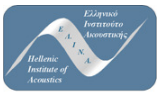

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ECHO PROBLEMS IN ANCIENT THEATRES AND A COMMENT TO THE 'SOUNDING VESSELS' DESCRIBED BY VITRUVIUS

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Abstract

Ancient Greek and Roman theatres are often considered acoustically perfect. However, the semicircular shape of the audience area in theatres built from hard and sound reflective materials may cause acoustic problems, and there is also evidence that the ancient architects were well aware of this. The Roman architect Vitruvius describes in his books on architecture four different kinds of sound reflections in a theatre, one of them called 'circumsonant' which is an acoustic phenomenon that we today would name a focused echo. Computer simulations of some examples of ancient Greek and Roman theatres confirm that this can be a real problem at some places in the audience area. For this study is used the echo criterion for speech as suggested by Dietsch & Kraak; this is implemented in the room acoustics software ODEON, and that makes it easy to identify positions with echo problems. A possible solution to these echo problems could be the introduction of sound absorption in the vertical, concave surfaces in a way similar to that described by Vitruvius for the sounding vessels, i.e. in niches between the seats arranged in a horizontal range halfway up. Reading the description by Vitruvius in this light, it makes good sense if the vessels are supposed to act as sound absorbing resonators. Since they are efficient in a narrow frequency band, it also makes sense to apply different sizes with resonance frequencies distributed over two octaves, as described in detail by Vitruvius. Finally, it is noted that the principle of installing the sounding vessels in the theatre comes from older Greek references; obviously Vitruvius had no experience with the vessels himself, but he refers to a scheme based on music theory made by Aristoxenus (4th century BC), who was a famous Greek philosopher and expert in music theory.

Keywords

Ancient theatre, focused reflection, echo, sounding vessel.

1. Introduction

In his famous books on architecture, the Roman architect Vitruvius has provided detailed information in book V about the design of theatres, in the Greek style as well as in the Roman style [1, 2]. However, there is no evidence that he himself has been involved in any theatre building; the information seems to be based on older, mainly Greek writings on architecture.

2. Sound reflections in the theatre

2.1 The knowledge of sound reflections in ancient times

Vitruvius describes four different kinds of sound reflections in a theatre [1, Book V.viii.1]; the Greek terms are quoted, and in translation they are named 'dissonant', 'circumsonant', 'resonant', and 'consonant'. He further explains [1, Book V.viii.2]: "The circumsonant are those in which the voice spreads all round, and then is forced into the middle, where it dissolves, the case-endings are not heard, and it dies away there in sounds of indistinct meaning. The resonant are those in which it comes into contact with some solid substance and recoils, thus producing an echo, and making the terminations of cases sound double."

The reflection called 'circumsonant' seems to be the focusing effect from concave surfaces. Although the description is not very clear, it is obvious that the focusing effect increases the risk of echo problems.

2.2 Echo in the theatre

In order to study the possibility of echoes in a typical Roman theatre, the room acoustic computer model ODEON version 11 is used. The theatre chosen for this study is the reconstruction of the Roman theatre in Aspendos [3], see Fig. 1.

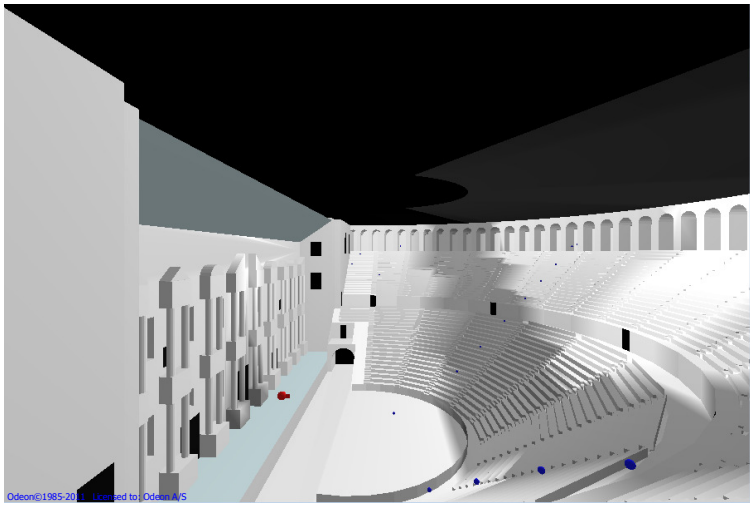

Figure 1 – Computer model of the reconstructed Aspendos theatre.

