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THEATRE DESIGN IN ANCIENT TIMES: SCIENCE OR OPPORTUNITY?

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Abstract

An accurate analysis both of the acoustical knowledge in ancient times and of the layout of Greeks and Roman Theatres, jointed with some historical background about people behaviour, seems to put in evidence that in ancient Greek times the design of theatres was based on ideas other than acoustical reasons in the strict sense we give today to the design of a cavea for theatrical performances. In Roman times some important modifications were fitted in the original Greek design, but again the onset of the reverberation seems more a consequence of other targets than a goal to met better acoustical conditions for the audience.

This paper will present some ideas supporting the up mentioned conclusions.

Keywords

Acoustical Field, Sound Perception, Theatre design

1. Introduction

Papers dealing with the acoustical quality of ancient and pre-Sabinian theatres generally enhance the skill of the architect in getting the structure ready to offer a good acoustical quality, even if it is not possible to find any document on this subject: the only one in ancient age is the famous Vitruvius' *De Architectura* [1] that, anyway, gives only general acoustical reasons.

So, if one likes to understand if there was some particular scientific thought under the design of Greek and Roman theatres, it is necessary to try to "read" it on the stones. Moreover, the same happens for the theatres of the European renaissance, when treatises bring sentences not acoustically justified, see for instance [2].

Following the publication of the classical Sabine's paper [3], many theatres and Auditoria where erected on the basis of the optimal value of reverberation time, and only with the Beranek's classical work [4] some clear rule was stated, bringing again at the right place the relevance of the geometrical study of the shape of the *cavea*.

Now in the computer age, when instruments are able to calculate any kind of objective parameter, the acoustics of quite any kind of shape can be adjusted by reflecting surfaces, clouds, a keen choice of materials and, last but not least, a good amplification system: so we have loosed the origin of the architectural design, that is to say pencil, ruler and square.

These where the only available instruments to Greeks, Romans and meddle age architects, till to the Piermarini and Galli Bibiena age: while in [5] some geometric aspect in a typical Italian Opera House was investigated in a strict link with the results of modern measurements, here some aspect of the design of the ancient theatres will be explored with the aim to discover their acoustical reasons in the frame of their acoustical background.

2. Location

In a previous paper [6] the problem of the choice of the site and the orientation of ancient theatres in the south of Italy was faced and it was clearly shown that the rising wind in the afternoon seemed to be useful to get a better understanding of words, even if this rising effect was not so big: may be it was enough to bring sound upper the heads' line and so avoiding the grazing absorption due to audience' hairs.

In short, a little research was made on the theatres built in the south of Italy during the period 330-50b.C. [7]: figure 1 shows the exposition related to the sunrise and sunset in the south Italy and (below) in Sicily. As we can see, the facing choice was firstly based on view reasons., in particular in south of Italy, where we found that attendants were not disturbed from sun in front, while in Sicily the preferred exposition claims for sun heating the terrace of the *cavea* in the first afternoon, may be a little time before attendants will be present.

This second choice allows to have some late afternoon rising wind along the terrace, or *cavea*, so to rise up sound rays just as necessary to reduce the absorbing effect from audience' hairs.

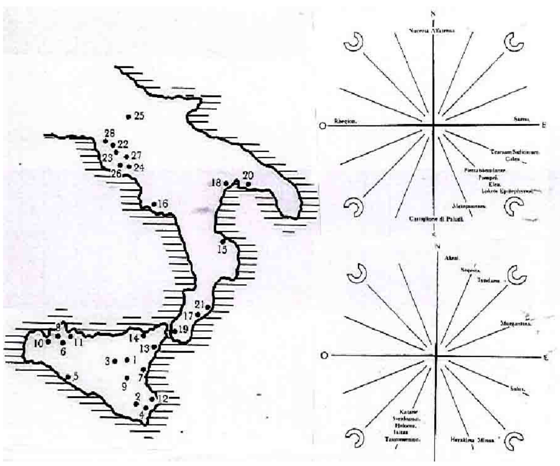


Figure 1 – Location of some Greek and Roman Theatres in the south of Italy and Sicily

The majority of them are oriented so the audience is in front of the sea, and it is well known that in the afternoon some kind of breeze is quite always directed from the sea to earth: again we have a little rising effect for sound rays coming from the scene that, in Greek Theatres, was almost completely open on the backside.

