

A Pipeline for the Implementation of Immersive Experience in Cultural Heritage Sites in Sicily

Roberto Barbera¹, Francesca Condorelli², Giuseppe Di Gregorio², Giuseppe Di Piazza⁵, Mariella Farella^{3,4,5}, Giosué Lo Bosco^{3,5}, Andrey Megvinov⁵, Daniele Pirrone⁵, Daniele Schicchi^{3,5}, and Antonino Zora⁵

¹ Dipartimento di Fisica e Astronomia "Ettore Majorana", Università degli studi di Catania, Piazza Università 2, 95131 Catania

² Dipartimento di Ingegneria Civile e Architettura, Università degli studi di Catania, Piazza Università 2, 95131 Catania

³ Dipartimento di Matematica e Informatica, Università degli Studi di Palermo, Via Archirafi 34, 90123 Palermo, Italy
`daniele.schicchi@unipa.it`

⁴ Consiglio Nazionale delle Ricerche, Istituto per le Tecnologie Didattiche, Via Ugo La Malfa 153, 90146, Palermo, Italy

⁵ Dipartimento SIT, Istituto Euro-Mediterraneo di Scienza e Tecnologia, Via Michele Miraglia 20, 90139 Palermo, Italy

Abstract. Modern digital technologies allow potentially to explore Cultural Heritage sites in immersive virtual environments. This is surely an advantage for the users that can better experiment and understand a specific site, also before a real visit. This specific approach has gained increasing attention during the extreme conditions of the recent COVID-19 pandemic. In this work, we present the processes that lead to the implementation of an immersive app for different kinds of low and high-cost devices, which have been attained in the context of the 3dLab-Sicilia project. 3dLab-Sicilia's main objective is to sponsor the creation, development, and validation of a sustainable infrastructure that interconnects three main Sicilian centers specialized in augmented and virtual reality. The project gives great importance to the cultural heritage, as well as to the tourism related areas. Despite the presentation of the case study of the Santa Maria La Vetere church, the process of the final app implementation guided by the general pipeline here presented is general and can be applied to other cultural heritage sites.

Keywords: virtual reality, cultural heritage, CAVE, headset

1 Introduction

The digital revolution has brought to the development of innovative technologies capable of revolutionizing the engagement of users during the digital experience. Virtual Reality (VR)[1], Augmented Reality (AR)[4] and Mixed Reality (MR)[24] are means to either project a user into a virtual world or to include digital elements into the real world to interact with. AR/VR and MR enable

the user to achieve an *immersive* experience, that is the perception of being part of a non-physical world, fostering the focus on the main activity to carry on avoiding distractions. Research on immersive technologies is ongoing and worthy to be more investigated since they provide fertile ground for supporting several application domains related to culture [11, 22], medicine [2, 3, 13], education [16, 12] and much more.

In particular, Virtual Reality is a human-computer interface that simulates a realistic environment [26]. In the virtual environment, the user can act according to the project specification in a 3D environment. For instance, in the virtual representation of an house, the user may behave like he would do in the real world, for example, by moving around and grabbing objects. The user does not need to use classical input devices like mouse and keyboard for inputting commands, but the interactions with the environment can happen by body-related devices. A VR experience can be joined by several devices. The most common are mobile devices that, if combined with cardboard helmets (e.g. Google Cardboard), can offer a low-cost and widely accessible immersive experience. A better experience can be provided through the VR headsets (e.g. Oculus Quest2) capable of tracking the head and eyes movements, recording voices and output sounds. Generally, VR headsets are equipped with specifically made physical controllers that improve the interactivity with the virtual world.

Finally, the Cave Automatic Virtual Environment (CAVE)[18] is a technology created for providing immersive experiences to people without using headsets. It is a cube-shaped room whose walls act as displays for rear projections. The CAVE creates a virtual environment in which the user can experience immersivity. Often, the user is equipped with special glasses useful for tracking the movements inside the room.

