Ancient Greek Theaters: Current Operation vs Contemporary Noise Environment

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Summary
For over seven centuries the ancient Greek theater spread all over the wider Mediterranean area. Starting with servicing the Dionysus ritual and drama contests, the Greek theatre followed the political and social transformations of the Greek-speaking world of antiquity. Although theatre is in the crossroad of various scientific fields (drama, architecture, archaeology and acoustics), a multidisciplinary approach was rarely used in modern restorations of the ancient theatres.
Reuse of ancient Greek theatres (from the early 20th century) as the prominent place for the revival of ancient drama, prioritized the issues of reversible interventions to ensure the proper conditions for the performances. Even though Ancient theatres underwent severe destructions – mainly due to roman interventions or destructions caused by time – their contemporary reuse could be possible in many cases. However, the sound environment (especially the traffic noise) exerts destructive nuisance on outdoor acoustic comfort and, at the same time, invasive temporary structures, required by the new interpretation of the classic drama, usually fail to activate the natural (passive) theatres' amplification potential, obstructing thus the clear transmission of the theatrical message.
The paper is part of a broader research (ongoing since 2004), aiming at monitoring the contemporary status of the ancient theatres in Greece. The whole sample includes a sum of twenty (20) theatres Amphiaraeion at Oropos, Argos, Delphi, Dilos, Dion, thenian og Dionysus Eleftheреus, Dodoni, Epidauros, Eretria, Larisa, Mantineia, Maroneia, Megalopolis, Messeni, Orchomenos at Voeotia, Philippi, Thasos, Thira, Thorikos, Zea in Piraeus. The parameters of the research include the integration of the theatres into the contemporary urban reality, the operational infrastructure, the sound environment and the acoustic evaluation of their current or potential reuse.

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1. Introduction

During the 20th century, the popular demand for the revival of ancient drama performances (which almost exclusively concerned plays of the classical period) and the request for re-organizing performances in their original settings, prioritized issues for mild interventions in the remaining ancient theatres in Greece and in other places of the Mediterranean Sea in order to ensure the appropriate conditions for the performances. However, diachronic interventions, each one corresponding to different social and cultural periods, have transformed these monumental constructions to palimpsests of successive building phases. Sometimes, the interpretation of ruins, the restoration and the fixing of the remaining structures -many of which belong to destructive interferences during the Roman period- undermine the requirements for a reliable reuse of the theatres [1]. In most cases, disagreements about the reuse of ancient theatres, among engineers and archaeologists, focus on fixing destroyed parts of the *koilon* (cavity), on installing modern infrastructure facilities, but primarily on protecting the surface of the orchestra and the ruins of the ancient stage building from contemporary, temporary constructions for drama performances scenery [2], [3].
During a performance, actors and spectators share the common goal of an uninterrupted communication, which is provided by the acoustic liveliness and speech intelligibility of the theatre space. As evidenced by many historical sources, the ancient Greek theatres succeeded to accommodate large audiences with maximum visual and acoustic comfort during the authentic conditions of use without, of course, any electro-acoustic amplification.
As it is also proved by many acoustic researches, especially by those of the second half of the 20th century, basic design principles have been successfully applied to serve the distinctive acoustic

behaviour of open and outdoor spaces. Meaning [1], [4], [5]:

-acoustics protection (elimination of exterior noises)

-harmonious development of the audience around the performances in the measures of the human voice and the human hearing capacity, (open floor plan)

-emergence of the direct sound and activation of a natural (passive) loud speaker thanks to positive, early reflections coming mainly from the orchestra, the scenery and their combination,

-low resonance, by minimizing the negative, late reflections from the roof, the upper side of the *koilon* and the side walls *parodoi*.

The famous acoustics of the ancient Greek theatre relies on the amplified acoustic response of the space, which is related to the replacement of the energy losses, thanks to early, strong -though of a limited number- sound reflections, especially toward the highest seats of the *koilon* [2], [4], [6].

Moreover, the acoustic comfort depends on two acoustic conditions:

-the difference between the useful signal and the background noise, and

-the clear distinction of the successive parts of the linguistic chain, in the specific performing occasion when the theatrical message is delivered by vocal trained and experienced actors.

