual diving experience has been designed to entertain users, but its added pedagogical value is explicitly emphasized too. In fact, the ludic activities, consisting in the simulation of a real diving session from the point of view of a scuba diver, are following a storyline described by a virtual diving companion who guides users during the exploration of the underwater archaeological site. The virtual diving system provides general and historical-cultural contents, but also information about the flora and fauna of the specific submerged site to the users.
The results collected through user studies demonstrate that the proposed VR system is able to provide a playful learning experience, with a high emotional impact, and it has been well appreciated by a large variety of audiences, even by younger and inexperienced users.

Keywords Serious games · Virtual reality · Virtual diving system · Underwater cultural heritage ·Underwater archeological sites

1. Introduction

The Underwater Cultural Heritage (hereinafter, UCH) is an immeasurable archaeological and historical resource, with extensive and varied assets (sunken cities, ancient shipwrecks, prehistoric submerged landscapes and sacrificial sites, remains of ancient fishing installations and ports), but it cannot be easily accessible by humans due to a number of limitations imposed by the underwater environment. In fact, only expert tourists, with a proper diving license, can overcome the difficulties imposed by the environment and depth, and eventually enjoy the submerged cultural treasures. As a result, it is quite evident how Virtual Reality (hereinafter, VR) is a still underrated way to leverage the enormous potential of the UCH. In fact, VR technologies can be efficiently applied in this field in order to improve, as much as possible, the accessibility of the UCH to the general public without any constraint given by distance or time.
The virtual diving system for the exploitation of the UCH takes advantage of the potentialities offered by VR technologies to allow any user to live an impressive learning experience with a high emotional impact. The system is an outcome of the VISAS project (Virtual and augmented exploitation of Submerged Archaeological Sites - http://www.visas-project.eu) (Bruno et al. 2016a), a collaborative research project funded by MIUR (Italian Ministry of Education, University and

Research) and aimed to develop an integrated package of services for improving the visitors' experience and enjoyment of underwater archaeological sites. These services are intended, on the one hand, to promote diving tourism by improving the divers' experience in the underwater site, and, on the other hand, to offer a new promotional tool to tourist operators through the development of an innovative virtual tour of the site (Bruno et al. 2016b). These needs have been pointed out by the European Commission, which decided to adopt the Blue Growth strategy (EU Commission 2014) for the development of innovative and sustainable solutions and products to boost tourism in coastal destinations. It represents, indeed, the biggest maritime industry in terms of gross added value and employment, and it is expected to grow by 2-3% by 2020 (Blue Growth Study 2013).

The proposed virtual diving system represents an innovative solution that fits the Blue Growth strategy and benefits of VR technologies to overcome the limits imposed by the underwater environment, whileoffering to the general public a playful and educational experience, by diving into realistic reconstructions of submerged archaeological sites. In particular, the VR system has been implemented for the testbeds of the VISAS project, i.e. two underwater archaeological sites of South Italy: Capo Colonna and Cala Minnola. The first one is located in the Ionian Sea, in the East coast of Calabria and 10 km away from Crotone, where raw and semi-finished marble products, transported by Roman cargo ships, lay on the seabed at a depth of 7 meters. The second one is located in the Tyrrhenian Sea, a few miles away from the west coast of Sicily, in the island of Levanzo (Aegadian Islands), where a wreck of a Roman cargo ship lies on the seabed at a depth of 27-30 meters.

2. VR applications in the UCH

VR technologies have proven their effectiveness in increasing the value of cultural heritage (Stone 1999; Barcelo and Forte 2000; Addison 2001; Roussou 2002; Vote et al. 2002; Lepouras and Vassilakis 2005; Pavlidis et al. 2007; Bruno et al. 2010), but the possible applications for underwater archaeology have not been investigated to a fair extent. For a few years now, various researchers are investigating and proposing different frameworks for the collection and visualization of the UCH by means of VR technologies, but these results either limit the exploitation to a single underwater archaeological remain (Varinlioğlu 2011), or are more oriented to digitization for scientific purposes (Katsouri et al. 2015), rather than focusing on edutainment for general audiences. Example of digital repositories of underwater remains are the Big Anchor (Hunter 2009), the Roman Amphorae (Williams and Keay 2005) and the VENUS (Virtual exploration of underwater site) project (Chapman et al. 2006). In particular, VENUS has been one of the first projects that strongly focused on the virtual reconstruction of underwater archeological sites and several campaigns have been conducted in order to acquire a detailed 3D model of ancient shipwrecks. The digital models of the underwater sites have been used in a couple of virtual and augmented reality tools for interactive and immersive visualization (Chapman et al. 2008), allowing archaeologists to study the virtual site from within. These VR based demonstrators have also been readapted for the general public, but the virtual exhibit is more oriented to the presentation and visualization of archaeological data (Haydar et al. 2011) rather than for edutainment purposes.

