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ACOUSTICS AND ARCHITECTURE IN ANCIENT OPEN AIR THEATRES

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Abstract

In the years 2000 there has been a flourishing of studies and projects concerning the acoustics of western ancient theatres, and especially those in the Mediterranean basin. In particular the EU project ERATO and the Italian project ATLAS focused on these spaces of performance. The interest of the acousticians was devoted to better know how they sound, to auralize them under several configurations and to clarify their acoustical evolution during the course of history. In this context the Engineering Department, University of Ferrara was involved in several activities such as in situ acoustical measurements, anechoic recordings of music samples and was in charge of detailed scale model researches. One of the main outputs of this long engagement was a clear view of the interplay of acoustics and architecture in open theatres from the most simple Greek design theatres to the more sophisticated Roman ones. It was found that typical acoustical conditions can be expected in accordance with a specific theatre layout. These findings will be reviewed in the work with hints to their relevance to the present usage of such spaces especially in view of the installation of a sound system to support the modern performance.

Keywords

Scale modeling, Architecture, Sound system.

1. Introduction

Greek and Roman theatres had a role of paramount importance in the history of western culture. Many of such spaces are still used nowadays for their original scope with minor or no adaptations at all. The outstanding achievement of ancient designers to provide such spaces of performance has long attracted architects and, in this framework, acoustics plays a key role. In fact, both for their architecture and its related acoustics, the Greek theatres can be considered the starting point of theatre history and design. The first part of this work is a review of the change of the acoustics from Greek to Roman ancient theatres and, in particular, traces back the acoustical characteristics to specific design elements introduced during this architectural evolution. The presented results are based on in situ acoustical measurements in a group of five Greek and Roman ancient theatres and on scale model measurements. Moreover, ancient theatres are widely used today for modern performances including drama, music and ballets. Despite the state of conservation of the stage, the scenery is seldom designed with little care about its acoustical efficiency and, depending on the specific venue, a sound system can be employed in the performance. To clarify the acoustical impact of all these elements in ancient theatres, different stage settings and a sound system were investigated by means of scale model measurements and the results will be reported in the second part of the work. This is a review article based on two previous works from the same authors in ref. [1] and [2].

2. In situ measurements

Within the ERATO project, two well preserved theatres were chosen for acoustical measurements. The former is located in Aspendos in the southern part of Turkey and the latter is the Jerash South Theatre in Jordan. In particular, the theatre of Aspendos is probably the best preserved Roman theatre in the world as it is the only one having a complete original stage wall and also an aisle covered by a colonnade in the upper part of the cavea.

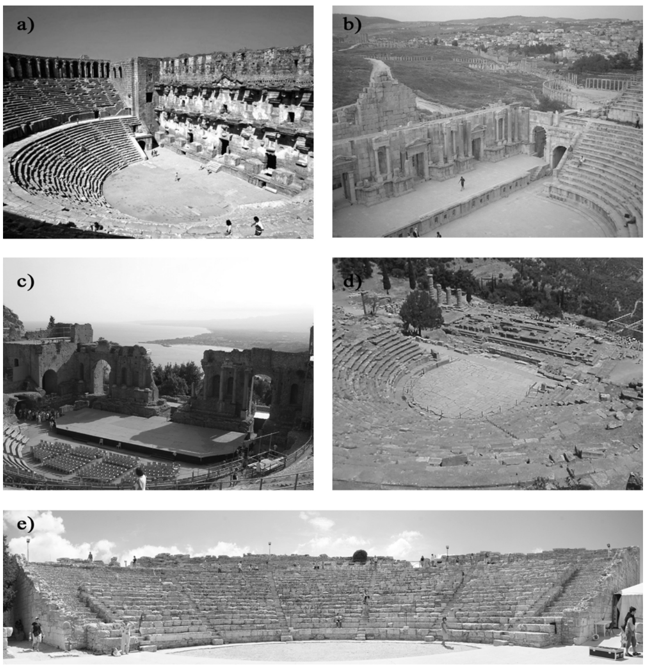

Figure 1 – (a) Aspendos, (b) Jerash, (c) Taormina, (d) Delphi, and (e) Segesta.

