How did the ancient Roman Theatres sound?

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The Roman theatre follows a natural evolution from the Greek theatre combining the acting area and the seating area into a single structure. Modifications of stage, orchestra and seating area have resulted in a considerable improvement in the quality of the acoustics. As a part of the ERATO project, the acoustics in Roman theatres and Odea (roofed theatres) have been recreated through computer simulations using the Odeon software. Computer models of five Roman theatres have been created based on data from archaeologists, architects and measurements in situ. The theatres have been modelled in their present state and as they presumably were built in the Roman era; the reconstructed parts of acoustical interest are the stage wall and top colonnade in the open-air theatres and the roof and windows in the Odea. The irregular absorption distribution in these rooms makes them challenging for acoustical simulations differing from traditional concert halls. Auralisation examples will be presented using fragments of Roman music recorded in the project.

1 Introduction

The simulations of the acoustics of ancient roman theatres presented in this paper are part of a larger research project named ERATO (identification Evaluation and Revival of the Acoustical heritage of ancient Theatres and Odea) part of the European Commission Fifth Framework INCO – MED Programme. One of the objectives of this project is to study the acoustical properties of ancient theatres and to discuss their ‘excellent’ acoustics as they generally are described. This task has earlier been carried out by different authors, most notably by F. Canac [1], who proposed canonical formulas derived from geometrical observations. With the advantage of modern computers and room acoustic simulation software, today we can get further information about the theatres by modelling them in a virtual environment.

Therefore it is within the scope of the ERATO project to provide a virtual reconstruction of the acoustics in the Roman period, both in its large open-air theatres and in smaller roofed theatres (Odea). This makes it possible for the first time to listen to these historical buildings as they sounded in the past.

In total, five theatres from the Roman era have been recreated in the ERATO project although we only discuss the computer models of two of the ancient theatres here. One of them is an open-air theatre and the other is a roofed theatre.

The Roman open-air theatres were used for popular theatre plays and music with an audience representing all social classes counting up to 7000 individuals as in the Aspendos theatre. Even though these theatres generally were placed in quiet places outside the cities, they still had a substantially high background noise from the surroundings. If we add the weather factors (rain, wind, etc.) and a noisy audience, this resulted in somehow poorer acoustics compared to the closed odea. The original materials of these open-air theatres were mainly hard stone and wooden structures in the acting stage area.

On the other side, the odea had the properties of being closed rooms with wooden roof structures used for more intimate music and theatre plays and often only for an exclusive audience. They were made of hard materials such as stone or marble and they were assumed to have open windows to the outside for lightning and ventilation which were occasionally closed depending on the weather conditions. The open windows and the audience seated in the cavea provided the main acoustical absorption in these buildings.

The degree of detail needed in the construction of the models and the influence of the seating area on the acoustics was determined in previous studies [2] and the models have previously been compared to measurements [3].

Models of the theatres were first created based on the remaining sites at present, and then the reconstruction was added to reproduce the theatres as originally built (to the extent that this is known). The acoustical simulations of these models were carried out with the use of the Odeon 7 acoustical simulation software.

In order to understand the acoustical importance of some chosen geometrical parts of the theatre, these were removed one at the time from the reconstructed models. The results of these modifications became both visible through the acoustical parameters but also audible
through the auralised sound signals which were calculated.

2 Acoustical computer models

The acoustical models of the theatres in the ERATO project were made using in the different stages the following software packages: Odeon Modeling Language, IntelliCAD and 3DStudioMax.

The absorption and scattering properties of the materials were indirectly estimated from comparing simulations of the present state models with in-situ measurements and with the available literature.

2.1 Aspendos open-air Roman theatre, Antalya, Turkey

The Aspendos Roman theatre was chosen since it is one of the best preserved theatres in the world and it strictly follows the recommendations of the roman architect Vitruvius [4]. The reconstruction of this theatre which could have an audience of up to 7000 people did not imply too many assumptions since its present state is close to the original building.

