Open-air theatre in the centre of the city: acoustic design and noise environment control

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The Garden Theatre has for decades been located in the centre of Thessaloniki. The intensification of traffic noise over the years led to the degradation of its acoustics and its use dwindled. In 1997, the organisation of the Cultural Capital of Europe served as a springboard for a study conducted by the author on redesigning the theatre (as part of a more general restructuring of the buildings and traffic in the city's historical centre, which was never implemented). Various problems and budget cuts experienced during the design and construction of the Garden Theatre led to restricted execution of the planned acoustic interventions. This paper deals with the design parameters that optimise acoustic function and maximise sound protection in an urban open-air theatre (location, theatre form, sound barriers) and includes an analysis of the theatre's initial state, acoustic proposals and an assessment of the final applications.

1. Introduction

The Municipal Garden Theatre is the last open-air space for hosting cultural events in downtown Thessaloniki, the second largest city in Greece with a population of approximately one million inhabitants. In the post-war period it has been operating on an ongoing basis in the waterfront area, an urban zone that has housed numerous recreational and cultural spaces throughout history, which have however gradually been abolished.

Although the mild climate of Mediterranean countries favours outdoor activities, urban planning and the road network in modern cities exert tremendous pressure on the acoustic and theatrical function of open-air cultural venues. The most covetable vacant spaces in urban centres are usually offered for roofed structures, and the few available spaces are not adequate in order to create natural protective embankments (mounds, banks), whereas the scale of the required interventions often tends to reverse the open, outdoor form of the venues.

The necessary reliance of the existing open-air theatres on electroacoustic enhancement systems is gradually shrinking the range of their activities; the limited repertoire reduces their appeal; and the inability to maintain and renovate these spaces results in the depreciation of their infrastructure and equipment. The Municipal Garden Theatre of Thessaloniki has – in the last operating period (before the overall redesigning under discussion) – presented serious problems, especially in terms of noise protection [1].

2. Theories of theatrical and acoustic design

A common basis for the participants of a performance is the requirement for smooth theatrical communication, easy visual contact, as well as intelligibility and clarity of the theatrical message. Long-term acoustic studies conducted in outdoor spaces have shown that the basic principles of design include:

-minimisation of external noise (noise protection),

-harmonic development of the functional elements of the theatrical space within the limits of the human vocal and acoustic scale (theatre form, capacity),

-sufficient emergence of directly propagated sound and its reinforcement through early positive sound reflections (from the amphitheatre gradient and natural loudspeaker response of the space),

-control of late sound reflections (limitation of the reverberation time, elimination of echoes) [2, 3].

The design of new open-air theatres goes back to the positive models of similar monuments that have been preserved in the contemporary urban plan [1]. In order to optimise the positive advantages of acoustic design, the usual cases involving adverse sound environments require the combined exploitation of the advantages of an open space plan and the limitation of the boundaries of the theatre space based on the model of the Greco-Roman theatre.

The basic guidelines for achieving a similar theatre layout include:

-limitation of capacity (700 to 1000 seats) and axial span,

-forwarding of the proscenium space into the orchestra area (covering half or a third of the radius),

-creation of a closed space plan (from the seating area and stage building, with limitation of the lateral openings at the side entrances –*parodoi*),

-harmonic development of the background scenery (position, height, length) and proper formation of its lateral ends (backstage –*paraskenia*, in order to neutralise any harmful, lateral sound reflections) [4, 5].

In outdoor noise protection, we intend to make good use of the phenomenon of acoustic diffraction by inserting natural or manmade sound barriers between the noise sources and the protected area. The extent and the critical frequency of the acoustic shadow, according to the Huygens-Fresnel theory, depend on the position and effective height of the sound barrier. The achieved reduction in noise levels can be calculated analytically (under limited conditions according to Fresnel or Sommerfeld, for spherical or plane waves) by means of the Bruckmayer formula, or graphically by means of the Harris chart [6, 7].

According to the Greek Building Code, the permissible limits of acoustic comfort are provided in average, hourly sound levels, without making mention of special criteria for open-air theatres. For the sound protection of the theatre performance, the relevant international standards (Noise Criteria) adopt noise criteria curves NC-25 to 30, whereas international practices concerning cultural venues of high significance recommend the correction of the statistically equivalent figures by using the maximum expected noise value [8].