Moreover, acoustical measurements were taken in three other ancient theatres: the Greek theatre in Delphi (Greece), the ancient theatre in Taormina, and the ancient theatre in Segesta, both located in the South of Italy. In this work those measurements are grouped with the results from the ERATO project to have a richer set of data. The theatres measured in situ are shown in Fig. 1. It can be noted that the layout is semicircular for all the theatres except for Delphi, which shows a lightly pronounced fan shaped cavea. The main architectural characteristics of the theatres are reported in Table 1. The following acronyms will be used to identify the different theatres: Aspendos (AS), Jerash (JE), Taormina (TA), Delphi (DE), and Segesta (SE).

Table 1 - Main characteristics of all the theatres investigated in the work.

Theater	Gallery	*Cavea* diameter (m)	*Cavea* slope	Stage building	Stage building height (m)	RT_{mid} (s)	Seating capacity
Siracusa Roman	Yes	143	20°–25°	Yes	20.0	1.63	15 000
Siracusa Hellenistic	Yes	143	20°	Yes	15.4	1.61	15 000
Aspendos	Yes	98	33°	Yes	26.0	1.68	15 000
Taormina	No	109	39°	Yes (part.)	20.0	1.16	5 500 (today)
Siracusa Greek	No	85	20°	Yes	8.6	1.03	5 000
Jerash	No	63	43°	Yes (part.)	8.5	1.19	3 000 (today)
Siracusa Greek–No stage	No	85	20°	No	···	0.40	5 000
Segesta	No	63	26°	No	···	0.45	4 000
Delphi	No	50	28°	No	···	0.50	5 000

3. Scale model measurements

The ancient theatre of Siracusa, situated in the south of Italy, is one of the biggest theatres of the "Magna Grecia". The venue had undergone major changes and fortunately the site excavations made it possible to trace with great detail three different layouts dating from the fifth century B.C. to the second century A.D., that is a Greek (SG), a Hellenistic (SH), and a Roman theatre (SR). Consequently, a modular scale model of the Siracusa theatre was built to deeply investigate in a single site the acoustical changes from the former Greek to the latter Roman design.

In order to reproduce the historical configurations described above and derived from the archaeological evidences the scale model was designed as a modular structure. This means that by adding or removing some structural parts such as tiers of steps, the colonnaded gallery, and different stage buildings, it is possible to assemble each of the above theatres. Moreover also some hybrid configurations, which were not historically proved, could be assembled to investigate the acoustical contribution of specific architectural elements. A 1:20 scale was chosen as the best possible compromise between the contrasting requirements of the space to settle the model on the one hand and the measurable frequency range on the other hand.

Basically, the cavea of the model consists of nine different circular sectors, each divided into three main parts : the lower, the middle, and the upper tiers of steps. Additional movable parts were also designed to allow a modification of the cavea structure and to introduce the two diazoma added in Hellenistic and Roman theatres, respectively. For each configuration the appropriate stage building was added in front of the respective cavea. The three different configurations of the scale model are shown in Fig. 2.

