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BEING A SPECTATOR IN A ROMAN THEATRE: A VR APP

1. Archaeology, auralisation, and digital applications

In the last years, studies and digital applications involving both archaeology and auralisation have increased but they are still uncommon, above all in the archaeological field. Here, our interest is to summarize a few of these works to discuss the success of such a combination, but also to highlight what can be done more to fully take advantage of this interdisciplinary approach.

The auralisation consists of the convolution of an anechoic file with an impulse response recorded in a specific position of a given space by a receiver. The result of the auralisation is an audio file that sounds as if it would be physically recorded in the specific space at the specific spot where the receiver recorded the impulse response. Thanks to 3D modelling and virtual acoustics, it is possible to obtain auralised files also of not preserved, or partially preserved, sites. In addition, the recreated sounds can be integrated with visual reconstructions and other information through virtual reality and augmented reality.

The project Archeoechi has been carried out by a team of scholars specialised in several disciplines (archaeologists, acousticians, actors and 3D experts), by the collaboration of the Department of Humanities of the University of Foggia and the AudioLab of the University of York. The project sees the development of a virtual reality application that offers an immersive experience within a Medieval cathedral in Southern Italy (Montecorvino, Puglia). The result is a fascinating educational instrument through which users, employing the head-mounted display Oculus Go, can explore the 3D reconstruction (which is based on information obtained from archaeological excavations and by analogies) of the cathedral not fully preserved. Users can interact with it, read descriptive panels and listening to a couple of auralised files as if they were at the centre of the church, back in the Middle Ages. One of the authors of the project stresses as the educational impact is higher when immersive applications take into account audio as well (Grazioli 2020).

A different digital application, for touristic promotion, has been developed by the University of Split (Croatia). It consists of a mobile audio augmented reality tool for soundscape auralisation of ancient archaeological sites, called Soundscaper. Different kind of auralised audios have been tested along Split's promenade to realize the correct audio augmented system by the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture (Sikora, Đana, Russo 2016). Subsequently, the developed system has been used and tested within an archaeological site whose soundscape was recreated.

A group of students visited the archaeological site of Crkvina (9th c. basilica dedicated to St. Mary and St. Stephen), accompanied by the audio augmented reality equipment that simulates sounds that, hypothetically, populated the site at Medieval times. Through a qualitative and subjective questionnaire, the scholars have demonstrated that it is preferable an augmented audio experience while visiting archaeological sites (Sikora *et al.* 2018). Despite the tool developed is probably a very good and user-friendly instrument to attract visitors, the archaeological aspect is a bit neglected. The experience of the visitors would be culturally enriched if there would be a historical study of the many possible medieval sounds of the specific landscape. Moreover, to deliver something realistic, the auralised sound should be listened to in a reconstructed environment, as similar as possible to the original aspect of the site. This audio augmented reality tool would be much more valuable if it would not limit itself only to a walk with pleasant background sound. Hopefully, archaeologists will take the best from it.

Another project which involves sounds related to a religious archaeological site is the Virtual Paul's Cross Project. The multidisciplinary team aimed to produce a digital re-creation of John Donne's gunpowder day sermon, that occurred on 5th November 1622, to investigate the acoustic phenomena and the communicative power in the area of St. Paul's Cathedral in London, in the early modern age. This work is very well structured and has produced fascinating results. The area surrounding the cathedral has been virtually reconstructed with great accuracy, on the base of several old images as paintings and drawings. At the same time, the speech of John Donne and the entire soundfield (crowd murmur, church's bells, dog barking, birds twitters, horses) has been auralised (Azevedo, Markham, Wall 2013). On the website where the full project is presented (https://vpcp.chass.ncsu.edu/), the user can choose 8 different positions within the churchyard from which to see the reconstructed surrounding area of the church and listen to the sermon accompanied by different soundscapes.

