3DLAB SICILIA and UNESCO-VR. Models for Cultural Heritage

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Abstract

In the forecasts of 2019, the trend of the VR AR MR and AI sector was growing strongly; due to the pandemic events, real growth in the following two years has largely exceeded expectations. The possibility of interacting remotely by VR AR and MR modes during the pandemic was one of the solutions that made possible to overcome distances and barriers. As part of the *3DLAB Sicily* project financed by the Sicily region and aimed at enhancing the resources of the cultural heritage of the territory, the Department of Civil Engineering and Architecture of the University of Catania (DICAR) participates in developing VR, AR, MR by a research team pertaining to the disciplines of design and representation, for the study of some UNESCO sites. The acquisitions of the models have been started using active and passive sensors for various cultural heritage; the case studies range from protohistoric archeology to medieval military architecture to the Baroque of the Val di Noto. The aim of the project is the creation of 3D navigable models for VR and AR viewers, or for two and three-walled VR caves that have been built as part of the same project. Below are the procedures, considerations and evaluations for the first results obtained.

Keywords
VR, AR, 3D survey, archeological storytelling, 3D modeling.

doi.org/10.3280/oa-845-c213

Introduction

In a historical moment of transition between material and immaterial, some reflections spontaneously arise, already raised by Tomas Maldonado [1] who mentions Kastler when he reminds us that, at the level of our senses, we are used to recognizing two key features in what we call objects: permanence and individuality [Maldonado 2015]. Recognition gives to the person certainties and confirmations. It remains to be understood why today is a widespread, and increasingly obsessive, craving for evanescent worlds, a feverish desire to project oneself, at least illusively, into the rarefied world of non-things [Maldonado 2015]. Several statements of Italo Calvino proposed in his invisible cities can be shared, when in the book-presentation he states that in invisible cities there are no recognizable cities [Calvino 2018], and later in chapter V: "Now I will tell how Octavia, the spider-web city, is made. There is a precipice between two steep mountains: the city is over the void, bound to the two crests with ropes and chains and catwalks. This is the foundation of the city: a net which serves as passage and as support. All the rest, instead of rising up, is hung below" [Calvino 2018], almost seems like a description of the fantastic scenario of a video game. The question therefore arises as to whether there is a search for science fiction or utopia. Utopia turns to a desirable or undesirable a possible-impossible, science fiction instead tells a desirable possible-impossible, and that's it [Maldonado 2015].
There remains the doubt to understand if there is a fascination for fantastic, utopian or real scenarios. On this issue, the evolution of film scenography has shown us a trend of screenplays that combine the three previous instances: scenarios that start from real places, or close to possible realities with fantastic or utopian insertions. But the real with insertions of any kind must be credible, so in the search for the "immersivity" of recognizable virtual places, the correspondence to the real takes on undeniable importance. In this sense, the geometric relationships, proportions, quality and detail take on an indispensable meaning. The part of the research that is shown focuses on transversal skills linked to representation in its connection with 3D modeling, to the survey of spaces that belonged to the past, looking for a usable quality result through the comparison between different mesh and texture elaborations, for of immersive peripherals. The three-dimensional spaces must be characterized by a correct proportion between the objects used to compose the scene, by a geometric but also historical reliability of the elements and by a recognisability of navigable places [Attademo 2021]. The definition of the detail can take on importance and meaning.
"Kublai Khan remains silent, reflecting. Then he adds: Why do you speak to me of the stones? It is only the arch that matters to me. Polo answers: Without stones there is no arch" [Calvino 2018].

Fig. 1. Cloud of points of Santa Maria la Vetere Church.

Fig. 2. Cloud of points of portic: Santa Maria la Vetere Church.

The 3DLAB Project – Sicily

Within the *3DLAB SICILY* project, the UNESCO VR work package deals with the development of VR and AR models of the cultural heritage (some of which are registered by UNESCO) of four municipalities that are partners in the project. The dataset of the use cases of the 3DLAB project crosses archaeological sites from different historical periods. We start from the Protohistoric period with the necropolis of Pantalica (SR) then we work on the Byzantine period with the military architectures including the Manfredonic Castle of Mussomeli (CL) and with the Castle of Vizzini (CT), that are also examples of religious architecture that have been strongly modified during a millennium. Then we focused on Cunziria, an example of industrial archeology of the eighteenth century, that was also a scenario for the famous novel *Cavalleria Rusticana* by Giovanni Verga and for the same theatrical transposition by Pietro Mascagni. The cultural contents of the use cases are very varied, representing topics for the development of augmented reality.

