
A student during a play session in a virtual scenario.

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Heritage education through serious games. A web-based proposal for primary schools to cope with distance learning.

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ABSTRACT

In recent years a growing amount of research has shown interest in studying how virtual reality (VR) could be relevant in many fields. In this respect, VR has gained consideration throughout many applications such as education. Among other aims for its use in education, serious games based on VR were used to promote heritage and make students experience either far or inaccessible scenarios. Until now, VR-based applications have been mainly implemented using head mounted displays (HMD), which actually reduced their circulation. This gap is particularly remarkable in the current Sars-CoV19 pandemic because students, being at home or being at school without sharing equipment, cannot exploit educational programs based on this technology. The current paper proposes a web-based platform on which VR applications could be accessed on any device, either desktop- or mobile-based. The serious game was initially set up on a computer with a specialized software using a HMD, while the process of turning it into a web-based platform is described so that the used methodology could be available to those, who would like to follow it. This project is probably also able to cope with the general aim of making inaccessible objects available to students and, thus, to make the application useful even beyond the current pandemic emergency.

KEYWORDS

virtual reality, serious game, heritage education, virtual tour, web-based app, webXR

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1. THEORETICAL BACKGROUND

In recent times the use of illusory three-dimensional environments generated by two-dimensional images is gaining a certain popularity. This was possible mainly thanks to the growing use of virtual reality (VR) and augmented reality (AR) technologies in many professional sectors, becoming rather inseparable from the use of HMD devices or the diffusion of 360 cameras and more generally of visualization, such as smartphones and tablets. Increasingly widespread, 360° interactive VR panoramas become the new standard of immersion for the enjoyment of photographic images. It was also integrated into social network platforms such as Facebook, or in the visualization of 3D film content such as those offered by YouTube and in services for geographic and territorial visualization such as Google Expeditions (Brown and Green 2016). These tools also offer users increasingly easy ways to upload and share their HDR 360-degree content.

The introduction of VR in the educational domain came right after its commercial use, but the surge of this application was noteworthy. On the one hand, education was considered a potential benchmark for the development of products and applications. The recent systematic review of Radianti and colleagues (2020) mapped the use of immersive VR technologies in higher education. The analysis of 34 papers showed that this technology was used for teaching purposes in many different domains. Notwithstanding, they complained that "the evaluation of educational VR applications has primarily focused on usability of the VR apps instead of learning outcomes" (Radianti et al., 2020, p. 1). On the other hand, many papers showed how academic performance could be positively influenced by VR technologies. The meta analysis by Merchant and colleagues (2014) examined 69 studies focusing on K-12 education and showed a clear learning improvement due to the VR technology. In particular, VR-based games showed higher effect as compared to simulations and virtual worlds.

The relevance of serious games in digital education was corroborated by several reasons. The review by Checa and Bustillo (2020) showed how immersive serious games impact onto two main aspects: Learning (that is, the acquisition of new knowledge) and training (the development of new skills). Secondly, the enjoyment of students was considered one of the key aspects for its appreciation, which can scaffold academic performance (Annetta et al., 2009). Finally, teachers could exploit immersive technologies to make students feel as if they were present in other spatio-temporal environments. Serious games allow recreating real and fictional but plausible educational scenarios. Examples for real environments could include the study of geography (Ashfield, Jarvis and Kaduk, 2010), while examples of fictional scenes are the simulation of dangerous situations (Feng et al., 2018) or historical events (Alisson, 2008).

The use of digital technologies for art and heritage education is a key research topic (Champion 2016; Luigini and Panciroli, 2018; Challenor and Ma, 2019, Luigini, 2019a; Hu et al. 2019) and shows a high growth trend. In particular, the use of serious games seems to be increasingly widespread in the context of digital heritage (Mortara et.al., 2013; Ioannides et al., 2017; Luigini, 2019b; Luigini et.al., 2019) probably also for the development and diffusion of the heritage digitization process.

Until now, VR-based applications have been mainly implemented using head mounted displays (HMD), which have probably contributed to reduce their circulation (Buń, et al., 2016). The associated costs may be high: although they are becoming more and more popular and affordable, so much so that they are entering the consumer electronics market in the same way as smartphones, gaming consoles or smart TVs, they are widespread devices in the advanced gamer community. The cost is the main issue also for Kamińska and collaborators (2016), although they have added further challenges for the educational use of VR-based applications. Among them, they highlighted the need of computationally powerful hardware for rendering, the trade-off between quality of immersion and portability of the device, and the unwanted psychophysical disease that some people experience induced by the use of HMDs.

