# Acoustic design optimization through the use of auralization: how does it sound?

Lorenzo Lavagna[1]; Louena Shtrepi[2]; Angelo Farina[3]; Antonella Bevilacqua[4]; Arianna Astolfi[5]

[1] Politecnico di Torino, Italy, lorenzolavagna@gmail.com
[2] Politecnico di Torino, Italy, louena.shtrepi@polito.it
[3] University of Parma, Italy, angelo.farina@unipr.it
[4] University of Parma, Italy, antonella.bevilacqua@unipr.it
[5] Politecnico di Torino, Italy, arianna.astolfi@polito.it

## ABSTRACT
The reuse of ancient theatres has been widely debated among acousticians; many of them still do not have functional activities due to the lack of acoustic comfort. Scope of this paper is to optimize the project of an acoustic shell using audio renderings played inside the VR environment. The sound signal was auralized in 3rd OA and played in two numerical models: the digital reconstruction of the Hellenistic configuration and the proposed acoustic project. A comparison between the two products has been then assessed by 12 students.

Keywords: Adaptive reuse, Ancient theatres, Auditory VR

## 1. INTRODUCTION
Recent years have seen a growing interest in the use of virtual reality, together with specialized audio, to make our cultural heritage more accessible [1]. Another possible application of these tools is the evaluation of the effect of architectural interventions on the acoustic performance of historical buildings during the design process [2].

This paper proposes a procedure to integrate ambisonic auralization in this task and describes how it was applied in the project of adaptive reuse of the ancient theatre of Tyndaris. A description of the geometry and the materials employed for the proposed acoustic shell is also introduced.

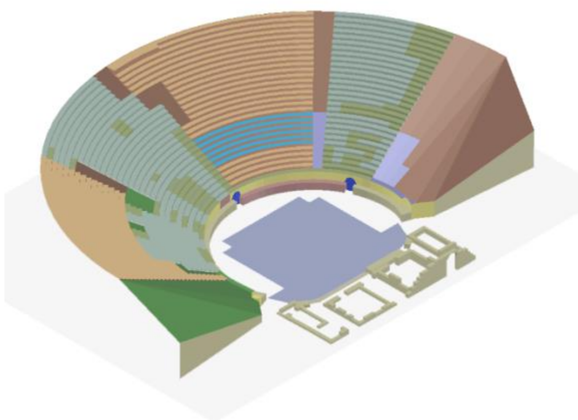
## 2. FRAMEWORK OF THE CASE STUDY
The ancient theater of Tyndaris is situated on the northern coast of Sicily, on a promontory facing the spectacular view of the Tyrrhenian Sea from a height of 180m. It is surrounded by the remains of the city of Tyndaris, founded in 396 BCE by the Greeks as a colony for exiles of Messenia (modern Messina).

Its shape has changed considerably during the centuries: in the 4th century BC a scenic building was added in front of the cavea while during the late imperial age of the roman empire, it underwent substantial changes necessary to be able to perform gladiators' spectacles and fights against ferocious animals.

Destroyed by a landslide and two earthquakes, Tindari saw the light again thanks to some archaeological excavations that started in 1838 and resumed later on between 1960 and 1998.

Today the theater is hosting concerts once again, but its current acoustic performance is compromised by many factors: the lack of the original scenic building, responsible of useful reflections supporting the actor's voice, the absence of a large part of the steps of the cavea and the general deterioration of the materials, impacting the reflectivity, and the increasing noise levels of the surroundings due to traffic.

## 3. CREATION OF THE MODELS
The study makes use of the results of a previous research, which has validated an acoustic model of the current deteriorated state of the theatre by matching the acoustic parameters obtained in the virtual simulation with those obtained by real on-site measurements [3].



10.58874/SAAT.2022.189

Figure 1 – Axonometric view of the calibration model of the theatre of Tyndaris showing the mapping of the materials.

### 3.1 Hellenistic configuration

From the baseline of the calibrated model, shapes and materials were modified to create a virtual reconstruction of the Hellenistic configuration of the theatre [4].

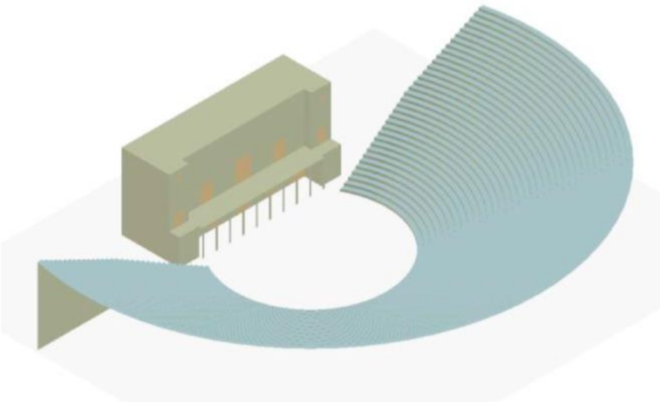


Figure 2 – Axonometric view of models used for the simulation of the Hellenistic configuration.

### 3.2 Proposed acoustic project

The solution chosen for the project of adaptive reuse was proposed in 2016 by Giovanni Bouvet. Its consists in a new scenic structure that take advantage of the Canac Laws to create early reflections that can contribute to the perceived loudness of the signal [5].

The curved shape of the reflector was generated by an evolutionary solver, Galapagos, a plugin for Grasshopper deploying computational morphogenesis, using a simple ISM (Image Source Method) algorithm, partially based on François Canac's studies.