One of the archaeological sites that is quite intriguing from an acoustics perspective is Stonehenge. Many scholars still wonder which was the function of such site: the most widespread hypothesis is that it would have been employed for ritual and ceremonial purposes, therefore the interest to study and reconstruct the soundfield a Neolithic man used to listen to (Fazenda 2013; Fazenda, Drumm 2013). The last acoustic researches about Stonehenge took advantage of 3D modelling and the real reconstruction of the site at Maryhill (Washington, USA) since it is not completely preserved nowadays. The approach to the study of the acoustics of Stonehenge and its auralisation is more advanced than simply knowing the acoustics characteristic of the place or experiencing a ceremony at Neolithic time. In this case, scholars think to acoustics and auralisation as instruments for archaeological interpretations

and to raise new questions: was the circles of stones build to valorise the acoustic aspect of the rituals? What kind of knowledge the Neolithic man had about acoustic phenomena?

The auralised files are contained in the interactive Soundgate app (http://www.emaproject.eu/content/soundgate-app.html). It shows the hypothetical reconstructions of the site at different times and it allows to listen to the auralised sound of an ancient bird bone flute which was found nearby. The night visualization of the reconstruction of Stonehenge is accompanied by the sound produced by different birds, owl, nightingale and corncrake.

This is only a short list of digital applications related to both auralisation and archaeology, but there are not many more, unfortunately.

Even by this short list, a couple of characteristics are evident: the auralisation in archaeology is chiefly used to offer experiences; the most popular sites for auralisation are churches (among the cited ones, we can mention also Agia Sophia in Istanbul (Pentcheva, Abel 2017) and San Vitale in Ravenna (Knight, Tronchin 2020), in the context of the contemporary pandemic known as the plague of Justinian. The ordered sequence of reverberant aural encounters at San Vitale is posited as a method of spiritual and physical cleansing. The original metrical verse in the atrium of San Vitale refers to the church as an arcem (stronghold, for instance). The case study of Stonehenge is interesting since it differs from the majority, not only because of the typology of the site but because the aim is to investigate through auralisation the Neolithic society which used to have activities in that space. Archaeology could benefit from the implementation of the auralisation if we start considering the latter as an interpretative instrument. We can inspect the results of the auralisation from a different point of view: was the acoustics of that space good according to subjective perception? Was the people who built it aware of the architectural rules for good acoustics? Did the sound there evoke specific emotions or feelings? Did the acoustics have a particular meaning, or role, at a specific time or place?

The importance of the role of auralisation in archaeological contexts may be strengthened if more archaeologists would be involved and interested in such researches. As we can see from the short literature review presented, the majority of the studies about this topic have been published by journals of acoustics scope and none by archaeological journals.

2. VR app "Roman Theatres"

Ancient theatres have been quite well investigated from an acoustic perspective but, mainly, such kind of studies focus on the acoustic characteristics of these ancient buildings and less on the recreation of typical sounds of those spaces. Moreover, such kind of researches remains in the academic

field, available and comprehensible only to specialists, without any involvement of or communication to the general public. An exception is the investigation of the acoustics of the ancient theatre of Paphos (Cyprus), which has combined acoustic measurements, auralisation and digital application (Till 2019). Through Soundgate application (already mentioned before) the user can visualize the 3D reconstruction of the Roman phase of the theatre and listen to several auralised files: waves, local birds and two Roman musical instruments played directly by the user.

The research presented in this paper is the final step of a wider PhD study finished in 2018 (Manzetti 2018). It sees the development of a virtual application for Oculus Rift, which enables the user to explore the 3D reconstruction of six Roman theatres located in Crete and, at the same time, to listen the auralisation of an ancient performance from different seats. The VR application can be downloaded at http://romantheatres.ims.forth.gr (created by Aris Kidonakis). The main aim of this VR application, developed through Unity, is to virtually bring back to life these ancient theatres and to experience the feeling of being a spectator in the past Roman times.

The VR application has been created through four main steps:

1. 3D modelling and texturing of six of the Roman theatres of Crete (the theatre of Aptera, the theatre of Hersonissos, the theatre on the acropolis of Gortyna, the theatre of the Pythion at Gortyna, the theatre at Kazinedes at Gortyna and the theatre of Koufonissi);
2. Auralisation of an anechoic file from several seats spread in the cavea of the 3D models of the six theatres;
3. Creation of icons and informative panels for each theatre;
4. Development of the VR application through Unity3D, a cross-platform game engine.