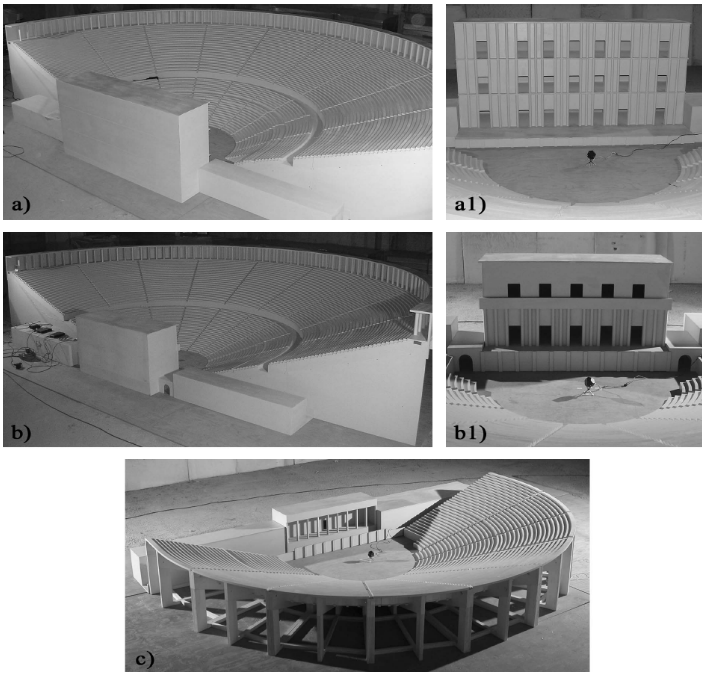

Figure 2 - Scale model of Siracusa Theatre in Roman (a), Hellenistic (b) and Greek (c) configuration.

4. The acoustic evolution of ancient theatres

As is evident from the acoustical measurement results, derived from real theatres and from the scale model configurations, the sound field in the ancient theatres has a unique character. The contributions of the specific architectural parts can be traced back in the impulse response. In particular, the orchestra floor and the stage building provide very strong early reflections and the cavea contributes with the scattered sound that makes up the reverberant tail. Anyway, even if the theatres have no ceiling, which can be replaced by an ideal surface of unit absorption, the reverberation time in Roman theatres is similar to closed ones, but in this case the clarity is higher and the sound strength is very low. The effect of the architectural elements can be tested through examination of the measured RT_{mid}, the average of the reverberation time in the 500 Hz, 1 kHz, and 2 kHz octave frequency bands. The results of such procedure are shown in Fig. 3 where different grey colours correspond to the presence of the various architectural parts, the full bars refer to real theatres, and the slashed bars to the scale model configurations. Three groups can be identified: the first including SR, SH, and AS, the second with TA, SG, and JE, and the last with SG without stage, SE, and DE. From this graph (Fig. 3) it can be seen that the RT_{mid} values can be grouped together according to their architectural layout. In fact, the measured RT_{mid} in the AS theatre almost matches those measured in SR and SH, having both the complete stage building and the upper gallery. Furthermore, it can be noted that, despite the slight slope differences and the spread of overall dimensions, the measured RT_{mid} is similar. Finally, as already noted, the RT_{mid} in SH and SR is similar even if they have very different stage buildings. Moving to the second group of data, those without the upper columned gallery, the JE and TA theatres have a RT_{mid} very similar to those measured in SG, even if they had different dimensions of the cavea and of the stage building. Theatres in the last group show almost identical RT_{mid}. Similar considerations come out from the analysis of clarity parameter averaged for the middle frequencies ($C50_{mid}$) and ΔG_{free} the averaged difference between the linear fit curve of the Strength versus distance (G_{mid}) and the free field regression. The results are shown in Table 2.

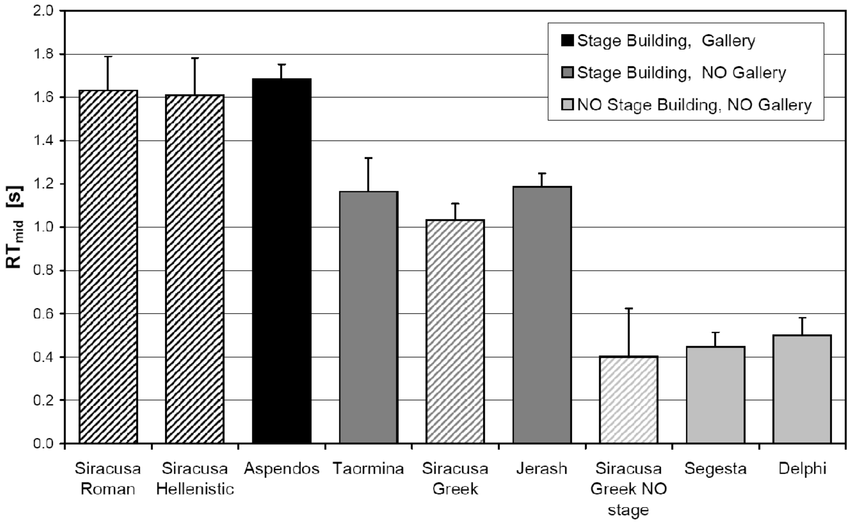

Figure 3 – Comparison between the RT_{mid} measured in all the analyzed theatres. Full bars: real theatres, slashed bars: scale model.

