Between the archaeological site and the contemporary stage: an example of acoustic and lighting retrofit with multifunctional purpose in the ancient theatre of Syracuse

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Between the archaeological site and the contemporary stage: an example of acoustic and lighting retrofit with multifunctional purpose in the ancient theatre of Syracuse

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Abstract

A research conducted on the contemporary use of ancient theatres is presented, focusing on sustainable solutions for passive acoustics and artificial lighting devices. The case study is the theatre of Syracuse, well known as archaeological tourist attraction and as traditional stage for theatrical events. A retrofit was suggested to avoid the use of loudspeakers in the theatre during representations, through the selection of the best performing orchestra shells. For the lighting part, the study focused on the theatre as archaeological site, improving the monumental light system present in the theatre from the maintenance and energy saving points of view.

Keywords: **:** Ancient theatre; Conservation; Retrofit; Acoustics; and Monumental light.

1. Introduction

Open-air theatres and amphitheatres are one of the most representative sign of civilization belonging to the Greek and Roman ancient culture. Designed for the perfect acoustics, during the antiquity they were used with different purposes: religious ceremonies, theatrical or musical performances, and political assembly. Nowadays those suggestive structures are mostly disappeared, and their archaeological rests characterize the landscape of the Mediterranean basin and other countries conquered by Roman Empire, as Germany and Britain. As part of the

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cultural and architectural global heritage, the ancient theatres are subject to strict controls in order to preserve them for the future generations: several international Charters and laws were developed during the last years, promoted by UNESCO, with the aim of an international common model both for conservation and modern usage. Many of them represent a touristic attraction, with an intense flow of visitors during the day, but also during the night. Particularly, always more contemporary artistic festivals take place in those ancient structures, indeed in the best conserved theatres. The introduction inside the archaeological areas of temporary scenic structures and modern devices (electro-acoustic and artificial lighting systems) represents a potential risk to which the theatres are constantly subjected. As suggested by the recent Syracuse Charter "for the conservation, fruition and management of the ancient theatrical architecture" [1], the definition of guidelines for the contemporary use of the ancient theatres becomes necessary, but unfortunately, in the practical experience this target has not been reached yet, especially in the technical and energetic domain (acoustics and lighting).

The ancient theatre of Syracuse, the south of Italy, was chosen as case study to evaluate different sustainable solutions, finalised to the acoustic and lighting retrofit. Firstly, it was necessary to conduct an investigation on the conditions of usage of the theatre, during performances and not. Subsequently, on its specific characteristics, some strategies of intervention were defined, as development of previous analysis concerning both light and sound [2]. From the acoustic point of view, the research focused on an objective and subjective analysis: different types of acoustical measurements were performed in occasion of the last edition of classical plays organized by INDA (2014); moreover, a survey on the acoustic perceptions was distributed in form of questionnaires to spectators and actors, pointing out a controversial general opinion about the use of loudspeakers inside the theatre. The solution proposed by the authors refers to previous researches [3] that revealed the significance of scenery design for the acoustics of open-air theatres. By appropriately designing scenery, useful early reflections can be increased, and sound can be distributed more evenly in the theatre, without using electro-acoustics devices. From the lighting point of view, the investigation concerned the monumental lighting system. Designed in 2008 with the intention of organizing tourist visits of the theatre during the night, unfortunately it is not in use anymore. Its analysis revealed that the technologies chosen at the time, mostly halogen lamps, could be reasonably substituted with more innovative solutions (i.e. LEDs), to guarantee energy saving, costs limitation and easier maintenance. This simple retrofit intervention could be interesting to suppose a rehabilitation of the lighting system today.

2. The Greek theatre of Syracuse: actual conditions

The theatre of Syracuse dates the V century B.C. The structure as it appears today is similar to the Roman type, even though the theatre was conceived in the Greek period, changing over time. The part that survived until today shows the *cavea* (where the audience sits) with a diameter of around 105 m (from the original 143 m at its maximum extension), that expands radially around the *orchestra* in a plane semi-circle of 29 m diameter located in front of the building stage (or *scaena frons*) not anymore preserved. Since 1914 INDA (Istituto Nazionale Dramma Antico) organizes every summer a festival on the ancient drama, giving back the original function to the survived ruins of the theatrical building.