2.1 *Step 1*

The 3D models have been created after having collected and studied the available documents about their architectural structure. The virtual reconstructions of these theatres are the result of several analyses and interpretations of the data acquired: comparisons with other Roman theatres in Rome and all the Empire, description of the architecture of the Roman theatres by Vitruvius, overlapping of aerial pictures with ancient plans and geophysical maps, 3D visibility analysis and virtual acoustics analysis (Manzetti, Parthenios 2018).

3D Studio Max 2016 is the software used to realize and texturize the 3D models. The materials applied to the surfaces of the objects composing the 3D models are Mental Ray materials and consequently, the renderer has been set on NVIDIA mental ray. Mental Ray materials have been preferred to

others because they offer sets of materials specific for architectural rendering (as Arch&Design Material) and a kit with pre-set characteristics for some materials, like stone and hardwood, which are present in the reconstructions of ancient theatres. Furthermore, the Mental Ray renderer eases the procedure of lightening of the scene, generating "correct simulation of lightening effects". Being an outdoor scene, the daylight system has been used in all the 3D reconstructions of the theatres, setting the real latitude, longitude and northern direction of the position of each theatre. To create a more faithful reconstruction, the terrain in its real shape has been used along with the 3D models of the theatres. Unity is a real-time engine and to maintain the characteristics set through the choice of the materials plus lightening and shadows in 3D Studio Max, the baking texture option has been chosen. Thanks to a texture procedure, it is possible to record in one image all the characteristics of the procedural texture applied to the object, which means it records the effects of the light on the object, the reflections coming from other objects and all the characteristics of the material set for that texture. After having mapped again the new images on the 3D models, they have been exported as .fbx, to easily import them in Unity.

2.2 *Step 2*

The auralisation was performed through the software Odeon Room Acoustics. For each theatre few audio files, from five to eight (depending on the size of the building), have been auralised for different positions of the cavea.

The anechoic file has been recorded in the laboratory of the Institute of Acoustics and Sensors "Mario Corbino" at the CNR of Rome Tor Vergata, with the collaboration of Dr Paola Calicchia, Dr Cristina Pace and Martina Giovanetti. The latter is a student of Classical Philology at the University of Rome Tor Vergata and she played a monologue in ancient Greek from the work "The Trojan Women" by Euripides, which has been recorded in the anechoic room of the above-mentioned laboratory. The recorded file, which is about four minutes long, has been imported in the project of each theatre in Odeon Room Acoustics and it has been automatically convolved with the impulse response recorded by the receivers placed in the cavea. Simplifying, the impulse response contains the information about the acoustic characteristics of the building (which depend on its architecture) and this is the reason why through the auralisation it is possible to create an audio file that corresponds to the real sound in a specific position of a building.

The auralised files of each theatre have been imported in Unity, so that the user can better experience the feeling of presence and, thanks to the possibility to compare various theatres, the user can also understand the influence that the architecture has on the sound. The VR application enables the user to select one of the seats of the cavea from the centre of the orchestra. He/she

will automatically move to the chosen position and will start listening to the auralised file. Then the user can select another seat to move again and listen to the audio file from another position.

2.3 *Step 3*

In order to create a more instructive and educational application, some informative panels have been added for each theatre. Information includes the history and the characteristics of the theatre, its location, pictures, drawings, and details. Each category of panels is represented by an icon and when it is selected it shows the corresponding panels. The book icon is related to the panels about the history and the characteristics of the theatre. They are text panels and they contain very brief information about the state of the art of the monument (who discovered it, when and who documented it, etc.), its architectural structures (the number of sectors in the cavea, the number of seats, etc.), its state of preservation and other typical features. The images icon is connected to panels showing pictures of the theatre, ancient and new plans plus sections, and aerial images. The icon representing the top view of a theatre is related to the drawings panels, which means the plan, the section and the representation of the hypothetical reconstruction of the theatre. The location icon is connected to a panel embedding a video realized through the tool Movie Maker in Google Earth Pro, which shows the full island of Crete from above and then zooms in till the exact area where the remains of the theatre are placed.