The present paper proposes a web-based platform

on which VR applications could be accessed on any device, either desktop- or mobile-based, and without the need of HMD devices. This improvement is likely to address many issues described above, for example: a) to reduce associated costs, b) to increase diffusion, c) to simplify and enhance the experience of every single user.
Moreover, this innovation could be particularly remarkable in the current Sars-CoV19 pandemic because students, being at home, cannot exploit educational programs based on this technology. The Sars-CoV-2 pandemic has brought Italy and other countries worldwide to set a period of lockdown in 2020 (Walters, 2020), in which schools were closed from March to the end of the summer semester. The situation in the winter semester has not changed a lot, and schools are only partially open. In this situation, distance learning was largely the main option available for schools (Daniel, 2020). Educational space and student interaction (Dali et al., 2020) were among the main areas in which changes should occur. In this context, many aspects inherent to the VR use in schools could not take place: first of all the use of HMD devices would require hygienization before and after use, and sharing the same device by several children is strongly discouraged, if not prohibited. Furthermore, the installation and use of HMDs requires the presence of specialised personnel who, in pandemic restriction, can only enter school environments following complex authorisation and health procedures. Therefore, research is asked to address these issues, in order to improve the implementation of VR-based projects.

2. THE SERIOUS GAME

After the recommendation No. R (98) 5 of the Committee of Ministers to Member States concerning Heritage Education of 1998, which underlines the role of heritage education, in 2005 the Council of Europe Framework Convention on the Value of

Figure 1.
A 10 year old student during a play session in the "snow" scenario.

