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ACOUSTIC DESIGN OF THE ANCIENT THEATRE OF KOURION, IN LIMASSOL, CYPRUS

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Abstract

The theatre of Kourion, in Cyprus is well preserved today and still used for theatrical and music performances. The simulation aims to calculate the acoustic parameters and speech intelligibility which help to define the acoustic behavior of the theatre. In addition to this, an auralization of the theatre was created, giving an impression of how the music, or the speech, would sound if replayed in the Ancient Theatre of Kourion.

Firstly, the model of the theatre was created in the AutoCAD software, after measuring the surfaces of the theatre as it stands today. A two dimensional plan of the theatre, indicating the theatre's form in antiquity, was very helpful for the design of the part of the theatre that wasn't reconstructed. Subsequently, the Ancient theatre was modeled using commercially available acoustic modeling software.

The findings are presented in color maps of the audience area, but they are also given with numbers in arrays located in the annex of this thesis. According to these results, the Ancient theatre of Kourion has a very good acoustic performance.

Additionally, a comparison was made, to the findings of the acoustic simulation of the Ancient theatre of Epidaurus.

Keywords

acoustic simulation
Ancient theatre of Kourion
Epidaurus

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1. Introduction

This study is based on a final year project originally supervised by Assist. Prof. Stamatis Vassilantonopoulos [1] and examines the acoustic simulation of the Ancient theatre of Kourion, located in Cyprus. This theatre was first built in the 2nd century B.C. during the Hellenistic era and later it took the form of a Roman theatre. The theatre is well preserved today and is described by visitors, as having quite remarkable acoustics for performing theatre plays and music concerts. The theatre does not have a scene construction and the spectators have an open view to the sea. The main purpose of this study is to examine the acoustic performance of the theatre at representative positions in the auditorium area (the cavea), which is constructed of porous stone. Moreover, the results are compared to the respective values of the Epidaurus Theatre simulations and measurements [2,3].

2. Method

In order to create the 3-Dimensional model of the Kourion theatre, all the required dimensions were measured from the theatre as it stands today. However, during the 2nd century, the theatre was larger and more impressive compared to its current state [4,,5]. Although the upper section of the tier has not been reconstructed, the model is based on the 2-Dimensional plan of the theatre (see Figure 1). Primarily, the model was designed in the AutoCAD2010 software application [6]. Next, the coordinates of all the necessary points where transferred to the acoustic modeling software application [7]. These points were used to create about 1000 planes, which constitute the model of the Ancient Theatre of Kourion (Figure 2). For source, two omnidirectional sources were defined at different positions. The first one was placed in the middle of the orchestra and the second one, 2 meters further back, in front of the scene. Nine receivers were defined along the auditorium area. The computer simulations were computed for 4 different scenarios. The first scenario is for an empty theatre, without the presence of an audience and the source placed in the middle of the orchestra. By moving the source 2 meters backwards, another configuration is generated. Initially, for the calculations of these 2 configurations the background noise was set to a low environmental noise. For other 2 scenarios, the absorption and scattering coefficients of the audience area were set to the corresponding coefficients of 2 persons per square meter and, the noise level was replaced by a typical audience noise level.

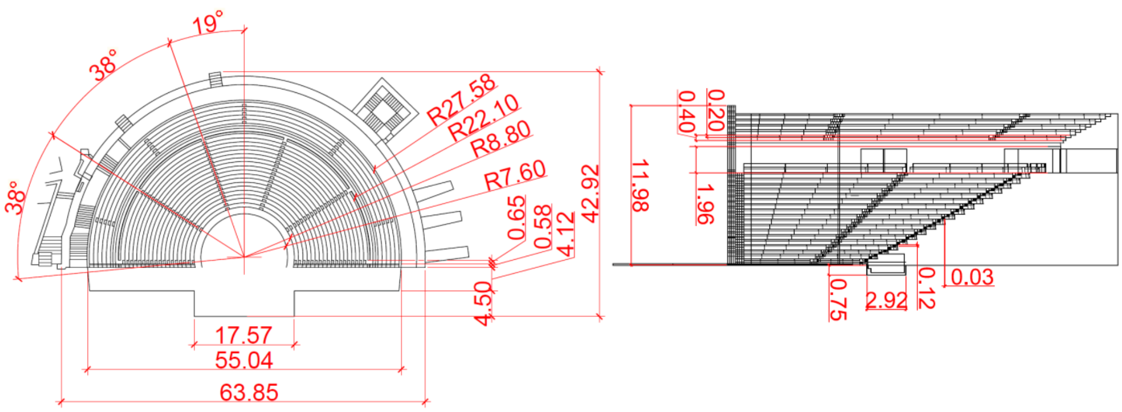

Figure 1 – Plan and side view plan of the theatre. All dimensions are given in meters.