There are very few examples of virtual heritage demonstrations applied to the underwater environment in which user's engagement is provided by means of an edutainment-oriented approach. Stone (Stone et al. 2009) has applied serious games to the underwater environment to raise the awareness of schoolchildren and public audiences about the importance of protecting global oceanic resources. In particular, the subsea environment, in which the wreck of the naval vessel Scylla lies, has been represented to simulate the life cycles of dynamic marine life and colonization processes in order to increase the cultural awareness about marine biology rather than underwater archaeology. On the contrary, the immersive underwater VR environment of the Mazotos shipwreck site (Liarokapis et al. 2017) has been designed for raising users' archaeological knowledge. This immersive visit allows users to explore the underwater archaeological site in order to get information about the shipwreck and its cargo but the 60% of the virtual environment is not a precise reconstruction of the real site. In fact, the placement of the amphorae, wood, rocks and vegetation is generated procedurally using a stochastic approach.

Differently from the abovementioned works, the proposed virtual diving system has been designed to raise users' archaeological knowledge and cultural awareness by providing them a faithful and realistic virtual replica of real underwater archaeological sites that can be explored by means of an edutainment-oriented approach. In fact, as mentioned in Section 1, the VR visit combines an educational purpose with ludic activities, allowing its users to enjoy the virtual environment by simulating a real diving session from the point of view of a scuba diver, other than learning archaeological and historical information in a playful manner.

3. VR system overview

The software architecture of the VR system consists of five main elements: a database, a web service, a scene editor module, an interaction module, and the controller. Both the scene editor and the interaction modules are software implemented by means of the cross-platform game engine Unity (https://unity3d.com/). The adoption of the Unity framework allows for the programming of a software that can be used directly via web and for communicating, by means of the web service software, with a database dedicated to data uploading and downloading. The scene editor module allows for operating (read, write, modify and delete) the database and for integrating these data to build the virtual scene (fig.1) of the underwater archaeological site. The key elements of a scene are the 3D texturized model of the underwater archaeological site, the 3D models of the flora and fauna, and the point of interests (POIs).

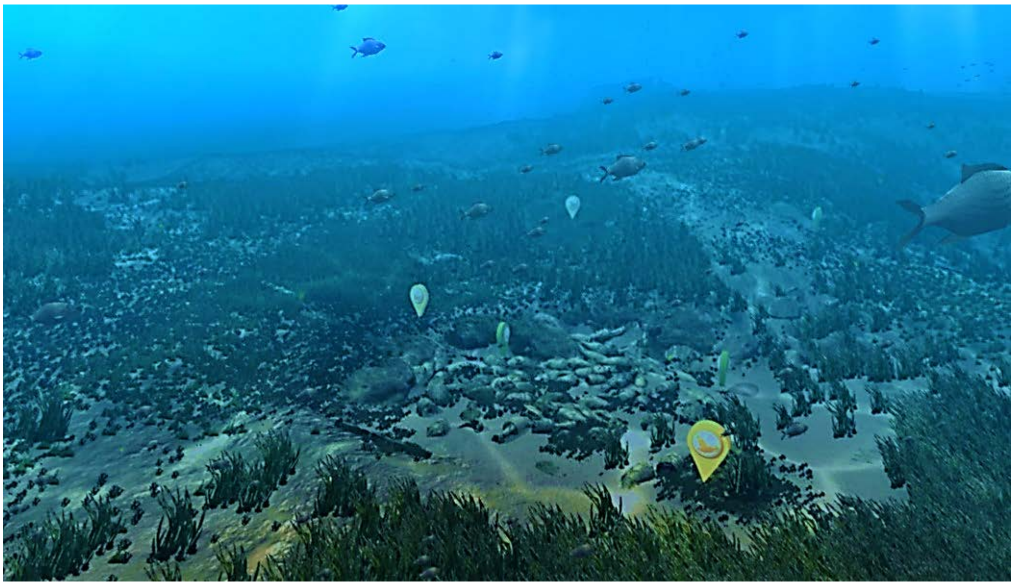

Fig. 1 Reconstructed archaeological site with 3D POIs, flora and fauna

The 3D reconstruction of the underwater archaeological site is a long and articulated process that integrates optical and acoustic techniques (Lagudi et al. 2016). In particular, a high frequency multibeam equipment has been adopted to obtain an acoustic bathymetry of the seabed, while photogrammetric techniques have been used to build a high resolution textured 3D model of the archaeological remains.

During the optical and acoustic survey activities, various useful and interesting locations are defined and geolocated.

These POIs indicate the location of interesting objects of specific feature types, such as one or a group of archaeological remains, flora or fauna, and are stored into the database in a fact-sheet format that includes their attributes (name, geographic coordinates, category/type) and multimedia content (text, image, audio and video). The POIs are added to the virtual scene in the form of 3D large head map pins (fig.1) whose color depends on the category they belong to, e.g. yellow for the historical and archaeological items, and green for biological ones.