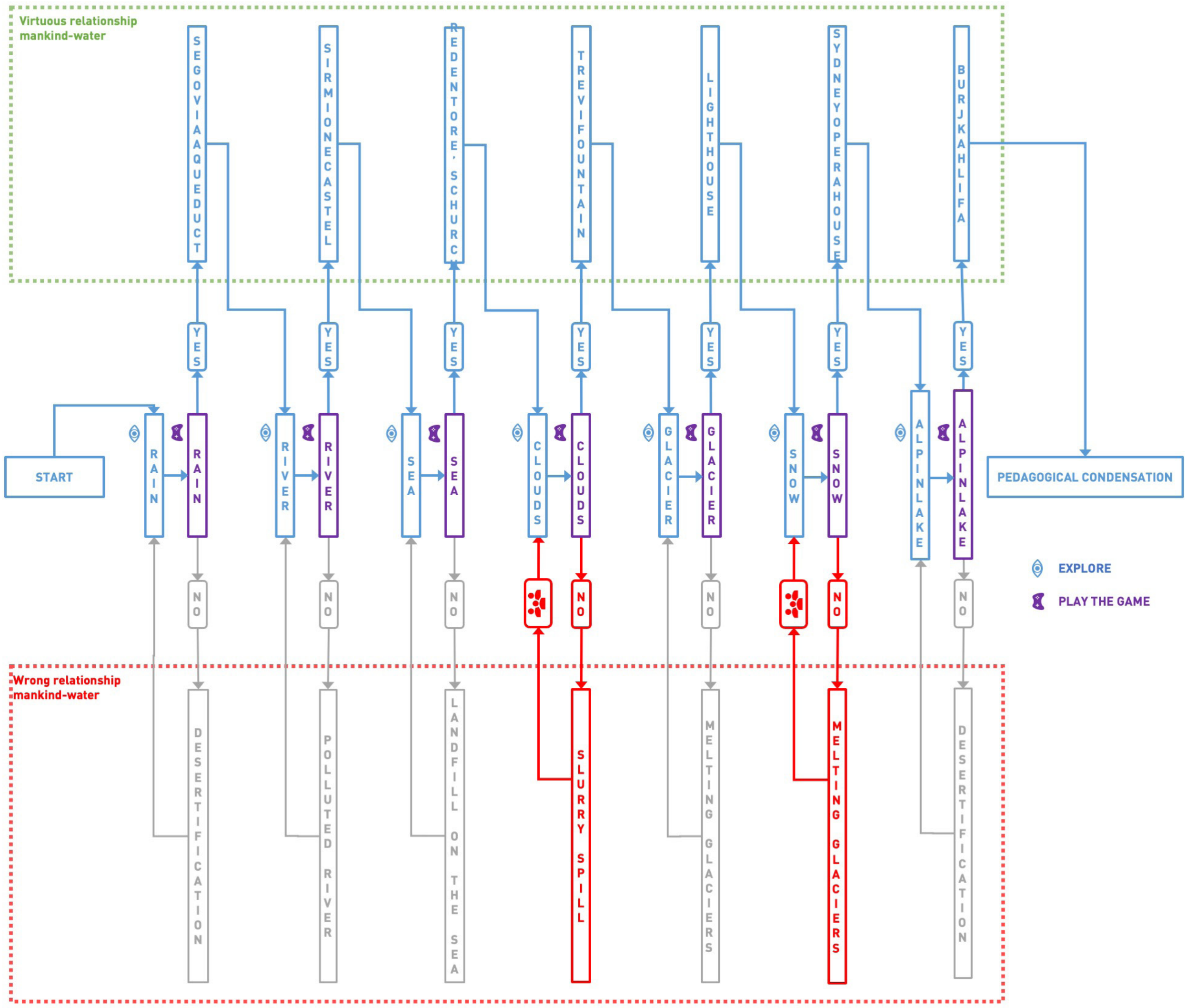


Figure 2.

Game scenarios scheme: from the natural scenarios the player can explore the scenarios that tell of the virtuous relationship that mankind has had with water or the scenarios that tell of the wrong relationship. To show the reversibility of the process and empower the player, it is possible to go back once wrong.

Cultural Heritage for Society, presented the Faro Convention, acknowledging the universal value of heritage education. Italy adhered to the Convention only in 2013, while in 2015 the General Direction for Education and Research of the MIBACT Ministry of Cultural Heritage and Activities and Tourism issues the fundamental Circular n.27/2018 DG-ER Piano Nazionale per l'Educazione al Patrimonio Culturale 2018-2019. In this situation, the research project VAR.HEE. Virtual and Augmented Reality for Art and Heritage Education in School and Museum Experiences, took place. Within this project, a series of serious games for primary school was developed between 2018 and 2019. These games were essentially virtual tours to explore with game techniques, which were experimented with students (Luigini, 2019b, Luigini et al., 2019). These educational virtual tours included play sessions for groups of 6-7 students, conducted through a large wall-screen and the use of an Oculus Rift type HMD viewer (taking turns).
The didactic programme has emphasized the relationship that our civilization has developed over the centuries with the water. The serious game includes 7 consecutive levels, structured according to a linear outline, in which the player follows the journey of a drop of water for two complete cycles: a general one (rain, river, sea, cloud) and a typically mountain one (snow, glacier, alpine lake). The gamer can move to the next level by answering a quiz: each question allows just one correct answer out of four options. The development of the experience was dependent on the accuracy: if the answers were correct, signs of a sustainable relationship between mankind and water were shown; with wrong answers, the consequences of vicious behaviour were presented. Thus, the exploitation of the natural landscape was complemented by the promotion of the cultural landscape.
In order to be applied to primary school students, in the realization of the serious game, the theory of cognitive load (Sweller, 1988) was taken into account from the very beginning. The theory suggested avoiding the redundancy of textual information and favouring visual information. To do so, the serious game used a sequencing process, that is, the "tasks" required by the children were broken down, re-aggregated into small groups (chunking) and presented in modular units with the same sequential internal structure. Moreover, several observation points, namely "visual stations", were defined for each environment: the first series were devoted to the observation of the environment itself, without further visual stimuli, and only the last one - following the activation of the "play" button - for the solution of the quiz. This sequencing of the internal structure - and relative decomposition - ensured that the children-players maintained their attention throughout the path and were free to explore the visual space whenever possible.
Particular attention was required by the visual system, both in relation to maintaining the balance of the cognitive load and to limit the side-effects of kinetosis or cybersickness (for more details see Al Zayer et al., 2018; Rossi and Olivieri, 2019). Indeed, for children from 2 to 12 years of age, who seem to be the most likely to present these symptoms (Reason and Brand, 1975), attention to the smallest detail is important to reduce or eliminate the manifestation of these symptoms. The design responses elaborated in the game foresee the reduction of these risks through some specific settings of the representation device. First of all, player's movements were limited to the visual system, by creating the serious game starting from 360° static photographic images - taken from open access archives - and by producing, in some cases, a teleportation effect. This is similar to what happens, for example, in Google Street view, probably already known and therefore "familiar" to the project's recipients. A walking-based system would have probably required a greater physical engagement of children, and in the case of locomotion managed by touchpad controllers, thus producing an increased risk of discrepancy between visual and motor stimuli and a possible onset of cyber sickness. In order to move from one point to another, to activate game phases and to interact with quizzes, it was therefore preferred to adopt a "point and click" system that could be activated both with a pointer sensitive to the movements of the VR viewer and with the touchpad controller. This choice allowed users to reduce adaptation times to an extremely reduced threshold,