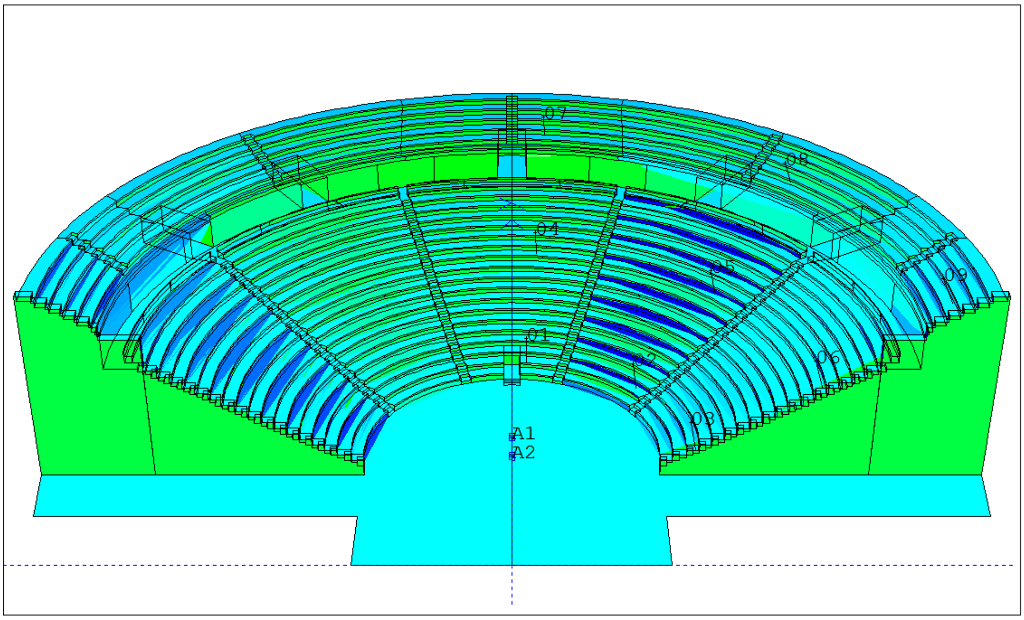

Figure 2 - The Kourion theatre acoustic model. The positions of the two sources A1, A2 and the nine receivers R1- R9 are marked.

3. Results

3.1. The acoustic parameters of the theatre (Rasti, Ts, D50, C80, LEF2, G-10, SPL)

Figures 3.a – 3.f illustrate the results obtained by the simulations. Concerning the case without audience and low background noise level the Rasti values are excellent with the source placed at either of the two positions. The center of gravity time (Ts) varies from 5 to almost 17 milliseconds. The Deutlichkeit (D50) has excellent values and the Clarity C-80 values vary from 12dB to 33dB. In general the clarity improves when the source is moved closer to the receivers. The percentage of the energy which reaches a receiver from side paths to the total energy (LEF2%), varies from 2.1% to 14.1%. The lowest value is at the receiver R9, with the source at the furthest position. The strength parameter was found at -5.7dB at the upper side receiver and increases to 5.7dB for receivers closer to the orchestra.

Changing the absorption and scattering coefficients of the auditorium surfaces, in order to represent 2 persons sitting per square meter in the tier and adding a typical background noise, the Rasti values are reduced, but they are still rated as good. In addition to this, the SPL is also reduced compared to the the case with more reflective surfaces. In this case, the center of gravity time (Ts) takes values from 2 to 9.3 milliseconds. The parameters D50 and C-80, for all the 9 receivers present quite high values. Also the proportion LEF2% is negligible at the upper seats of the auditorium and increases up to 5.1% at the lateral receiver closer to the orchestra, when source is positioned nearest to the audience.