The function of an open-air theatre must fulfil the dual goal of maximising the advantages of acoustic design and minimising the effects of noise pollution on the environment, an objective that can be described with the signal-to-noise ratio (S/N). On the basis of a practical method for applying this acoustic evaluation criterion, we should evaluate the spatial distribution of the relevant derivative values of 'Emergence' and 'Spectral Density' i.e. we are searching for a distinguishable difference in the sound level between the positive message and background noise (in spherical and frequency values), in accordance with the following graduated limits:

-excellent (>25 dB), good (20-25 dB),

-fair (15-20 dB), unsatisfactory (<15dB) [9, 10].

refreshment bars near the park and the trespassing of motorcycles (through the park's alleys late at night),

-the background scenery (with the spectators looking at the concave side) drew part of the noise from the environment and reflected it on the proscenium stage and the seats,

-the broad axial span did not favour the emergency of the direct sound, and the low gradiation of the seats *–platea-* caused the creation of poor auditory angles ($< 5^0$) over a large part of the seating area,

-the form of the theatre space and the arrangement of its functional elements (*platea*, raised proscenium stage and background scenery) did not provide the space with natural loudspeaker enhancement [1]

Observing the 1st column of the Table, one notices that the signal rising was limited to 10-15dB in a large part of the seats, thus making it necessary for theatrical performances to be supported by an electroacoustic enhancement system. This fact limited the movements of actors and distorted the characteristics of their voices, thus destroying the necessary familiarisation of the audience with the events taking place.

Source: actor (85dB at 1m)	**Before**	**Model**	**After**
Distances between first to last row (m)	3 ~ 16,5	15 ~ 27	20 ~ 28
Reduction due to distance (dB)	(-9,5) ~ (-24,5)	(-23,5) ~ (-28,5)	(-26) ~ (-29)
Emergency due to design (dB)		(+4,5)	(+3,5) ~ (+4,5)
due to electro acoustic system	(+10) ~ (+15)		
Intensities (first to last row) (dB)	85,5 ~ 75,5	66 ~ 61	62,5 ~ 60.5
Background noise (dB)	66	42 ~ 43	46 ~ 47
Raising (dB)	19,5 ~ 9,5	24 ~ 18	16,5 ~ 13,5
Divergence (first to last row) dB	+/- 5	+/- 3	+/- 1,5

Table: The evaluation of the space's acoustic function

It was often the case that background noise was enhanced by the electroacoustic system, whereas inevitably the distribution of sound intensities and the intelligibility of speech presented major divergences (>10dB) between the first and the last row.

3. The Garden Theatre before its reconstruction

The Municipal Garden Theatre is the only open-air cultural space that remains in downtown Thessaloniki (near the White Tower waterfront). Following successive relocations and modifications, the theatre space was built on an area covering approximately 3,000 sq. m. in the sole urban park in the centre of the city, which is only a short distance (approximately 80m) away from a busy interchange where five arterial roads meet. In its last period of operation, the Garden Theatre had a seating capacity of 630 seats and presented serious disadvantages in terms of limited visibility from the seats, difficult access between the stage and backstage areas, as well as lack of safety and auxiliary spaces. However, the most important problem of the theatre was its poor acoustics resulting from the venue's non-existent noise protection:

-the background noise was at 66 dB(A) (frequency extreme 81dB at 50Hz) and presented significant excess [69 to 75 dB(A)] due to the heavy traffic (buses) down the neighbouring street (N. Germanou), the operation of

4. The targets and the estimations for the new design

On the occasion of undertaking the organisation of the Cultural Capital of Europe in Thessaloniki (1997), a study was conducted on redesigning the Garden Theatre as part of a more general restructuring of the buildings, which was never implemented. According to the author's initial proposals, the planned reconstruction should have provided a set of guidelines that would optimise its acoustic function and maximise its noise protection:

-slight displacement of the theatre area (layout according to the existing buildings in the area, rotation of the central axis towards the main noise front),

-subsidence of the theatre (approximately 4.2m in order to create natural embankments along the perimeter),

-creation of additional horizontal and vertical sound barriers (approximately 4-metre-high protective shield and shelters at a level of approximately 8.5m above the natural ground) in order to deal with sounds coming from the environment,

-adoption of a closed plan space (based on the model of the Greco-Roman theatre).

While preparing the design for the Project, the above main options combined with a set of acoustic evaluations and solutions, determined – first and foremost – the architectural design and building applications.