The details icon shows a panel about the reliability and accuracy of the 3D reconstruction of the theatre. Three images in the central part of the panel indicate three different sectors of the theatre: cavea, scene and *parodoi*. On the left side of the images, the instruments used to study the theatre and helpful for the formulation of the hypothesis about its architectural structure are listed: archaeological excavations, written sources, ancient plans, aerial pictures, geophysical maps, 3D visibility analysis, and virtual acoustics analysis. On the right side of the panel, the words "reliable, possible and hypothetical" suggest the accuracy of the 3D reconstruction for each sector of the theatre. Accuracy is one of the principles listed in the Seville Charter (Lopez-Menchero Bendicho 2013) and it is fundamental to explain that the presented reconstruction is not the only possible. When we are dealing with destroyed buildings we can never be sure about their original structure, but some clues (as archaeological remains) bring us closer to reality and some others can be useful only to assume the real aspect of a building. It must be explicitly clear if the 3D reconstruction is based on reliable data and if it is an exact reconstruction rather than a conjecture based on information but without material evidence. This is fundamental if we want to have a scientific approach and if we want to disseminate culture rather than only attractive 3D models.

2.4 *Step 4*

The VR application of the Roman theatres of Crete has been developed through the cross-platform game engine Unity3D (its programming language is based on C#) for Oculus device.

The reasons to opt for Unity instead of other game engines are several. First of all, it is an open-source software that has many functionalities and often does not need any external plug-in since it has numerous libraries embedded. The second main advantage is that it can export to many platforms, more than 25 across mobile, desktop, console, TV, VR, AR and Web. In addition, Unity3D has an asset store from where many packages can be downloaded for free too; it is constantly updated with the latest techniques and tools developed; it allows you to distribute your applications for non-commercial reasons without any fee. Being a VR application, the best device to use is a head-mounted display that allows you to have a 360° view, which enhances the feeling of presence in the virtual world and the sensation to physically live the virtual experience. In addition, some of the head-mounted displays enable the user to easily interact with the objects in the virtual world.

Oculus Rift is the device that has been chosen to be used for the VR application of the Roman theatres in Crete. Oculus Rift has been preferred to the cheaper Google Cardboard for two main reasons: the better quality (the screen resolutions and the quality of the lenses) and its functionalities (the orientation tracking, the gyroscope, the accelerometer and the magnetometer).

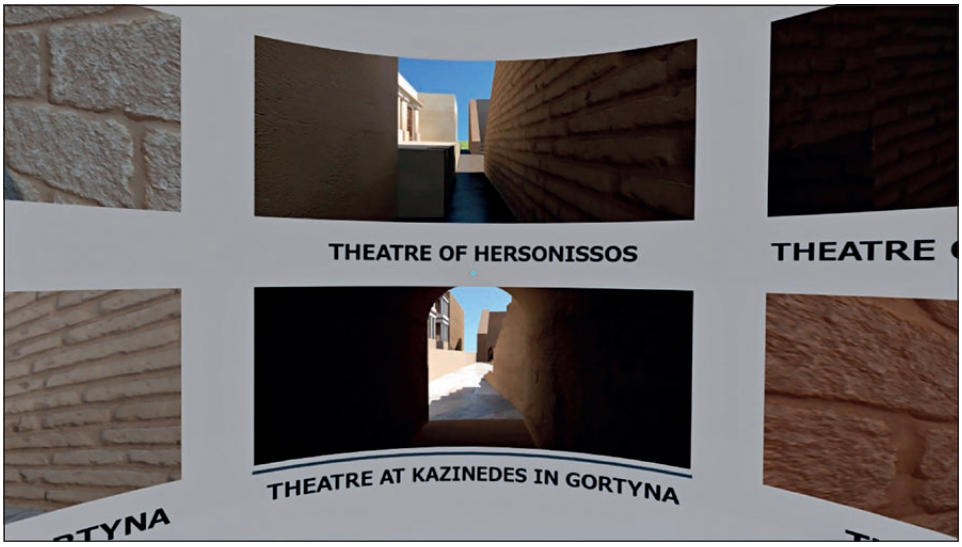

Fig. 1 – Main menu of the VR application of the Roman theatres of Crete.

Fig. 2 – Icons in the theatre of Kazinedes, at Gortyna, in the VR application.

