Proceedings of the Institute of Acoustics

THE VIRTUAL RECONSTRUCTION OF THE ANCIENT ROMAN CONCERT HALL IN APHRODISIAS, TURKEY

JH Rindel Ørsted-DTU, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark
AC Gade
M Lisa

1 INTRODUCTION

About two thousand years ago one of the world's earliest and most beautiful concert halls were built in the city Aphrodisias, named after the goddess Aphrodite. It was a rich society, renowned for its marble and mastery in sculptures. Like many other cities in the Roman Empire there was an open-air theatre for plays and a roofed theatre, odeon, for concerts (from Greek: *Odeion*, a hall for song and declamation with music). In the framework of an EU-project the Odeon or concert hall has been reconstructed in a virtual environment, visually and acoustically. The capacity of the hall was around 1700 in the audience. There has been some uncertainty about the original height of the ceiling; but with the suggested reconstruction the reverberation time with a full audience is around 1.6 s at mid frequencies. The influence on the acoustics of various architectural elements has also been studied. The virtual reconstruction, including some auralisation examples with reconstructed music, has been made with the ODEON room acoustic modelling program. From January 2006 the reconstructed concert hall will be open for visitors, although in a virtual environment.

The ancient Greek and Roman theatres are famous for the excellent acoustics. However, it is not generally well known that different kinds of theatres were built, for different purposes and with different acoustical conditions. The method in the EU-project ERATO has been to make computer models of the spaces, first as they exist today, and adjust the acoustical data for surface materials by comparison to acoustical measurements from some of the best preserved examples, namely the Aspendos theatre in Turkey and the South theatre in Jerash, Jordan. Next step was to complete the computer models in accordance with archaeological information, to make virtual reconstructions of the spaces. It is found that the Roman open-air theatres had very high clarity of sound, but the sound strength was quite low. In contrast, the odea had reverberation time like a concert hall, relatively low clarity, and high sound strength. Thus, the acoustical properties reflect the original different purposes of the buildings, the theatre intended mainly for plays (speech) and the odeon mainly for song and music.

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. This makes it possible for the first time to listen to these historical buildings as they sounded in the past.

2 COMPUTER MODELS

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

An important source for the reconstruction was the suggested reconstructions shown in the book by Izenour[1]. However, the building was not made as high as suggested by Izenour. 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 and the models have previously been compared to measurements[2].

The absorption and scattering properties of the materials were indirectly estimated by comparing simulations of the present state models with these in-situ measurements and with the available literature. The model was first created based on the remaining site at present, and then the reconstruction was added to reproduce the odeon as originally built (to the extent that this is known). The acoustical simulations were carried out with the use of the ODEON 7 acoustical simulation software.

The Aphrodisias odeon as reconstructed has a volume of 20190 m^3 and a seating capacity of approximately 1700 people. The archaeological site is seen in Figure 1. The computer models of this odeon, shown in Figures 2 - 4, are based on the reconstructions suggested by Izenour[1] and the number of surfaces in the acoustical model is 5058. The roof is carried by a timber structure with a suspended coffered ceiling. It was tested how the coffered structure influenced the acoustics compared with a flat roof, see Table 1. The windows were usually open but had also wooden shutters that could be used depending on the weather conditions. The acoustical effect of closing the windows was also studied, see Table 1.

