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The audience effect on the acoustics of ancient theatres in modern use

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ABSTRACT

Ancient theatres are used in modern contexts for different types of shows. When ancient theatres are used for musical performances, the audience criticizes the acoustics due to either not being able to understand what is spoken or the weakness of the music. An important aspect is the presence of the audience in the cavea, with it being important to understand whether it can have a negative role. Since it is not possible to take acoustic measurements during theatre performances, the evaluation of the effects of the presence of the audience on the acoustics is carried out virtually through the software, “Odeon”, in which the presence of the audience is simulated by changing the absorption coefficient value of the cavea

1 Introduction

Nowadays, ancient theatres are used for different types of events such as plays, concerts and opera. The ancient Greek or Roman theatres, that are used for these performances, are the outcome of a long process of excavation and restoration, lasting many years and often resulting in the reconstruction of part of the stage, cavea as well as the perimeter walls. These theatres reached their greatest magnificence during the Roman imperial age, with the cavea being covered with marble and the stage adorned with plasters and columns [1]. Over the centuries, they have been destroyed by earthquakes, looted and even demolished so that the materials could be used to build other palaces, churches, defensive walls and other structures [2]. The ancient theatres have been returned to be the centre of cultural activities during the summer, although many shows are not well received by the critics and audiences due to the weak acoustics. This work aims to analyse the effects on the acoustics of ancient theatres in modern contexts, with the presence of an audience sitting in the cavea [3-4]. The acoustic characteristics were measured in the ancient theatres of Taormina, Pompeii and Benevento. The acoustic measurements were taken without an audience, by placing a spherical omnidirectional sound source on the stage and with the measurement microphones placed on the steps of the cavea, with a constant pitch, in order to obtain the average spatial values of the acoustic characteristics. The measurements were taken according to the ISO (ISO 3382), with the monaural acoustic parameters considered being T_{30}, EDT, C_{80} and D_{50}. For the evaluation of the effects of the audience in the cavea on the acoustic parameters, an architectural acoustics simulation software, "Odeon", was used since it was not possible to take any acoustic measurements during the theatre performances due to the presence of an audience. The software adopts a 3D model of the theatre to be analysed and returns the desired acoustic parameters. The first phase is the calibration procedure. This procedure uses the average value of the T_{30} measured as the referring acoustic parameter and assigns the values of the absorption coefficient to the virtual surfaces of the model. The values of the T_{30} calculated (obtained processing the software "Odeon") therefore coincide with the values of the T_{30} measured. Finally, for the evaluation of the presence of the audience on the acoustic parameters, the values of the absorption coefficient of the audience found in current literature are replaced with the values of the absorption coefficient of the reflective cavea [5-7]. The theatres studied are the Greek-Roman theatre of Taormina, the Greek-Roman theatre of Pompeii and the Roman theatre of Benevento. All three theatres are in the South of Italy. For There are no fully comprehensive studies on the theatre of Taormina. It was built at the end of the third century B.C., with the cavea resting on the hill. The diameter of the cavea is about 110 m, the orchestra pit with an elongated U-shaped plant has a diameter of 35 m, the stage building is 70 m long and 20 m wide. The theatre has undergone renovation and expansion work, with the construction of a summa cavea and stage building connected to the cavea. In the 2nd century B.C., it was transformed into an arena for gladiator shows. Today, the cavea has been partly rebuilt with terracotta bricks. The theatre is used for different types of shows: opera, drama, dance as well as symphonic, jazz and pop concerts. The maximum capacity is about 4,500 spectators. Figure 1.A shows a view of the Greek-Roman theatre of Taormina, while Figure 1.B shows the virtual model created by the architectural acoustics software "Odeon". The theatre of Pompeii was built around the 2nd century B.C. and in part rests on the slope of a hill; its cavea has a diameter of 58 m (divided into ima and summa cavea) and an elongated "U" shaped orchestra pit, with a diameter of 11 m [8]. The stage is 30 m wide and 10 m wide, with a pulpit of 1.0 m high. It was remade for a second time in the Augustan age. The cavea was divided into 3 parts with the stage building with marble and the realization of the summa cavea and the stage that was united to the cavea, creating a closed sideways building. After the earthquake of 62 A.D. it underwent further restoration work which involved the building stage [9]. The theatre was buried in 79 A.D. by the eruption of the Vesuvius and was unearthed in 1739. In recent decades, the theatre has been used for various events and shows. Since the cavea was made of grass and hard court, some wooden planks were placed on metal supports fixed to the cavea covered with earth and grass so as to allow to the audience to watch the performances until 2009. The theatre has recently been substantially renovated, which was completed in 2010 and affected the whole cavea, that was covered in squared tuff blocks, steps with a height of 0.40 m and depth of 0.70 m; with a maximum capacity of about 1,800 spectators. The theatre is currently used during the summer. Figure 2.A shows a view of the Greek-Roman theatre of Pompeii, while Figure 2.B shows the virtual model created by the architectural acoustics software Odeon.