and to navigate in the game almost naturally.
Due to the school restrictions in the Sars-CoV-2 emergency, it was not possible to further run the above described serious game. In fact, it does not meet several requirements: a) it required the presence of researchers to assist students while performing the task and in order to collect data; b) it was not allowed run to group experiments in closed environments; c) the use of HMD is prevented. Therefore, although many aspects of the application could be maintained (e.g. the game outline, the didactic structure and experience, the game scenarios, the level of interaction, the relationship between the user's choices and the effects on the water) some other ones must be modified to make experimentation possible and to expand the range of application of the project. The two main features, which needed to be modified, were 1) the fruition method, and 2) game playing time. The new fruition method does involve the use of any device, both desktop and mobile but also HMD (which are no longer necessary but can still be used) that can access the web. This way all the difficulties due to the need to share specific devices are overcome, greatly expanding the possibility of people to enjoy serious games. The range of variability (from desktop computer to smartphone or HMD) allows the possibility to experience VR according to both a weak definition (digital environments that involve only a part of the field of view) and a strong definition (immersive environments that involve the whole field of view) (Maldonado, 1993). The devices that provide a weak VR are desktop computers, tablets and smartphones: the former requires mouse and keyboard, the latter ones are used with touch controls. The devices that provide strong VR are HMD or smartphones used through a VR box or a Cardboard. While HMD has a lower diffusion and considerable cost, both the other solutions are accessible devices, also from the economic point of view.
The second variation concerns the game structure, that is, how each single participant experiences the game. In the previous structure of serious games only a scenario was played immersively from a player and the other six were played as observer in the support group. This served to achieve cooperative dynamics in the gaming group but also to control for the risks of cyber sickness. With the use of non-immersive devices there is no risk of either motion or cyber sickness. Indeed, by using the smartphone in the cardboard the cognitive immersion is likely to be less intense because the eyes can be instantly turned away from the device. In the end, it is not possible to play in a group of seven children and everyone will have to play all seven scenarios by themselves. It remains to be ascertained whether the success of the didactic path may depend on the experience of playing the role of actor for all scenarios, or on the contribution of the group.

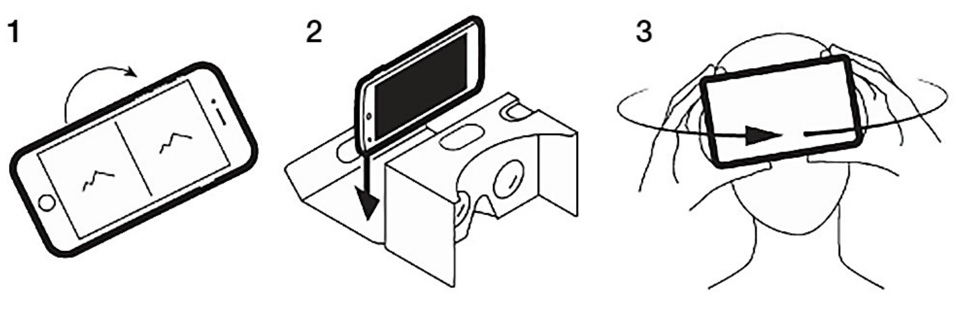


Figure 3.
To use a cardboard you must: 1) start the binocular display, 2) insert the smartphone into the cardboard and 3) use the cardboard as a stereoscopic viewer.

3. VRT THROUGH THE MANAGEMENT OF EQUIRECTANGULAR PHOTOGRAPHIC PROJECTIONS

The Serious game products for experimentation within the VAR.HEE project (In the new web-based release will be used the same scenarios) are based on the integrated use of 360° equirectangular images to generate the illusion of being in real space. By exploiting the virtual reality viewers, immersive inputs are provided in order to impress users without arousing too many visual-interactive stimuli, potential destabilizers during the first exploration experiences