For instance, figure 2 represents the remains from the Tauromenion (Taormina) Theatre.

With an higher rising effect it would be possible that some spectator didn't receive enough acoustical energy, so lowering what we call, today, *listening* or *perceived sound level*.

Figure 2 – The scene in Tauromenion Greek Theatre

Incidentally, this rising effect can result now enhanced in Theatres and Auditoria as a consequence of a wrong sizing of the heating and air conditioning system and a consequent unsuitable distribution of sound pressure near the spectators in the stalls: as I know, no one simulation program takes into account of this effect.

3. Geometry

May be it is the evolution of the shape that can give us a better idea of the level of knowledge that Greeks and Romans had in acoustics.

In [8] we found that may be it was about 130 centuries b.C. that someone began to work on acoustical instruments, but the first manuscripts speaking about musical consonances are ascribed to the Chinese philosopher Fohi, XXX century b.C.; surely Pythagorean school already knew that sound is propagating with spherical surfaces, connecting this idea to the propagation of waves on a water surface when a stone falls in it: a good collection of informations about the knowledge of acoustics can be found in [9], where Hunt reveals also a certain difficulty to state a good chronological list among them. Surely the first well organized treatise on rules to be followed while designing Theatres is that of Vitruvius [1] who refers to the Aristotelian school and explain that the shape of the *cavea* must be based on spherical surfaces like those generated in water.

If we look to the evolution, if known, of the shape of the *cavea*, we can see that at the first beginning it was squared, as this shape allows to seat down more persons that the circular one, but quite suddenly it evolved towards the circular model, may be for the reason put in evidence speaking about the propagation of sound (figure 3).

Vitruvius speaks also of the problem of echo, a reason for conveying "*an indistinct meaning to the ear*" , so, he says, reflections must be avoided, if not useful to the reinforcement of sound.

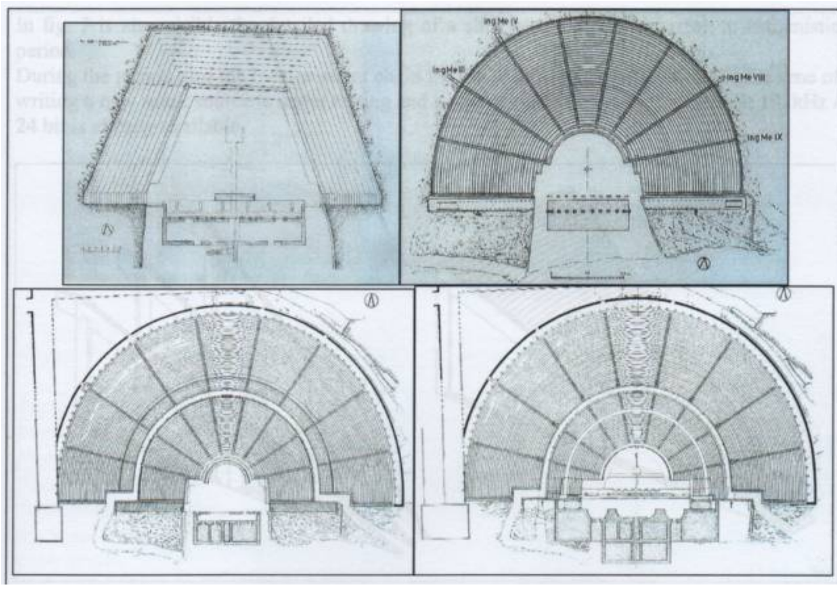


Figure 3 – The evolution of the shape in the Syracuse Theatre

Among the others, Aristotle had also some knowledge of the law of reflection of sound, relating the propagation of sound to the propagation of light, as quoted in the book [10] may be written by someone of his pupils; so it is allowed to us to think that those who designed theatres based on the Aristotelian ideas already knew that the back of the stage (the *scaena*), the frontal wall (called by Romans *pulpitum,* see for instance figure 4, left) of the stage and the lateral walls, or *parascaenia*, of the stage itself, and the surface separating the *pulpitum* from the *cavea*, either *orchestra* or *arena*, could generate reflections useful to reinforce sound coming from the actors.