2.1. Acoustical measurements on-site

Two types of acoustical measurement were carried out in the theatre in unoccupied condition: A-weighted background noise level (BNL) and speech sound pressure level (SPL). The instrument used for the analyses, provided by the Politecnico di Torino, Department of Energy, was a calibrated sound level meter (Bruel & Kjaer, type 2222). Background noise is mainly due to surrounding nature and traffic from a road at about 60 m under the *orchestra*. The BNL is based on measurements on three microphone positions, two inside the *cavea* and one in the *orchestra*. Ten minutes long measurements were taken in each position, revealing constant BNLs. The measurement of SPL involved an expert actor as a source: the task requested was a 1 min long speech with and without the aid of loudspeaker system, keeping the same vocal effort. The measurements referred to 5 receiver positions inside the *cavea*, while the source position was at the centre of the *orchestra*. Figure 1 shows the measured overall A-weighted BNL and SPL. For corresponding receiver positions (3 and 4) it was possible to calculate A-weighted speech-signal-

to-background-noise ratio (SNR), which represents an indicator for the intelligibility inside the theatre (Fig. 2). Higher values than 10 dB could be considered as fair for speech intelligibility [4].
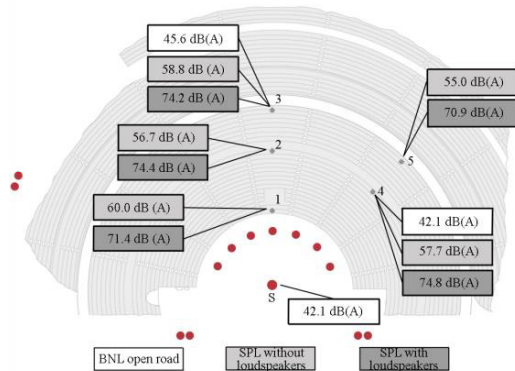

Fig. 1. Overall A-weighted background noise levels and speech sound pressure levels dB(A), unoccupied condition. Sources in red.
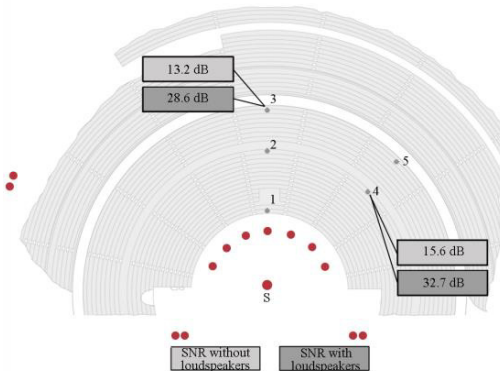
Fig. 2. Speech-signal-to-background-noise ratio dB with and without loudspeakers

2.2. Survey on acoustic perceptions (audience and actors)

A survey on acoustic perceptions was conducted in the ancient theatre of Syracuse during 4 days of the last cycle of representations (14th-18th May 2014): it involved 42 participants from the audience and 39 actors. The questionnaires were distributed at the end of the plays in order to collect subjective opinions on different acoustical aspects; e.g. it was requested to quantify the quality of the sound, to indicate possible disturbing factors or to express appreciation or not on the use of microphones. Subsequently the answers, rated on 5-points grading scales, were analyzed on the basis of statistical methods; the most interesting results are resumed in Table 1.

Table 1. Results of the survey on the acoustic perception in the Greek theatre of Syracuse

Query	*Cavea* (42 Spectators)	*Orchestra* (39 Actors)
Mainly perceived nuisance	Background Noise	Low Volume
Highest level of nuisance	Background Noise	Low Clarity
Mainly perceived noise	Car Traffic	Church Bells
Contrary to microphone use	26%	49%

The survey stressed the need to control background noises, although the measurements revealed quite low levels. Moreover, the use of the actual electro-acoustic system could represent a disadvantage for the actors, since it is not designed for the propagation of the sound in the *orchestra* area.