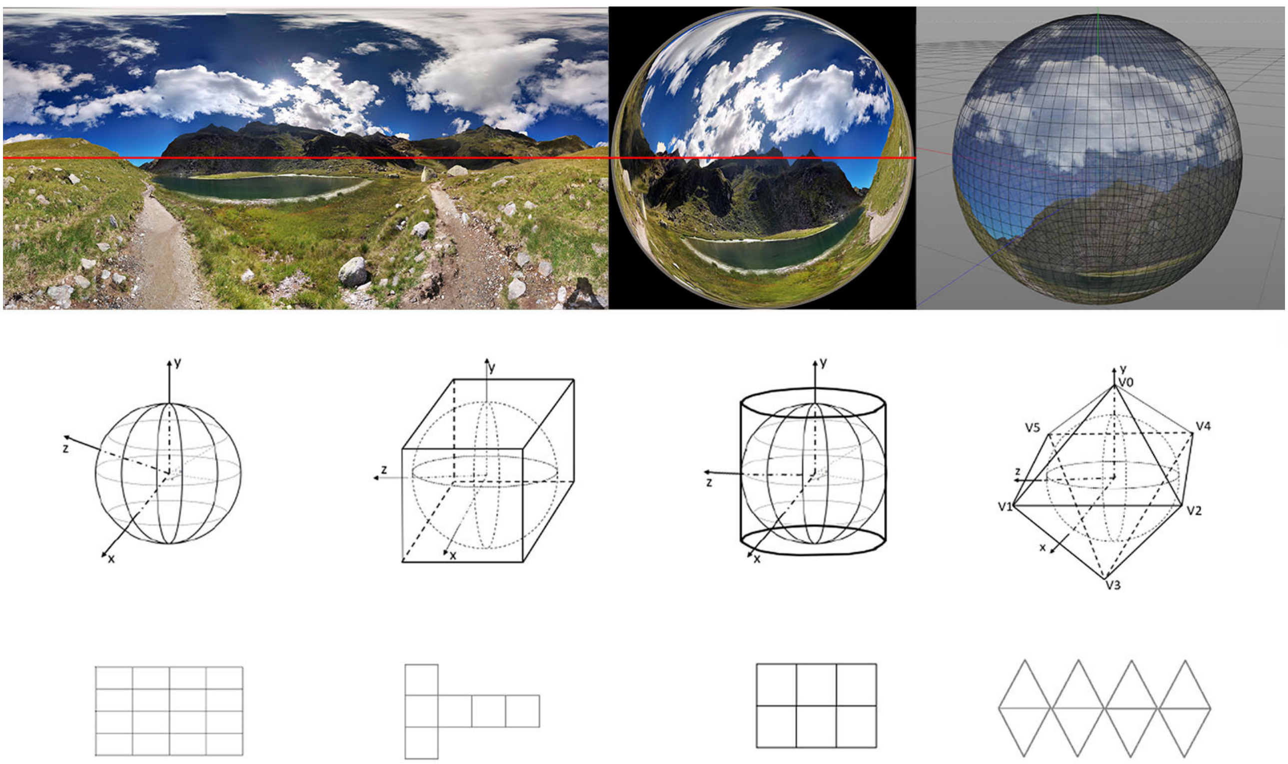
Figure 4.
Three scenarios of the same game level: the natural environment - Carezza Lake -, the virtuous relationship mankind/water - Sirmione Castle - and the wrong relationship m/w - waste on a rock beach.

to focus on factors such as the pleasantness of the experience and general comfort. Despite greater interactivity, from a technical point of view the game structure is very similar to that of Virtual Tours where the scenarios are simulated thanks to equirectangular images, also called ERP Image, hyper-detailed with a resolution varying between 4k and 8k.
Apparently such a high resolution may seem excessive but in VR visualization it is fundamental to be able to limit to the minimum artifacts such as blurs or pixel/texel[1] visible to unaided eye in a virtual session, which is possible to be manifested with the use of medium resolution images: in a 360° space usable with viewers, the equirectangular image is displayed in a spherical form, making the actual pixel density and any colour alterations very visible. It is therefore necessary to use an image resolution of no less than 8192 x 4096 pixels, providing an excellent source material for editing a high-quality interactive virtual tour. In the specific case of the Serious Game H2O the views have been taken from various open Access sites with free and royalty license[2]. In some cases it was necessary to generate 360° panoramic images using textured three-dimensional scenarios, then rendered in spherical mode thanks to OTOY's Unbiased Octane rendering engine, obtaining a good level of photorealism of the image thanks to the software's proprietary Global Illumination effects. The ERPs used in VRT (Virtual Reality Theatre) type virtual exploration platforms to simulate the fruition of real environments can be developed through special techniques of projection and spherical mapping, using Skybox or Cubemap projection methodology (Araújo, 2018). The Equirectangular image, used as a matrix to generate this type of 360° panoramas, is presented in synthesis as a curvilinear perspective that is closely linked to the concept of conical anamorphosis[3] due to the flattening of the sphere on a plane (Araújo, 2015). The anamorphosis influences the central projection map P->OP$^{->->->}$/|_OP| where O is the centre of the sphere, representing the point of view. In analogy with any spherical perspective, anamorphosis is a deformation that transforms spatial lines into meridians with exactly two antipodean vanishing points. The first equirectangular representation can be assimilated to

the image representing the terrestrial hemispheres in cartographic maps. To better define the operation of projecting a 3d sphere on a flat surface, which can be assimilated to a 2d photographic image, through unwrapping operations it is therefore necessary to distinguish the traditional perspective camera, which fields a limited field of view of the 3D scene projected on a 2D plane, from the 360° camera, which has the ability to capture the entire environment in a spherical projection starting from an optical projection centre, providing a complete image in an omnidirectional field of view and a more engaging and complete representation of reality visible in every direction from the same point of view.