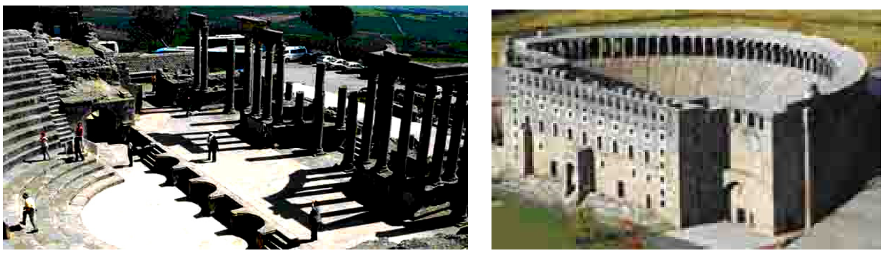


Figure 4 – Left: the Roman Theatre in Thugga, Tunisia. In front the *pulpitum* articulated to enhance sound diffraction. Right: the Roman Theatre in Aspendos, Turkey

Looking to Lucretius' books, a Roman writing in the first century before Christ, we can find some idea about reverberation [11], so it seems possible to think that when Romans allowed the Senators to occupy the *orchestra*, so loosing the reflection of sound from this important surface (as we will see later on), this was made possible as in the same time they firstly close the back of the *scaena* (figure 4, right) then begun to close the ceiling, at the beginning with curtains, after with stones sustained by arcs.

In the same time, Romans erected their theatres also far from hills, as they got cleverness in building pillars and arcs, but this evolution is not connected with acoustics, even if moving Theatres from the country to the hearth of towns corresponds to some growing of the background noise.

4 Resonators

Near Greeks, to enhance the voice of the actors the only device was a mask.

In Vitruvius [1] we find the first idea of a new device not directly put on the actor: the resonant cavities said *echeia,* originally introduced by Aristoxenus, a pupil of Aristotle, who utilized them as musical instruments to produce sounds of particular frequencies.

Vitruvius says that it was useful to introduce under the tiers of the *cavea*, as for instance it was found in an excavation of a Roman Theatre at Beth Shean in Israel: Izenour [12] exposed a conjunctural reconstruction showing how these jars were to be put (figure 5, left), without giving any acoustical reason of these devices.

P.V. Bruel tried to sketch an arrangement in the cavea and suggested to dimension these jars in such a way to cover a wide field of frequencies (figure 5, right).

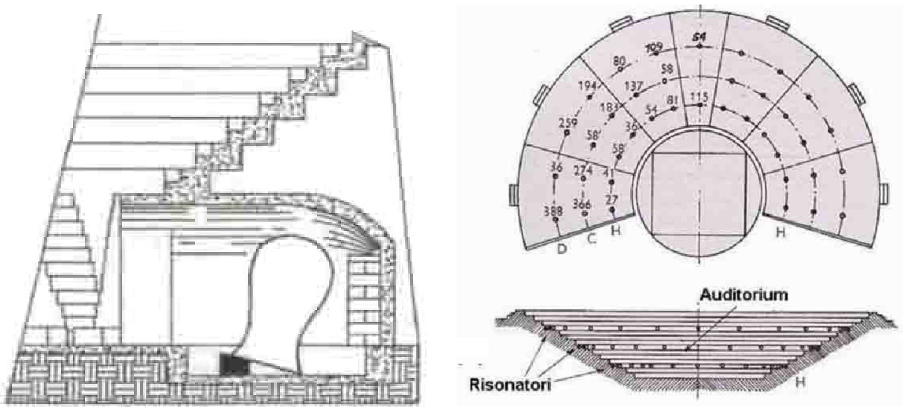


Figure 5 – Left: how resonant cavities must be put under the tiers, as sketched in [12] – Right: a possible arrangement of *echeia* as foreseen by P.V. Bruel

In [1] one can read that these jars were copper made, but we now found only some cavities under the tiers, and we think that they housed them, but we cannot be sure.