The above-mentioned devices need proper implementations in order to be usable. There are nowadays several possibilities to implement immersive VR applications [25], yet there are two engines that are dominating the development market: Unity3D and Unreal Engine 4. Both of them are used to realize 3D games and are open source solutions. Unity3D was first released in 2005 and nowadays is broadly adopted for AR/VR content and mobile games. This is also motivated by the fact that it is highly multiplatform. Unreal Engine has a long history started in 1998. Most of the biggest Video Game Companies provided their top titles using this engine, but it is not due to superiority concerning others. The platform compatibility of Unreal is reduced compared to Unity. For the specific case the VR development, what is very useful is the possibility to dispose of the so-called assets, i.e. virtual objects that represent a real or imaginary world. Both Unity and Unreal Engine have assets markets, with the first providing 3 times more assets than the latter (30.000 vs 10.000).

The aim of this paper is to present the processes and the results in support of cultural heritage which have been attained in the context of the 3dLab-Sicilia⁶ project. 3dLab-Sicilia's main objective is to sponsor the creation, development, and validation of a sustainable infrastructure that interconnects three main Sicil-

⁶ <https://www.3dlab-sicilia.it>

ian centres specialized in augmented and virtual reality. The project gives great importance to the cultural heritage, as well as to the tourism-related areas. Thus, we made a virtually explorable iconic Sicilian monument: Santa Maria La Vetere church. This church is located in Militello in Val di Catania. It was built by the Normans around 1090, after having taken these lands from the Muslim rule. Destroyed and rebuilt several times over the centuries, in increasingly large and monumental, the last suffered partial destruction due to the earthquake of 1693. The church, stripped of many architectural elements, was adapted to the cult thanks to the plugging of the arches of the only surviving aisle.

The paper is organized as follows: in section 2 are presented some correlated research useful to understand the state-of-the-art and current direction of this research topic; in section 3 is presented the pipeline used to develop VR application in the domain of cultural heritage; in sections 4 and 5 will be discussed the 3D scanning techniques used for the acquisition of cultural assets and then for creating a 3D model; in section 6 will be shown how the model is made accessible through virtual reality devices and CAVE. Finally, conclusions are given.

2 Related works

The literature shows several examples of successful applications of VR systems in support of cultural heritage. According to [7], such applications can be classified on the basis of their purposes. Some of them are specifically developed for *education* aims such as for helping user to learn more about historical details of tangible and eventually non-tangible heritage assets. *Exhibition* enhancement addresses the visitor experience by enriching it with virtual elements (e.g. maps, virtual tour guide). VR has been shown useful also for *exploration* purposes, in which tangible heritage assets are made viewable and manipulable. Often, cultural heritage assets that have existed only in the past are made explorable by VR systems after a *reconstruction* process. Finally, Virtual museums applications aim at proposing the experience of visiting physical museums virtually, including its tangible and intangible assets.

In [23] is presented a gesture-based system created to educate people about the cultural heritage. The system acts as a vehicle to make people capable of interacting by body movements with the virtual representation of tangible and intangible assets. It has been shown capable of improving the engagement of the public in the ancient Maya archaeology context. Authors of [19] present a solution to improve immersivity in a VR context based on mobile devices and exploitable in several applications. Their approach addresses the problem of lacking controls during the usage of such devices mixed with Google cardboard. The solution provides a system based on two smartphones in which one of them is used as a main display, and the second one as a controller for implementing functions such as rotation and scale. In [5], HBIM and VR have been combined to virtually create the Unesco World Heritage site of Lombardy known as *Santa Maria delle Grazie*. Moreover, the paper presents a new methodology for creating intangible parts of monuments that have been lost through time.

In [21], *Villa Ad Gallinas Albas*, ancient Roman villa, has been made accessible by creating a VR application that leveraged on both Unity3D and reconstruction technologies. The application provides a mid-air gestures that the visitor can use to explore the villa. Alongside the mere exploration, it is made possible to enjoy an innovative storytelling approach combining several media, that make the experience instructive. Virtual tours of the historical town centre of Mons in Belgium are proposed in [19]. The description of cultural assets is made by a storytelling approach, in which the user is informed about the historical value of the building is going to be visited. In the same direction, in [15] an historical graveyard (i.e. *Salla World War II graveyard*) placed in a remote area between Russia and Finland is made available to visitors by using VR headsets. The application provides a high quality representation of the site, including the possibility of acting as in the real world such as turning on candles.