With the source near the centre of the stage at a height of 1.5 m above the stage floor, the early reflections are shown for a receiver position in the orchestra (height 1.2 m) in Fig. 2, and for a receiver in a rear position to one side in Fig. 3. The focusing of reflections from the concave seating arrangement is clearly seen in Fig. 2, but there are also reflections from the concave diazoma via the canopy above the stage, and late reflections from the colonnade surrounding the theatre. The calculated impulse response in the latter position shows a clear echo, see Fig. 4.

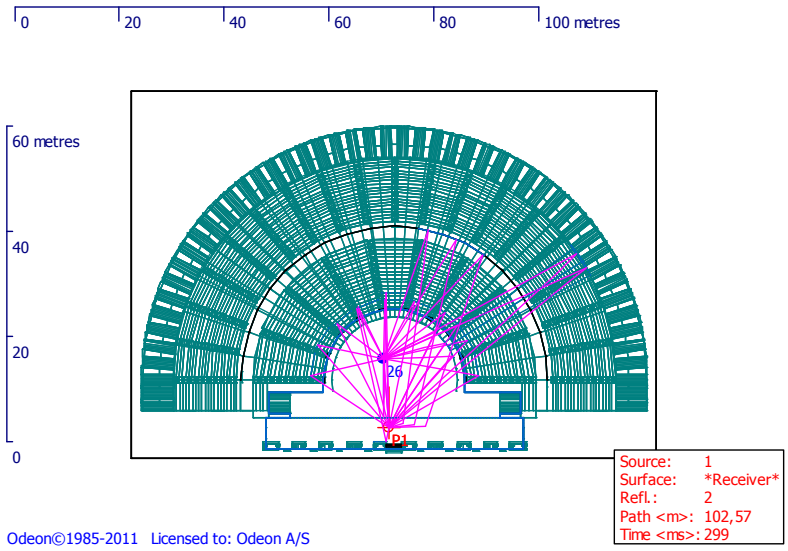

Figure 2 – Early reflections from the stage position to a receiver in the orchestra.

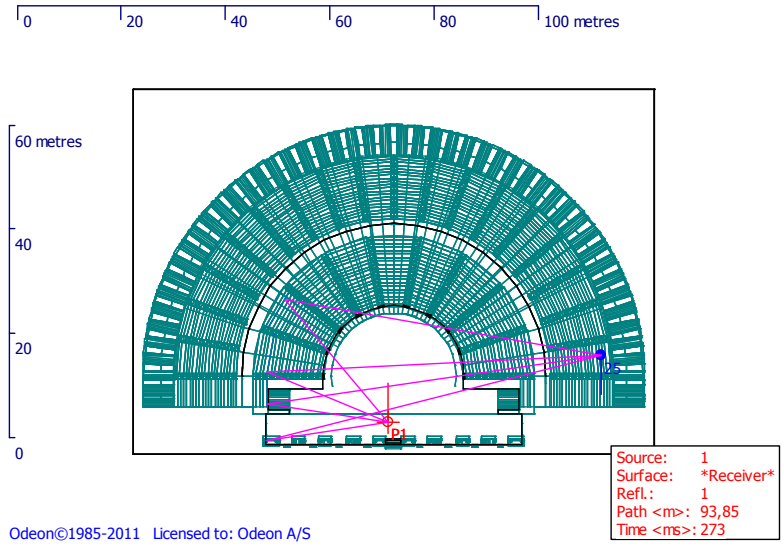

Figure 3 – Early reflections from the stage position to a receiver a rear side position.

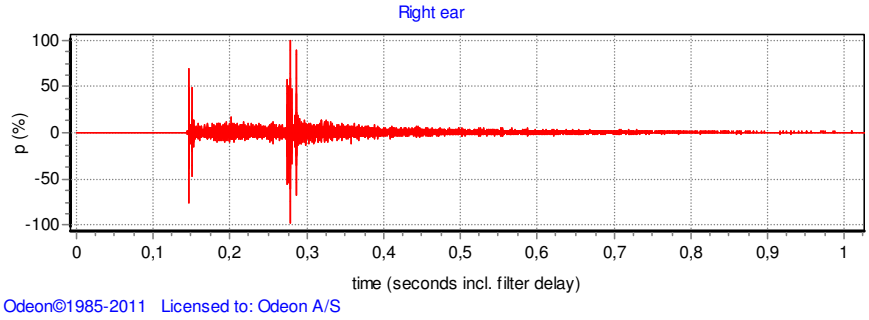

Figure 4 – Calculated impulse response in the receiver position from Fig. 3.