Flora and fauna are added to the scene to make the virtual environment more visually and behaviorally realistic. As depicted in figure 1, 3D models of fishes and schools of fish, typical of that site, are settled into the underwater environment and animated by means of artificial intelligence techniques. The vegetation is placed exactly as it was captured during the optical survey and it has been reproduced by means of texture effects that mimic the movements of the real plants.

Once the virtual scene of a specific underwater archaeological site is composed, all the information about the type, number, position, orientation, and scale of all the 3D elements are saved into a configuration file and loaded into the database.

Once the scene is created, the interaction module is adopted to implement the logics of the virtual scenario and to define the physics of the elements in the scene. Furthermore, the module loads the graphical assets of the submerged, terrestrial, and aerial environments, such as refractions, fog, caustics of the particulate, etc. from the database. The interaction module is used also to perform the exploration within the virtual scenario following the user input received from the device controller.

3.1. Semi-immersive and immersive setups

The virtual diving system presents two different versions, each one characterized by the type of devices, the provided levels of immersion, interaction, and presence: the VR semi-immersive and VR immersive experiences.

The semi-immersive environment is built by means of a full HD monitor based on passive 3D technology (fig.2a). The passive technology has been preferred to the active one, because active 3D glasses are expensive and need batteries to operate. Furthermore, passive 3D glasses are inexpensive, lighter, and more comfortable. Users interact with the system by means of a multi-touch tablet featuring a user interface (UI) that provides all the input functionalities needed to explore the 3D environment and get access to the multimedia content. In particular, the UI provides to the user a large bidirectional command button to go back and forth and an omnidirectional command button to rotate the point of view of the camera. At the same time, on the top left side of the UI, a slider controls the depth of the camera view from the water surface.

Fig. 2 Semi-immersive and immersive setups

The immersive diving environment is built by means of Head Mounted Display (hereinafter, HMD) technology (fig.2b). The HMD isolates the user from the distractions of the actual physical environment and encompasses the entire field of view, including the peripheral space. The user navigates in the virtual environment by moving his/her head and interacting with a single wireless handheld controller. The diverse technologies adopted to enable the different levels of immersion strongly affect the user interaction. As mentioned above, the input devices are a multi-touch tablet for the semi-immersive environment and a hand-held controller for the immersive scenario. Through the input devices, users instruct the software about the desired orientation and direction to follow for exploring the submerged virtual area. While in the immersive environment these instructions are provided by using a single hand and tracking the user's head movements, in the semi-immersive environment the user interaction occurs with both hands, by holding the tablet with one hand and giving instructions with the other hand, or by holding the tablet with both hands and simultaneously using the thumbs to provide inputs. Therefore, in both cases the controllers are mainly used for directional inputs for exploring the virtual underwater environment. Nevertheless, when the user reaches a POI, this needs to be enabled to get access to its multimedia contents. This interaction has been implemented differently for each of the two environments. In fact, in the semi-immersive environment, when the user approaches a POI, he/she can activate or skip it by means of two action buttons that appear at the center of the multi-touch screen. If the activation button is selected, a modal view containing textual, graphical, and audio information about the POI is displayed on the screen of the multi-touch tablet. In the immersive environment, the POIs are enabled directly by the user, by pointing and selecting them by squeezing the hair trigger of the handheld controller. In this case, the multimedia contents are displayed within the virtual scenario into a 3D frame.

3.2. Game design

Intrinsic motivations, such as enjoyment or fun, produce deeper engagement and higher persistence in learning activities (Vansteenkiste et al. 2006). This would explain the successful adoption of video games for educational purposes in several domains such as the cultural heritage field. In fact, there are many applications for cultural heritage (Jacobson et al. 2009; Djaouti et al. 2009; Paolis et al. 2011; Bellotti et al. 2012; Coenen et al. 2013; Mortara et al. 2014) that use game technology to create entertaining and cultural learning experiences. Both these characteristics can coexist without conflicting, because the entertainment factor engages the public to participate, but their understanding of what they have learnt could take place after the experience (Simon 2010). The importance of these digital learning tools based on playful activities is more evident when they let players simulate real-life situations that are otherwise inaccessible for them (Shaffer et al. 2005), as is the case of the underwater archaeological sites.
The proposed virtual diving system has been developed according to the best practices related to the gamification design process (Anderson et al. 2010; Wei and Li 2010; Kapp 2012; Morschheuser et al. 2017) in order to maximize enjoyment and engagement through capturing the interest of learners (Huang and Soman 2013). In particular, the serious game presents three distinct elements: exploration, interaction, and storytelling.
The exploration of the underwater archaeological site starts above the water surface in the diving spot (fig.3). In order to make a more attractive and engaging experience, the terrestrial environment has been added and constructed in the most realistic way possible. The buoy and the inflatable boat have been added to the virtual scene, as well as the stretch of coastline that overlooks the diving site.