Figure 1 – Photo from the archaeological site of the Odeon in Aphrodisias

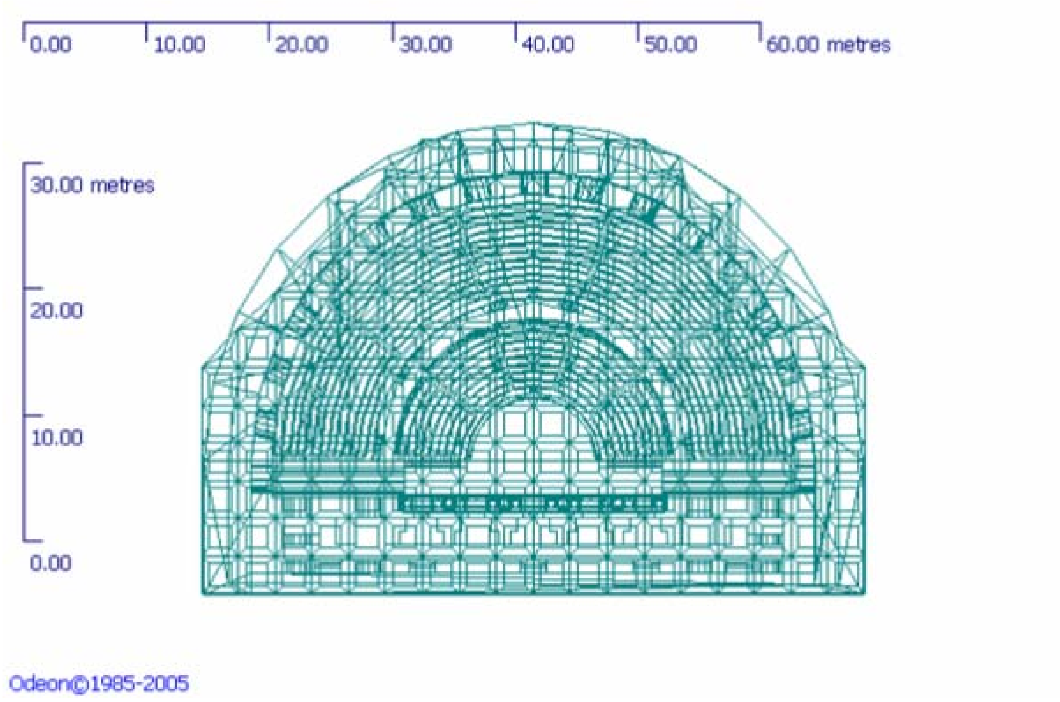

Figure 2 – Plan of the reconstructed Odeon

Figure 3 – View into the acoustical computer model

Figure 4 – View into the visual computer model

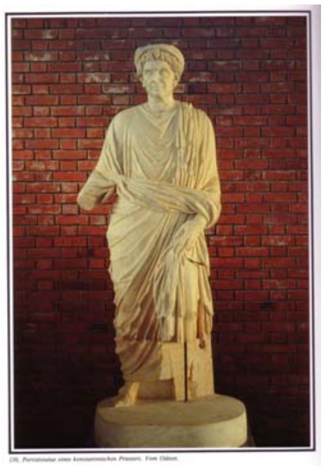

Figure 5 – One of the original statues from the odeon

3 SIMULATION RESULTS

The simulations in the Aphrodisias Odeon were made with 100.000 rays. The theatre model has 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 and odea 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. The parts judged to be of acoustical interest were altered one at the time from the reconstructed model. The reconstructed model is hereby mentioned as the Reference model, see Table 1.

Theatre Configuration	Acoustical Parameters				
	T_{30} (s)	G (dB)	C_{80} (dB)	STI	DL_2 (dB)
Reference model	1,61	5,61	2,22	0,54	3,47
Flat Ceiling	1,66	4,84	2,49	0,55	4,08
Closed Windows	1,80	6,10	1,46	0,52	2,89
Absorbing Orchestra	1,54	5,07	2,97	0,57	3,32

Table 1 - Simulated acoustical parameters averaged over the 500 - 1000 Hz octave bands for the Aphrodisias odeon with audience and averaged over 15 receiver positions in different configurations.

The reconstructed model includes a coffered ceiling and open windows. All the simulations in this odeon show a similar tendency in frequency, a long reverberation time at lower frequencies and a 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.

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 (the semi-circular floor in front of the proscenium) does not cause dramatic changes but gives a higher clarity. 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 ANECHOIC RECORDINGS AND AURALISATION

4.1 The Music

As part of the ERATO project four different musical instruments were reconstructed, aulos, kithare, tympanon and scabellum. Examples of musical pieces were composed in accordance with musical style of period around first century AD. Some pieces included solo song and chorus, see Figure 6. The newly developed multi-channel auralisation technique[4] was used. This implied that four microphones were used for the anechoic recordings in order to capture some of the directional characteristics in the recording. This technique makes it possible to give the source acoustical width and depth when applied in the auralisation. In addition it is even possible to reproduce acoustically the movements of the performers in the auralisation, which all together makes the auralisation very realistic.