In the diagram '*time-sound intensity*', the emergence of the message appears like the tip of the iceberg on the sea of noise, in other words, it is the visible part of the sound energy that is not distorted by

Table 1 the first part of the sample

THEATRE	B	C	D	E	min SPL
A1 Amph. Oropos	B2	C3	D1	E2	32
N / O	traffic 37 / birds 41				
A2 Argos	B1	C1	D1	E2	37
U / P	activities 43 / traffic 46				
A3 Delphi	B3	C2	D1	E1	34
S / O	traffic 46 / tourist activities 50				
A4 Dilos	B3	C3	D2	E1	27
N / O	wind 40				
A5 Dion	B1	C3	D1	E1	31
N / O	birds 36 / agricultural activities 39				
A6 Ath. Dionysus	B3	C2	D2	E2	38
U / P	BN 45 / tourist activities 54				
A7 Dodoni	B1	C2	D1	E2	27
N / O	wind 34 / restoration activities 36				
A8 Epidauros	B1	C1	D1	E1	27
N / O	wind 36 / tourist activities 46				
A9 Eretria	B2	C3	D2	E2	39
S / P	activities 41 / traffic 47				
A10 Larisa	B2	C2	D1	E2	43
U / P	activities 45, traffic 62				

background noise, as it is called every permanent or temporary parasitic sound in the acoustic communication.

Table 2 the second part of the sample

THEATRE	B	C	D	E	min SPL
A11 Mantineia	B3	C3	D1	E1	32
N / O	restoration activities 41 / airplane noise 48				
A12 Maroneia	B1	C1	D1	E1	37
N / O	wind 45 / occ. traffic 68				
A13 Megalopolis	B2	C3	D2	E3	32
N / O	birds 37 / activities 35 / wind 41				
A14 Messini	B1	C3	D1	E1	35
N / O	wind 40 / agricultural activities 46				
A15 Orchomenos V	B2	C3	D3	E1	38
S / P	activities 46 / traffic 57				
A16 Philippi	B1	C1	D2	E1	40
S / P	wind 44 / traffic 52				
A17 Thasos	B2	C2	D2	E1	37
N / O	BN 44				
A18 Thira	B3	C3	D3	E1	29
N / O	wind 38 / airplane noise 58				
A19 Thorikos	B1	C1	D1	E3	34
N / O	birds 37 / wind 48				
A20 Zea Piraeus	B3	C2	D2	E1	44
U / P	traffic 52 / airplane noise 67				

The acoustic emergence, in global or frequency values, depends on the response of the space, meaning it depends on objective criteria such as: *spectral density*, *ratios direct / total intensity*, *early decay of sound*, and *reverberation time*, which are all connected to the basic subjective criteria of a space acoustic quality, such as *colorization* and *intimacy*, *clarity*, and finally, speech *intelligibility* [1], [7].

The contemporary environment is dominated by traffic and urban noises, which are usually much stronger than those existing in outdoor conditions. In open air performances unexpected reactions caused by the audience (whispers, coughs and movements) should also be taken under consideration. The background noise covers a portion of the useful signal producing a kind of *sound mask* either permanently or occasionally. The gravity of this masking phenomenon is proportional to the level and the frequency spectrum of the parasitic signal. In general, noises distort the higher frequencies of the useful signal. Noises of a broad or continuous spectrum tend to totally destroy speech communication, especially in the middle frequencies (700 - 1000 Hz), which are vital for human hearing [8].

During the theatrical communication, the masking of the message is a complex psycho-acoustic process related to the visual comfort or the hearing angle of each spectator. Pure tone noise, even with high intensity (up to +10 dB) has a negligible effect on speech. Nevertheless, when the noise spectrum shifts from high to low frequencies, the acoustic effects of the masking become subjectively important. It has been established that the parasitic signals of the continuous spectrum may eliminate the intelligibility of speech, even in low levels intensity circumstances (20dB lower than the intensity of the useful signal).