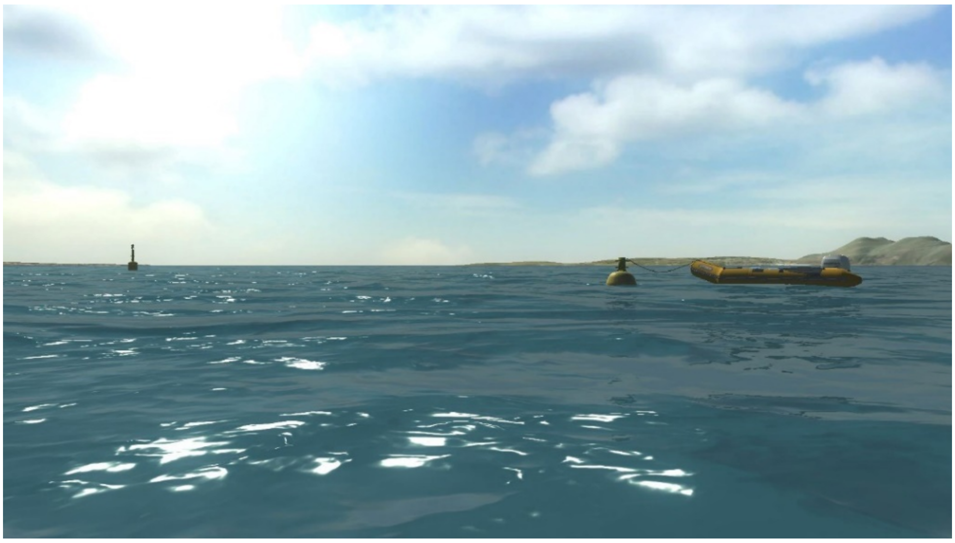

Fig. 3 Diving spot of the virtual session

Once the user dives in the submerged virtual environment, he/she is guided by a directional 3D arrow (fig.2) toward the archaeological site. The exploration of the site can be performed in two different modes that can be selected by the user on the UI: free or guided tour. In both cases the player is engaged into an active state of learning where he/she is motivated to create his/her own knowledge rather than to receive information passively. In particular, in the first mode, the user can dive freely in the archaeological area and he/she is free to pick the desired POI or simply take an overview of the submerged area. In the other case, the guided tour mode features a virtual diver (fig.4) who guides the user during the exploration of the underwater archaeological site. In particular, the virtual diver implements a logical follow-on of the POIs that, according to a storyline approach, allows users to follow one or more itineraries and 'theme routes'.

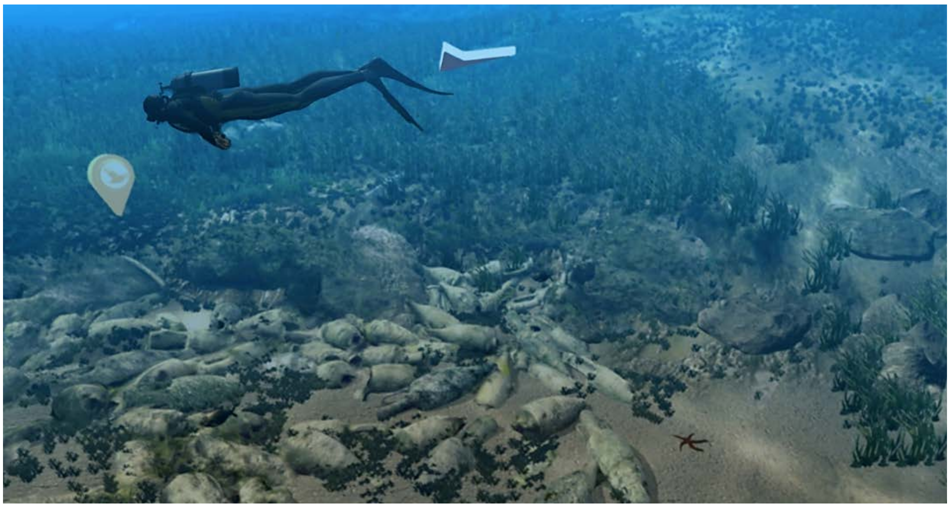

Fig. 4 Scuba guide for the exploration of the underwater archaeological site

The storytelling approach motivates players to follow the scuba guide and discover new POIs to interact with. Coupled with the game elements provided by the immersive virtual environment, this allows for maximizing enjoyment and engagement, capturing the interest of users, and inspiring them to keep learning.

In the guided tour mode, the 3D POIs are hidden and they become visible, one at a time, when the scuba guide moves closer to them. At that point, the user can either decide to skip the POI and pass to the next one, or to activate it and receive specific information by means of multimedia content (audio, video, and text). As mentioned above, the POIs can provide information about different objects that characterize the specific underwater archaeological site. These objects indicate archaeological remains, historical information, or animals and vegetables typical of the area (fig.5).