Figure 1. (A) View of the Greek-Roman theatre of Taormina.

The theatre of Benevento was built in the imperial age, during the Trajanic period, inaugurated in 126 A.D. and enlarged by Caracalla between 200 and 210 A.D.. It could originally contain over 10,000 spectators, with a semi-circular orchestra pit of 30 m in diameter, a cavea of 98 m in diameter (divided into ima and summa cavea), a stage 44.2 m long, 3.5 m wide and about 1.50 m above the orchestra pit. The theatre was abandoned after the barbaric invasion. The materials were used to build the city walls as well as decorate churches and palaces. Over the centuries, some houses were built in the cavea and then demolished in 1930 so as to rebuild the cavea and a part of the columns of the stage building. Only the church (Santa Maria della Verità) built in 17th century, over a part of the cavea, has survived.

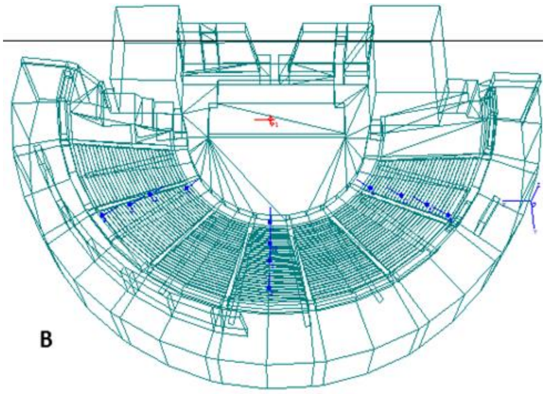

Figure 1. (B) Virtual model in Odeon

Figure 2. (A) View of the Greek-Roman theatre of Pompeii.

The ima cavea was rebuilt with terracotta bricks, while the summa cavea was only partially rebuilt and cannot be accessed by the audience. The theatre began to be used for events in the 1950s. Fifteen steps, with a height of 0.40 m and depth of 0.70 m [10] remain of the Roman theatre. The theatre is used for different types of shows: opera, drama, dance as well as symphonic, jazz and pop concerts.

During the annual national cultural meeting "*Benevento città spettacolo*", the theatre becomes the centre of the most important performances including comedy, drama and musical shows, with the maximum capacity of about 1,800 spectators. Figure 3.A shows a view of the Roman theatre of Benevento, while Figure 3.B shows the virtual model created by the architectural acoustics software Odeon

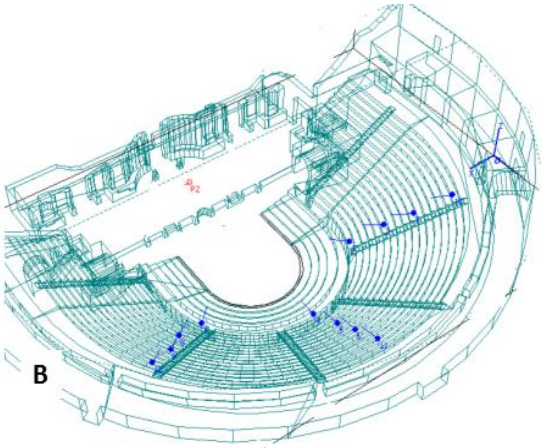

Figure 2. (B) Virtual model in Odeon

2 Acoustic measurements

The acoustic characteristics were measured on site by placing an omnidirectional sound source on the stage (actor's position). The sound source used to carry out the acoustic measurements consisted of a dodecahedron loudspeaker, Peeker Sound JA12 (Peeker Sound Corporation, Reggio Emilia, Italy) a power amplifier KT 150. MLS signals of order 16 with a length of 5 seconds were generated by a 01 dB Symphonie system. The impulse responses were detected by a microphone type GRAS 40 AR ½". The sound source height from the floor was 1.60 meters; the microphone height was 1.0 meter. The theatres were empty.