By the use of the process of audience area mapping, the above acoustic parameters are presented in colorful maps (Figure 3). This feature of the simulation software offers to the user the possibility to see and examine the sound propagation and the distribution of the parameters above any desired plane of the model.

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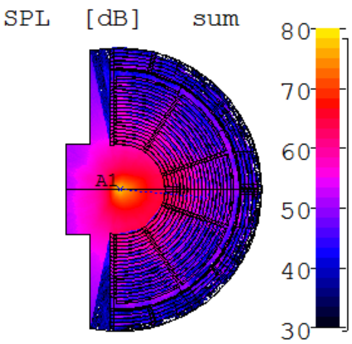

Figure 3.a – SPL(dB)

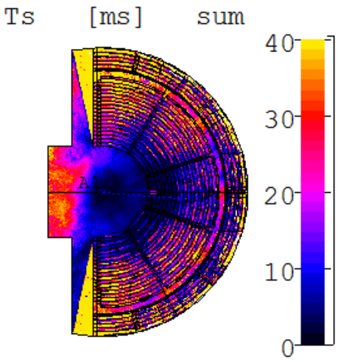

Figure 3.b – Ts (ms)

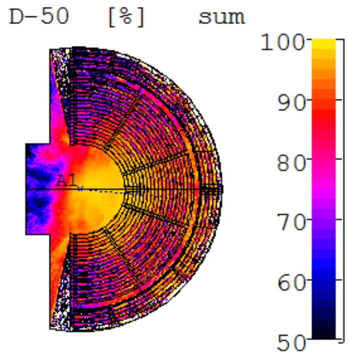

Figure 3.c – D50 (%)

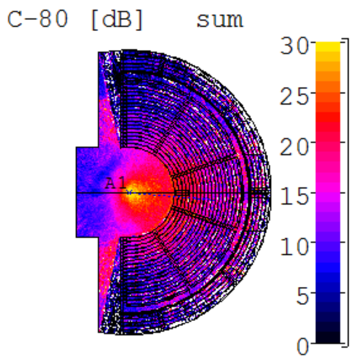

Figure 3.d – C80 (dB)

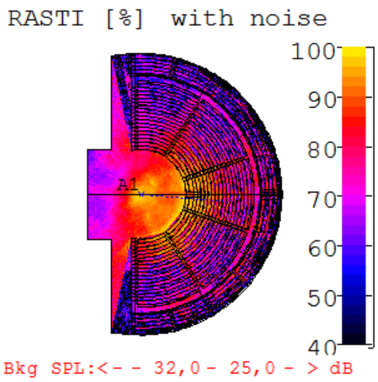

Figure 3.e – Rasti (%)

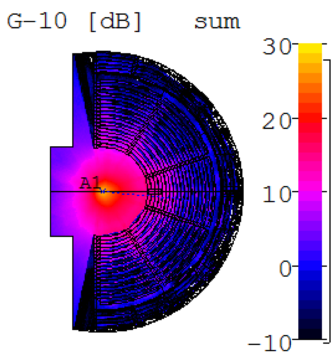

Figure 3.f- G10 (dB)

3.2. The echograms at the receivers

Figure 4 illustrates the total energy of the sound reaching a receiver from reflections and scattering - diffusion, considering the source positioned at the middle of the orchestra.

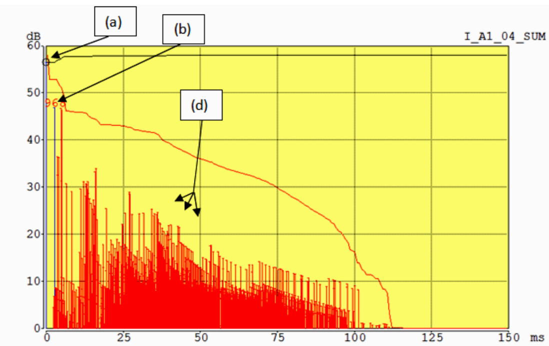

Figure 4.a - The echogram of receiver R4, with no audience in the theatre.