The Procedures

The data acquisition to develop the three-dimensional models has been carried out by 3D laser scanners, multi-image photogrammetry (SFM) with a full-frame digital camera, an Autel Evo Pro 2 drone, and a 3D Matterport Pro2 structured light camera.
The objectives of VR and AR were aimed at a uniform visual quality, where the differences of scales conjugated to the details, did not always allow to use a common workflow. Having already acquired scans with active sensors on a wide range of cases, we have focused on creating quality uniform 3D models, defined by meshes and textures. One of the major criticality has connected to the macro-clouds coming from different instruments: lidar, photographic cameras, drone and matterport. Also the big amount of data represent a criticality, because it is needed to balance quality of details with the easy "usability" of the model. The outputs of the project have two purposes: the first, based on lighter or simplified data, is the creation of VR and AI models starting from 3D models, the second, based on very detailed data, is intended to support research. Scanning data acquired for clouds combine the two paths although contents for research requires more detailed point clouds, as opposed to 3D models for VR and AI headsets. It is necessary to proceed with segmentations or decimations of the acquired data, continuously verifying the degree of visual definition in an iterative process. It should also be noted that some of the used software, during the merging phase of different models, in case of overcoming certain dimensions, automatically proceed to decimate the clouds, acting uniformly on the entire dataset of the cloud. This method cannot be accepted for archaeological models where even a single detail in the rock or stone element can have a particular value.

Also in the other cases analyzed, this procedure has limitations. The core of 3D modeling is the acquisition by 3D laser scanners, completed with SFM drone models for roofs and territory, and with digital terrestrial photos for mesh processing. Terrestrial laser scans were performed using reflective spheres with an overall average maximum error below 20 mm for models within 50 m. The models from the drone photos were set using a GPS-based flight plan, so the multi-image photogrammetric union (SFM) always provided accurate results. The SFM models from terrestrial photos have required continuous experimentation to arrive at a quality result. The next step was the union of the SFM terrestrial model with the drone model. Coming from different elaborations, the criticalities were represented by the search for a common software environment in which results from different file formats were manageable, without losing significant information such as color. The problem is well known: for example, the application Scene (Faro) allows excellent management of clouds both in quality and quantity but does not allow to combine and process clouds from other instruments. On the other hand, filters are automatically executed during exports operations, causing loss of characteristics and of quality of clouds. The right compromise was found in two software: Zephyr and Metashape. For the creation of VR models for standalone and smartphone viewers, the amount of data is an already known criticality, from which studies and researches for the segmentation of clouds have derived, that are still in evolution. There is a wide range of literature on the subject, with a wide range of typological cases in archeology and historical architecture. The recent works are always valid as a reference: *Semantic segmentation of the point cloud using a deep learning framework for cultural heritage* [Pierdicca et al. 2020], but other works have also shown the complexity of the problem [2], that is more important for very detailed architectures such as religious.
The visual result linked to the quality of the 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 [3]. The problem for the CAVE is different.

Fig. 3. Cloud of points of Santissimo Crocifisso Calvario Church.

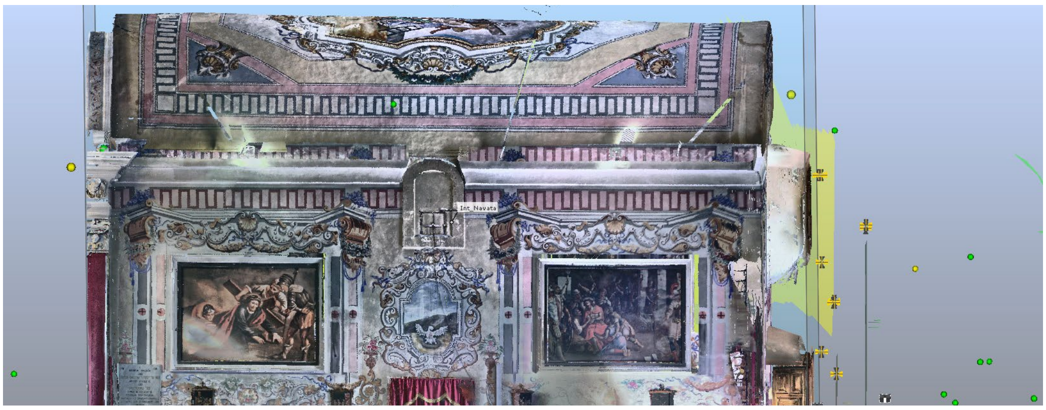

Fig. 4. Cloud of points of the inside: S. Crocifisso Calvario Church.