To the best of our knowledge, there are few similar works that have supported cultural heritage about Sicily, an island that is well-known rich of tangible and intangible cultural assets. In [9] is proposed a virtual diving system, created for education purposes. It allows the user to explore *Cala Minnola*, an underwater archaeological sites located near Levanzo (Aegadian Islands). With similar purposes, a virtual reconstruction of the archaeological site of Ancient Noto, a city located in the Est part of Sicily is proposed in [6]. The work has been done in the context of the EFIAN project that aims at valorizing the ancient Noto by meeting the principles of the Italian Code for Cultural Heritage and Landscape. In [8], an approach based on high-resolution photo-realistic texture mapping onto 3D models has been exploited for make virtually accessible the temple C of Selinunte, one of the foremost Greek colonies in Sicily.

3 The Pipeline

This section describes the sequence of steps, hereinafter pipeline, that have led to the creation of the immersive scenarios. As shown in figure 1, the first step of the pipeline is the digital acquisition of cultural site through specific 3D scanners. The output obtained from the scanning process is then processed by 3D modeling software to arrange a *point cloud* as a 3D model. To do so, main components such as norms, meshes and textures are computed to compose such a model then stored as *obj* format. The model is imported in Unity3D, that is the software utilized to implement the applications deployed to VR devices – i.e. smartphones in combination with cardboard (section 6.1), Oculus Quest 2 (section 6.2) – and CAVE (section 6.3).

4 Digital acquisition and data-processing

The objects of the surveys described in this paper is a church located in the municipality of Militello in Val di Catania: Santa Maria la Vetere Church. The data acquisition described below has been obtained by different instruments (SFM with terrestrial and drone photos), but we focus in particular about the point

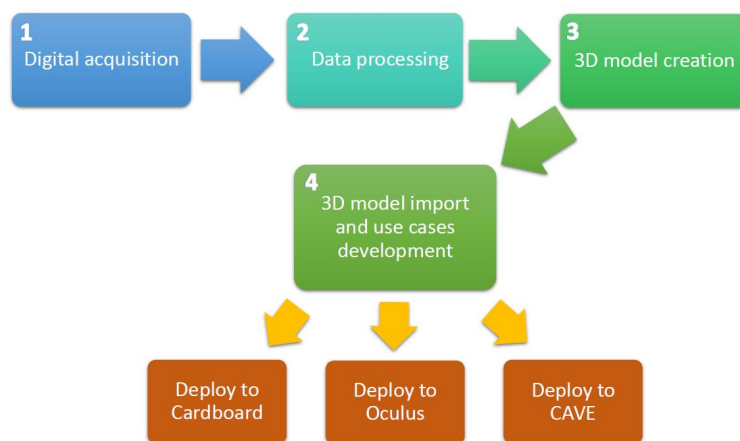


Fig. 1: The proposed Pipeline

clouds created with the Faro Focus 350S laser scanner. The surveys were carried out for this church both outside and inside using white reflective spheres to improve the subsequent orientation and alignment in the joining and registration phase. These spheres were positioned in order to be clearly visible from each station point. In Santa Maria la Vetere Church (figure 2) the external surveys are applied to the remains of the right aisle (the only persisted at south) and of the central portico (open to the west), to the surroundings: the stone churchyard in front of the Church with baptismal font, the pit tombs below the missing aisles and a Norman turret located at north east of the site (figure 3 (a)).



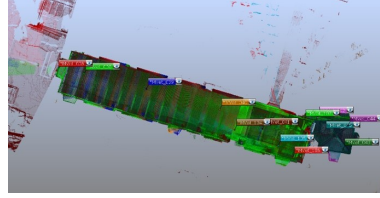
Fig. 2: Santa Maria la Vetere Church - Militello in Val di Catania

The station points for the outside survey are 49 and 9 for the inside; also in this case many of the points has been chosen for the connection between inside and outside and to take care of the connection between the nave and the chapel located behind the altar (figure 3 (b)). The correct alignment of the clouds has

been obtained thanks to the spheres but even by evaluating the homologous points and planes in the different clouds and considering them as constraints.



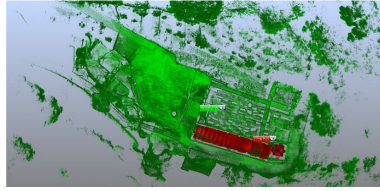
(a) Survey of outside: point of station



(b) Survey of inside: point of station

Fig. 3: Distance between one station point and another

The church has required a quite long processing time to obtain the union and registration of the clouds in a resulting 3D model with very dense points (figure 4). The transition from the cloud (namely from the discrete model) to the mesh (namely the surfaces resting on the points of the cloud) has instead created considerable problems both for the very high number of points and for the size of the files (about 100GB).