According to the above analysis, the values of the sound emergence (namely the acoustic comfort) in theatre spaces are evaluated according to the following behaviour:

-excellent (> 25 dB),
-good (20 - 25 dB),
-acceptable (15 - 20 dB)
-non-acceptable (< 15 dB) [7], [8]

2. Research data

This paper is part of a broader research (ongoing since 2004), aiming at monitoring the current status of the ancient theatres in Greece (modifications, destructions, protection works, sound source and environmental noise levels) and evaluating their

Figure 1. The locations of the twenty theatres

acoustic quality for contemporary operation conditions [9], [10], [11].

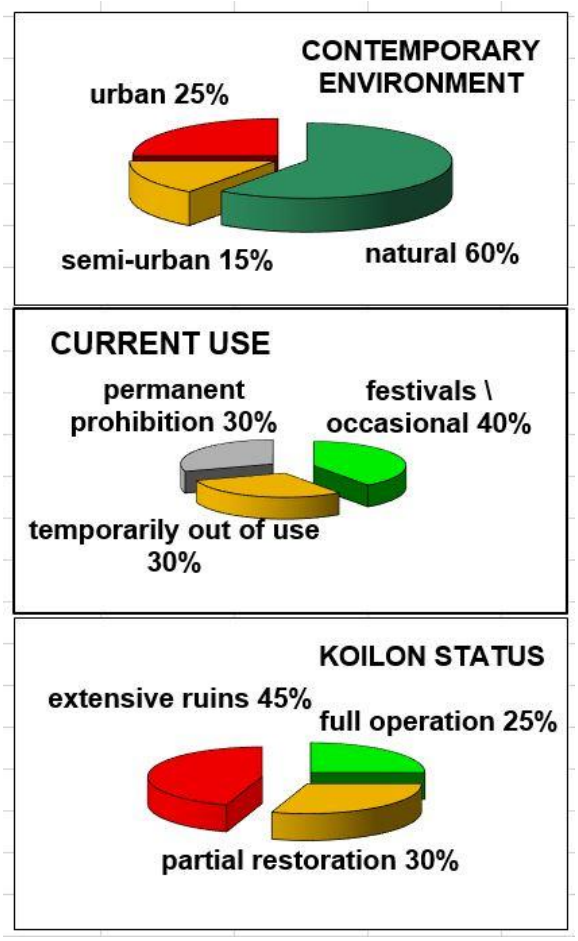
At present, the whole research sample includes a sum of twenty (20) ancient Greek theatres: Amphiaraion at Oropos, Argos, Delphi, Dilos, Dion, Athenian theatre of Dionysus Eleftherеus, Dodoni, Epidauros, Eretria, Larisa, Mantineia, Maroneia, Megalopolis, Messini, Orchomenos at Veotia, Philippi, Thassos, Thira, Thorikos, Zea at Peireaus.

The research data is briefly recorded in **Table 1 & 2**, including:

-in the column "Theatre", the location of each theatre (with a serial number for the present sample),

-beneath that, the index for the contemporary location (U urban, S semi-urban, N natural] and for the type of noise [O occasional, P permanent]