Figure 3. (A) View of the Roman Theatre of Benevento.

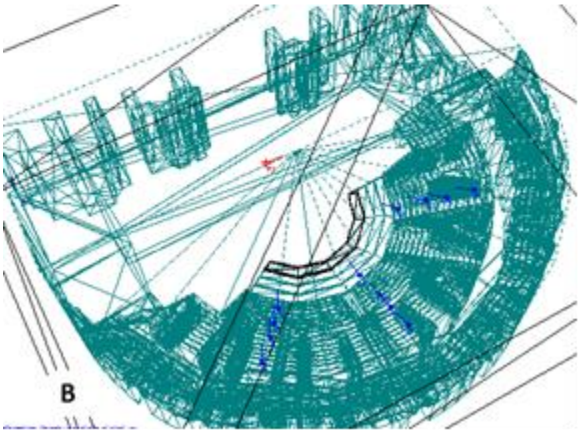

Figure 3. (B) Virtual model in Odeon

The impulse responses were analysed with the software Dirac 4.0. The microphone receivers were placed on the steps of the cavea with a fixed pitch along three radial directions, one central and two laterals, in order to obtain the average spatial values of the acoustic characteristics of the theatres. The acoustic measurements were carried out with the method of the impulse response, the monaural acoustic parameters analysed in accordance with the ISO (ISO 3382, 2012): are T_{30}, EDT, C_{80} and D_{50}. Then, the average values of the reverberation time T_{30} in octave bands from 125 Hz to 4000 Hz were reported. Figure 4 shows the average value of T_{30} measured in the Greek-Roman theatre of Taormina [11]. The average value of T_{30} measured in the Greek-Roman theatre of Pompeii and the average value of T_{30} measured in the Roman theatre of Benevento. Upon analysing the results, it is possible to note a low value of the reverberation time not greater than 1.0 second. This low value of the reverberation time is due to the absence of the walls of the stage house (which are only partially present). The cavea is in part reconstructed and the surfaces of the cavea are covered with terracotta bricks and for this reason have a sufficiently high value of the absorption coefficient, the summa cavea is partially reconstructed too [12]. The low value of the reverberation time is the main cause of the dissatisfaction of the audience that watches the performances.

3 Virtual Models

The Odeon software imports a virtual model realized by 3D CAD. The virtual models were designed in 3D on the geometric measurements obtained from measurements on site. Odeon uses a hybrid method of images plus ray-tracing [13].

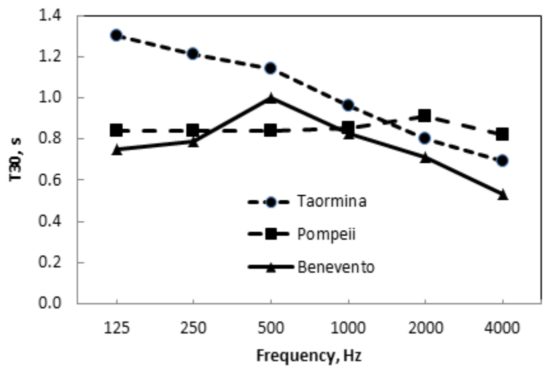

Figure 4. Average value of T30 measured in theatres of Taormina, Pompeii and Benevento.