(a) Union and registration of point cloud



(b) Overall view of point cloud: Santa Maria la Vetere Church

Fig. 4: Point cloud

5 Models Creation

During the process of creating 3D model for cultural heritage related to religious architecture, the level of detail of the formal elements requires special care. For the Mesh and Texture processing phase, different software were used to then compare the results, including: Faro Scene, Meshlab, Cloud Compare, and Zephyr by 3DFlow. The amount of scans and data does not allow to arrive at an acceptable mesh processing with standard procedures, in which it is possible to

appreciate the details. For the creation of navigable VR models with standalone viewers and with smartphone viewers, the amount of data is an already known criticality, from which studies and researches for the segmentation of clouds have derived, the state of affairs in this sector is still in evolution. There is extensive literature on the subject, by way of example, recent works may be used as a reference [20], but other works have also shown the complexity of the problem [17, 14], most felt for religious architecture. The visual experience linked to the quality of details in virtual reality, therefore conflicts with the amount of data. Automatic procedures do not solve the problem of the different concentration of points in the areas with more details. The problems described have manifested themselves in different ways, both in the case of use illustrated and in others of the same project. In relation to the model of the Church of Santa Maria La Vetere (figure 5), among the detailed scale elements of considerable visual impact there are: the altar, the two internal portals and the external porch with low reliefs. The first overall elaborations of the mesh process gave a low quality visual result where it was not possible to appreciate the detail of the formal elements (figure 6).

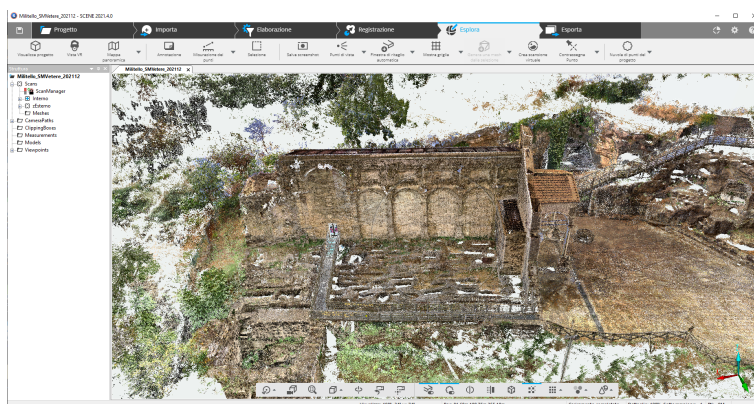


Fig. 5: Santa Maria La Vetere Church, union of the clouds in the area in the ruins of the aisles that collapsed in 1693

Then the point clouds of the various internal parts of the church have been disassembled into their constituent elements: the altar (figure 7), the two portals separately, the floor, the ceiling, the walls, the space behind the altar, the cross vault behind the altar. Different processing modes and different software for creating meshes were followed, the two results that provided better visual quality saw the use of Meshlab and the mixed one of Faro Scene and Meshlab. The pipeline with Meshlab had the following steps: importing the cloud of Scene software into Meshlab, simplification through decimation algorithms, normal calculation, mesh calculation. The processing with Faro Scene combined with Meshlab was handled as follows: the processing of the mesh of the individ-

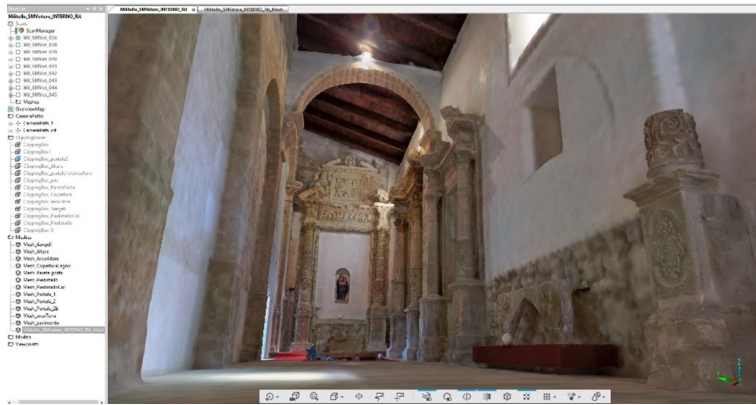


Fig. 6: Santa Maria La Vetere Church, mesh elaboration of the surviving aisle

ual elements through Faro Scene, then the point cloud from the laser scanner was imported into MeshLab and simplified through decimation procedures, the individual meshes, previously processed with Scenes, have been relocated to the cloud previously loaded in MeshLab. An overall model has been defined with a differentiated detail for the various formal elements. The external model acquired by laser scanner was then combined with the photogrammetric model of the aerial shots of the drone.