5. Design proposals – predictions of the acoustic model

The noise mapping of the area and thorough analysis of sound measurements have indicated that the degree of noise disturbance to which the theatre area is subjected due to the ongoing traffic on the interchange (levels of up to 81dB(A) at 3m) is extremely high and is due to:

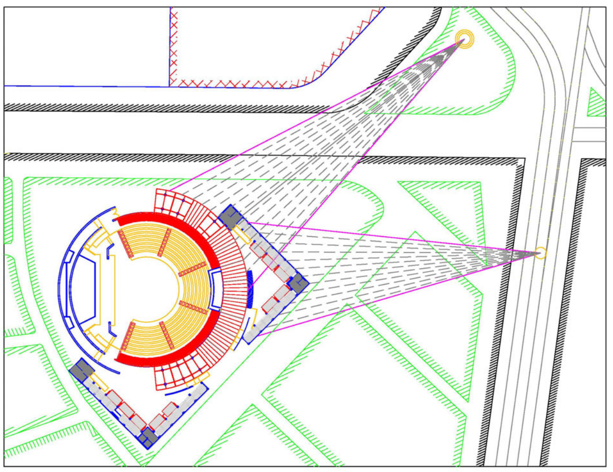

Fig. 1 The noise mapping of the area

-the serious effects of the congestion on the main road axis behind the spectators (frequent and successive breaking – acceleration due to the short duration of the green traffic light),

-the refuelling of noise due to the area's topographic relief (two coplanar roads, three uphill roads, maintenance of noise within the interchange),

-the reinforcement of the road noise in the theatre area due to its reflections on the sole neighbouring building.

At the initial phase of the Project, the reconstruction of the Theatre was to be integrated in a wider planning of the whole region for the benefit of recreational and cultural activities, which was finally abandoned:

-rerouting of the interchange,

-unification of building blocks and pedestrianisation of the neighbouring street

-redesigning the central alley of the park and prohibiting the neighbouring refreshment bars from operating electroacoustic systems.

At the intermediate phase of the Project, it was decided to move the boundaries of the theatre area, as well as to incorporate a number of existing big trees along the perimeter of the structure. The new layout arose from the exposure of the theatre space to the shade of the neighbouring building, as well as from the rotation of the theatre's central axis (the main body of protective measures) towards the front of the interchange,

Lastly, upon the completion of the Project's preliminary design, a set of acoustic and sound protection measures was prepared, whose type and extent provided scope for continual discussions, even disagreements, and modifications (from the preliminary design to construction). Specifically, the final design of the Project provided for:

-the implementation of a closed plan theatre space (seating capacity: 1050) with a Greco-Roman-style layout,

-the adoption of sound barriers with a total effective height of 7.2m,

-subsidence of the theatre space by 4.2m,

-the construction of a surface peripheral shield with a height of approximately 4m and the addition of a horizontal shelter at a height of 8.5m (above ground level) in order to provide shade to the *koilon* and orchestra area,

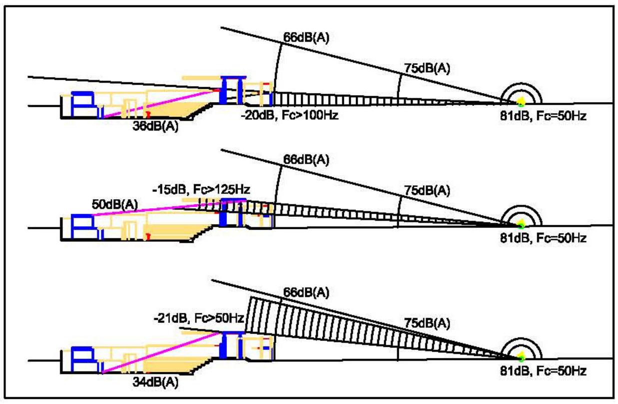

Fig.2 Section of the acoustic model. The efficacy of the barriers to the interchange

In brief, the acoustic design of the theatre included the following:

-restriction of the axial span (seating area, orchestra, proscenium stage) to a shady area with a radius of approximately 35m,

-a relatively small-sized orchestra (10m radius) surrounded by the amphitheatre (with a 225^0 opening), with the proscenium area entering the periphery of the orchestra (covering a third of the radius),

-an amphitheatre with a unique *diazoma* (12 rows with 23^0 gradient, 11^0-15^0 auditory angles),

-scenic background (20m length) with shallow side wings (approximately 3.5m deep) in front of the background stage,