In order to make it possible to locate positions with echo problems, the echo criterion suggested by Dietsch & Kraak [4] has been implemented in ODEON version 11. As an example Fig. 5 shows the echo-curve in the same position as the impulse response in Fig. 4. The echo parameter has a value above 1.0, which means that more than 50% would evaluate this as a clearly audible echo when listening to speech.

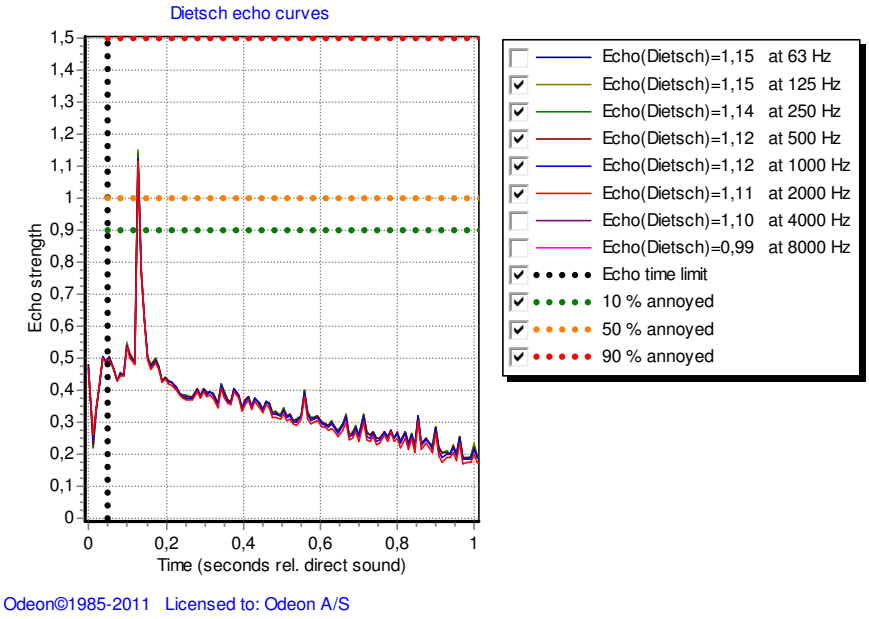

Figure 5 – Echo criterion curves for the same position as in Figs. 3 and 4.

Fig. 6 shows a calculated grid mapping of the echo parameter at 1 kHz. Echo is mainly seen in the orchestra close to the stage, but there are also a few places at the outmost sides of the audience area. However, in general there are only few seats in the audience area with a risk of echo.