Fig. 7: The church of Santa Maria La Vetere, the individual elaborations of the altar, the arch and the portals

6 Use case development

After the creation of the 3D model as described in section 4, we proceeded to implement the applications for Virtual Reality devices and the CAVE. The application have been developed by exploiting *Unity*, a game engine cross-platform that enables the development of VR applications by providing effective tools and a handy visual development environment. The application behavior can be defined programmatically by using *C#* programming language.

Below, we will discuss the development phases that have led to the creation of an application, compatible with Smartphone combined with Cardboard, Oculus Quest2 and CAVE (figure 8), that allows the user to visit Santa Maria la Vetere church.

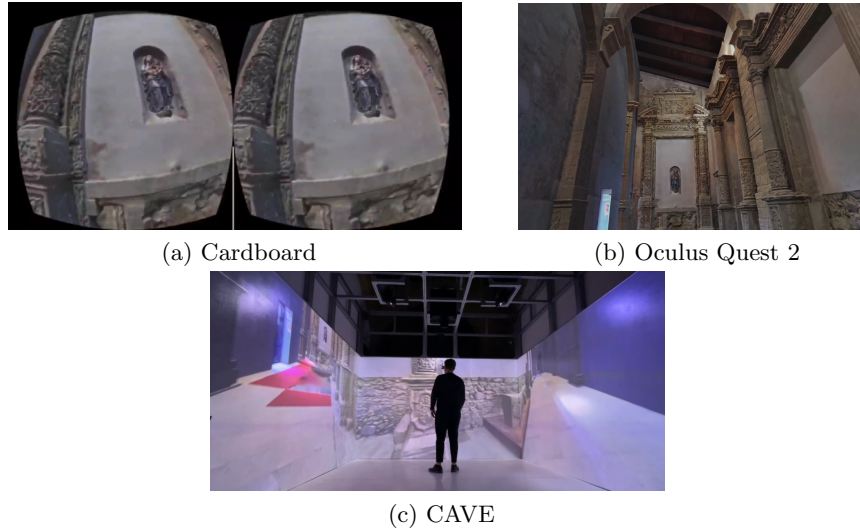


Fig. 8: VR Systems

6.1 Smartphone with Cardboard

The application development addressing smartphones has leveraged Unity version 2020.3.x alongside plugins to simplify the whole process. In particular, XR-Plugin Management and Cardboard XR Plugin have been used.

XRPlugin Management was used to manage, load and initialize Extended Reality (XR) plugins useful for developing VR/AR and MR systems. The second plugin, Cardboard XR Plugin, has allowed us the management and the creation of a stereoscopic VR system for Google Cardboard. It supports base VR features like motion tracking and stereoscopic rendering simplifying the creation of the user interface. To allow the user movements within the virtual environment,

“trigger points” have been implemented. Trigger points are located in several different place in the environment. They are utilized as means for teleporting the user towards a different area of the environment. Therefore, if the user looks at one of the trigger points (e.g. a floor’s point) for a specific interval of time, the user’s position will be set-up nearby such a point.

In terms of optimization, various elements have been considered. Lights have been pre-compiled and shadows have been managed in such a way to make possible running the application even for smartphones with limited computational resource, that otherwise, would not be capable of providing a fluid experience. Regarding the computational complexity of the system, it depends the texture resolution. The correct resolution choice provides an optimal model navigation including a good detail level. In fact, providing a high level experience avoid the user to run into VR sickness or Cybersickness [10], that is the sensations of lightheadedness, disorientation or sickness caused by the delay in latency⁷. This delay can produce a dissonance between body movements and actions in virtual environment, generating a sense of disorientation.

6.2 Oculus Quest2

To develop VR application for VR headsets, in particular for Oculus Quest2, Unity3D provides several useful plugins. We used *Oculus XR Plugin* to include motion control functions; *XR Interaction Toolkit* to manage the user interface since it implements several functions such as hover and selection of objects in the virtual environment; and *XRPlugin Management* that was used for the creation and management of the XR plugin.