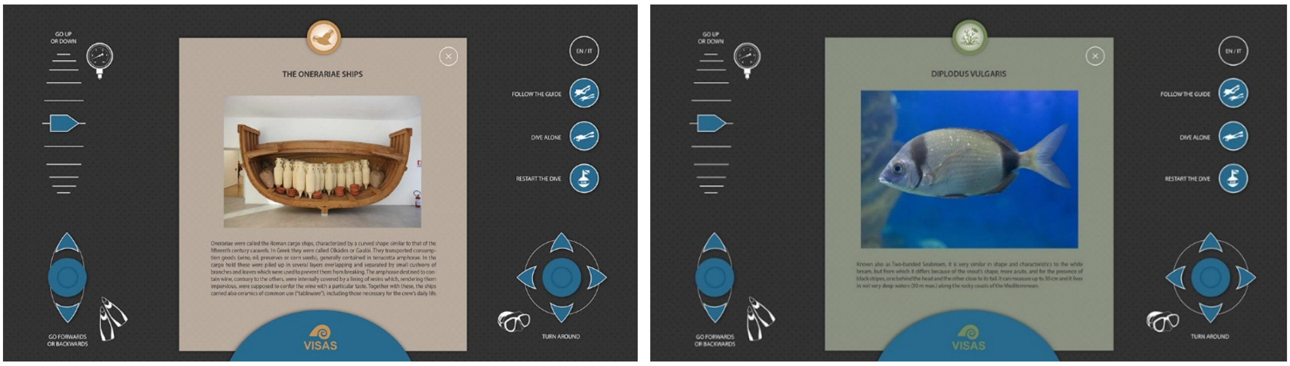

Fig. 5 Image, audio and textual information about different typology of historic (left) and biologic (right) POIs

4. User study

The virtual diving system has been developed on the basis of the standard ISO 13407 (ISO 1999) to implement a User Centered Design (hereinafter, UCD) process that allows for improving users' experience and make an easy-to-use interaction system that can be easily understood and interpreted by a large variety of audiences, even by technologically naïve users. The UCD approach provides for the involvement of users at every stage of the design process, especially during validation and experimentation activities, to obtain an immediate recognition of users' needs, behavior, and satisfaction. According to the UCD's recommendations, the virtual diving system has been evaluated by means of user studies carried out at the Department of Mechanical, Energy and Management Engineering (DIMEG) of the University of Calabria (Italy).

4.1. Research design and sample

A comparative user study has been carried out for evaluating the usability and enjoyment provided by the semi-immersive and immersive configurations implemented for the virtual diving system. Since experimentations focused on user satisfaction, subjective measures have been preferred to objective ones, which are usually adopted when the goals are related to the productivity and efficiency.

The number of participants has been defined on the basis of the most influential articles on the topic of sample size in user studies (Lewis 1994; Dumas et al. 1995; Borsci et al. 2013; Sauro et al. 2016) and its minimum value has been chosen according to a technique for accurate adjustment for small-sample size (Turner et al. 2006). This technique consists of adjustment and normalization procedures that increase the required number of participants when there are factors (virtual environment, match between the test and the context of real world usage, skill of the evaluator, etc.) that introduce other sources of usability problems and, as a consequence, could have an impact on the user study. The test sample size has been calculated on a problem discovery rate of 95% and it has turned out to be of ten participants. This value has been adopted as a threshold to deploy participants among the groups. Nevertheless, as many users as possible have been involved in the test in order to collect a greater number of feedbacks and personal opinions.
Four representative user groups (fig.6), divided by age, have been involved in the comparative study:

- G1: 28 preteens from 10 to 13 years old (mean=12 - standard deviation=0,82);
- G2: 24 teenagers from 14 to 16 years old (mean=14,83 - standard deviation=0,76);
- G3: 18 male young adults from 17 to 22 years old (mean=18,11 - standard deviation=1,23);
- G4: 31 female young adults from 17 to 24 years old (mean=18,06 - standard deviation=1,21).

Fig. 6 Preteens (a), teenagers (b), male (c) and female young adults (d) participating to the user study.

4.2. Procedure

The comparative procedure has consisted of three main steps. In the first step, after a short presentation of the virtual diving system, a quick demo of its main features and of the different user interactions in the semi-immersive and immersive environments has been shown to the participants.

In the second step, each participant has conducted a free exploration of the semi-immersive and immersive scenario without any limitation in time. In order to minimize the skill transfer, two preventive measures have been taken: the semi-immersive and immersive configurations have been counterbalanced over the participants and tested at least 15 minute apart from each other. Participants have been observed while performing the free exploration of the virtual environment: each time they encountered any difficulty or they were faltering while using of the system, this has been noted down.

Furthermore, by the end of the second step, users have been invited to fulfill a satisfaction questionnaire and to perform a one-on-one personal interview aimed to comprehend their enjoyment and catch all their possible personal judgements. The satisfaction questionnaire has been developed on the basis of standard questionnaires whose definition is based on psychometric methods (Lewis 2006). In particular, the questionnaire is composed of 10 items that follow a preliminary survey about users' demographics (gender, age) and technological experience. The first eight items are 7-point graphic scales (Likert scale), anchored at the end points with the term "Strongly disagree" for 1 and "Strongly agree" for 7. The last two items allow users to clearly express their preference between the two environments and to suggest improvements.