The equirectangular images generated by the 360° cameras substantially perform an inverse mapping operation to reconstruct the visual information ideally projected on a sphere. For the visualization of 360° images there is not only the equirectangular projection method (ERP), although it is the most used in the virtual tour visualization industry and the most performing in terms of quality, but also alternative export formats, such as cubic projection (CMP), which is frequently used in the videogame industry thanks to lower calculations, octahedron projection (OHP) and cylindrical projection (CP), which preserves

Figure 5.
Equirectangular image of Serious Game starting panorama compared with azimuthal equidistant perspective of the same. Below various examples of map projection: ERP, CMP, CP and OHP formats in 3d visualization.



the correct scale and proportion along vertically arranged objects, 'fixing' the deformation along the y-axis. For the development, editing and compilation of the serious games that are the object of the experimentation, two software were used, specifically Pano2VR6, for the definition of the virtual tour and interactions, and VRTourViewer, a versatile application that allows the direct passage on the Virtual reality platforms connected to the most common HMD Visors. Pano2VR, thanks to a versatile learning curve, offers many features in relation to a very complete virtual tour customization: any kind of control interface can be designed through the skin editor, the use of any image, both static and video, it is possible to use sounds and music to make the experience even more immersive. Through the insertion of simple links you can connect in real time with websites and you can use a large number of pre-filled visual effects through a very simple system of "Tags", i.e. keywords to which the software associates particular features. The use of the script language has been limited in favour of a fully graphical functionality control interface that brings even the average user, hobbyist or researcher, closer to the creation of serious games with point and click dynamics in 360° environments. The software has allowed a versatile development compatible with external WXR systems that can be exploited on web platforms and implemented in other specific software for remote education, in "cardboard VR" version or optimized for desktop visualization.

4. IMMERSIVE VR ON THE WEB

Large advancements within the presentation and dissemination of interactive 3D content on desktop and mobile web browsers have occurred through recent web technologies. Since the introduction of the first WebVR open specification (Pakkanen et al. 2017) it became possible to consume immersive VR experiences through common web browsers (Google Chrome, Mozilla Firefox, Oculus browser, etc.) using consumer-level HMDs. Because of its inherent openness and accessibility, the web represents an incredible opportunity to enable a universal access to immersive VR experiences without requiring additional software. The specification so far played a big role in democratizing VR: a large audience can experience 3D content through low-cost (e.g. cardboards or VR box) or high-end headsets (HTC Vive, Oculus Rift, Oculus Quest, etc.) directly through a web page. It is also fueling content creators who need to test and deploy immersive VR content on the web, through a wide range of web-applications and viewers (see for instance SketchFab platform). The open specification recently evolved into WebXR (Jones and Waliczek, 2019; González-Zúñiga & O'Shaughnessy, 2019): the new standard aims to unify VR and AR (Augmented Reality) worlds, supporting a wide range of user inputs (e.g. voice, gestures) giving users options for navigating and interacting in virtual spaces over the web (Macintyre and Smith, 2018).

Immersive computing introduces precise demands and strict requirements for low-latency communication in order to deliver a consistent, smooth and acceptable experience. These have to be taken into strong consideration, especially within limited resources available on mobile web browsers, compared to desktop counterparts. Due to the lightweight nature of image-based data, panoramic content is often employed to deliver immersive experiences even on low-end HMDs. Past research (Fanini and d'Annibale, 2016) also investigated compact image-based approaches to easily transport omnidirectional depth and semantic information on the web, in order to restore a rich, egocentric approximation of a 3D space targeting immersive visualization.