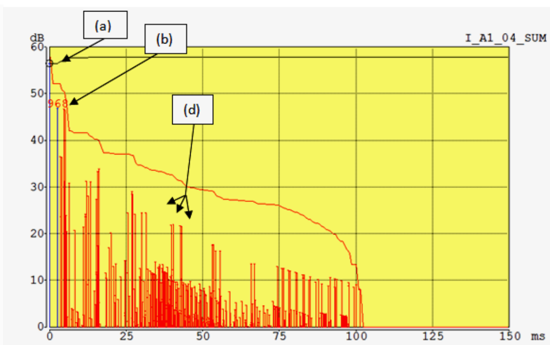

Figure 4.b - The echogram of receiver R4, with full audience

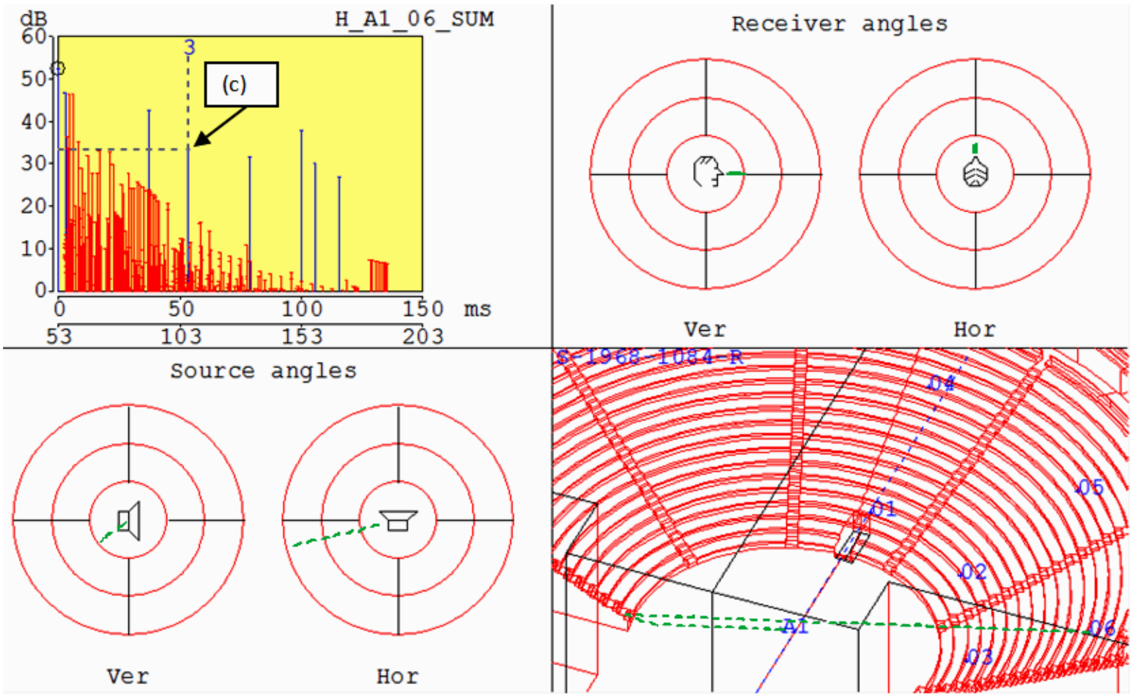

Figure 5- The echogram of the receiver R6, in the presence of audience and when source A1 is active. For the 3rd reflection, the trace indicates the departing angles from the source and the arriving angles to the receiver.

The sound field is composed of:
(a) the direct signal, which is attenuated by the distance between source and receiver,
(b) the first order reflections. Most of those reflections are from the orchestra floor and reach the listener's ears in less than 10ms after the arrival of the direct sound. This results to a better speech intelligibility and enriches the source's acoustic quality.
(c) the second and higher order reflections. Those reflections, for listeners sitting in the central seats of the cavea, are very few. Figure 5 shows the trace of a second order reflection, which reaches receiver R6, from source at A1, after hitting on the ground of the orchestra and on the side of the cavea, indicating also the source and receiver angles. However, most of these higher order reflections do not contribute to the perceived sound field, since they arrive at lower amplitude than the ambient noise level.
(d) the diffuse field which is generated by multiple scattered reflections, which is attenuated at an exponential rate. These scattered reflections in all directions are more evident when no audience is present. For the case of receiver R6 (Fig.5), the diffuse field does not last more than 140ms after the arrival of the direct sound to the receiver.
Significantly, the echograms indicate 40dB decay within 50 msec from the arrival of the direct signal, hence greatly enhancing the source signal and speech intelligibility.