The reflections take into account the scattering properties of the surfaces. A computer software simulation requires a first step aimed at the development of a model of the space as it exists and for which acoustic measurements are available. Unavoidable approximations about the geometry and the acoustic behaviour of the materials must be dealt with. This is seldom a straightforward operation. A second step consists of comparing the measured quantities with analogous calculated quantities. If the difference is unsatisfactory, a suitable calibration of the acoustic model is carried out in order to reduce the difference to a reasonably low value. Based on previous experience, the calculations were carried out by fixing set-up parameters: TO = 2 (transition order); impulse response length = 3,000 ms with a resolution = 3.0 ms; number of late rays = 100,000 and other parameters with values suggested by the default of Odeon. The acoustic model calibration is the first step and is made by setting the absorbent coefficient values for all the virtual model surfaces and the scattering coefficients. The scattering coefficients are related to the geometrical characteristics of the surfaces and not to the frequency; for this reason the seats were simulated considering an unoccupied condition with a scattering coefficient s=0.7. When at each octave band frequencies (125 Hz – 4000 Hz), the calculated and measured reverberation time value (T_{30}) are the same, the calibration is stopped. The virtual receiving points were positioned in the cavea, along three radial directions with a fixed pitch, with a virtual point sound source being placed on the stage to simulate the voice of an actor, since this is the most commonly used configuration. The theatres are open, since there are no ceilings, a box closed the virtual model with an absorbent coefficient, at all frequencies, equal to 1.0. For each theatre, after the calibration (the calculated values of T_{30} coincided with the measured values of T_{30}), the monaural acoustic parameters analysed are: T_{30}, EDT, C_{80} and D_{50}. After the calibration procedure, the values of the absorption coefficient of the audience in the cavea were considered. These values have been reported in current literature [14, 15, 16, 17, 18]. Table 1 shows the audience absorption coefficient used in the virtual model. In the virtual models, the absorbent coefficients of the terracotta bricks of the cavea have been replaced with the absorbent coefficients of the audience. The comparison between the average acoustic parameters obtained through a numerical simulation when the cavea is empty and with the presence of an audience are reported in Figure 5 (A, B, C, D). For the theatre of Taormina. In Figure 6 (A, B, C, D) for the theatre of Pompeii. In Figure 7(A, B, C, D) for the theatre of Benevento.

Frequency, Hz	125	250	500	1000	2000	4000
Audience	0.51	0.64	0.75	0.80	0.82	0.78

Table 1. Audience absorption coefficient used in the virtual model

4 Discussion

The numerical simulations were performed both with empty theatres as well as in the presence of an audience. The results of the two configurations were then compared. The more reflective and diffusing surfaces (remains of the building stage, the stage, the walls around the stage and the orchestra pit) were not changed between the condition with and without the audience. Analysis of the numerical simulations (reported for the theatre of Taormina in Figures 5 and for theatre of Pompeii in Figure 6) shows that for these theatres, the presence of the audience has a significant influence on the average values of the acoustic parameters. The area occupied by the audience is 70-80 % of the entire area of the cavea. The greatest effect is for the energy descriptors at low frequencies, especially for EDT.

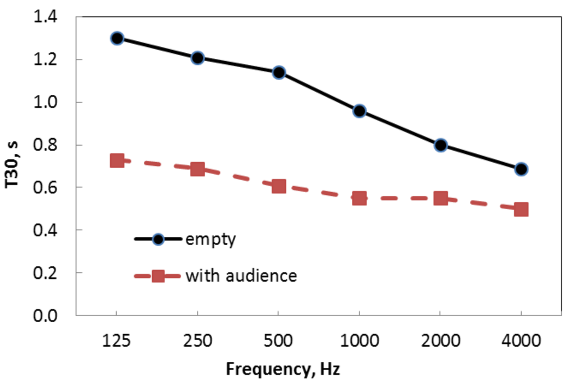

Figure 5 A. Theatre of Taormina, T_{30} values

In fact, this parameter evaluates the first energy reflected by surfaces. The T_{30} values are very low and the absence of significant sound reflections results in either poor music quality or the voice of the actors on the stage not being understood, with the consequent dissatisfaction of the audience. For the theatre of Benevento (Figure 7), the differences are appreciable in the medium frequency bands, the variation of the absorption coefficient caused by the presence of the audience is relatively small. For safety reasons related to the fire escapes, the area occupied by the audience is only about 50 % of the entire area of the cavea.