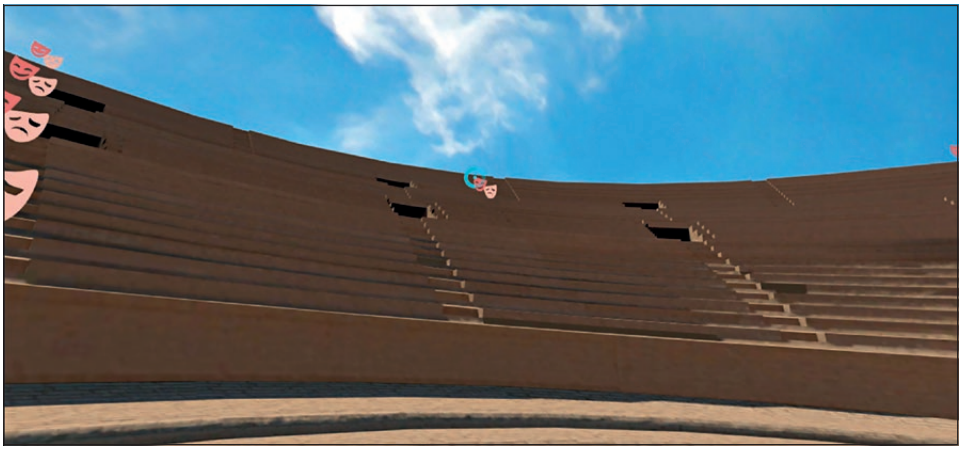

Fig. 3 – Seat selection in the theatre of Kazinedes at Gortyna through the VR application.

Samsung Gear as well is very convenient because it has functionalities too and it has the advantage to be portable, but the quality depends on the graphic card of the mobile used along with it. However, once an application has been built in Unity for Oculus Rift, it can be easily exported for Samsung Gear as well, without any further modifications.

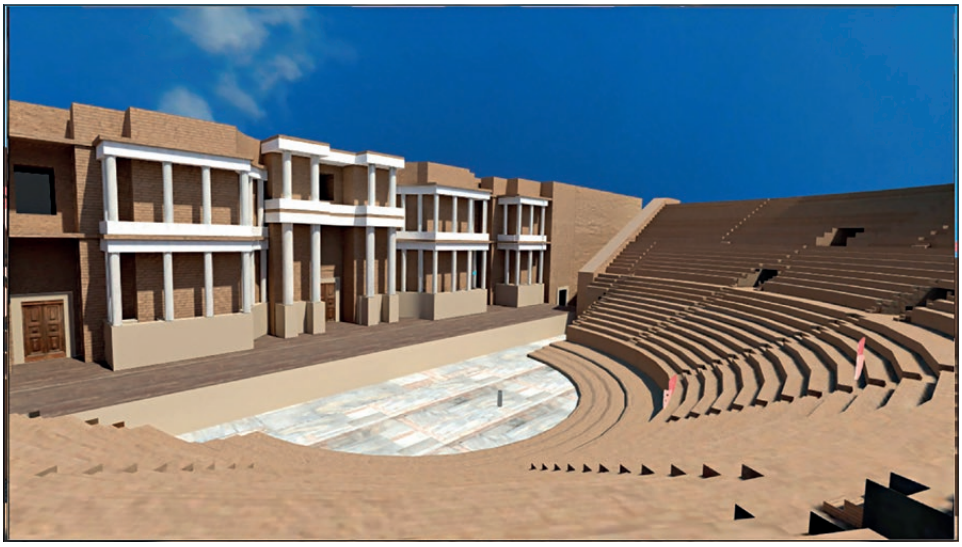

Fig. 4 – View of the stage from one of the seats of the theatre of Kazinedes at Gortyna in the VR application.

The VR application includes six of the Roman theatres of Crete (Fig. 1). The main menu shows six panels with the name of each theatre and with an image of its 3D model.

Once the user targets the name of the theatre he/she wants to explore, after three seconds the user will automatically enter the selected theatre and he/she will be in the orchestra facing the stage and the scene building. In this position, the five icons (book, images, drawings, location and details) are visible and they can be selected (Fig. 2).

If the user looks around, he/she will see several icons representing two theatrical masks, used to indicate the seats of the cavea, that can be selected. Targeting one of the couple of masks, the user will automatically move to the position occupied by the icon from where he/she can look at the stage, and at the same time listen to the auralised file (Fig. 3). Moving across the different positions indicated by the masks, the user will be able to appreciate the diverse acoustics according to the distance from the source and to the architectural characteristics of the space (Fig. 4).