3. Acoustics applied to the scenic design

On the basis of the analysis of the acoustic conditions of the theatre of Syracuse, and following the indications reported by [1], an orchestra shell was evaluated as solution for a better distribution of the sound in the whole theatre during the performances. Since the target was to improve the original acoustical apparatus without limiting the scenic design, the orchestra shell was conceived as a *minimum interventum* and composed by modular elements.

The exploration of the different variants was performed by means of computer-based simulations. All simulations were done in Odeon version 12.1, a geometrical acoustic software based on a hybrid calculation method that combines two classical methods – the Image Source Method (ISM) and the Ray-Tracing Method (RTM). In order to characterize the acoustics of the theatre, the criteria defined in the ISO 3382-1 standard were used [5].

3.1. General settings and preliminary acoustical analysis

A preliminary analysis was based on the Sound Strength (G) by using an omnidirectional source, conducted to explore differences in acoustic conditions, arising from the use of different materials or source positions of a hypothesized basic scenery element in the theatre (a wall). Previous researches [6] demonstrated that G is a more suitable parameter to characterize the acoustics of an open-air space than Reverberation Time (RT). As shown in Figure 3, 57 receivers were distributed in the model on the five main axes of the *cavea* (central, diagonals and laterals), starting from the centre of the *orchestra*. Height of each receiver is 1.2 m; source S is located in the *orchestra*, 1.5 m high, in different positions (S1, S2).
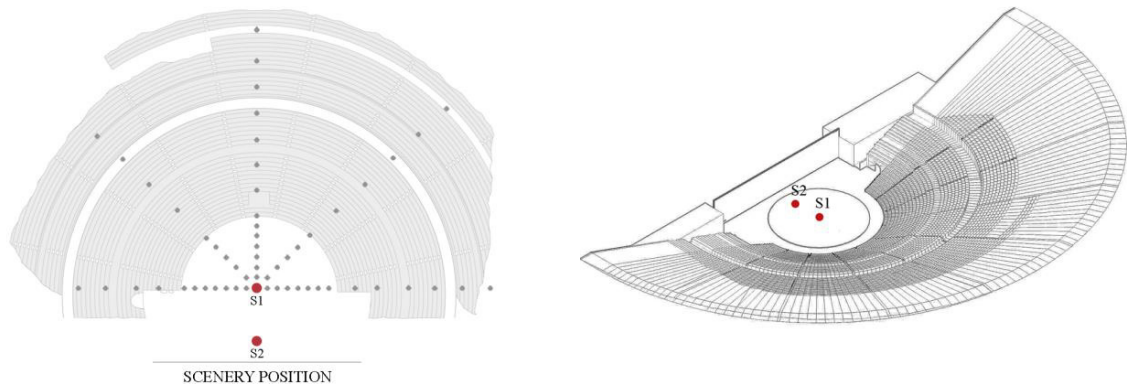

Fig. 3. (a) Layout of sources and receivers' positions in the computer model; (b) Odeon visualization

Empty theatre model has already been calibrated [2]; simulations were run in occupied conditions. Subsequently, a series of different alternatives were analysed by modifying the characteristics of the source and the materials; this allowed to define some fundamental statements, resumed as follows:

- Presence of the scenery: it is registered an increase of the G around 2 dB for last row positions with the source in S1 respect to without scenery condition. The presence of a general architectural element evokes reflections that enhance the Sound Strength.
- Material of the scenery: good results are achieved with wood, plasterboard and plexiglass; any material could be potentially used, provided that its mass per unit area should be at least 15-20 kg/m^2.
- Scattering: different scattering coefficients (0.1 - 0.7) seem not affect the results from the point of view of the G.

3.2. Simulations on modular orchestra shells

Three principal modular elements were identified: I. central body; II. lateral wings; III. upper panel. Different versions for each component were defined through geometrical acoustics and simulated using both omnidirectional and directional sources, in order to evaluate music and speech, respectively. Following a methodology already experimented in [2], in case of omnidirectional source the elements were estimated by means of Sound Strength (G), to assess the reinforcement of the propagation of the sound, Clarity (C_{80}), to evaluate the possibility of execution of other kind of performances; SPL and C_{50} were analysed in case of directional source with raised human voice frequency spectrum. Echo Criterion (EC) by Dietsch and Kraak [7] was also considered in order to detect potential echo problems at low frequencies, typical in ancient theatres [8]. Figure 4 shows a resume of the elements analysed.