Because there is not an unique and simple solution for each model, we analyze single samples, proceeding by parts, separating the constituent elements of the various architectures and evaluating the results. The following elements were therefore identified: wall surfaces, vaulted surfaces, arches, portals, columns, etc. Then, we proceeded with the decimation and subsequent processing of 3D models of individual elements using the most popular software for mesh and texture, and then reassembling a single model as a sum of the individual processing.

Data acquisition by active and passive sensors:
- LiDAR system – Faro Focus S plus 350 3D laser scanner
- 3D structured light scanner system – Matterport
- Multi-image photogrammetry (SFM) – Canon EOS Mark III Full Frame Digital Camera
- Drone – Autel

The post-processing and merging phase of the clouds by:
- FARO SCENE software for point clouds
- Matterport Cloud for Matterport camera acquisitions
- Zephyr from 3Dflow and Metashape from Agisoft for SFM models

The Mesh and Texture phase:
- SW FARO SCENE for the union
- SW Meshlab for meshes
- SW Cloud Compare for meshes
- SW Zephyr – mesh and texture

Critical issues:
Using automatic software procedures does not allow to obtain an acceptable mesh and texture processing, in which it is possible to appreciate the high level of surveyed details stored in the data:
- rock sites have irregularities due to the roughness of the walls that cannot be managed with an overall elaboration;
- military and religious architectures present a very large amount of data that cannot be managed as a unit:
- the castle of Mussomeli: 105 scans for the internal courtyard and the covered areas;
- the castle of Vizzini – once Bourbon prison, 95 scans;
- the church of Santa Maria La Vetere 9 internal scans, 33 external;
- the church of the Crucifix of Calvary 12 external scans, 8 internal.

For the church of the Crucifix of Calvary the E57 file processed with the texture has a size of 13 Gb, for the church of Santa Maria La Vetere the number of polygons have been reduced, obtaining a size of 2 Gb. Currently we are looking for an optimal solution between the visual quality of the models and the fluidity of the scene, evaluating different options, including loading only one environment at a time. In parallel, the results of Matterport Pro2 are being evaluated, which involves a size of 30 Mb for each station.

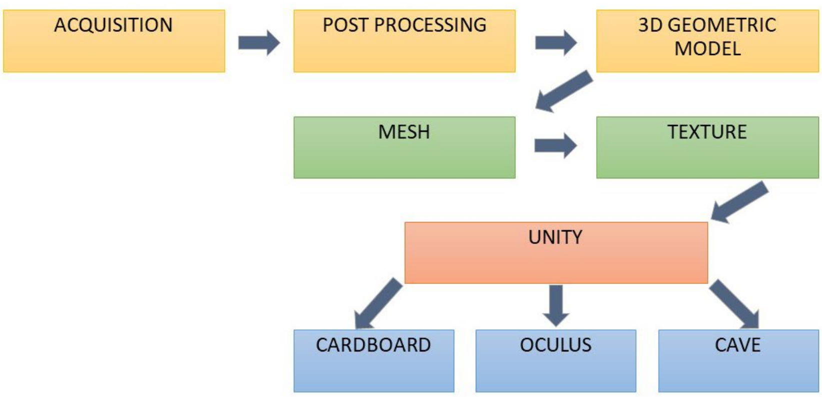

Fig. 5. Pipeline.

Immersive Models

After the creation of the 3D model, the result was verified using the applications for the Virtual Reality devices and the VR CAVE. The most used software are Unity3D and Unreal Engine 4. It should be noted that to develop VR, the software Unity3D allows a better interaction to manage the "assets", that are virtual objects representing a real or imaginary world. The compatibility of the Unreal Engine's platform is limited compared to Unity3D, so we preferred to use it: no wonder that Unity has a market 3 times higher than Unreal Engine (30,000 vs 10,000). We will show below the development phases that led to the creation of an application, compatible with Smartphones (combined with Cardboard), with Oculus Quest2 and with VR-CAVE, which allow the user to visit the object of the application.