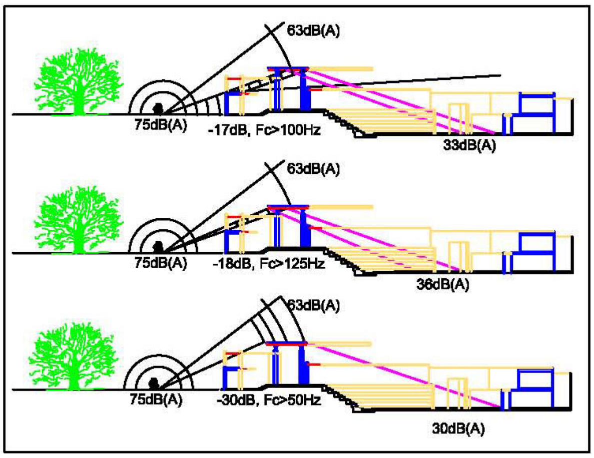

Fig.3 Section of the acoustic model. The efficacy of the barriers to the central alley of the Garden

-evaluation for positive sound reflections (from the orchestra, the scenic background and their combination) and reduction of the *parodoi* (the oblique passages between the ends of the seating area and stage structure towards the emergency exits).

As can be noticed in the 2nd column of the Table, in accordance with the computational model of the acoustic design, the anticipated background noise was expected to be limited by about 23dB in order for the anticipated sound rising to approximate 20dB (divergences of +/-3dB from the first to the last row).

6. Modifications and final evaluation

During the preparation of the Project's design, the architectural choices (intending to incorporate the greatest possible number of existing trees along the new perimeter, as well as to aesthetically reduce the volume of the surface structures) ended up limiting the span of the shelter (from 2/3 of the periphery to a semicircle) behind the seating area. They also reduced the height of the peripheral shield (3.5 instead of 4 metres), adopting an additional covered peristyle at the crown of the seating area (4.5m above ground level) as a counterbalance in order to protect the opening of the theatre's main entrance.

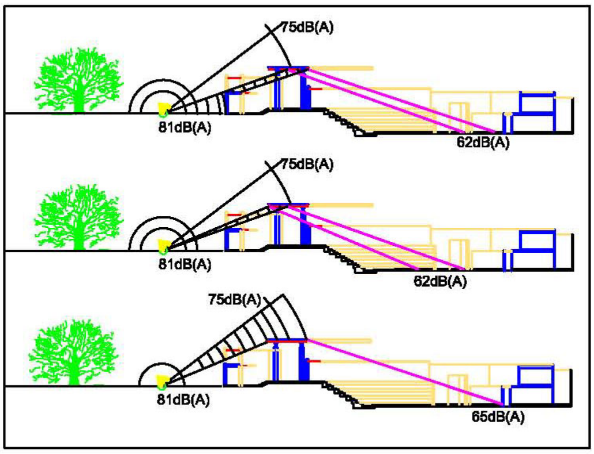

Fig.4 Section of the acoustic model. The non-efficacy of the barriers to the heavy traffic from the neighbouring street

Furthermore, certain unexpected adversities arose during the implementation of the Project, which led to a series of modifications. The budget cut (approximately 30% of the initial approved budget) led to the limitation of the initial level of the subsidence due to the high groundwater level (3.36m instead of approximately 4.2m), whereas the discovery of certain archaeological finds during the excavation of the orchestra area resulted in the further limitation of the subsidence (to approximately 2.7m).

The need to preserve the size of the surface sound barriers – due to the new facts – brought about the alteration of the proportions of the theatre space (reduction of capacity to 830 seats, increase in the radius of the orchestra, increase in the distance between the stage and spectators). In order to maintain the gradient of the seating area that was initially provided for, the architecture solution of increasing the size of the standard row and reducing the number of rows (from 12 to 7) was adopted for the amphitheatre, resulting in the disproportionate increase in the central and transverse span of the area. Lastly, the preservation of certain large trees in relatively new spots in the amphitheatre caused the appearance of unanticipated side parapets at the edges of the seating area.

The present paper attempted to describe a complex process involving successive alterations that eventually limited the magnitude of the acoustic interventions, reduced the span of the shaded area and altered the acoustic function of the selected form and arrangement of the space. Consequently, the acoustic function of the Garden Theatre was led to qualitatively crucial cancellations and quantitatively minimal reductions as regards the calculated figures of the acoustic model predictions, as well as the actual function of the theatre.

The limited subsidence of the theatre space restricts the necessary sound protection of the proscenium area, thus pushing the actors towards the orchestra. At the same time, the modification of the geometric proportions of the space conduces to the movement of the theatrical action (especially, in some hosted productions) away from the influence of the permanent background scenery (outside the anticipated limits of the Haas zone). That is to say that the rising of the desired signal is not adequately emerged by the overall passive loudspeaker function of the theatre space.