Best results were achieved with Fan Wall (FW) both for speech and music. Although the similar shape, simulations with lateral wings did not give more satisfying results than FW. Upper panel resulted useless for the great dimensions of the theatre. For sake of easier comprehension the following discussion in detail of the most interesting results will refer only to central body simulations.
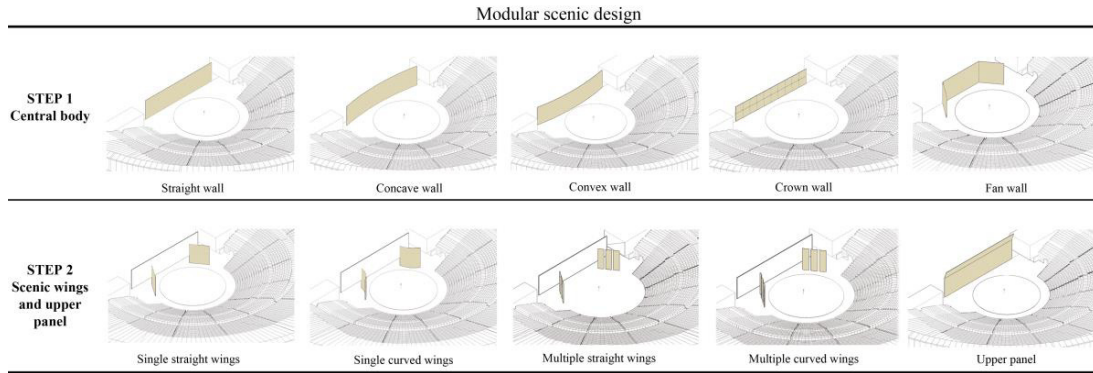
Modular scenic design

Fig. 4. Simulated versions of modular orchestra shells

Logarithmic regression curves related to G values simulated with omnidirectional source in position S2 are reported in Figure 5. With FW the sound propagation improves both in *orchestra* and *cavea* with regular trend, reaching an improvement of 5 dB in last positions. C_{80} reported in Figure 6 is calculated with omnidirectional source in central position S1, to simulate a musical ensemble. Results obtained from FW are closer to the typical range of C_{80} indicated in [5], referred to closed spaces, 5 dB < C_{80} < -5 dB. In Figure 7 best results for echo at low frequencies (125 Hz) were obtained with directive source in position S2, even if the echo phenomena is present in lateral areas and last central rows (EC > 1).
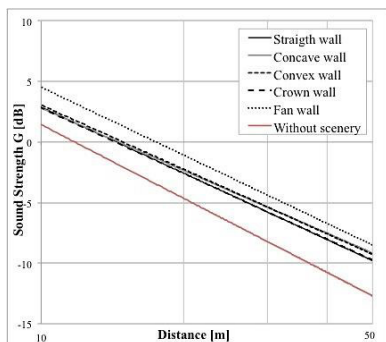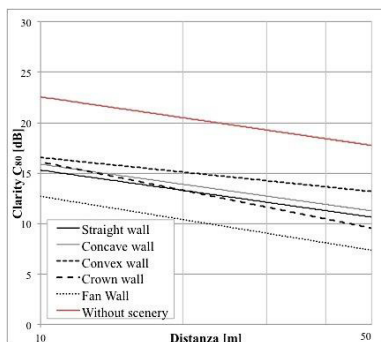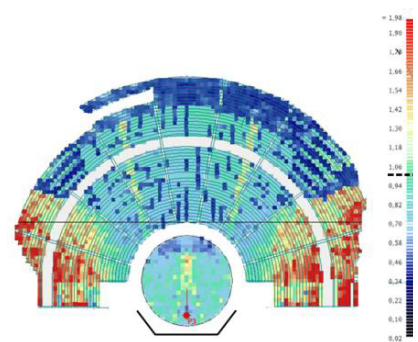

Fig. 5. Simulated $G_{0.5-1kHz}$ logarithmic regression curves, omnidirectional source S2.