Table 2 – Values of the main acoustical parameters expected in ancient theaters.

Type	Real	Model	RT_{mid} (s)	$C50_{mid}$ (dB)	ΔG_{free} (dB)
Complete Roman	Aspendos	Siracusa Roman and Hellenistic	1.64 ± 0.13	5.4 ± 2.3	5.7 ± 1.0
Roman or Greek without gallery and incomplete stage building	Taormina Jerash	Siracusa Greek	1.13 ± 0.10	6.4 ± 2.0	4.9 ± 1.2
Greek without stage building	Delphi Segesta	Siracusa Greek without stage building	0.45 ± 0.12	16.5 ± 2.1	2.9 ± 1.0

5. Use of ancient theatres for modern performances

Ancient theatres are very striking places and for this reason they are widely used today as concert halls or drama theatres. Apart from the state of conservation of the venue and the presence of a stage wall, the modern stage setting is designed mainly for scenographical purposes, disregarding its acoustical efficiency. Moreover, a sound system is used very often to amplify the actors or some musical performances. To investigate the interaction between the theatre architecture and both the stage set and the sound system, the same scale model of Siracusa developed in the former work was used.

5.1 Natural acoustics

The scale model was firstly used to define some typical stage sets which allow to enhance the acoustics of the bare theatre for the needs of a musical performances or a play. In these case the basic requirement is not to use a sound system but to make the most of the natural acoustics with passive devices. Since music and drama have very different scenographic requirement it was not possible to design an unique arrangement. For this reason three configurations (reported in Fig. 4) were set up: an orchestra shell, and eight reflective screens, having bigger and smaller dimension, both arranged in a trapezoidal shape. Eleven points were measured in the cavea.

The scale model was configured having only the cavea and no surfaces useful for first reflections as could be provided by a stage building. This condition is representative of most of the ancient theatres that remains nowadays and obviously is unfavorable for the acoustics in a large part of the cavea. In particular the reverberation time in this condition is very short, the strength is very low and the clarity is too high. The aim is to add to the impulse response some useful reflection close to the direct sound which contribute to increase the sound level and the perception of the reverberation, reducing the clarity too.

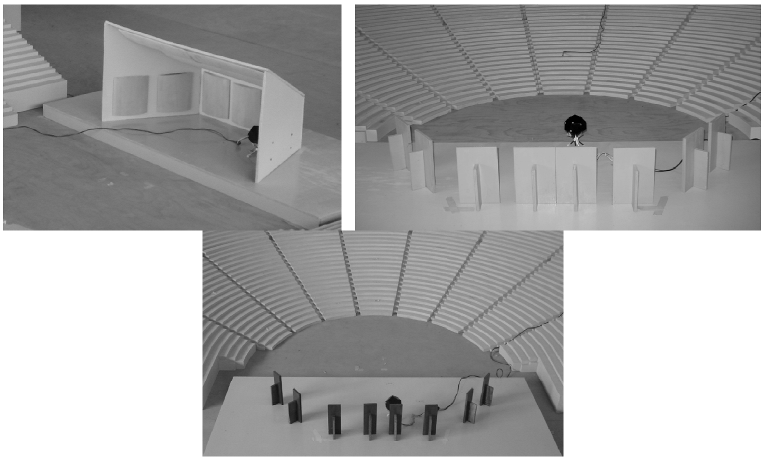

Figure 4 – The three configurations of the stage.