During the creation of the VR application, some issues arose. One of the main issues concerned the size of the application: several scenarios (six different 3D models of theatres accompanied by the correspondent terrains) are contained in the Unity project plus videos, audios and images for each one of them. The application is consequently very heavy in terms of volume

size. In order not to burden it even more, some modifications have been made, as decreasing the quality and the length of the videos and removing trees from the 3D models. The second issue noticed is that the visualization through Oculus is not optimal: it is not completely clear, the pixels and the grid between the pixels are visible, producing the so-called "screendoor effect" (the Oculus version used during this research is the development kit 2). This feature makes it harder to focus on details, therefore also reading texts might be annoying through Oculus.

The next step to improve the VR application dedicated to experiencing and knowing the Roman theatres of Crete, will be to create an evaluation test about the ease of use, the ease to learn from the application, the level of entertainment, the level of comfort in using Oculus. The questionnaire will be presented to people of various age, various type of education, and various cultures.

Once the VR application about the Roman theatres in Crete will be improved and enhanced, it would be interesting and attractive to use it directly in the involved archaeological sites. The 3D models along with a VR application facilitates the learning process so that visiting an archaeological site is going to become both an educational and exciting experience. Such a formative experience will motivate a larger part of the society to visit archaeological sites and museums, facilitating the economic and scientific growth of these cultural institutions.

3. Conclusion

This paper briefly shows the current relationship among archaeology, auralisation and digital applications plus a new approach and a new VR application that exhibits the fruitful combination of the above-mentioned different disciplines.

The cooperation of such disciplines is offering a unique experience for visitors of museums and archaeological sites. Such kind of experiences can be a powerful instrument to attract society towards culture and history with the resulting educational enhancement of people. This aspect is without any doubt important and specialists should improve the number of similar products addressed to the general public. However, this is not the only advantage of combining archaeology, auralisation and digital media, and unfortunately, other meaningful aspects are still a bit neglected.

Auralisation should be considered a real technique to apply in many archaeological contexts and not only churches or ritual spaces. The research about acoustics in ancient theatres can be expanded with a deeper archaeological focus: what kind of performances used to take place? Which were the subjective perceptions and the feelings theatrical performances used to evoke? Did ancient theatres have different acoustic quality according to the

cultural and technical knowledge of the place? In addition, more sites should be considered as Roman basilicas where the emperors used to communicate with people, ancient courts, *mausoleum* and other funerary spaces, battlefields, prehistoric settlements, with subsequently other questions as: did ancient people use sounds to provoke specific emotions in the in individuals?

The study of acoustics and the auralisation of such places will highlight new insight into past civilizations. Planning a standard methodology for the auralisation of ancient spaces would provide a rigorous approach that would assure consistent and meaningful results. In order to achieve important archaeological information from auralisation, scholars from different disciplines must cooperate at the same level and towards the same directions to answer punctual research questions. Among the specialists, beyond archaeologists, historians, acousticians, actors, experts of psychoacoustics are also indispensable. The combination of psychoacoustics and archaeology would determine a phenomenological approach able to investigate the perceptions of past societies in specific contexts or events.

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ABSTRACT

This paper aims to present the advantages of including auralisation techniques in archaeology. Archaeology can benefit from auralisation under several aspects. Not only does it offer the possibility to live a unique experience listening sounds originated within ancient buildings, but it allows to formulate subjective interpretations of the quality of the audio of a specific space. In addition, the subjective feeling evoked by the auralised audio can be further investigated through psychoacoustics analysis. The combination of archaeology and auralisation is also attractive for the general public thanks to digital applications that can be employed for educational purposes. The involvement of society through digital applications is important to bring it near to research and archaeology. After a short literature review about the implementation of archaeology, auralisation and digital applications, the final elaboration of a PhD research will be presented: the development of a virtual reality app that shows the 3D reconstruction of six Roman theatres in Crete, including the virtual auralisation from different seats within the theatres. The VR app is the ultimate product of a research that studied hypothetical reconstructions of the Roman theatres in Crete through 3D visibility analysis and virtual acoustics analysis. Through the VR app, users will not only experience an ancient performance in different Roman theatres, but they will also be able to observe the influence of architecture on the sound.