Nevertheless, we can admit that the idea of something not only reinforcing sound, but also changing its "*color*" enhancing some frequencies even with harmonics works well, if for instance we think to violins and so on. Personally, I'm aware that this idea was resumed in the renaissance introducing under the orchestra pit a cavity, somewhere in stone (like in Orvieto) or, better, in wood, like in Ravenna' s Alighieri Theatre [13] (figure 6, left), but not only there; another example, I think without any real effect, was found by me during the restoring works in the backstage of the Goldoni Theatre in Livorno (figure 6, right).

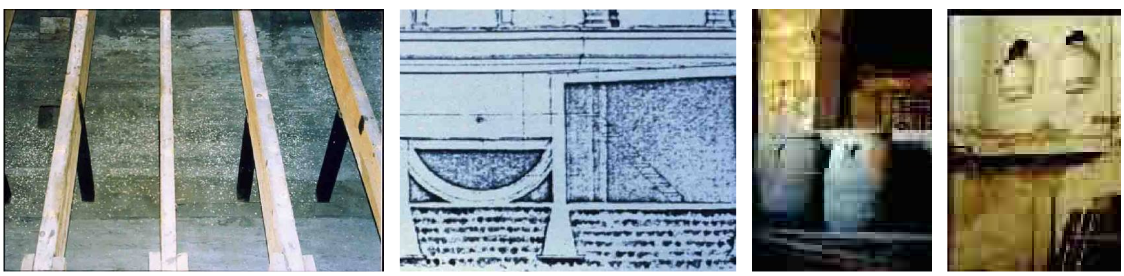


Figure 6 – The wooden cavity as found under the orchestra pit (left) and the original design center); right: jars found in the backstage of Goldoni Theatre in Livorno

5. Pencil and ruler

Surely the availability of a computational model and the high calculation speed of modern computers offer to the designer a lot of opportunities, but the major defect that is concealed within computer results is the deceptive accuracy of the numerical values, due at least to the limited possibility to know the acoustical properties of materials lining the hall of a theatre and the impossibility to take into account their spectral articulation in front of a sound (music or words) that is quickly changing during any kind of performance. Many structures in a hall, like not only sculptures but also capitals, balconies, boxes, pillars, *parastae* and other architectural devices, cannot be modelled or, anyway, even if correctly represented they have a different behaviour face to different frequencies (absorption, reflection, diffraction), usually not taken into consideration: so the accuracy of values, sometime even with decimals of decibel, doesn't correspond to what really happens near the ears of spectators.

This problem is enhanced if one tries to work with computer models in ancient theatres surely not regular in shape and surfaces.

From this point of view, a geometric study like that probably familiar to the architects from the ancient to the renaissance age, may be preferred to simulate the path of sound rays and evaluate shapes not able to generate flutter echo or echoes, focalization, and so on.

To do this work it is necessary only to dispose of a pencil, a ruler and either a square or a protractor: surely the results are less accurate, but this level of approximation is about of the same order of that of the drawings, in particular if we are dealing with Greeks and Romans Theatres.

From this point of view, it is interesting to take into consideration the book [14] where a generic section of an ancient theatre is utilized to evaluate the contribution of some typical reflected rays to the perceived sound pressure level in some positions usually occupied by spectators.