Figure 6 – From the anechoic recording of music with reconstructed musical instruments

4.2 The Plays

Anechoic sound recordings of a group of 10 actors from Yildiz Technical University, Istanbul were made in June 2005. The two Greek dramas Antigone and Agammenon as well as the sound of an audience crowd in different moods were played. These performances were recorded with a four microphone setup as for the music recordings and filmed with a video camera to capture the movements.

The anechoic sound recordings of the plays and the previously recorded music pieces were auralised in the ODEON software using the following procedure[4]: First the sound source position in the virtual room is placed on the stage, and the source is split into four parts (front, left, back, right) corresponding to the four microphone directions used for the recordings. Then each signal is fed to each part and its contribution to the room is calculated separately. Finally a listener position is chosen in the sitting area and all the calculated contributions are added together at this position. The sound of the performance in the simulated room can be listened to over headphones and the movement of the actors during their performance can be heard, particularly when the receiver is near the stage.

4.3 The Crowd Sounds

For the auralisation of the audience crowd a different approach was used. This task was rather difficult since the anechoic recordings only included the sound of 10 people and the capacity of the Odeon is around one thousand. The procedure for the crowd simulations was the following:

Ten people in an anechoic room were told to perform as an audience in different moods: clapping, supporters, opponents, cry, laugh, surprise, idle talk. Each of the moods was recorded separately and the signals were auralised in a computer model of the theatre.

A random distribution of 20 sources (the maximum number of simultaneous calculations in ODEON) in the audience area was generated. The anechoic sound signal for a selected emotional reaction of the crowd was fed to each of the sources. The contribution of each source to the sound heard at a chosen receiver was calculated. All the sounds from each of the sources were then mixed together and attenuated and delayed randomly to create a greater sense of mixture.

In order to create the impression of a bigger audience and get more diversity, the different crowd signals were edited in the AUDITION software. Using a multi-track set-up, the different crowd reactions were displaced in time and filtered and finally mixed with the play or music. It was hereby possible to fit the reactions of the crowd to the actions of the actor in the different parts of the play as well as the music.

The total number of final sound files with music/play and crowd for the integration was 61. In the integration process the auralised sounds of the crowd and actors were used to synchronise the visual actions of the virtual humans.

Figure 7 – View from a performance in the virtual reconstruction of the Odeon in Aphrodisias

5 CONCLUSION

The acoustics of a typical Odeon or concert hall from the Roman era has been studied in detail by using computer simulations. The simulations show that this highly reflective room (mainly marble and stone surfaces), has acoustical properties similar to modern concert halls, even though the only absorption is provided by the audience and the open windows and a small amount by the wooden ceiling at low frequencies.

Some short examples of different typical performances can be experienced in the virtual reconstruction and auralised sound examples can be heard at the ERATO website[5] .

6 ACKNOWLEDGEMENT

The ERATO project (Contract Number ICA3-CT-2002-10031), is financed by the European Commission under the Fifth Framework INCO-MED Program. The visual reconstructions were made by the project partners from EPFL, Lausanne and MiraLab, University of Geneva. The archaeological and architectural research was made by the project partners from The Hashemite University, Jordan and Yildiz Technical University, Istanbul, Turkey. The reconstruction of music and plays was created by the Music department of Yildiz Technical University, Istanbul, Turkey. Acoustic measurements and sound recordings were made in collaboration with colleagues from the University of Ferrara, Italy. Evaluation and subjective testing of results were made by AEDIFICE, Lyon, France.

7 REFERENCES

1. G.C. Izenour, 'Roofed Theatres of Classical Antiquity', Yale University Press, New Haven and London (1992)
2. A.C. Gade, M. Lisa, C.L. Christensen, J.H. Rindel, 'Roman Theatre Acoustics: Comparison of acoustic measurement and simulation results from the Aspendos Theatre, Turkey'. Proc. ICA 2004, Kyoto, Japan (2004)
3. M. Lisa, J.H. Rindel, C.L. Christensen, A.C. Gade, 'How did the ancient Roman Theatres sound?' Forum Acusticum, Budapest (2005), Proceedings (CD Rom) pp. 2179-2184.
4. F. Otondo, J.H. Rindel, 'A new method for the radiation representation of musical instruments in auralizations', Acta Acustica/Acustica (2005) Vol. 91, pp. 902-906.
5. ERATO website: http://www.at.oersted.dtu.dk/~erato/index.htm