4.3. Data analysis

Descriptive statistics, *t*-test and analysis of variance tests have been used for statistically significant differences between the semi-immersive and immersive environments. All analyses have been conducted using the statistical packages Microsoft Excel and IBM® SPSS. The statistical significance level has been set at $p<0{,}05$.

4.4. Results and discussions

Thanks to the widespread use of stereoscopic displays, especially due to the vast distribution of 3D televisions sold by consumer electronic stores, all the participants had some background experience with VR. On the contrary, HMD and multi-touch devices were not so well-known. In fact, as depicted in figure 7, most of the participants were familiar in the use of multi-touch technology, except for the preteens group, where only 50% of them use a touch-screen based interface daily. The HMD technology, by contrast, is almost unknown among the participants: in fact, only a 10% of male and female young adults had previous experience in the use of this display device.

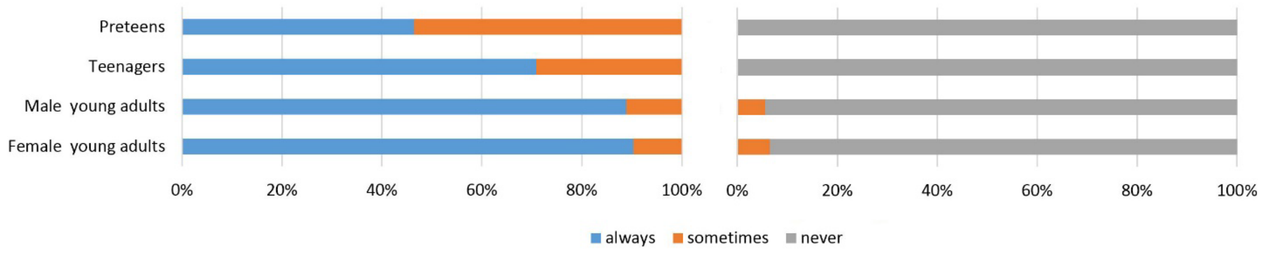

Fig. 7 Multi-touch tablet (left) and HMD (right) frequency of use among the groups

The following graphs (fig.8) show the results of the satisfaction questionnaire fulfilled by users after performing the free exploration of the semi-immersive and immersive environment provided by the virtual diving system. The questionnaire items have been gathered in three groups, addressing very important components of user satisfaction related to the virtual diving system. In particular, for each environment, one item has been designed to assess the learnability of the system, two for the system efficacy, and one for the enjoyment evaluation.