In Figure 1 the reconstructed model of the Aspendos theatre counting 6613 surfaces is shown, with indication of the geometrical parts that might have an acoustical interest. First the stage wall was chosen as an interesting geometry, having sound diffusing geometries as columns, niches and architectural relief decoration. The effect of the diffusing elements and the removal of this wall were studied.

At a height of 25m over the stage there was a wooden tilted roof which might have worked as a stage reflector. The semicircular orchestra was separating the stage and the seating area and could have the effect of a reflecting surface when not covered by people. On the upper part of the theatre behind the last rows of seats there was a colonnade similar to an arcade where the audience were able to rest in the shade and enjoy light breezes from the outer windows.

2.2 Aphrodisias Roman Odeon, Antalya, Turkey

The Aphrodisias Roman Odeon had a volume of 20190 m³ and a seating capacity of approximately 1700 people. The computer models of this odeon, shown on Figure 2, were based on the reconstructions suggested by Izenour [5] and the number of surfaces used was 5058.

Changes on the shown parts were studied in the simulations. The roof was made of a timber structure hidden and decorated with a coffered ceiling. It was tested how the coffered structure influenced the acoustics by replacing it with a flat roof.

The windows were usually open but had also wooden shutters that could be used depending on the weather conditions. The effect of closing the windows was studied.
3 Simulations

The simulations in the Aspendos open-air theatre were made with 500000 rays and in the Aphrodisias Odeon with 100000 rays. The greater amount of rays in the open-air theatre was needed due to the totally absorptive roof which represents the sky and which represents one third of the total surface area.

The theatre models have been simulated as fully occupied in order to be able to make comparisons with existing concert halls. Contrary to today’s halls, the acoustics of the Roman theatres differ dramatically when empty and full as the seats are not upholstered.

In all the simulations the sound sources are omni directional and they are placed on the acting stage. There are 15 receivers distributed in two radial lines diverging from the orchestra as shown in the theatre model of Aspendos in Figure 3.

In the Aphrodisias Odeon the placement of sources/receivers follow the same distribution.

As mentioned before, the parts judged to be of acoustical interest were subtracted one at the time from the reconstructed model. The reconstructed model is hereby mentioned in this paper as the Reference model.

3.1 Aspendos open-air theatre

In the acoustical simulations of the reconstructed Aspendos Roman theatre, the reverberation time at mid-frequencies is shown in Figure 4 to be of 1,8 s. In all the configurations the simulations show that the reverberation time is around 0,5 s higher at low than at mid-frequencies. The tendency towards a lower reverberation time at higher frequencies for all configurations is mainly due to air and audience absorption. For being an open building it should be noticed that there is a considerable reverberation in the room.

The stage wall and the colonnade seem to be the largest contributors to the reverberation time. By removal of these parts the reverberation time is seen to fall substantially, particularly at lower frequencies.

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In Figure 5 the strength is seen to be between 0 and -7dB in most of the configurations. These values are critically low if compared to existing concert halls were it is known that the strength should not be lower than +3dB. Furthermore the level differences between different receiver positions are rather big. These differences are to a large extent caused by the great distances and the missing roof reflections. The strength decreases over distance at almost the same rate for the different theatre configurations, except for the configuration where the stage wall is removed. In this case it is seen that the sound decay rate is greater and comparable to free field conditions.

Although it seems as an extreme case to remove the stage wall we have to bear in mind that the ancient greek theatres didn’t have a stage wall united to the seating area but often a small stage building.

The stage reflector seems to have a small influence on the overall acoustics of the theatre modifying slightly the reverberation time, strength and clarity. The excessive height over the stage makes it an ineffective reflector which only redirects reflections towards the lower part of the audience area, being these reflections weak and delayed due to the long path length.