Within Cultural Heritage, open-source frameworks such as ATON by CNR ISPC (http://osiris.itabc.cnr.it/scenebaker/index.php/projects/aton/) allow to craft scalable, cross-device and WebXR-compliant web applications - also offering spatial UI components to develop and present advanced immersive interfaces. The framework has been already employed in several research projects ranging from european infrastructures (Fanini, Pescarin, Palombini, 2019), museum 3D collections (Gonizzi et al., 2018), to applied games (Lo Turco, 2019). The framework is designed around a "develop once, deploy everywhere" concept, thus allowing web applications

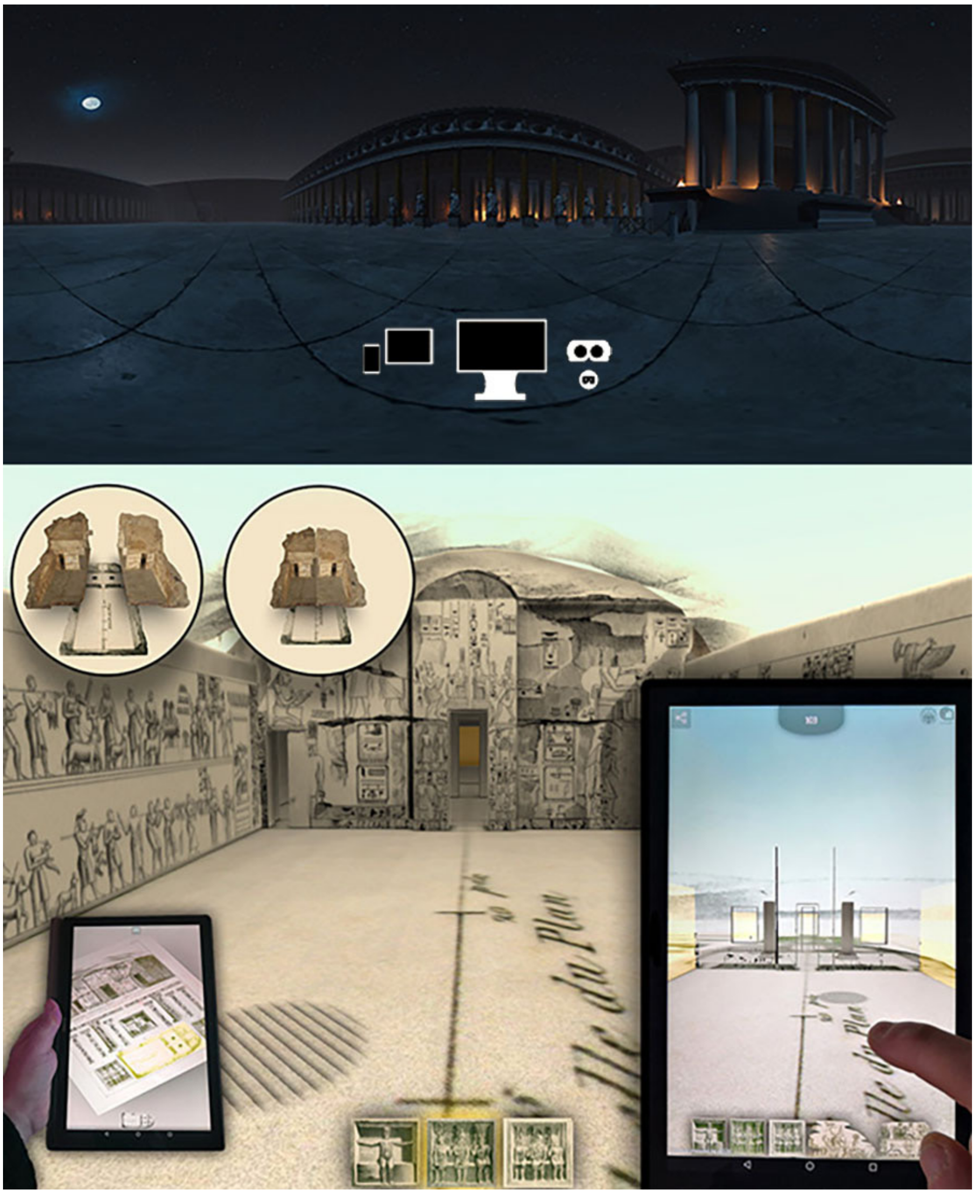


Figure 6.
Samples from past ATON projects with mixed panoramic + 3D content, targeting cross-device consumption (from mobile devices to HMDs)