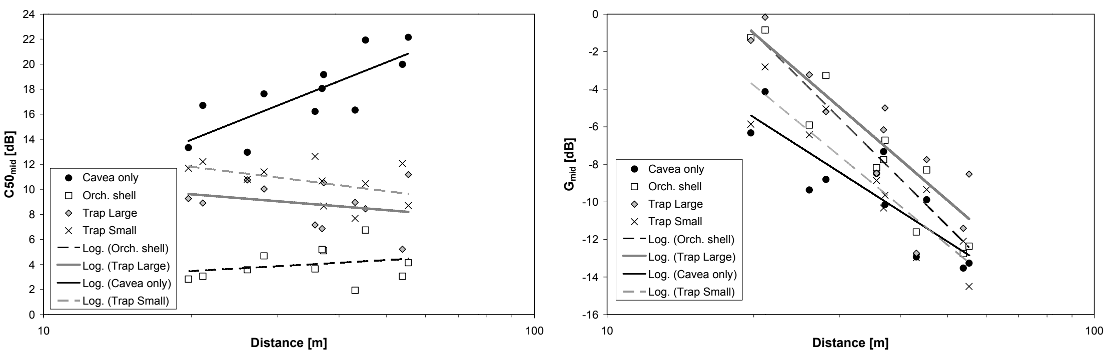

Figure 5 – Clarity $C50_{mid}$ (left) and Strength G_{mid} (right) as a function of distance.

The main results coming from the measurements are shown in Fig. 5 were Clarity $C50_{mid}$ and Strength G_{mid} are reported as a function of distance. In the bare condition, the clarity increases when increasing the distance from the source. Adding a few reflections from the stage set make the regression line flatter. Moreover, the improvement produced by the stage sets is very pronounced as C50 decreases of more than 10 dB and in many positions the parameter is close to its optimal range. As one can expect the strength is very low in the bare condition and in order to increase the parameter the small panels are not enough: the large ones are needed. Although the orchestra shell has an effect similar to the large panels in a large part of the cavea, its performance is not as good as the panels in the farthest positions. Two reasons can explain this behaviour. Firstly the reflection from the shell roof should be optimized and directed towards the higher rows of steps in the cavea also when the source is positioned in the frontal part of the stage. Secondly the typology of reflection is actually different. In fact, the reflection from the shell are diffuse, as required for performers, and hence the sound energy is much more spread.

5.2 Amplified sound system

Two directional sound sources in scale were designed and optimized to simulate a PA system in the ancient theatre. The two units were 25 cm high and each one comprises two drivers: a dome tweeter for the lower frequencies and a ribbon tweeter for the higher ones. The frequency response was optimized using a passive crossover and an equalization via software of the swept sine signal, obtaining a range of use from 1 kHz to 75 kHz. The coverage of the cavea was optimized taking into account the directivity (also measured) and the distance between the two sources which were placed on the edge of the stage (Fig. 6). The sound system was measured in the bare configuration of the theatre (cavea only) and in other three configurations obtained adding the gallery, the stage building and both structures respectively. In the measures 30 points in the cavea were used in half of the cavea with 6 simmetric control points on the other half.

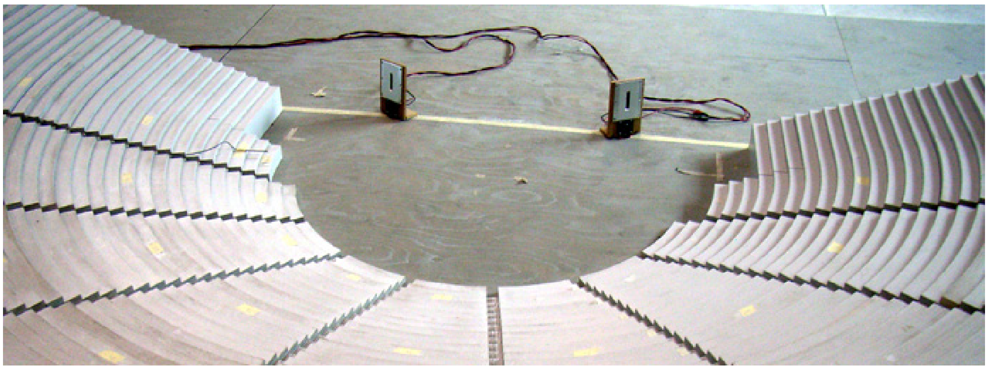

Figure 6 – The scale modelled PA system.