-in column B, the current use of the theatre Figure



2. The current circumstances of the sample

B1 for official festivals or for occasional performances,

B2 for temporary ban due to restoration works,

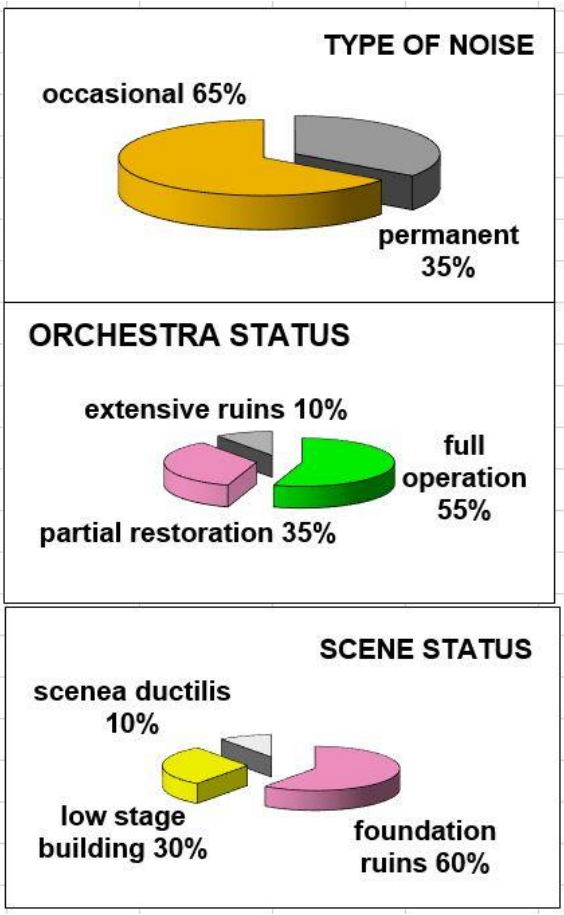


Figure 3. The current circumstances of the sample (second part)

B3 for permanent prohibition],

-in column C, the status of the *koilon*

C1 stands for full operation,

C2 for temporary restoration works,

C3 for permanent damages by illicit stone traders,

-in column D, the status of the orchestra

D1 stands for full operation,

D2 for partial restoration works,

D3 for extensive ruins]

-in column E, the status of the scene

E1 for damaged building or foundation ruins,

E2 for *hypo-scenium* (low stage building) ruins,

E3 for *scenea ductilis* (infrastructure for mobile stage],

-in the last column, the minimum SPL measure and on the below line the different type of noises with the recorded sound levels

maxL in dB for civil / agricultural / tourist activities and natural environment,

Leq,h in dB(A) for ring road / highway traffic and airplane noise.

A general overview for all the theatres of the sample is provided in **Figure 2**:

-in 60% (12/20) of the cases, the existing environment is rural (60%, 12/20) **(Figure 2 up)**

-70% (14/20) of the theatres operate on a permanent or occasional basis **(Figure 2 middle)**

-in 55% (11/20) of the cases the koilon guarantees in full or limited conditions the security of the spectators **(Figure 2 down)**

-in 65% (13/20) cases, there is occasional noise **(Figure 3 up)**

-55% (11/20) of the theatres fully serve the actions and the security of the actors **(Figure 3 middle)**

-in 60% (12/20) of the cases only the ruins of the scene building remain **(Figure 3 down)**

3. The acoustic evaluation of the sample

In order to understand the impact of the environmental noise on contemporary performances in the theatres, it is appropriate to make some clarifications. The recommended background noise in areas for cultural activities corresponds to the standard frequency curves of international noise criteria NC-20 / 25.

It should be mentioned that performances in outdoor conditions rely on a peculiar and fragile acoustic circumstance, where feasible or infeasible communication depends not only on the equivalent noise level of the environmental nuisance, but often (especially at crucial moments of the action) on the occasional occurrence of a noise. Therefore, it is more accurate to correct the hourly equivalent sound level (Leq,h) by the maximum expected value of noise (Lmax).

Taking a closer look at the number of diverse measured noise sources (Lmin, excluding the indeterminate back ground noise BN) of the sample, we find the following circumstances (in brackets the noise levels in the interior of a theatre):

-3 with restoration activities [maxL: 36-53 dB]

-3 with urban activities [maxL: 51-70 dB(A)]

-5 with surrounding agricultural activities [max L: 43-48 dB]

-5 cases with ring road & highway traffic [Leq,h: 47-54 dB(A)]

-7 cases with urban traffic & airplane noise [Leq,h: 48-67 dB (A)]