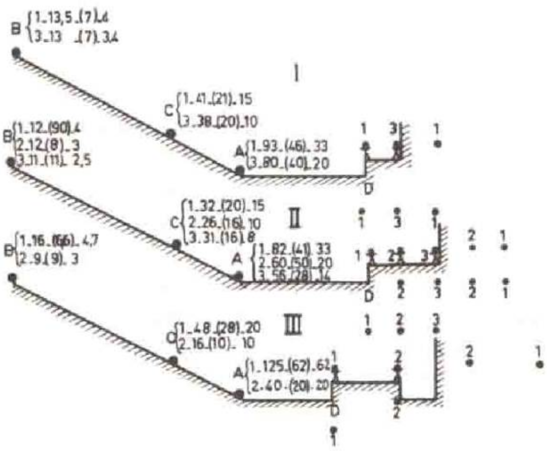


Figure 7 – Three different locations of sources (first figure from left) and receivers as presented in [14] and related sound pressure levels as generated by direct (first figure from right), reflected sound from the orchestra surface (within brackets), direct plus all reflected sounds (second figure from the left)

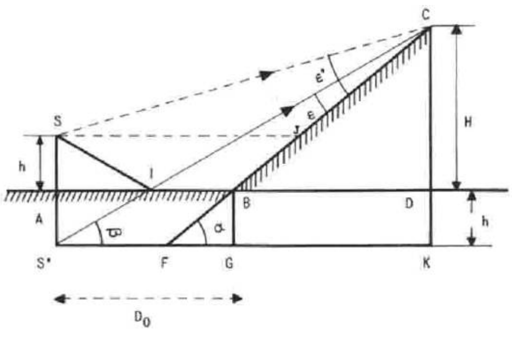
So it is possible to appreciate not only the effect of the wall back to the stage, but also that of the position of the actor and the height of the stage related to the orchestra surface, all supposed perfectly reflecting; it is also possible to appreciate the effect (from 3 to 5 dB) of the surface of the orchestra, so understanding the reason why in some theatre it is possible to find in the centre of the orchestra some particular surface perfectly reflecting (see for instance figure 8).

Figure 8 – The Dionysus Theatre in Athens: left the actual situation, right an imaginary reconstruction

In [14] we find also another interesting result deriving from the simple application of trigonometric calculus, that is to say an equation, named from the author *"the ancient theatres canonical equation*" that links together some geometrical element with the angle ε, a parameter that Canac define "*the acoustical quality of the theatre*".

In the same book it is possible also to find some consideration about the best height of the steps and the maximum height of the theatre; the role of the *orchestra* surface is also analyzed in the same way.

The important role of the *orchestra* surface acoustical properties is put in evidence already from Aristotle and Pliny the Elder, who says that holes or sand on this surface "*wear away*" the voice [14].



$$\frac{D_0 - h \operatorname{cotg} \alpha}{\operatorname{Sin} \varepsilon} = \frac{D_0 + H \operatorname{cotg} \alpha}{\operatorname{Cos}(\alpha - \varepsilon) \sin \alpha}$$

Figure 9 – Some geometrical characteristic and the related "*canonical equation*" [14]

6 Concluding remarks

This paper presented some result of a research on a particular aspect of a more ample work in which the Author is engaged, related to the influence of acoustical culture of the time being in the design procedure of a theatre, from Greek's age to now; in particular I have tried to put here in evidence that it is possible to get some teaching also where papers written by the Architects are not available, that is to say chiefly in Greek's and Roman's age.

It seems interesting also to put in evidence that the actual custom of utilizing computer models and objective parameters is in some way deceptive, as we don't know the real response of each spectator when attending to a musical performance, but we can refer only to that of some qualified listening person, like a conductor or a musician, and we know that even those performers are not always of the same advice, sometime they are completely opposing one to the other may be for sympathy towards one or another composer or for career' reasons. The precision with which we sometime present our computer results is also deceptive, as we don't pay attention enough to the spectrum, while the accuracy in transmitting the musical message from the orchestra to audience relies on the absence of frequency distortion: so the teaching coming from ancient architects is very important to better define the boundaries of our work of acoustical engineers.

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