3.3. Comparison of the acoustic parameters between theatres of Kourion and Epidaurus

The figures, Fig.6.a – Fig.6.c represent a comparison for 3 acoustic parameters, between the theatre of Kourion and the well-known for its excellent acoustic, theatre of Epidaurus [2,3]. The values calculated by simulation were averaged for equal distances between source and receivers. The results of the measurements at the Epidaurus theatre [3], for the corresponding acoustic parameters, are also presented in the graphs.

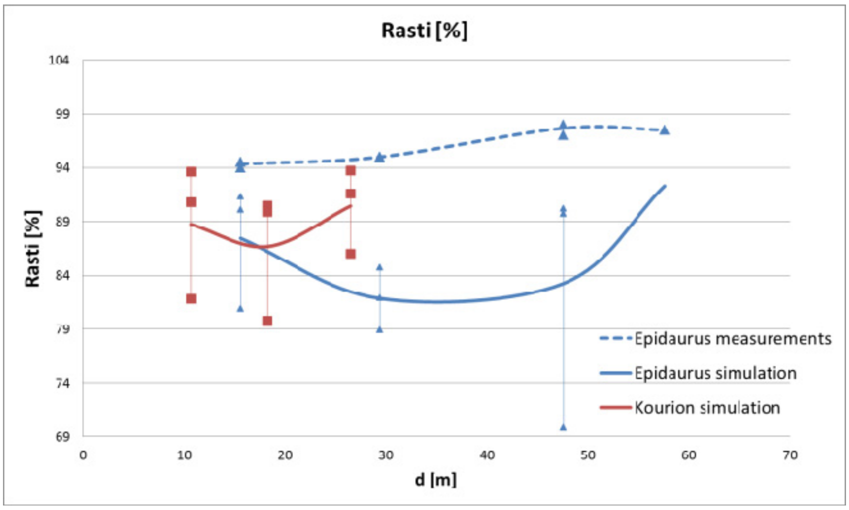

Figure 6.a – Comparison between the Rasti values of the Ancient Theater of Kourion and the Ancient Theater of Epidaurus (from [2, 3])

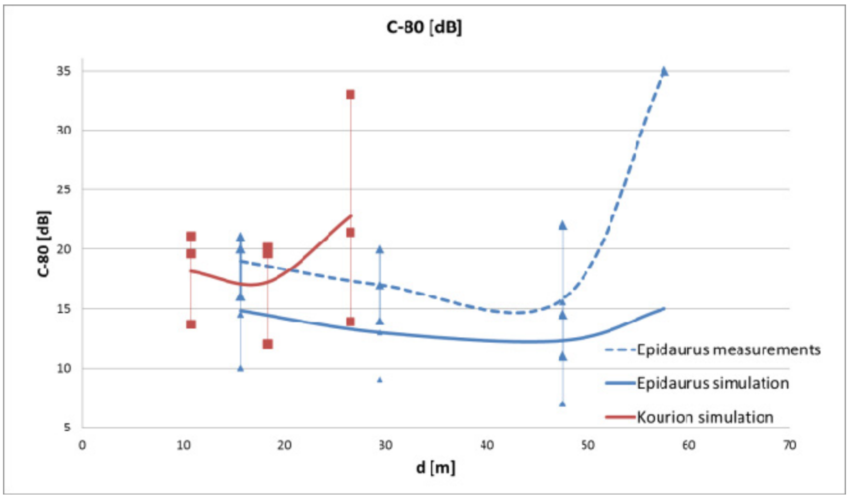

Figure 6.b – Comparison between the C-80 values of the Ancient Theater of Kourion and the Ancient Theater of Epidaurus (from [2, 3])

