Virtual reconstruction of the ancient Roman concert hall in Aphrodisias, Turkey

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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 - an odeon - for concerts (from the Greek *odeion*, a hall for song and declamation with music). In an EU-funded project the odeon or concert hall was reconstructed in a virtual environment, visually and acoustically. The audience capacity of the hall was around 1000. There was been some uncertainty about the original height of the ceiling; but with the suggested reconstruction the reverberation time with a full audience is around 1.6s at middle frequencies. The influence on the acoustics of various architectural elements was also studied. The virtual reconstruction, including some auralisation examples with reconstructed music, was made with the ODEON room acoustic modelling program. From January 2006 the reconstructed concert hall has been open to visitors, albeit in a virtual environment.

The ancient Greek and Roman theatres are famous for their excellent acoustics. However, it is not generally well known that different kinds of theatres with different acoustical conditions were built for different purposes. The method adopted in the EU-project ERATO was to make computer models of the spaces, first as they exist today, and then adjust the acoustical data for surface materials by comparison with acoustical measurements from some of the best preserved examples, namely the Aspendos theatre in Turkey and the South theatre in Jerash, Jordan. The next step was to complete the computer models in accordance with archaeological information, in order to make virtual reconstructions of the spaces. It was 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 times 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 being intended mainly for plays (speech) and the odeon mainly for song and music.

With the advantage of modern computers and room acoustical simulation software, we can nowadays get further information about the theatres by modelling them in a virtual environment. The ERATO project is to provide a virtual reconstruction of the acoustics in the Roman period, both in large open-air theatres and in smaller, roofed theatres. For the first time, this makes it possible to listen to these historical buildings as they sounded in the past.

Computer models

The acoustical models of the theatres in the ERATO project were made using three different software packages at various stages: the ODEON modelling language, IntelliCAD, and 3DStudioMax.

An important source for the reconstruction was the book by Izenour[1], with its suggested reconstructions. However, the building was assumed to be less high than was 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 by previous studies, and the models were previously compared with 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 current remains on site, and then the reconstruction was added to reproduce the odeon as it was originally built (to the extent that this is known). The acoustical simulations were carried out with ODEON 7 acoustical simulation software.

The Aphrodisias odeon as reconstructed has a volume of 20190m^3 and a seating capacity of approximately 1700. The archaeological site is shown in Figure 1. The computer models of this odeon, shown in Figures 2, 3 and 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 in order to determine how the coffered structure influenced the acoustics in comparison with a flat roof, as shown in Table 1. The windows in the real theatre were usually open, but had wooden shutters that could be closed when the weather so dictated. The acoustical effect of closing the windows was also studied.

Theatre Configuration	Acoustical Parameters				
	T30 (s)	G (dB)	C80 (dB)	STI	DL2 (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 and 1000 Hz octave bands for the Aphrodisias odeon with audience, averaged over 15 receiver positions in different configurations.

Simulation results

The simulations in the Aspendos open-air theatre were made with 500,000 rays, and those in the Aphrodisias Odeon with 100,000 rays. The greater number of rays in the open-air theatre was necessary because of the simulated 'open-air' effect, whereby a totally absorptive roof was introduced representing one third of the total surface area.

The theatre models were simulated as fully occupied in order to be able to make comparisons with existing concert halls. Unlike today's halls, Roman theatres had dramatically different acoustics full and empty, because the seats were not upholstered.

In all the simulations the sound sources are omni-directional, and 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 could then be subtracted one at the time from the reconstructed model. The reconstructed model is the 'reference model' in Table 1.

Figure 1

Photo from the archaeological site of the Odeon in Aphrodisias

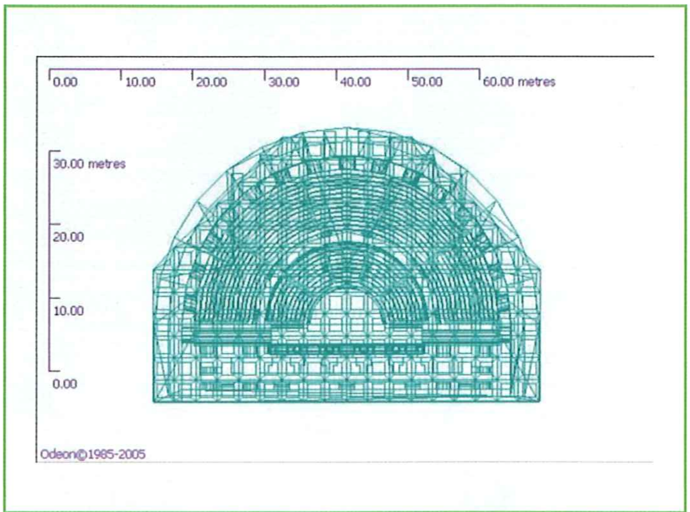

Figure 2

Plan of the reconstructed Odeon

Figure 3

View into the acoustical computer model

The reconstructed model includes a coffered ceiling and open windows. All the simulations in this odeon show similar tendencies, with 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-frequencies and high frequencies the reverberation time of the reconstructed model suggests that it is a room suitable for musical performances.