The structure was designed taking into account recommendations of the Syracuse Charter [6], asserting that temporary structures can integrate the gaps in order to optimise the acoustic performance: the modular approach allows for a lightweight removable structure, that doesn't impose any permanent impact on the archeological site [5].

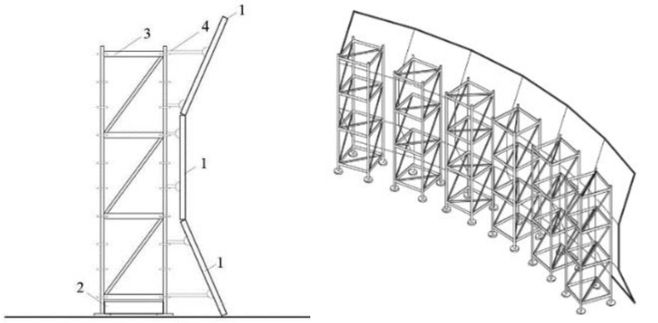



Figure 2 – Structure of the acoustic shell

## 4. OPTIMIZATION THROUGH AURALIZATION

The dimensions and materials of the acoustic shell were modified to find the configuration that was more effective in recreating the contribute of the original scenic building to the sound field of the theatre.

A summary of procedure for the optimization of the acoustic project is presented here with the names of the specific software utilized in this case, but the general workflow can be applied using many other applications:

1. Define the expected values for the quantitative parameters (T20, G, C50, C80).
2. Define a geometry for the project.
3. Cad modelling in Autocad and export in .dxf format.
4. Import into GA software Ramsete [7].
5. Add source and receivers.
6. Define absorption and scattering coefficients.
7. Trace and check the values of the quantitative parameters. If they are not comprised in the attended range, go back to steps (6.), or (3.) if major changes are needed.
8. Export IR and choose a sample for convolution.
9. Convolve IR and chosen sample with Aurora Convolver, a plugin for Adobe Audition and Audacity, or X-MCFX [8] for real time convolution in any DAW.
10. Mux audio with the 360° video (which in this case was made with the equirectangular rendering function in Blender) with FFmpeg.
11. Inject the proper metadata with Spatial media Metadata Injector.
12. Proceed to the evaluation of the project through listening tests. View the resulting 360° video with a HMD (such as an Oculus Quest 2).

Figure 3 – Rendering of the 3D model of the theatre in the current state with the addition of an acoustic shell.

Figure 4 – Rendering of the 3D model of the theatre in the Hellenistic configuration of the theatre.

## 5. LISTENING TESTS

The videos resulting from the optimization phase were evaluated by 12 students with different levels of musical education. The subjective parameters considered in the questionnaire where: loudness, reverberance, apparent source width, definition, distance, and coloration.

Three different anechoic samples were chosen for the auralizations: an instrumental music sample, a speech sample and a soprano singing.

## 6. CONCLUSIONS

The conjunction of VR and spatialized audio can provide new insides on the projects of adaptive reuse beyond what the analysis of objective parameters can tell us. It can also allow more people to appreciate the protentional results of architectural interventions on the sound quality in ancient theatres [9].

The comparison between the values of subjective and objective parameters for the reconstructed Hellenistic configuration and the project solutions chosen, shows that an optimised acoustic shell can recreate part of the contribution that the scenic building had on the theatre before its collapse, but it can't counterbalance the effects of the high degree of deterioration of the cavea on the sound field of the theatre.

Currently the procedure allows an immersive experience with three degrees of freedom (3DoF), further development will be focused on reaching 6DoF, making it possible to move around the virtual reconstruction of the site.

## ACKNOWLEDGEMENTS

The funding for this study has been provided by the European Union's Joint Programming Initiative on Cultural Heritage project PHE (The Past Has Ears, phe.pasthasears.eu).

## 7. REFERENCES

[1] B. Katz, D. Murphy, e A. Farina, «The Past Has Ears (PHE): XR Explorations of Acoustic Spaces as Cultural Heritage», 2020, pagg. 91–98. doi: 10.1007/978-3-030-58468-9_7.

[2] J. Llorca Bofí, «The generative, analytic and instructional capacities of sound in architecture: fundamentals, tools and evaluation of a design methodology», 2018.

[3] A. Astolfi, E. Bo, F. Aletta, e L. Shtrepi, «Measurements of Acoustical Parameters in the Ancient Open-Air Theatre of Tyndaris (Sicily, Italy)», *Applied Sciences*, vol. 10, pag. 5680, ago. 2020, doi: 10.3390/app10165680.

[4] L. Lavagna, «Ambisonics as a tool for architectural preservation. The virtual soundscape of the ancient theatre of Tindari - Webthesis». https://webthesis.biblio.polito.it/21074/ (consultato 7 maggio 2022).

[5] G. A. Bouvet, L. Shtrepi, E. Bo, T. M. Echenagucia, e A. Astolfi, «Computational design: acoustic shells for ancient theatres», in *Forum Acusticum*, Lyon, France, dic. 2020, pagg. 1581–1585. doi: 10.48465/fa.2020.0838.

[6] «Carta di Siracusa "per la conservazione, fruizione e gestione delle architetture teatrali antiche"». 2014.

[7] A. Farina, «RAMSETE-a new Pyramid Tracer for medium and large scale acoustic problems», gen. 1995.

[8] M. Kronlachner, «Plug-in Suite for Mastering the Production and Playback in Surround Sound and Ambisonics», 2014.

[9] T. Lokki, H. Vertanen, A. Kuusinen, J. Pätynen, e S. Tervo, «Auditorium Acoustics Assessment with Sensory Evaluation Methods», gen. 2010.