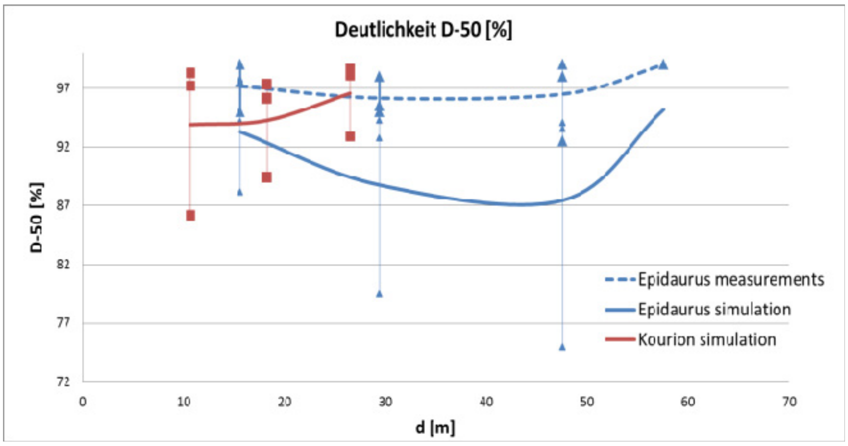

Figure 6.c – Comparison between the D50 values of the Ancient Theater of Kourion and the Ancient Theater of Epidaurus (from [2, 3])

3.4. Auralization

The acoustic software application was also used for auralization of the modeled theatre. After the processing of the anechoic .wav files, by the auralization process, the simu-

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lated theatre can be heard to produce a characteristic metallic tone largely due to the effect of the ground (orchestra) reflection, which for this theatre consists of reflective stone material.

4. Discussion – Conclusions

This study confirms the very good acoustic performance of the Ancient Theatre of Kourion. Generally, speech intelligibility was found to be remarkably good at all the seats of the cavea, even with typical audience backround noise. The sound that reaches the front receiver positions, in the middle of the theatre, is sharper and has more clarity when the source is at the farthest of the two positions in the orchestra. Also, the energy of the sound field at the central positions of the theatre is dominated by the direct sound. The signals reaching the listeners at side positions, display inferior acoustic parameters than those at the central positions. These results for the estimated acoustic parameters are more pronounced for the case of a theatre with no audience and the source at position at the centre of the orchestra.

Additionally, the late-arriving reflections are mostly encountered at the side positions of the cavea, observed for time intervals greater than 100ms and are generated by multiple paths, hitting the orchestra floor and the stone seats (or the audience). However, in all cases, a significant amount of reflected energy seems to arrive at intervals shorter than 50 msec, hence contributing to the perception of greatly enhanced source signal.

Furthermore, it is noticed that the slope of the cavea seems to trap many scattered reflections, enhancing the sound field reaching the audience's ears. Comparing the echograms of any receiver for the cases of the theatre with audience and the having only the reflecting stone seats, it is evident that the listeners in the full-audience case receive this late reflected sound at the same timing but at an attenuated level.

By comparing the Rasti, D50 and C80 values, for the Kourion theatre to that of the theatre of Epidaurus, it is clear that the two theatres have comparable acoustic performance, taking into account the smaller size of the Kourion theatre. This confirms again, the remarkable achievements of the ancient engineers, so that the theatre could accommodate audiences of 3500 people as early as the 2^{nd} century A.D and still nowadays being excellent space for performing theatrical plays.

References

[1] P.Polykarpou "Acoustic simulation and analysis of the Kourion Ancient Theatre in Cyprus", final year thesis, University of Patras, 2011.
[2] S. L.Vassilantonopoulos, J. N. Mourjopoulos: A Study of Ancient Greek and Roman Theater Acoustics, Acoustica 89, 2002.
[3] Vassilantonopoulos S. L., Zakynthinos T., Hatziantoniou P. D., Tatlas N.-A., Skarlatos D., Mourjopoulos J. N., "Measurement and Analysis of Acoustics of Epidaurus Theatre", Helina 2004 conference (in Greek), Thessaloniki, 2004.
[4] Richard Stillwell, "Kourion: The Theatre", Vol. 105, No. 1, Feb. 28, 1961
[5] personnal communication, the Department of antiquities, Cyprus
[6] http://usa.autodesk.com/
[7] http://www.catt.se