By closing the windows with wooden shutters a considerably longer reverberation time is obtained: it is not very different from the reverberation times of modern concert halls of similar volume. Linked to the higher reverberation time are an 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. In general it can be stated 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 configurations, making this room a suitable place for both music and spoken word.

Anechoic recordings and auralisation

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 the musical style of the period around the first century CE. Some pieces included solo song and chorus, performed by an ensemble as shown in Figure 6. The newly developed multi-channel auralisation technique was used. This implied that four microphones should be used for the anechoic recordings in order to capture some of the directional characteristics in the recording. The 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 taken all together gives considerable realism.

In the case of the odea the simulations show that the highly reflective rooms with 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 rather than a plane surface. The results were presented in the Forum Acusticum 2005 Conference, Budapest.

Plays

Anechoic sound recordings of a group of ten actors from Yildiz Technical University, Istanbul were made in June 2005. The two Greek dramas *Antigone and Agamemnon*, as well as the sound of an audience crowd in different moods, were played. These performances were recorded with a four microphone setup 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 ODEON software using the following procedure[4]: First the sound source position in the virtual room was placed on the stage, and the source was split into four parts (front, left, back, right) corresponding to the four microphone directions used for the recordings. Then each signal was fed to each part and its contribution to the room calculated separately. Finally a listener position was chosen in the sitting area and all the calculated contributions were added together at this

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position. The sound of the performance in the simulated room can be listened to over headphones and the movements of the actors during their performance can be heard, particularly when the receiver is near the stage.

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 ten people and the capacity of the Odeon was around a 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: applauding, supportive, hostile, crying, laughing, surprised, and idly talking. 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) was generated in the audience area. The anechoic sound signal for a selected emotional reaction of the crowd was fed to each of the sources, and 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 AUDITION software. Using a multi-track set-up, the different crowd reactions were displaced in time, filtered, and finally mixed with the play or music. It was thus possible to fit the reactions of the crowd to the action on stage in the different parts of the play as well as during the music.

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

Conclusion

The simulations show that the highly reflective (marble) surfaces in odea rooms give similar acoustical properties to modern concert halls, even though the only absorption is provided by the audience and the open windows.

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

Acknowledgement

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Figure 4

View into the visual computer model

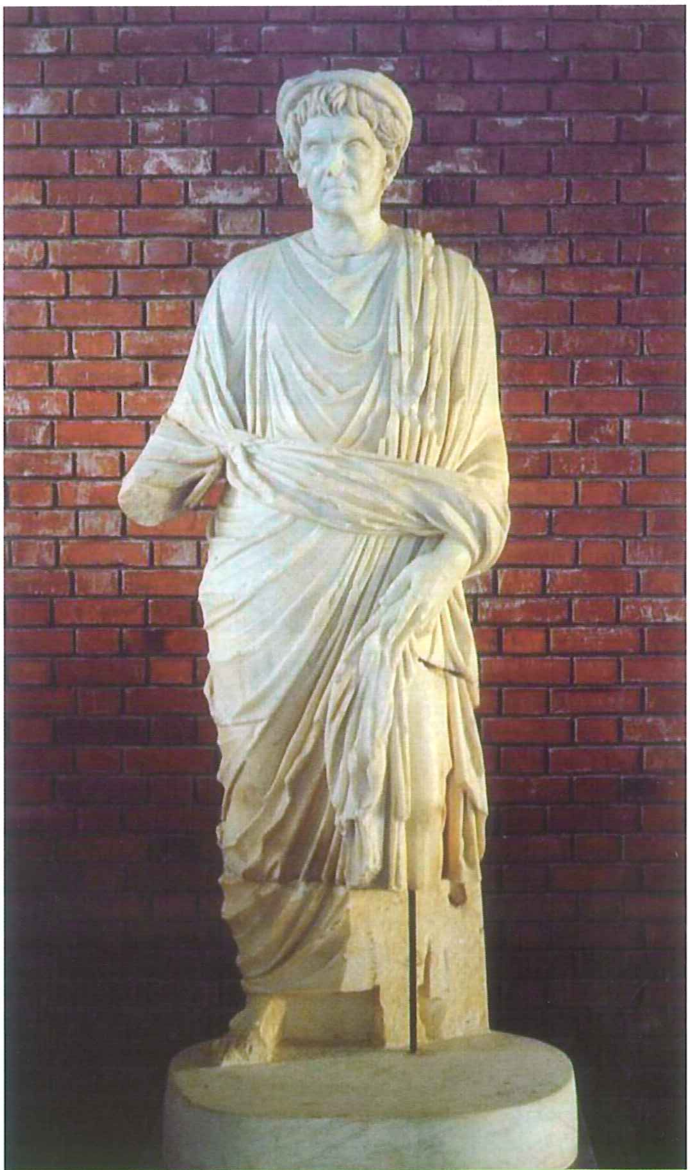

Figure 5

One of the original statues from the Odeon

Figure 6

From the anechoic recording of music with reconstructed musical instruments

Figure 7

View from a performance in the virtual reconstruction of the Odeon in Aphrodisias

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