Fig. 6. Simulated $C_{80\ 0.5-1kHz}$ logarithmic regression curves, omnidirectional source S1.

Fig. 7. Simulated EC map at 125 Hz, directive source S2.

4. Retrofit of the monumental lighting system

The monumental lighting system of the theatre of Syracuse was completed in 2008. The idea, developed by the Italian architect F. Panzera was to accompany, with light, the guided itinerary from the *orchestra* ascending to the top of the theatre. The analysis of the project revealed that the installed luminaires mainly used halogen lamps, typically characterized by short average lifetime and low luminous efficacy. The estimation of the overall power of the existing lighting system corresponds to 7 kW. Due to high costs of management and maintenance, the lighting system is actually not in use. In this work the potential of a lighting retrofit intervention was verified: without changing the concept of the project, the benefits of substituting halogen lamps with LED equivalent solutions was assessed. In Figure 8 the luminaires in use and the corresponding lamps, in actual condition and in a hypothetic retrofit are shown. With respect to the performance of existing lamps, LED sources give benefits in terms of energy consumptions and maintenance costs. With the retrofit solution proposed in Figure 8 the overall power of the

lighting plant would be reduced to approximately 1.5 kW. It should be noticed that the luminous flux of the LED sources is slightly lower then the one of the existing halogen lamps.
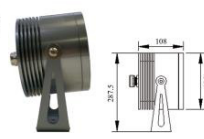
Monumental lighting system						
Luminaries	VM Minilight Led-walk	VM Box	VM Minilight Proof	VM Minilight Archeo	VM Minilight Proof AR111	
Number per type	83 luminaries	16 luminaries	16 luminaries	47 luminaries	34 luminaries	
Lamps model (state of the art)	LED (e.g. Philips MASTER LEDluster)	LED (e.g. Philips MASTER LEDluster)	Halogen dichroic (e.g. Philips Brilliantline Dicro)	Halogen dichroic (e.g. Philips Brilliantline Dicro)	Halogen (e.g. Osram Halospot 111)	**Overall Power: 7 kW**
Power	3.5 W	3.5 W	50 W	50 W	100 W	**Halogen Average Lifetime: 3000 - 4000 hours**
Lumen output	250 Lm	250 Lm	775 Lm	775 Lm	1200 Lm	
Colour Temperature	2700 K	2700 K	3000 K	3000 K	3000 K	
Colour Rendering Index (CRI)	80	80	100	100	100	
Lamps model (retrofit proposal)	No replacement	No replacement	LED (e.g. Philips MASTER LEDspot LV)	LED (e.g. Philips MASTER LEDspot LV)	LED (e.g. Philips MASTER LEDspot AR111)	**Overall Power: 1.5 kW**
Power	3.5 W	3.5 W	10 W	10 W	15 W	**LED Average Lifetime: 25000 - 45000 hours**
Lumen output	250 Lm	250 Lm	650 Lm	650 Lm	790 Lm	
Colour Temperature	2700 K	2700 K	3000 K	3000 K	2700 K	
Colour Rendering Index (CRI)	80	80	80	80	80	

Fig. 8. Luminaires and lamps characteristics [9 - 10], comparison between actual condition and hypothetic retrofit

5. Conclusions

This article presented acoustical and lighting solutions for the sustainable contemporary usage of ancient theatres. Acoustically, the aim was to avoid the use of the loudspeakers during performances through an orchestra shell that could be hidden in the scenery. It was demonstrated that complex scenic schematisations are achieved by using the results of the acoustic simulation of generic categories. In particular, positive effects were obtained with the Fan Wall, both for music and speech conditions. The lighting analysis is concerned with the lighting system conceived for nocturnal fruition of the archaeological area. At present the system is not in use due to high maintenance costs but with new lighting technologies (LEDs) the economical sustainability of the system can be obtained, as demonstrated with the retrofit hypothesis presented in this study.

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