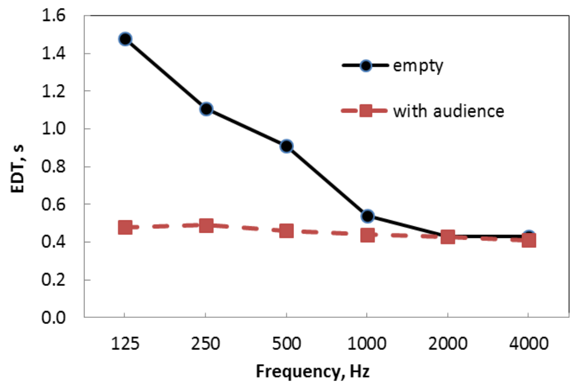

Figure 5 B. Theatre of Taormina, EDT values

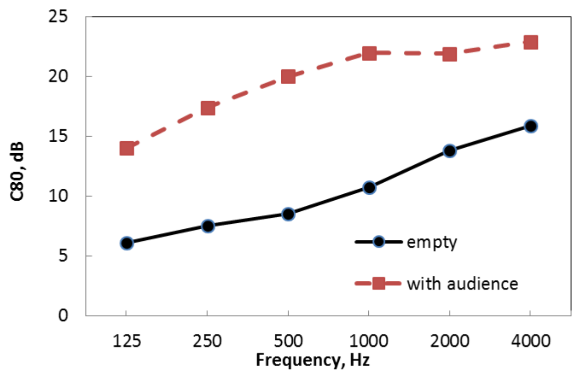

Figure 5 C. Theatre of Taormina, C_{80} values

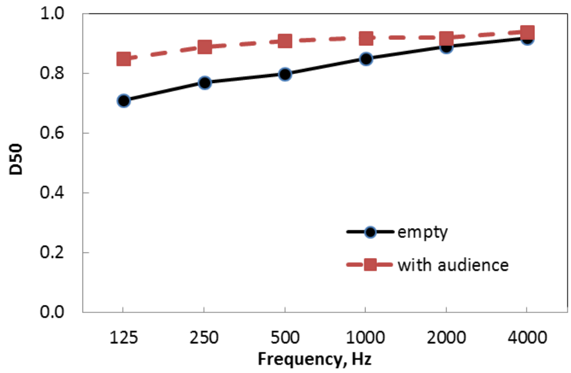

Figure 5 D. Theatre of Taormina, D_{50} values

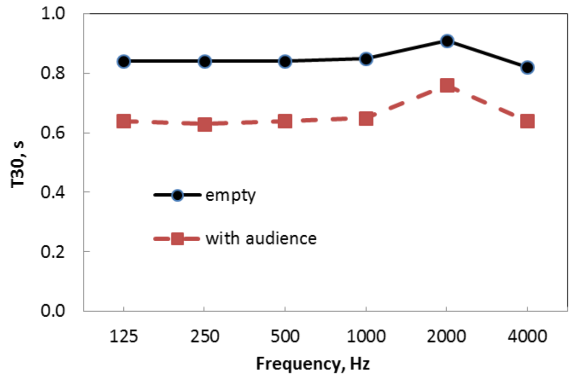

Figure 6 A. Theatre of Pompeii, T_{30} values

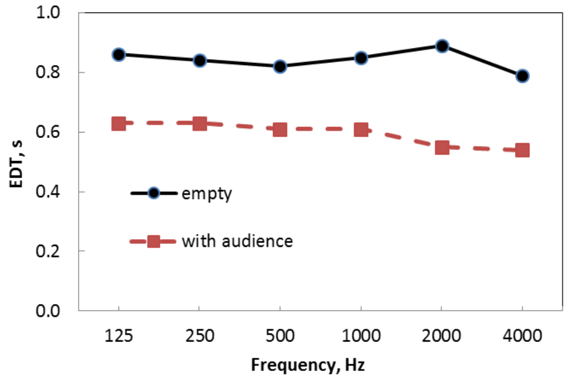

Figure 6 B. Theatre of Pompeii, EDT values

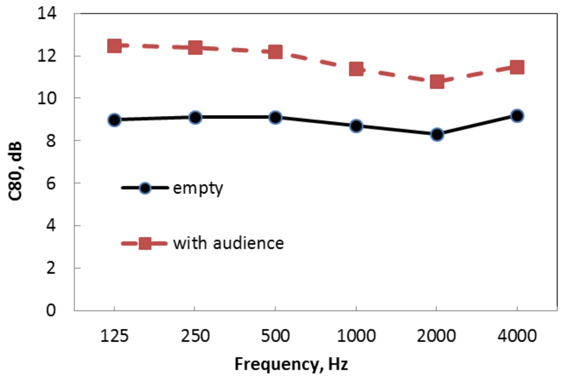

Figure 6 C. Theatre of Pompeii, C_{80} values

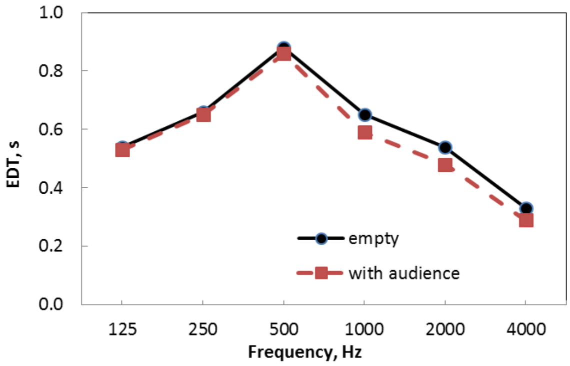

Figure 7 B. Theatre of Benevento, EDT values

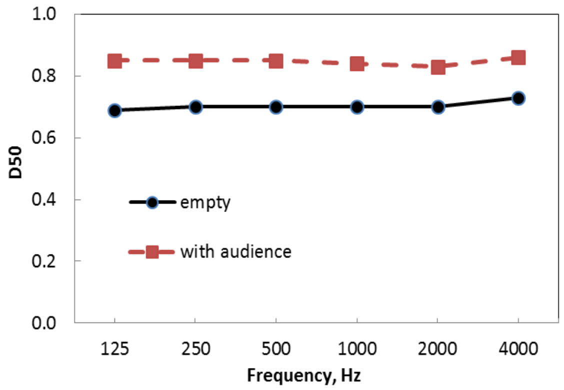

Figure 6 D. Theatre of Pompeii, D_{50} values

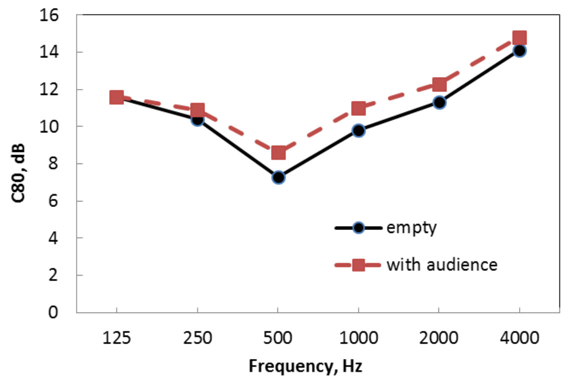

Figure 7 C. Theatre of Benevento, C_{80} values

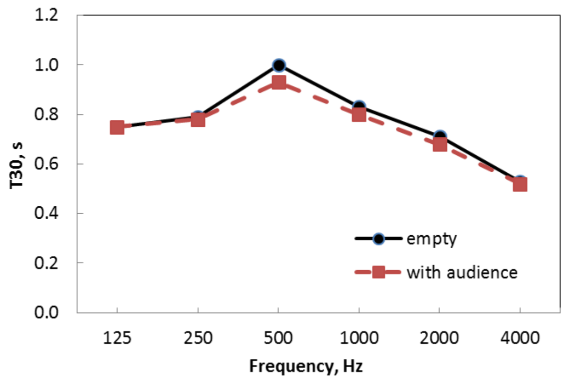

Figure 7 A. Theatre of Benevento, T_{30} values

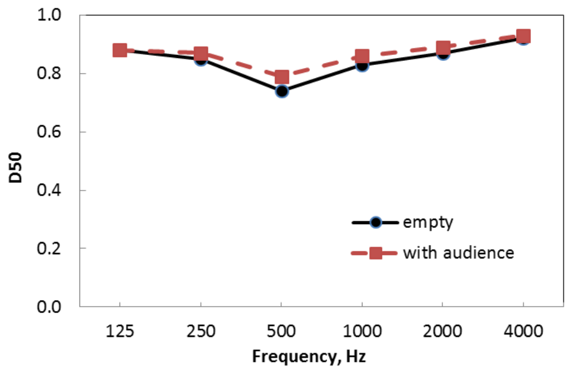

Figure 7 D. Theatre of Benevento, D_{50} values

5 Conclusion

The analysis of the numerical simulations shows that the influence of the audience on the acoustics of theatres varies depending on the geometry of the theatre as well as the area of the cavea occupied by the audience. For the theatres of Taormina and Pompeii, there is a depletion of the energy in the first part of the impulse response especially at low frequencies due to the presence of the audience. In fact, the EDT values are very low. The theatres studied have acoustics equal to those of other ancient theatres with a similar state of preservation and whose main features are the clarity and scarcity of the reverberating reflected field. The live music of a symphony or classical orchestra or even a soloist is not substantially supported by the acoustics of these theatres.

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