The removal of the colonnade seems to have a considerable effect on the overall reverberation time which is reduced by 0,4 s and up to 0,5s for the upper seats of the theatre. This removal provides a higher clarity although it reduces slightly the overall strength level, more considerably at the upper seats. DL2 is close to 6 dB which could be seen in relation to the reduced strength in the highest part of the seating area. The number of reflecting surfaces becomes smaller the further away from the orchestra the receiver is positioned and without the colonnade this becomes even more prominent. Even though the overall STI doesn’t change much by removing the colonnade there is a raise of STI in the last seat rows. All this shows that the colonnade creates a small reverberant field which raises the overall reverberation and strength of the theatre particularly at the upper rows of the seating area.

The simulations with a totally absorptive orchestra show that there is a small decrease in the overall reverberation time and in the strength, but the orchestra surface has less influence in the overall acoustics of the room than expected. When the source is positioned in the middle of the stage most reflections come from the stage floor and the stage wall. For the orchestra to have a greater influence on the overall acoustics either the source has to be positioned at the edge of the stage or a smaller stage width is needed.

### 3.2 Aphrodisias Odeon

In Figure 6 the reverberation time as a function of frequency in the different configurations is shown. The reconstructed model includes a coffered ceiling and open windows. All the simulations in this odeon show a similar tendency in frequency, a long and constant reverberation time at lower frequencies and an abrupt fall toward the mid-frequencies. At higher frequencies the audience and air absorption make the differences between the curves smaller. At mid- and high frequencies the reverberation time of the reconstructed model suggests that it is a room suited for musical performances.

<table>
<thead>
<tr>
<th>Theatre Configuration</th>
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<tbody>
<tr>
<td></td>
<td>T₃₀ (s)</td>
</tr>
<tr>
<td>Reference model</td>
<td>1,81</td>
</tr>
<tr>
<td>Flat Stage Wall</td>
<td>1,78</td>
</tr>
<tr>
<td>No Stage Wall</td>
<td>1,22</td>
</tr>
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<td>1,69</td>
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<td>No Colonnade</td>
<td>1,41</td>
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<tr>
<td>Absorbing Orchestra</td>
<td>1,70</td>
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In Table 1 are shown the overall differences of the modified theatre models compared to the reconstructed reference model at mid-frequencies.

By using a flat stage wall without diffusing geometries it is seen that the overall strength level G is reduced and the DL₂ rate is increased. By removing the geometries of the stage wall the sound field in the theatre becomes less diffuse and more dominated by specular reflections. These dissipate quicker through the open roof resulting in a lower sound level in most of the seats.

By removing the stage wall it is seen that the reverberation time decreases dramatically resulting in a substantial increase of clarity and STI but in detriment of the strength level.

Without stage wall few early reflections from a vertical surface reach the receivers. The sound propagates in a similar way to free field conditions and this is exemplified by the level decay per distance doubling which is about 6dB.

In most of the seats. These dissipate quicker through the open roof resulting in diffuse and more dominated by specular reflections. stage wall the sound field in the theatre becomes less DL₂ over 15 receiver positions in different configurations. The removal of the colonnade seems to have a considerable effect on the overall reverberation time which is reduced by 0,4 s and up to 0,5s for the upper seats of the theatre. This removal provides a higher clarity although it reduces slightly the overall strength level, more considerably at the upper seats. DL₂ is close to 6 dB which could be seen in relation to the reduced strength in the highest part of the seating area. The number of reflecting surfaces becomes smaller the further away from the orchestra the receiver is positioned and without the colonnade this becomes even more prominent. Even though the overall STI doesn’t change much by removing the colonnade there is a raise of STI in the last seat rows. All this shows that the colonnade creates a small reverberant field which raises the overall reverberation and strength of the theatre particularly at the upper rows of the seating area.

The simulations with a totally absorptive orchestra show that there is a small decrease in the overall reverberation time and in the strength, but the orchestra surface has less influence in the overall acoustics of the room than expected. When the source is positioned in the middle of the stage most reflections come from the stage floor and the stage wall. For the orchestra to have a greater influence on the overall acoustics either the source has to be positioned at the edge of the stage or a smaller stage width is needed.