The above plugins help to control the player’s movements within the environment and manage the interactions with other objects. As for the development of VR systems on smartphones, the set of optimizations related to 3D models and the virtual system has considered. Such a process allows the user of experiencing an optimal navigation by Oculus devices (see section 6.1).

6.3 CAVE

For what concerns the VR application for the CAVE, the use case was designed for a 3-wall CAVE composed of a front wall, a left side wall, and a right side wall. Leveraging on Unity3D 2019.4.x version, the *Mirror* library was used to implement the communication among the CAVE’s walls through the network. This library serves for managing and synchronizing two workstations. The first workstation is dedicated to manage the front wall and the second one manages the two side walls. The network components make possible to synchronize the player’s position and the virtual objects in the CAVE.

For the real-time management of the controllers and the user position in the

⁷ the time gap between the moment in which the command input is sent to the system and the moment in which it is outputted.

CAVE, the *UVRPN* plugin (VRPN wrapper for Unity3D⁸) has been used. It simplifies the management of the tracking data sent by the worn devices and acquired through the VRPN technology. Thus, the user can move around, and in real-time the virtual environment can be arranged in respect of the user actions. Regarding the optimization of the models, the use of dedicated hardware has made possible to choose a higher 3d-model texture resolutions if compared to the ones of the previous systems (section 6.1 and section 6.2). Moreover, both lights and shadows rendering are computed in real time.

7 Conclusions

The pipeline here presented has been used for the development of the virtual exploration of the Santa Maria La Vetere church. The Oculus Quest headset gives the most immersive effect, due to the specific nature of the device because the viewer hides the real-world perception. In terms of resolution, the Cave implementation is the best, but with quite low immersivity with respect to the headset. The cardboard version is the worse in terms of resolution and interactions capabilities, despite representing a very efficient low-cost alternative. Following the presented approach we are working on the implementation of new apps related to new sites, making more evident the generality of the pipeline process.

Acknowledgements

The following paper has been supported by the project “Creazione di una rete regionale per l'erogazione di servizi innovativi basati su tecnologie avanzate di visualizzazione” (3DLab-Sicilia), Grant No. 08CT4669990220, funded by Operational Program 2014–2020 of the European Regional Development Fund (ERDF) of the Sicilian Region.

References

1. Anthes, C., García-Hernández, R.J., Wiedemann, M., Kranzlmüller, D.: State of the art of virtual reality technology. In: 2016 IEEE Aerospace Conference, IEEE (2016) 1–19
2. Argo, A., Arrigo, M., Bucchieri, F., Cappello, F., Di Paola, F., Farella, M., Fucarino, A., Lanzarone, A., Bosco, G.L., Saguto, D., et al.: Augmented reality gamification for human anatomy. In: International Conference on Games and Learning Alliance, Springer (2018) 409–413
3. Arrigo, M., Cappello, F., Di Paola, F., Farella, M., Lo Bosco, G., Saguto, D., Sannasardo, F.: Heart mobile learning. In: 10th annual International Conference on Education and New Learning Technologies, EDULEARN 18, IATED Academy (2018) 10899–10905
4. Azuma, R.T.: A survey of augmented reality. *Presence: teleoperators & virtual environments* **6**(4) (1997) 355–385