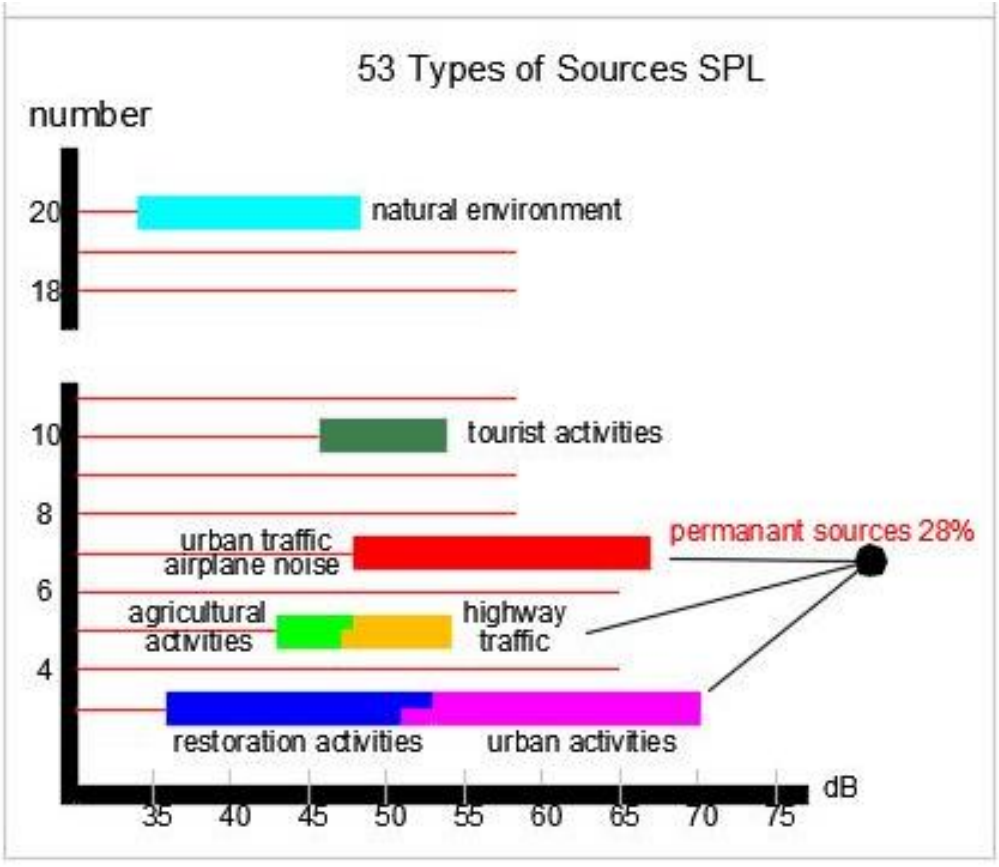


Figure 4. The types of the measured sources in SPL

-10 with tourist and amusement activities [max L: 46-54 dB]

-20 cases in a quiet, natural environment [Leq,h: 34-44 dB(A)]

Based on these distinctions, **Figure 4 & 5** depicts the sound levels to the totality of the fifty three (53) distinct sources of the sample and the grouping of these sources depending on the characteristics of the noise nuisance:

-occasional sources 20 (38%),

-permanent periodic sources 18 (34%),

-permanent continuous sources 15 (28%).

The distribution of the above sources shows that a small proportion (28%) corresponds to a continuous, permanent nuisances of high sound level, while in the majority of the cases occasional or periodic sources easy to control or ignore (relatively to background noise of a normal outdoor performance) are detected.