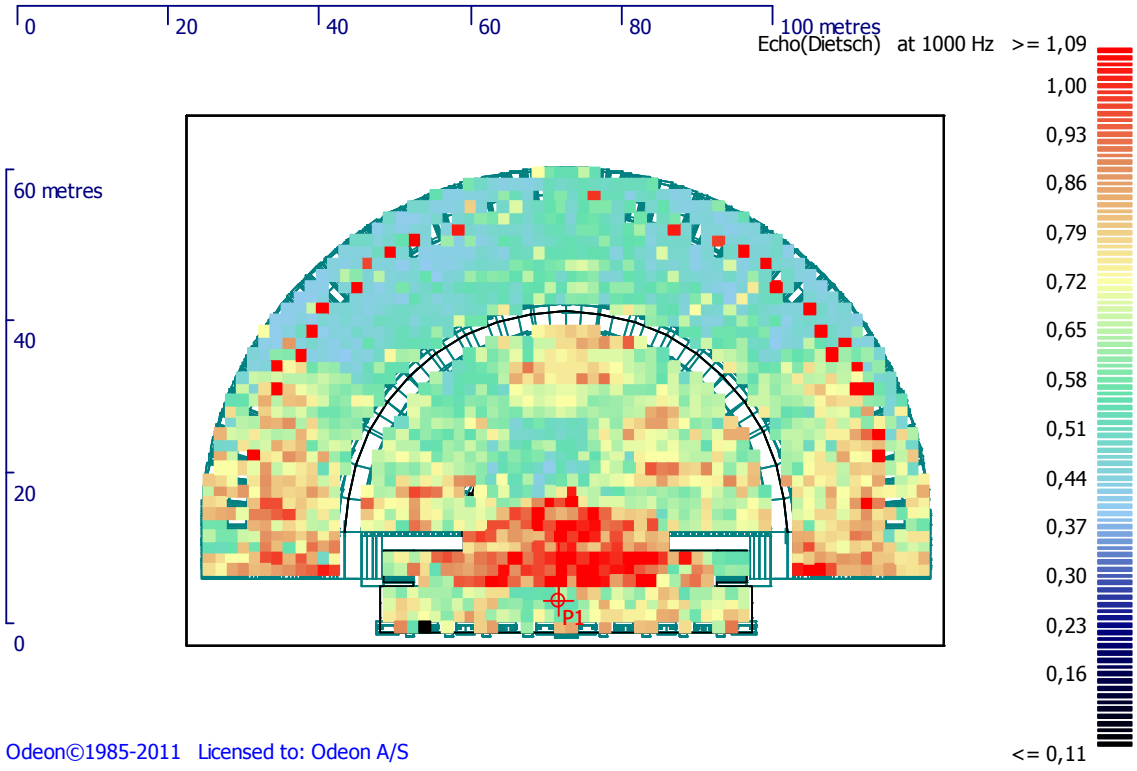

Figure 6 – Grid mapping of echo criterion at 1 kHz with the source on the stage.

3. Vitruvius and his books on architecture

3.1 The author and his background

Marcus Vitruvius Pollio was a Roman architect and engineer, known today as the author of ”The ten books on architecture” [1, 2].

The exact years of his birth and dead are unknown. However, he mentions in the preface of the books that he had served under Julius Caesar during wars. If he means the Gallic wars (58-51 BC), Vitruvius cannot have been born much later than 80 BC. He mentions that he served to supply and repair ballistae, scorpiones, and other artillery [1, Book I.preface.2].

The books were written over a long time, dedicated to the emperor Augustus and probably finished c. 16-13 BC [5, p. 186]. He draws extensively on older, mainly Greek, writings on architecture and building technology, none of which exists today [1, Book VII.introduction.1]:

” It was a wise and useful provision of the ancients to transmit their thoughts to posterity by recording them in treatises, so that they should not be lost, but, being developed in succeeding generations through publication in books, should gradually attain in later times, to the highest refinement of learning. And so the ancients deserve no ordinary, but unending thanks, because they did not pass on in envious silence, but took care that their ideas of every kind should be transmitted to the future in their writings.”

[1, Book VII.introduction.14]:

"... From their commentaries I have gathered what I saw was useful for the present subject, and formed it into one complete treatise, and this principally, because I saw that many books in this field had been published by the Greeks, but very few indeed by our countrymen."

Concerning his own experience as an architect he mentions, that he superintended the basilica in Fana, Italy [1, Book V.i.6]. This is the only building that we know Vitruvius has actually worked on.

3.2 The development of theatre design in the first century BC

As a background for evaluation of the description of theatre design in the fifth book of Vitruvius, it is interesting to look at the development of theatre design in the first century BC.

In Rome it was not allowed to build permanent theatres for political reasons; instead smaller, temporary theatres were built of wood. The first permanent (masonry) theatre in Rome was built 61 – 55 BC by Pompejus on his private property and he claimed that it was a temple, not a theatre - hence the small Venus temple in the top rear of the audience area. It had room for about 17 000 people. The Marcellus theatre was the second permanent theatre in Rome, inaugurated in 13 or 11 BC, but it had already been used for a feast in 17 BC. It seated about 15 000 people. Probably Vitruvius had finished his books before the Marcellus theatre was inaugurated.

In Pompeii a lot of building activity started after it was made a Colony in 80 BC. In addition to the older Hellenistic theatre from 3rd – 2nd century BC, two completely new types of Roman building were erected in Pompeii: The Odeum (lat. Teatrum tectum) for song and music (around 75 BC), and the amphitheatre for gladiator fights and entertainment with wild animals (probably around 70 BC) [5, p. 174, 177]. The odeum was relatively small and surrounded by thick walls to carry the roof covering both auditorium and stage. Both new buildings were erected by Quinctius Valgus and Marcus Porcius, and both building types became very popular in the following centuries as a supplement to the theatre, the odeum in many Roman cities all over the empire, and the amphitheatre in the western part of the empire, only.