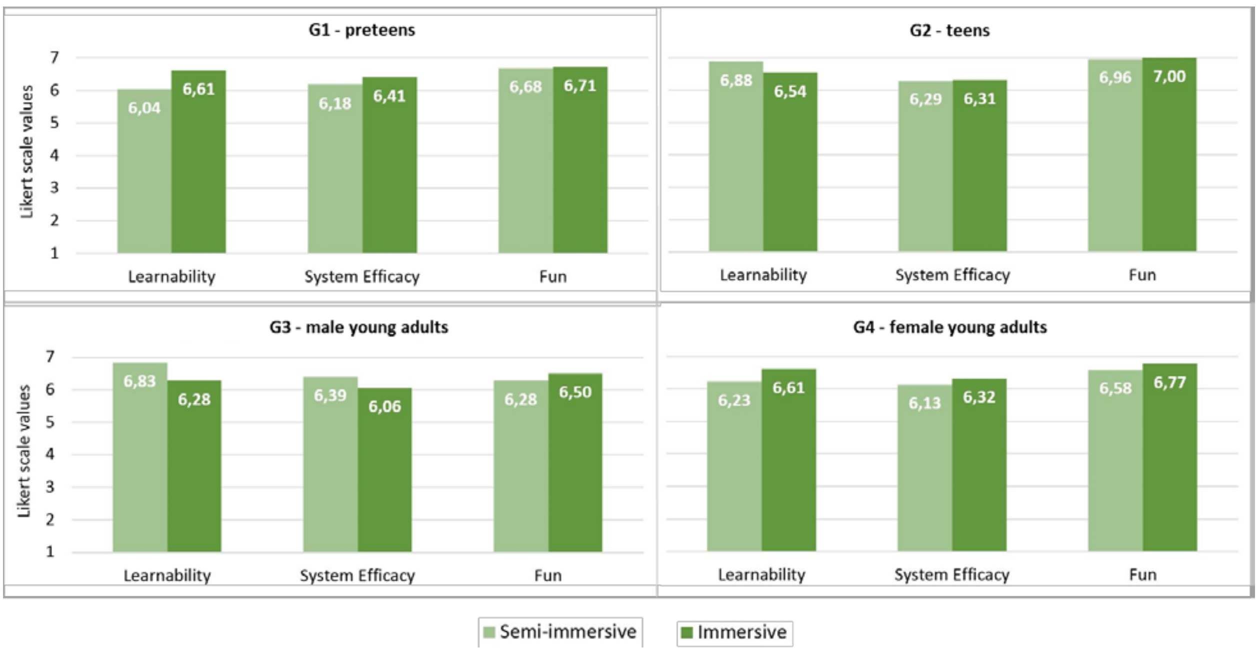

Fig. 8 User satisfaction questionnaire results by groups

The graphs show little differences in subjective opinions between the semi-immersive and the immersive environment. In particular, each group shows different levels of learnability, efficacy, and enjoyment between the two environments, but on the contrary, statistical analysis hasn't provided enough evidence to confirm these small gaps. In fact, the results of statistical analysis shown in table 1 - performed by means of paired sample t-test technique with a confidence level of 95% - indicate that only the male G3 group presents a significant difference in the learnability of the two environments: $t(17)=-2{,}26$, $p=0{,}04$. This result reveals that the young male adult participants consider the semi-immersive environment slightly easier to use than the immersive configuration. Since user interfaces are similar in both the environments, this outcome could be justified by the different types of user interaction devices. In fact, as mentioned above, male young adults are very familiar with the use of multi-touch tablets, but they are unaccustomed to HMD technologies and their handheld devices. Furthermore, this difference has emerged only in the G3 group, possibly because, among all the groups, it represents the greater portion of the game-playing population in which the most frequently used devices are PCs and game consoles, and only 17% of gamers play with handheld systems (ESA 2016).

Table 1 Paired sample t-test results

Group		Paired differences: mean	Paired differences: std. deviation	*t*	df	Sig. (2-tailed)
G1	Learnability	0,57	1,95	1,55	27	0,13
	System efficacy	0,23	1,66	1,04	55	0,30
	Fun	0,03	1,48	0,13	27	0,89
G2	Learnability	-0,33	1,00	-1,62	23	0,12
	System efficacy	0,02	0,96	0,15	47	0,88
	Fun	0,04	0,20	1,00	23	0,33
G3	Learnability	-0,55	1,04	-2,26	17	0,04
	System efficacy	-0,33	1,01	-1,97	35	0,06
	Fun	0,22	0,81	1,17	17	0,26
G4	Learnability	0,39	1,74	1,23	30	0,23
	System efficacy	0,19	1,37	1,11	61	0,27
	Fun	0,19	0,87	1,23	30	0,23

Differences among the groups have been investigated by means of the variance analysis with a 95% level of significance. The results of a one-way ANOVA indicate a significant difference $F(3,97)=3,43$; $p=0,02$ in the learnability of the semi-immersive environment on the different groups. However, a Levene's test turned out to be highly significant ($p<0,01$) violating the assumption of homogeneity of variance. Therefore, the Brown-Forsythe and the Welch versions of the F-ratio have been investigated, revealing that the difference in learnability among the groups is still significant because of their results that are lesser than 0,05 (0,012 and 0,006, respectively). A Tukey post hoc test has been carried out to perform a pairwise comparison of the groups that revealed a statistically significant difference in the learnability of the semi-immersive environment between G1 and G2 ($p=0,045$), as well as between G2 and G4 (0,026). In particular, the teen participants have expressed a higher level of learnability than the female young adult group and the preteen group. Even if these levels are quite similar, the small differences can be still attributed to the different familiarity with touchscreen technology and video games.

On the whole, the user satisfaction questionnaires have revealed that both the semi-immersive and immersive environments of the virtual diving system gained similar levels of learnability, efficacy, and enjoyment. In particular, these levels reached high values in all the groups with a minimum score of six out of seven.