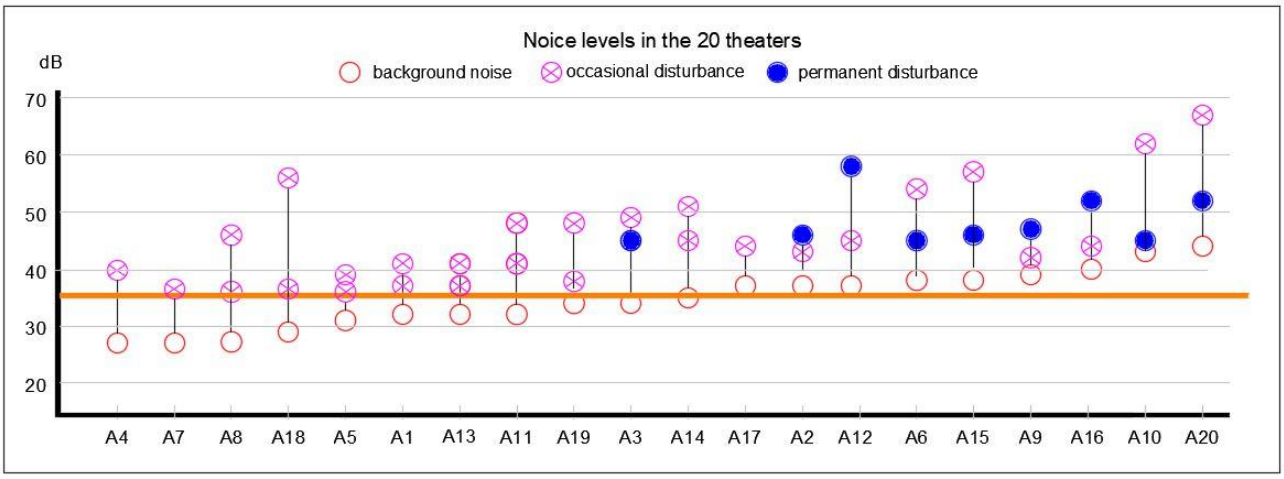


Figure 5. The measured noise levels in the sample

Additionally, the values of the undefined back ground noise BN recorded in all the ancient Greek theatres of the sample are shown in **Figure 6** [sound levels in dB, Lmin].

In order to evaluate the sample for contemporary performances or for potential future re-opening, we have laid out a numerical model to calculate the acoustic comfort **(AC)**, as the effective signal rising, based on the following assumptions [11]:

-the actor is at the back of the orchestra (not in the center, but at intersection of the potential scenography with the main axis of the koilon). In this case, the human sound source is 1,7m above the level of the orchestra,

-**Lo**, the initial intensity (the human voice of an experienced actor) is 82 dB [A]/1m (normal intensity) or 87 dB [A]/1m (strong intensity), with spherical wave conditions (with no electrical reinforcement). The above mentioned sound intensities do not correspond to the relative levels of an ISO, but have been already measured in ancient drama performances with trained and experienced Greek actors [12],

-the audience sits in a distance (ray) from the actor corresponding to the 75% of existing seats either in lateral or central positions, 1,1m above the gradients,

-**Ld**, the corresponding decrease of the direct sound in each theatre due to distance,

-**Ro**, the natural (passive) loudspeaker amplification of the theatre space (+3dB) thanks to the reflections coming exclusively from the orchestra (for minimum predicted values)

-**Rosc**, the natural (passive) loudspeaker amplification of the theatre space (+6,5dB) thanks to the reflector of the orchestra, plus the reflector of the scenography, plus the combination of all the active positive reflectors near the actor (for maximum predicted values)

-**Nbn**, is the background noise due to the presence of the spectators during the performance (+5 dB),

-the predicted values accounted in accordance to the formula 1:

$$AC = Lo - Ld + \{R\} - (Nbn + 5) \quad (1)$$

As shown in **Figure 7**, the ancient Greek theatres of the sample are classified, relatively to the limit of the red line (AC = 15 dB) and the green line (AC = 20dB), as follows:

I. For normal human voice intensity and in cases that active reflections come only from the orchestra,

-four (4) theatres seem to be in good acoustic conditions (CA>20dB): Amphiaraion at Oropos, Thira, Mantineia, Dilos (small number of