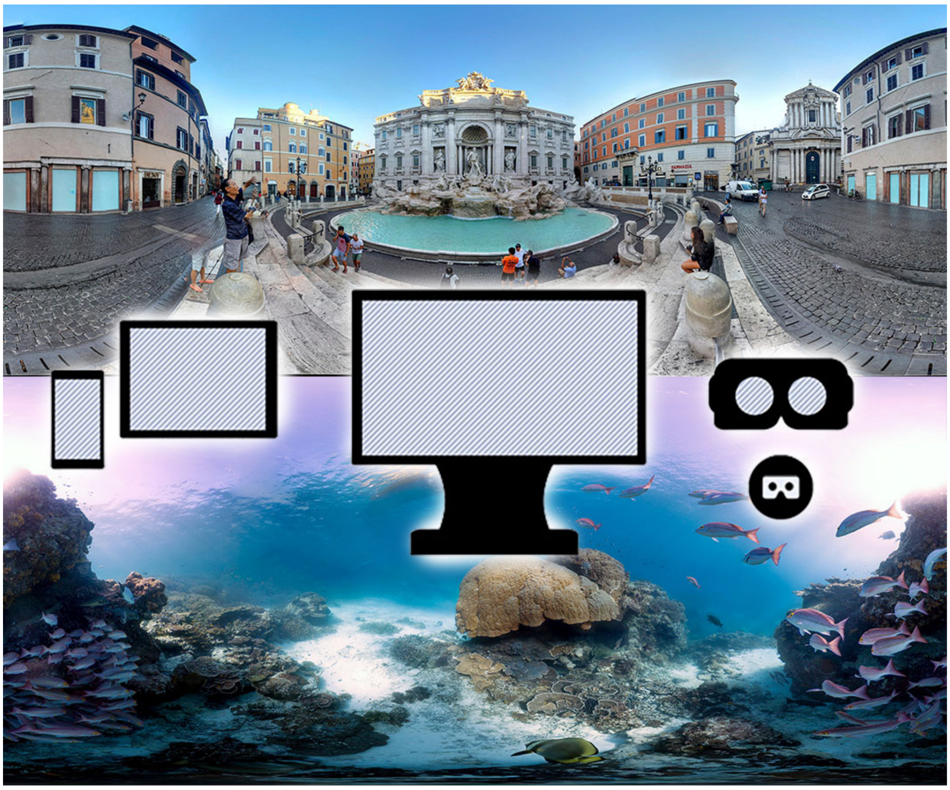


Figure 7.
A serious game 360 natural heritage scenarios (Sea) and a cultural heritage scenarios (Trevi Fountain) which will be accessible from mobile, desktop or HMDs.

to be consumed not only on all consumer HMDs, but also on desktop and mobile devices. For the latter, modern browsers' hardware integrations can be exploited (e.g. device orientation) with both UI and interaction model (selection, locomotion, etc...) automatically adapting to the device. Since the framework is based on three.js library (Sukin, 2013) it offers components and functionalities for developing gamified experiences, including spatialized audio for consistent immersive experiences.
We foresee for the project also fruitful integrations with visual/immersive analytics web-based tools, already employed in past research (Fanini and Cinque, 2020; Fanini, 2020) that would allow us to collect, visualize and remotely analyse spatial data captured during online sessions and how students will perform in the immersive scenarios.

5. CONCLUSIONS

In this paper, a web-based application of an immersive serious game was presented as a suitable solution for addressing the problem of how VR could be applied to distance learning. The positive trend in the development of VR technologies for education offered a fruitful opportunity to merge WebXR-compliant web applications with serious gaming, so that students, independently from their physical location, could profit from significant real-like experiences. This innovation seems particularly relevant for the heritage educational field, in which serious games are used to show and teach about distant or fictitious places, by mimicking them with digital navigable environments. Scientific representation of environments, with an extremely natural rendering, is also considered a

target, and spherical visualization technologies may allow achieving it.
This improvement is currently particularly relevant along with the pandemic scenario of 2020, in which many students are constrained to be at home from school due to health-related prevention. Before this emergency, quite all VR-based educational games and activities were created for common classes. These have become de facto impossible to be accomplished. The adaptation of a previously developed game through the open source WebXR technologies was conceived to overcome the limits imposed by health-related restrictions. As a further advantage, this platform will allow fruition of serious games on any type of platform that can access the web. In the near future, the updated game system will be implemented so that a data collection in the participating schools could show whether the application was successful. Based on expectations about the web-based version of the immersive serious game, we would predict that many schools will appreciate it.
Along with this proposal, the limitations due to the crisis were transformed into an opportunity to spread our serious game throughout national and international schools. Indeed, the technical improvement would make it suitable for every digital device (desktop, mobile, and with HMD as well) and potentially available by everybody everywhere. Moreover, the ease of use allows people with a medium level of computer literacy to access the paths which, in this way, can also be used by teachers or trainers without the support of researchers or external experts.

NOTES

1. A Texel, texture element, or Pixel Texture, is basically the smallest unit relative to a texture map composed of pixels.
2. For example: https://kuula.co/
3. In geometry it is the correspondence obtained by projecting from a point O (centre of projection) a figure F, belonging to a plane S, on a portion of surface S' flat or curved; a figure F' normally deformed with respect to F is obtained.

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AUTHOR CONTRIBUTIONS

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