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The coffered ceiling structure does not seem to affect the reverberation time significantly when comparing to the flat ceiling.

By closing the windows it is seen a raise in the reverberation time particularly at lower frequencies.

By inserting totally absorptive material on the orchestra surface (which simulates the presence of musicians or a choir) the overall reverberation time becomes slightly shorter. This might be explained by the fact that there are a number of reflections interacting between roof and orchestra that then become absorbed. It should be noticed though, that the orchestra in this Odeon is more like a modern orchestra pit with a depth of 1 m, so it is rather unlikely that it had the function of a reflector.

From Figure 7 it seems that the strength is good even at its lowest levels in all the configurations.

When the ceiling is made flat, the strength seems to decrease more than in the other configurations at the farthest seats. The sound field becomes less diffuse resulting in fewer reflections from the roof arriving at a receiver placed far from the stage.

By closing the windows the strength differences over distance seem to become smaller. When replacing the window openings with wooden shutters the total absorption area becomes smaller and this creates a more reverberant room where the strength is increased at all positions.

Figure 8 shows that the clarity is rather high in most of the configurations. When the windows are closed the clarity falls with 1-2dB which results from the higher reverberation time and the higher energy content in the late part of the room impulse response. This can be verified by the case of the absorptive orchestra where the clarity is improved in connection with the reduced reverberation time.

From Table 2 we see that by comparison with the reference model, the flat ceiling reduces the overall strength. Together with the higher DL2 this shows that it is advantageous to have a coffered ceiling which has a diffusing effect.
Table 2: Simulated acoustical parameters averaged over the 500-1000 Hz 1/1 octave frequency bands for the Aphrodisias Roman odeon with audience and averaged over 15 receiver positions in different configurations.

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<tr>
<td>Reference model</td>
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</tr>
<tr>
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<tr>
<td>Closed Windows</td>
<td>1,80</td>
</tr>
<tr>
<td>Absorbing Orchestra</td>
<td>1,54</td>
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By closing the windows with wooden shutters a considerably longer reverberation time is obtained. It is almost comparable to the reverberation time of modern concert halls of similar volume. Linked to the higher reverberation time are the overall higher strength and lower clarity. Although in general the clarity seems to be good in any of the configurations.

Omission of the reflections coming from the orchestra does not cause dramatic changes but gives a higher clarity. But in general it can be said that reflections from the stage wall and the roof are more important than the reflections from the orchestra.

The STI seems to be good in all the configurations making this room a suitable place for both music and spoken word.

4 Conclusions

The acoustics of typical performance venues in the Roman era have been studied in detail by modelling an open-air theatre and a roofed odeon in a computer. In the computer models certain parts of the theatre have been changed or removed and the acoustical consequences of these alterations have been studied.

The computer simulations show that at least two modifications introduced by the Romans in the open-air theatres had a large influence on the acoustics. Firstly the extension of the stage wall in its width and height which meant a connection with the seating area into a single structure, and secondly the colonnade in the upper part of the theatre which provided a retreat area with shade for the spectators.

These two geometrical modifications of the theatre seem to increase the overall reverberation time with half a second each, amplifying the overall strength level with up to +4dB. This has to be seen as a significant improvement in this type of theatres where large distances between stage and audience implied very low levels (almost inaudible in the upper rows). Furthermore, the level difference between seats near and far from the stage is reduced with the introduction of these geometries.

In the case of the odea the simulations show that these highly reflective rooms (marble surfaces), have similar acoustical properties to modern concert halls when the windows are closed, even though the only absorption is provided by the audience. The roof has shown to give more satisfying results when using a coffered ceiling than a plane surface.

In order to answer the question addressed in the main title in a more intuitive way, auralized sound examples of the theatres can be heard at the ERATO website [6].

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References