⁸ <https://github.com/hendrik-schulte/UVRPN>

5. Banfi, F., Bolognesi, C.: Virtual reality for cultural heritage: New levels of computer-generated simulation of a unesco world heritage site. In: *From Building Information Modelling to Mixed Reality*. Springer (2021) 47–64
6. Barone, Z., Nuccio, G.: For a conscious fruition of the cultural heritage of ancient noto (sicily). efan project as opportunity for valorisation. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences* **42** (2017)
7. Bekele, M.K., Pierdicca, R., Frontoni, E., Malinverni, E.S., Gain, J.: A survey of augmented, virtual, and mixed reality for cultural heritage. *J. Comput. Cult. Herit.* **11**(2) (mar 2018)
8. Beraldin, J.A., Picard, M., El-Hakim, S.F., Godin, G., Paquet, E., Peters, S., Rioux, M., Valzano, V., Bandiera, A.: Virtual heritage: the cases of the byzantine cript of santa cristina and temple c of selinunte. *Virtual Heritage: the cases of the Byzantine Cript of Santa Cristina and Temple C of Selinunte* (2004)
9. Bruno, F., Lagudi, A., Barbieri, L., Muzzupappa, M., Mangeruga, M., Cozza, M., Cozza, A., Ritacco, G., Peluso, R.: Virtual reality technologies for the exploitation of underwater cultural heritage. *Latest Developments in Reality-Based 3D Surveying and Modelling*; Remondino, F., Georgopoulos, A., González-Aguilera, D., Agrafiotis, P., Eds (2018) 220–236
10. Chang, E., Kim, H.T., Yoo, B.: Virtual reality sickness: a review of causes and measurements. *International Journal of Human–Computer Interaction* **36**(17) (2020) 1658–1682
11. Donghui, C., Guanfa, L., Wensheng, Z., Qiyuan, L., Shuping, B., Xiaokang, L.: Virtual reality technology applied in digitalization of cultural heritage. *Cluster Computing* **22**(4) (2019) 10063–10074
12. Farella, M., Arrigo, M., Taibi, D., Todaro, G., Chiazzese, G., Fulantelli, G.: Arlectio: An augmented reality platform to support teachers in producing educational resources. In: *CSEDU* (2). (2020) 469–475
13. Goo, H.W., Park, S.J., Yoo, S.J.: Advanced medical use of three-dimensional imaging in congenital heart disease: augmented reality, mixed reality, virtual reality, and three-dimensional printing. *Korean journal of radiology* **21**(2) (2020) 133–145
14. Griffiths, D., Boehm, J.: A review on deep learning techniques for 3d sensed data classification. *Remote Sensing* **11**(12) (2019) 1499
15. Häkkinen, J., Hannula, P., Lühr, E., Launne, E., Mustonen, S., Westerlund, T., Colley, A.: Visiting a virtual graveyard: Designing virtual reality cultural heritage experiences. In: *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia*. MUM '19, New York, NY, USA, Association for Computing Machinery (2019)
16. Maas, M.J., Hughes, J.M.: Virtual, augmented and mixed reality in k–12 education: A review of the literature. *Technology, Pedagogy and Education* **29**(2) (2020) 231–249
17. Matrone, F., Lingua, A.: Tecniche di deep learning per la segmentazione semantica di nuvole di punti del patrimonio architettonico
18. Muhanna, M.A.: Virtual reality and the cave: Taxonomy, interaction challenges and research directions. *Journal of King Saud University-Computer and Information Sciences* **27**(3) (2015) 344–361
19. Papaefthymiou, M., Plelis, K., Mavromatis, D., Papagiannakis, G.: Mobile virtual reality featuring a six degrees of freedom interaction paradigm in a virtual museum application. *Institute of Computer Science* (December) (2015)
20. Pierdicca, R., Paolanti, M., Matrone, F., Martini, M., Morbidoni, C., Malinverni, E.S., Frontoni, E., Lingua, A.M.: Point cloud semantic segmentation using a deep learning framework for cultural heritage. *Remote Sensing* **12**(6) (2020) 1005

21. Pietroni, E., Forlani, M., Rufa, C.: Livia's villa reloaded: An example of re-use and update of a pre-existing virtual museum, following a novel approach in storytelling inside virtual reality environments. In: 2015 Digital Heritage. Volume 2., IEEE (2015) 511–518
22. Plecher, D.A., Wandinger, M., Klinker, G.: Mixed reality for cultural heritage. In: 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), IEEE (2019) 1618–1622
23. Richards-Rissetto, H., Robertsson, J., von Schwerin, J., Agugiaro, G., Remondino, F., Girardi, G.: Geospatial virtual heritage: a gesture-based 3d gis to engage the public with ancient maya archaeology. In: Archaeology in the Digital Era. Amsterdam University Press (2014) 118–130
24. Speicher, M., Hall, B.D., Nebeling, M.: What is mixed reality? In: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems. (2019) 1–15
25. Voštinár, P., Horváthová, D., Mitter, M., Bako, M.: The look at the various uses of vr. *Open Computer Science* **11**(1) (2021) 241–250
26. Zheng, J., Chan, K., Gibson, I.: Virtual reality. *IEEE Potentials* **17**(2) (1998) 20–23