"While the Romans built amphitheatres side by side with the theatres, the Greeks built music halls or auditoria even in remote parts of the Greek world during the imperial period." [5, p. 222]

In Rome the gladiator fights originally took place in the Forum [1, Book V.i.1], but in 29 BC they were moved to an amphitheatre built from wood. However, this burnt down in AD 64. Later the Flavian Amphitheatre (Colosseum) was built AD 75 – 80. Only one odeum was built in Rome by Domitian in AD 86. While the wooden amphitheatre existed when Vitruvius wrote his books, both the Colosseum and the odeum came much later.

But in the provinces outside Rome many theatres were being build. For example the city of Aosta in Northern Italy was founded by Augustus in 24 BC, and both an odeum and an amphitheatre were among the public buildings [6].

On this background it is remarkable that the odeum as a building type is not mentioned at all by Vitruvius, and the amphitheatre is mentioned only once in connection with the sites for temples [1, Book I.vii.1]: "Apollo and Father Bacchus near the theatre; Hercules at the circus in communities which have no gymnasia nor amphitheatres".

The question is: Was Vitruvius up-to-date in theatre design? No, obviously not. He relies heavily on older, mainly Greek descriptions.

4. The mystery of the 'sounding vessels'

4.1 The purpose

The so-called sounding vessels described by Vitruvius have given rise to many speculations, because it is not very clear what should be the purpose for the acoustics of the theatre. They were obviously acoustic resonators, but today we know that the effect can either be sound absorption or sound radiation, depending on the internal losses of the resonator.

The vessels in the theatre are mentioned several times by Vitruvius, first in book I [1, Book I.i.9]:

"In theatres, likewise, there are the bronze vessels (in Greek ηχεια) which are placed in niches under the seats in accordance with the musical intervals on mathematical principles. These vessels are arranged with a view to musical concords or harmony, and apportioned in the compass of the fourth, the fifth, and the octave, and so on up to the double octave, in such a way that when the voice of an actor falls in unison with any of them its power is increased, and it reaches the ears of the audience with greater clearness and sweetness."

The explanation of the purpose in book V [2, Book V.v.3] reads in the original Latin:

"ita hac ratiocinatione vox a scaena uti ab centro profusa se circumagens tactuque feriens singulorum vasorum cava excitaverit auctam claritatem et concentu convenientem sibi consonantiam."

- which is, in the translation by Bill Thayer [2]:

"By the adoption of this plan, the voice which issues from the scene, expanding as from a centre, and striking against the cavity of each vase, will sound with increased clearness and harmony, from its unison with one or other of them."

In both quotations it is said that the purpose is to increase the clearness, not the strength. Thus this is the opposite of creating reflections that might increase the reverberance. The description could make some sense if the vessels are meant for sound absorption. The position of the vessels should be under the seats, i.e. in the concave semicircle that can create focusing reflections, and thus the sound absorption by the vessels will attenuate the reflections that might cause an echo problem.

Today it is well known that sound absorption is possible with Helmholtz resonators. However, they are only efficient in a narrow frequency bands, and so it also makes sense to apply different sizes with resonance frequencies distributed over two octaves, as described in detail by Vitruvius. This may correspond to the frequency range 220 – 880 Hz [7], which reference contains a thorough analysis of the frequencies of the vessels in relation to the ancient Greek musical system developed by Aristoxenus.

Another remark from Vitruvius that is interesting in this connection is in [1, Book V.v.7], where he says that there is no need for the sounding vessels in the wooden theatres that were built every year in Rome, because the boarding itself is resonant - "But when theatres are build of solid materials like masonry, stone or marble, which cannot be resonant, then the principle of the "echea" must be applied." As we know today, the low frequency absorption can be obtained with panel absorbers, which may be more efficient than the rather small number of Helmholtz resonators that has been recommended.