As one notices in the 3rd column of the Table, the sound measurements under real operating conditions present a background noise of over 45 dB(A), that is an increase of approximately 4 dB compared to the acoustic prediction model, whereas significant excess (approximately 7 to 11dB) is recorded in circumstances where there is a continuation (without any temporary cessation) of heavy traffic (busses, garbage trucks) down the neighbouring street (N. Germanou). As a combination of the low acoustic emergence and the high noise disturbance, the rising of the desired signal is around 15 dB (approximately 7 dB lower than the acoustic prediction model), with divergences of +/-1,5 dB from the first to the last row. This fact cannot ensure continual satisfactory audibility conditions during a performance.

The overall result of the above new acoustic capacities of the open-air theatre is that the space can function efficiently for lectures, concerts or other music-dance events, but can only allow for limited success when it comes to theatrical performances (without electro acoustic enhancement systems). Nevertheless, the proper exploitation of the stage area and suitable acting techniques (correct elocution and familiarisation with the conditions of the contemporary revival of ancient Greek theatres) can ensure the appropriate conditions for the intelligibility of the message conveyed, with the exception of the initial phase of familiarization of the spectators and the unforeseen disturbances caused by the passing of heavy vehicles or motorcycles nearby the theatre.

In the author's opinion, the reconstruction of the Garden Theatre remains a useful and advantageous option for the city of Thessaloniki, despite the adversities that have arisen. If we had the gift of foreseeing the difficulties arising in-between, then the most likely development would involve a decision to permanently abolish the Theatre in this specific area. However, the existence of an open-air theatre in a prominent position in the urban plan always constitutes a creative occasion for more general adjustments for the benefit of recreational and cultural activities in the city centre. The positive conclusion drawn from the acoustic design is that the predictions of the acoustic model have proven to be accurate, without of course being capable of protecting the acoustic function of the area against the successive modifications. Finally, the negative conclusion drawn from this creative experience is that in theatre design the initial agreement between acoustic and architectural objectives does not suffice; it is also necessary that they continue to cooperate smoothly at all stages of the Project's implementation.

References

[1] N. K. Barkas, "The Thessaloniki Municipal Garden Theatre: Open-air Theatre Design in an Urban Area", *proceedings of the Hellenique Institute of Acoustics (ELINA 2004)*, 25 – 30, (2005)

[2] Fr. Canac, "L` Acoustique des Théâtres Antiques", Paris, CNRS (1967)

[3] N. K. Barkas, "The Acoustical Parameter in Ancient Creek Theater Design" *Monument & Environment 2,* 39 – 56, Thessalonique (1994)

[4] Chr. G. Athanasopoulos, "Contemporary Theater: Evolution & Design", New York, Wiley Interscience Publication (1983)

[5] G. Izenour, "Theater Design", New York, Mc Graw-Hill (1977)

[6] M. Bruneau, "Introduction aux Théories de l` Acoustique", Le Mans, Université de Maine (1984).

[7] J. Stryjenski, "L` Acoustique Appliquée à l` Urbanisme", Génève, Les Editions Techniques (1975)

[8] Chr.G. Athanasopoulos, "Buildings Protection: Thermal – Noise Isolation", Athens (1991)

[9] J.P.Vian, "Critères Permettant de Caractériser l' Acoustique d' une Salle", Grenoble, édition CSTB (1983)

[10] S. Storm, "Room Acoustical Parameters with High Correlation to Subjective Preference", Trondheim, edition ELAB (1982)

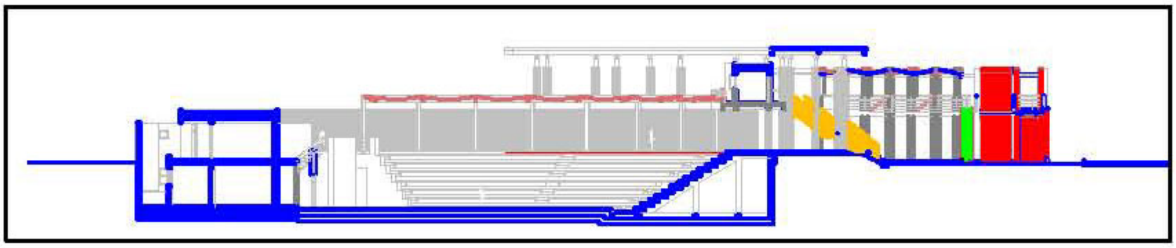

Fig. 5 Cross-section of the Garden Theatre