Smartphone with Cardboard

For the development of applications aimed at smartphones, the software Unity3D 2020.3.x version was used together with some plugins needed to simplify the whole process: XR-Plugin Management and Cardboard XR. The first was used to manage, load and initialize the extended reality. The second plugin, Cardboard XR Plugin, allows the management and creation of a stereoscopic VR system for Google Cardboard. It supports basic VR features like motion tracking and stereoscopic rendering which make it easy to create the user interface. The difference in scale between the confined environment of the VR-CAVE and the reproduction of the real environment, as well as movements of users within the virtual environment, has been managed by the implementation of "trigger points". The triggers are placed in different points in the VR space and are used to teleport users to different areas. If the user looks at one of the trigger points (for example a point on the floor) for a preset time interval, the user's position will be translated near to that point.
The optimization of the different elements involved in the immersive experience was managed. Lights have been pre-calculated and shadows have been managed in order to make it possible to use the application even by smartphones with limited computational capabilities, allowing a fluid experience. About the computational complexity of the system, it is known that it depends by the resolution of textures. Choosing the correct resolution provides optimal and fluid navigation of the model, but it is needed also to maintain a realistic visual experience thanks to a good level of detail. Providing a high-level experience prevents users from VR sickness or Cybersickness, that are the sensations of dizziness, disorientation or malaise caused by the delay in latency. This delay can produce a dissonance between body

Fig. 6. Application for Oculus.

movements and actions in the virtual environment, generating a sense of disorientation. More generally, a conflict between the signals transmitted by the different sensory systems and their inconsistency with respect to the central nervous system creates perceptual difficulties: therefore the quality of the model is undeniable.

Oculus Quest2

To develop VR applications for headsets, such as the Oculus Quest2, Unity3D provides several plugins. The Oculus XR plug-in was used to include motion control functions; XR Interaction Toolkit for user interface management and XRPlugin Management was used to create and manage the XR plugin. These plugins help to control the user's movements within the VR environment and manage interactions with other objects.

CAVE

The development of the VR application for the CAVE was organized for a 3-wall CAVE, consisting of a front wall, and two side walls. Taking advantage of the Unity3D 2019.4.x version, the Mirror library was used for the management and synchronization of two workstations. The first workstation is dedicated to managing the front wall, while the second manages the other two. The network components allow to synchronize the player's position and the virtual objects in the CAVE. The UVRPN plug-in was used to manage the controls and the user's position in the CAVE in real time. This simplifies the management of tracking data sent from weared devices and acquired by VRPN technology. Therefore, the user can move around, while the virtual environment can be processed and organized in real time, in compliance with the actions traced. About the optimization of models, using dedicated hardware allows to choose higher resolution of the texture of the 3D model than the resolution used for Oculus and Smartphones. In this case, the rendering of lights and shadows is calculated in real time [4].

Conclusion

The 3DLab-Sicilia project funded by the region aims to create a regional network for the provision of innovative services based on advanced visualization technologies through virtual reality for archaeological sites and museums. The results in progress are visible on the project

Fig. 7. VR CAVE

website [5]. This article gives the results obtained in the first year of activity for two churches. The pipeline presented here was used for the development of the VR models of the church of Santa Maria La Vetere and of Calvario located in the municipality of Militello val di Catania (CT). Three software environment (for smartphones, oculus quest 2, VR Cave) has been used, in order to guarantee full access to every kind of users, but with different qualities in terms of results. Among these, the oculus quest 2 viewer constitutes the right compromise and offers the most engaging effect, due to the specific nature of the device. The VR Cave represents the optimal result, but remains confined to the location of the Cave. The Card\ board for smartphones is an efficient alternative at low cost but with a lower quality. The 3DLAB project still in progress, based on the development of continuously and rapidly expanding technologies, aims to optimize results for future applications.

Acknowledgements

This work, equipment illustrated were 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 Opera-tional Program 2014-2020 of the European Regional Development Fund (ERDF) of the Sicilian Region.

Notes

[1] Maldonado Tomas (2015). *Reale* e *Virtuale*. Milano: Feltrinelli.

[2] Matrone Francesca, Lingua Andrea Maria (2021). *Tecniche di deep learning per la segmentazione semantica di nuvole di punti del patrimonio architettonico*.

[3] Griffiths David, Boehm Jan (2019). *Una rassegna sulle tecniche di deep learning per la classificazione dei dati rilevati in 3D*.

[4] Barbera Roberto, Condorelli Francesca, Di Gregorio Giuseppe, Di Piazza Giuseppe, Farella Mariella, Lo Bosco Giosuè, Megvinov Andrey, Pirrone Daniele, Schicchi Daniele, Zora Antonino (2022). A Pipeline for the Implementation of Immersive Experience in Cultural Heritage Sites in Sicily.

[5] The works in progress of the 3Dlab-Sicily project are available on the website: https://www.3dlab-sicilia.it/it_it/

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