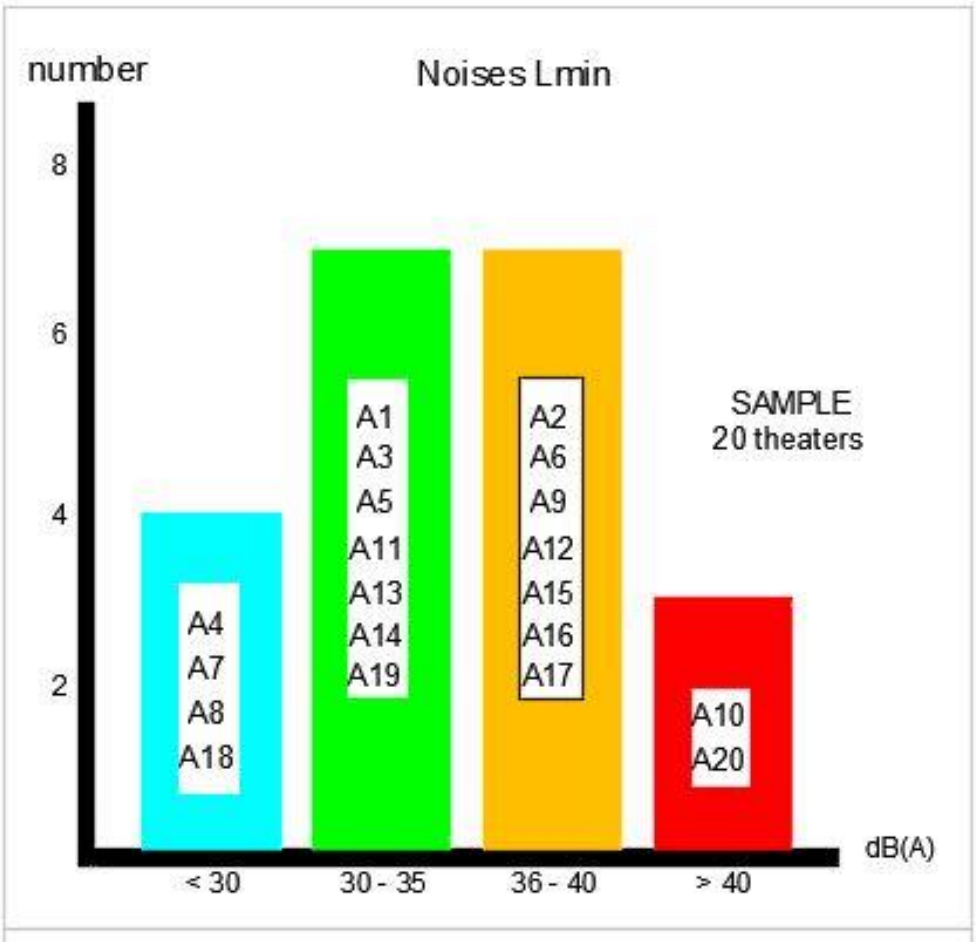


Figure 6. The measured Lmin noises in the sample

remaining seats, quiet environment with occasional rural or tourist activities)

-seven (7) theatres seem to be in acceptable acoustic conditions (15< CA <20dB): Delphi, Dion, Dodoni, Epidaurus, Maroneia, Messini, Thorikos (medium or big number of remaining seats, quiet, rural or semi-urban environment, with rare / occasional activities).

-all the other nine (9) theatres of the sample do not seem to provide acceptable acoustic comfort (CA <15dB).

II. For strong human voice intensity and in cases that active reflections come from the orchestra, plus the scenography background, plus the combination of all the active positive reflector near the actor

-only two (2) theatres seem to be in non-acceptable conditions (CA <15dB): Larisa, Zea at Piraeus (urban environment, traffic and activities),

-only three (3) theatres in acceptable acoustic conditions (15<CA<20dB): Argos, Athenian of Dionysus Eleftherеus, Philippi (urban environment with rural activities or traffic),

-all the other theatres (15) of the sample are in good (CA >20dB) or excellent condition (CA >25 dB).

4. Conclusions

The systematic monitoring of the existing conditions in the theatres of the Antiquity enables the clear identification of their potential reuse for contemporary performances. The acoustic evaluation of their surrounding environment provides the ability to predict the intelligibility of the theatrical message.

Generalized destruction of the stage buildings is the most important problem in all cases. This fact, as discussed in previous paper, makes unavoidable the presence of a movable, low and lean scenery (a mobile stage background in the correct position and of a suitable size to be used during a performance), which could contribute mainly as an active sound reflector (+2 / +3,5dB supplement to useful signal), and secondly as a small noise barrier (-1 or -3dB decrease of the environmental noise) on the exposed part of the open floor plan of the ancient Greek theatre [2], [6], [9], [11], [12], [13]. Such an

intervention could improve the acoustic quality to eight (8) of the twenty theatres (40%), ensuring well accepted acoustic comfort at others ten (10) of the twenty theatres (50%).