4.2 The origin of the sounding vessels – Aristoxenus

Concerning the principle behind the sounding vessels and the musical scales used for the tuning, Vitruvius refers to the ancient Greek music theoretician and philosopher Aristoxenus [1, Book V.v.6]. He lived in Athens around 350 BC, was a pupil of Aristoteles, and wrote a large number of treatises on topics within music, ethics and philosophy. His theory on musical scales was in opposition to the one by Pythagoras based on mathematical principles. Aristoxenus claimed that the superior evaluation of musical intervals should be made by the human ear. He said that we evaluate the size of the intervals by the ear, and the properties by the brain. In fact he suggested the equally tempered scale more than two thousand years before this scale became generally accepted in the 18th century.

4.3 Where did they exist?

The evidence of the existence of sounding vessels in theatres is very sparse. Obviously Vitruvius has never seen them himself, but he refers to [1, Book V.v.8] "the districts of Italy and in a good many Greek states. We have also the evidence of Lucius Mummius, who, after destroying the theatre in Corinth, brought its bronze vessels to Rome". It is a fact that Lucius Mummius was a Roman general who conquered Corinth in 146 BC, demolished the city and brought lots of treasures to Rome. The theatre was a Hellenistic theatre from the 3rd century BC [8]. The time and location of this theatre fit quite well with those of Aristoxenus, see above.

Izenour has described the existence of nine equally spaced cavities located behind the diazoma in the ruins of a Roman theatre in Beth Shean, Israel [9, p. 39-40]. Although the number should have been 13 according to Vitruvius, and not only nine, Izenour has shown in sketches how the vessels might have been installed in the cavities.

In 1958 some clay vessels were found when a theatre was excavated in Nora, Sardinia. The site was visited by Dr. Brüel, who made a photo of the vessels together with other observations [10, p. 18]. However, he concludes that from the findings there is nothing making it likely that the vessels have improved the acoustics of the theatre in any way.

So, the sounding vessels have actually existed in some theatres, but only very few and seldom cases. In the vast majority of Greek and Roman theatres the sounding vessels were not used.

5. Conclusion

Echo problems can occur in certain places in the ancient theatres, particularly in the orchestra area due to the focusing effect of the concave shaped steps of seats. In this respect the diazoma is particularly important because of the higher wall, and this is precisely where the sounding vessels described by Vitruvius should be installed.

From careful reading of the description given by Vitruvius, and collection of information from excavated theatres, the following is concluded:

- The idea and the guidelines for the sounding vessels goes back to Aristoxinus in the 4th century BC, in those days an outstanding capacity in music theory,
- The purpose might have been to attenuate sound reflections from a concave surface that could create a focused echo,
- The sounding vessels could not possible make any improvement to the acoustics in practice,

- Only very few theatres had the sounding vessels installed; in general they were not used, neither in Greek nor in Roman theatres.

References

[1] M. Vitruvius, "The ten books on architecture", 1st century BC, translated by Morris Hicky Morgan (Harvard University Press, 1914), reprint by (Dover Publications, New York, 1960).

[2] http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Vitruvius/home.html, Vitruvius, "The ten books on architecture", 1st century BC, Original text in Latin and English translation by Bill Thayer.

[3] J.H. Rindel, "The ERATO project and its contribution to our understanding of the acoustics of ancient theatres", Proceedings of the Acoustics of Ancient Theatres Conference, Patras, Greece, 2011.

[4] L. Dietsch, & W. Kraak, "Ein objektives Kriterium zur Erfassung von Echostörungen bei Musik- und Sprachdarbietungen" (in German). Acustica **60** , 205-216 (1986).

[5] Margarete Bieber, "The history of the Greek and Roman theater", Second Edition (Princeton University Press, 1961, 1971).

[6] F. Corni, "Aosta Antica – Aoste Antique, La città romana – La cite romaine" (In Italian, French translation by A. Perrin), (Tipigrafia Valdostana, Aosta, Italy, 2004).

[7] A. Barba Sevillano, R. Lacatis, A. Giménez, J. Romero, "Acoustics vases in ancient theatres: disposition, analysis from the ancient tetracordal musical system", Proc. of Acoustics'08, Paris, 2008, 4155-4160.

[8] R. Frederiksen, "Typology of the Greek Theatre Building in Late Classical and Hellenistic Times." Proceedings of the Danish Institute at Athens - III, S. Isager & I. Nielsen (ed.). Athens, 2000, 135-175.

[9] G.C. Izenour, "Theater Design", (McGraw-Hill, New York, 1977).

[10] P.V. Brüel, "Episodes and Achievements within Acoustics before 1954" (In Danish). Danish Acoustical Society, 2005.