In Fig. 7 the maps for reverberation, sound level and clarity are reported. The directivity of the sources makes the reverberation very short in most of the measured positions and causes longer values when moving towards lateral positions. Comparing this results with the reverberation time measured with an omnidirectional sound source in the same theatre, the average values are different and a remarkable variability is obtained.

Regarding the sound level one has to note that in this case it does not correspond to the sound strength since a directional sources cannot be effectively calibrated with IR. The values are relative to a given reference, so the absolute values are not important since they depend on the sound power output of the sound system. Anyway Fig. 7 shows that the levels are uniform in the cavea and this indicates a good design of the PA system. Obviously the levels change with the distance and there are about 18 dB difference between the closer and the farthest positions.

Finally, it can be noted that the Clarity has a great variability as this parameters are strongly affected by the splitting of direct sound. In the lateral position the signals from the two loudspeakers arrive with a delay close to the integration limit (50 ms) but in the central position this delay is much shorter. To compensate this problem a cluster system could be designed to preserve the uniqueness of the direct sound, but this solution would probably be too invasive for an ancient theatre.

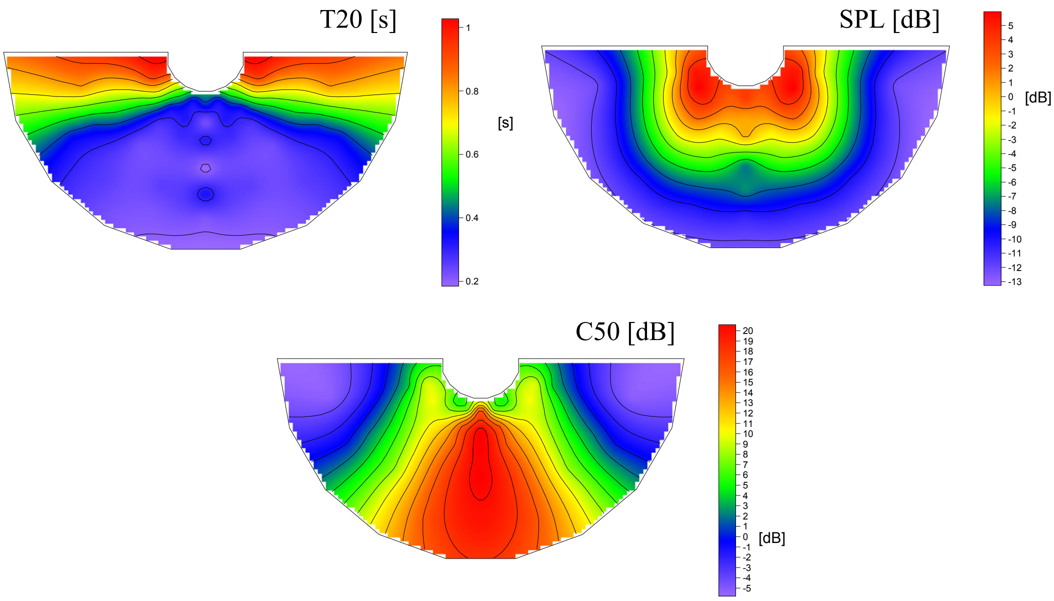

Figure 7 – Maps for reverberation, sound level and clarity in the cavea.

The values for the model with gallery and stage building show notable differences with respect to the basic configuration. The stage building works on all of the listening positions with an overall positive effect on the acoustics. On the contrary the gallery has a minor effect, which is localized mainly in the central part of the cavea.

6. Concluding remarks

From the measurements taken in real and scale modeled ancient theatres we found that the evolution of acoustics in those spaces can be qualified by architectural details and can be quantified by acoustical measurements. In this respect a few elements were isolated, namely, the stage wall, the upper columned gallery, and the slope of the cavea. Their interplay seems capable of describing the overall acoustical properties of several types of ancient theatres. Moreover, the second part of the work shows that simple stage structure and a correct positioning of a PA system can replace some lost architectural elements improving the overall acoustical conditions.

References

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