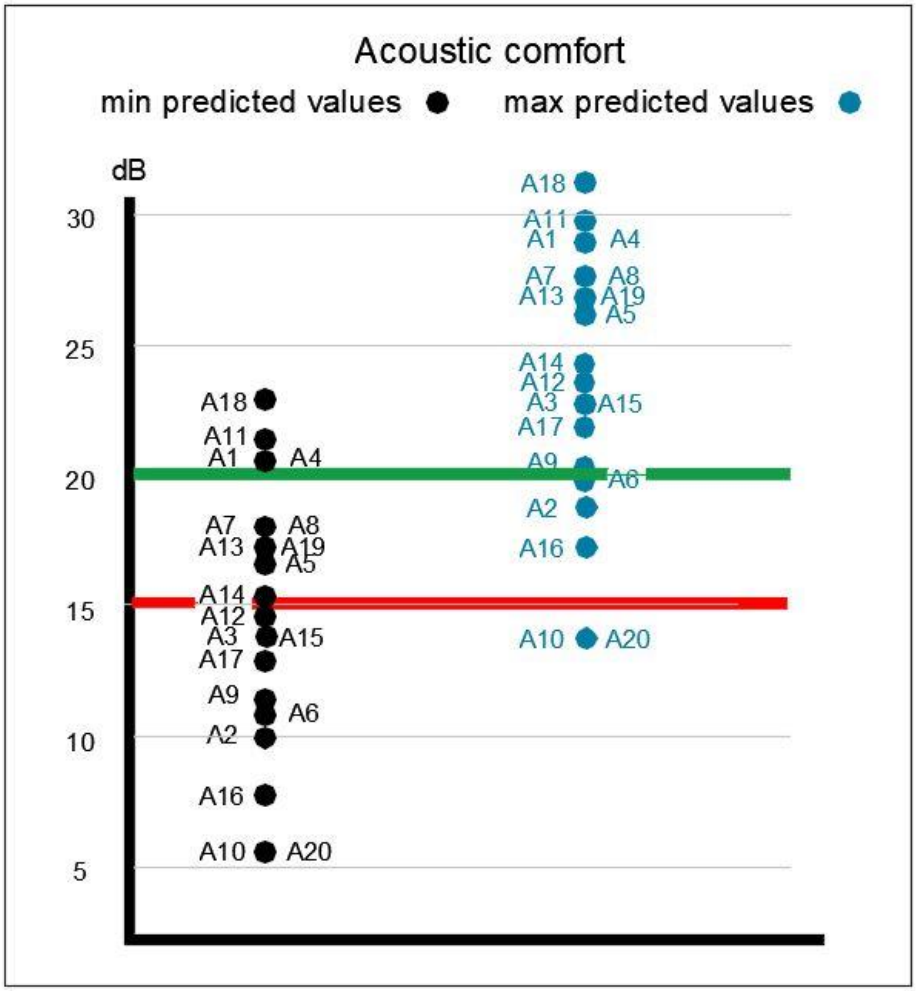


Figure 7. The classification of the calculated acoustic comfort, in the 2 alternative case

The above estimation is rather conservative, because the usual absence of a scenery in contemporary performances obliges the actors to move towards the cavity in an attempt to compensate sound loss. As a result, the main sound reflector of the orchestra is also cancelled.

Furthermore, during our research we identified and recorded intense urban pressure, mainly traffic noise, which exercises serious nuisance (51-70dB) in the acoustic environment of the theatre monuments. Therefore, in case of strong nuisance conditions (>>35dB), the famous acoustics of the ancient Greek theatres is destroyed during the performances due to the crucial combination of the large theatre space and the human audio and hearing physiology. The above sound limit coincides with the international standards for silence in cultural venues (noise criteria NC - 25).

Given all that, it is the responsibility of the Greek authorities to

-institute an appropriate silence criterion in the extent area of the monument,

-impose compulsory measures regarding noise protection (from urban or traffic activities)

-adopt temporary or occasional arrangements in the region until the final removal of permanent noise sources.

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-Heliana Andoniadou - Nikos Vardaxis - Anna Moyses (sample of 4 theatres),

-Alexandra Tsatsaki (sample of 3 theatres in Peloponnese)

-Mary Katsafadou - Christos Lagoudas (sample of 5 theatres)

-Melina Vyzika (sample of 3 theatres in North Greece).

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As a traditional Greek song states: *"no bridge can be constructed, unless someone is sacrificed".*

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