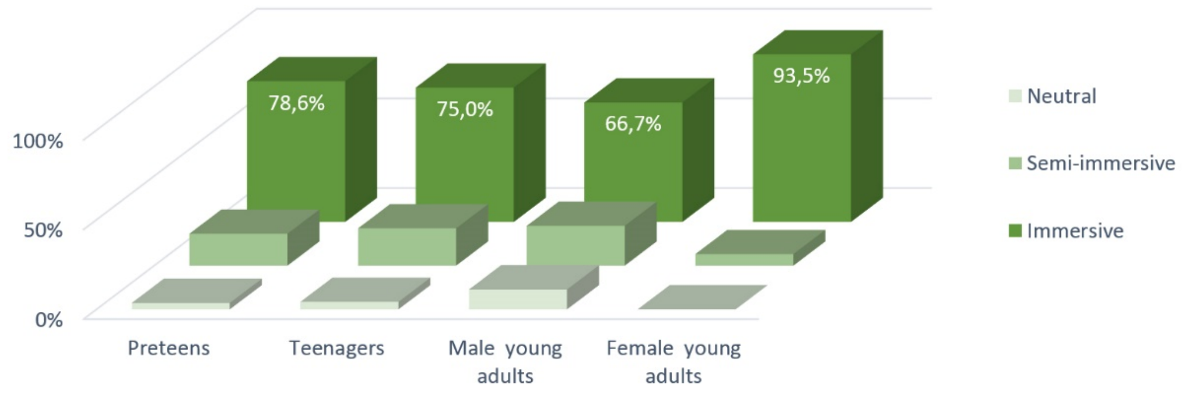

Fig. 9 Subjective preference results

On the contrary, from a subjective point of view, when participants were asked to express their preference, the vast majority of them clearly expressed their preference for the immersive environment and consequently for the HMD device (fig.9). This result has been unexpected because, as shown in figure 7, even if all the users were confident in the use of 3DTV and multi-touch devices, only few of them had previous experience in the use of HMDs. In the one-on-one interviews, the subjects motivated their preference asserting that, even if they felt comfortable with the adoption of 3DTV, the HMD technology provided a much more immersive virtual experience and allowed them to behave in a more natural way: in fact, they were able to turn their heads or their whole body whenever they wanted. Furthermore, the outcome of the verbally expressed preference can be also justified by the fact that pleasantness and attractiveness increase with novelty (Berlyne 1970; Silvia 2006).

To sum up, on the basis of this user study, the virtual diving system provides high equivalent levels of usability and enjoyment to its users, both for the semi-immersive and the immersive environments. As a consequence, the choice between these environments could be made according to factors related to the specific application context or to subjective preferences rather than usability metrics. In fact, as it was observed in the participants' personal interviews, the HMD technology is an appropriate choice, especially when users need to make frequent turns to look around and enjoy the virtual environment. In fact, unlike the semi-immersive environment where the intermodal integration of concordant visual and kinesthetic stimuli gives to the user a robust perception of the real surrounding world (Ernst et al. 2002), in the immersive environment the dominance of the visual modality (Spence et al 2001) influences the overall perception and interpretation of perceptive inputs (Rock et al. 1964), resulting in a kinesthetic depth perception of the virtual environment that improves users' engagement, since it gives a more realistic feeling of being in the actual underwater site (Van Dam et al 2002). Regardless of the participants' comments and personal opinions, the semi-immersive configuration system could be more adequate for museums and schools, where there is the need to make the virtual experience available to a large number of visitors or to allow for a shared exploitation of the virtual scenario with more than one person at a time. Furthermore, the touch-screen remote control could be a handheld device or a device fixed in a specific position. The first solution can be adopted when there is an operator that stands over the system, while the second solution can be employed when the system is intended for unattended operation and, since the console cannot be moved, it is possible to increase the screen size of the touchscreen to enhance its legibility (Barbieri et al. 2017).

5. Conclusions

This paper has presented a virtual diving system for the exploitation of the Underwater Cultural Heritage. Thanks to this system, users can live a virtual experience and explore the 3D reconstruction of real underwater archaeological sites that, due the various limitations imposed by the submerged environment, are usually accessible only to a restricted public.
The virtual experience has been designed to entertain users, but its added pedagogical value is explicitly emphasized too. In fact, the ludic activity, consisting in the simulation of a real diving session from the point of view of a scuba diver, is combined with the educational purpose by means of a storyline approach based on a virtual scuba diver that guides the user among the different and various POIs that populate the underwater site. When activated, POIs offer specific information about historical and archaeological peculiarities related to materials and construction techniques. Flora and fauna are also described, with a particular attention on their interaction with the submerged artifacts. The virtual diving system provides also a free exploration mode that can motivate users to keep playing, especially when the game's learning content has been ultimately explored.
The evaluation study has been designed to assess users' satisfaction of the semi-immersive and immersive set-ups. It has demonstrated that both the set-ups present high levels of usability and enjoyment for all the categories of participants, which differ on the basis of age and sex. Since serious games are traditionally designed for the younger learner, the user studies have been carried out on teenagers and young adults, but further usability tests will be performed by recruiting adult and elder participants too. Furthermore, the transmission of knowledge to the user, after having experienced the virtual diving environment, will be explored to assess the learning benefit of the system.
The virtual diving system developed in the VISAS project has been presented to the general public at the BPER Optimist European Championship 2016, which has been held in Crotone (Italy) on 16-22 July 2016. Visitors have been able to try the experience of the virtual diving in the underwater archeological site of the Punta Scifo. At the end of the event, the VR system has been installed at the Area Marina Protetta of Capo Rizzuto's headquarter until September 2016.
From 6 November 2016 until 6 March 2017, the virtual diving system was showcased at the exhibition "Mirabilia Maris. Treasures from the seas of Sicily" that takes place inside the Palazzo dei Normanni in Palermo (Italy). The virtual diving experience reproduces the underwater archaeological site of Cala Minnola.
Future improvements will occur in the iMareCulture project (www.imareculture.eu) by addressing the design and integration of digital storytelling components within a serious gaming approach in order to enhance the user experience and the educational effectiveness of the virtual diving system. Moreover, in the context of the BLUEMED project (http://interreg-med.eu), the VR system will be enriched by additional virtual environments replicas of underwater archaeological sites from Italy, Greece, and Croatia.

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