Evaluation of the acoustic performance of a theatrical space set up in a restored Latomia in Ragusa Iblea

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ABSTRACT

Sicily has many artistic and architectural treasures, wonderful historical buildings, monasteries, abbeys and convents that are often restored and used as government buildings, university buildings, theatre and collective spaces for exhibitions. They often have elliptic or irregular shapes and characteristic values of absorption and diffusivity coefficient of wall surfaces that cause serious acoustical problems such as standing waves, flutter echo, sound focusing and intensive late reflections (greater than 100 ms). Moreover, long and flat parallel walls cause undesirable flutter echo which decreases speech intelligibility seriously and diminishes the effectiveness of early arriving sound energy. The paper presents the results of an acoustic study on outstanding Latomia of Gonfalone located in Ragusa Iblea that was restored and is used as marvelous theatrical space. Firstly, the Authors carried out an acoustic measurement campaign to evaluate the main acoustic indices and parameters and set the current acoustic quality. After that, they applied acoustic computer simulations on the Latomia in order to compare the measured data coming from the survey measurements and the data coming from the code. In this way, it has been possible to test the reliability and accuracy of the code and to evaluate on the spatial distribution patterns of speech intelligibility and other acoustic indices defined in ISO 3382. Finally, they have determined the suitable interventions of acoustic correction to improve the acoustic quality of the theatrical space.

Keywords: Latomia, acoustic indexes, acoustic correction I-INCE Classification of Subjects Number(s): 51.1

1. INTRODUCTION

Ragusa Ibla was founded on the site of ancient Sikel town Hybla Herea, of which remains have been found, such as rectangular burial niches in the Gonfalone valley, along the road to Modica. Located in Gonfalone valley there is the famous Latomia of Gofalone which stones was used to construct the castle and temples in the surrounding area during the Greek period. Nowdays, the Latomia is restored and set –up as theatrical space.

So, it is important that the theatrical space satisfy acoustic parameters, experimentally measurable, which define the sound field quality and the listener sensations. These parameters, according to ISO 3382, include the Sabine’s Reverberation Time (T30), the Index of Clarity on 80ms (C80), the Definition Index (D50), the Early Decay Time (EDT). The T30 is the reverberation time of the room evaluated over a 30 dB decay range (from -5 to -35 dB), using linear regression techniques The EDT parameter (Early Decay Time) is the reverberation time, measured over the first 10 dB of the decay.

The D50 parameter (Definition or Deutlichkeit) is the early to total sound energy ratio. It is defined as:

$$\mathrm{D50}(\%) = \frac{\int_0^{0{,}050s} p^2(t)dt}{\int_0^{\infty} p^2(t)dt} \quad [\%] \tag{1}$$

The C80 is used for concert hall acoustics and it is defined as 10 times the logarithm of the ratio of the energy arriving within 80 ms of the direct sound and the energy arriving later.

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$$C80(dB) = \frac{\int_0^{80ms} p^2(t)dt}{\int_{80ms}^{\infty} p^2(t)dt} \quad (2)$$

Where p is the pressure level measured in Pa

In this context, the paper presents the results of an experimental investigation on the acoustic performance of Latomia of Gofalone used as theatrical space at the University of Catania. In order to determine the distribution of the sound energy and the room acoustic parameters [1,2], the authors have proceeded by the following steps:

- definition of the geometrical and architectural features of the hall;
- definition of the acoustic properties of the surfaces;
- measurement of the sound insulation performance of the structure;
- calculation of the sound energy and acoustic indexes (T30, C80, EDT, D50) measured within the Latomia;
- modeling of the hall by means of a ray tracing computer model (Catt-Acoustic);
- verification, validation and calibration of the computer model;
- analysis of the “acoustic response”;
- determination of the suitable interventions of acoustic correction, in order to improve the acoustic quality.

2. The case study

The quarries Gonfalone are amongst the most unique and spectacular expressions of archeology in the province of Ragusa. They have an easy access from a tiny street called" Risorgimento" and have a vertical wall facing South-East , extending for several hundred meters , with an height above the valley floor up to 12 meters . The space destined to the theater, object of this study, is located in the most easterly of the “Latomie and , specifically, in front of the last cave.

It is characterized by the presence of a natural stage (14.50 m wide, 11.00 m long, 12,00 m height), whose " backstage " is made up of a niche carved into the rock . The floor of the stage was leveled with the help of white cement. The bleachers of reinforced concrete, made in the past, are able to accommodate up to 200 people.

Figure 1 –Picture of the Latomia and ground plan

The lateral bleachers are rotated respect to the center bleachers of about 60° and they are in a non-optimal position for the presence of the pillars of the ceiling. Behind the central bleachers, there is the access to the valley floor. All the theater space is surrounded laterally by the pillars that supports the ceiling rock , with the presents of some access to other lateral caves. Although the rocks and the huge volume of the theatrical space offer an outstanding scenic design, they are the major causes of bad acoustics, which severely limits the usability of these spaces for artistic events.

This study aims to deal with this problem and propose interventions to improve the sound quality of the theater, making it suitable for the performance of theatrical events and musical performances.

3. Measurements and acoustic simulations.

The goal of the present study is to evaluate the current acoustic behavior of a theatrical space set up in a restored Latomia in Ragusa Iblea structure in order to evaluate suitable interventions of acoustic correction applicable to similar structures. With this aim it was preliminarily characterized the ultra-lightweight structure through the evaluations of the classical acoustic room indexes: reverberation time (T30) and early decay time (EDT) for the evaluation of reverberation characteristics; clarity (C80), definition (D).

The measurements were carried out using a 01dB-Stell Symphonie precision audio-acquisition unit powered with the 01dB software dBBATI32. The "Symphonie" is a device with two PRE 12H microphones connected to an acquisition unit (dual channel), which transfers data in real-time to a notebook computer and allows simultaneous analyses in both time and frequency domains. The "Symphonie" platform permits data acquisition and calculation of Leq and Peak values conform to IEC 804 and IEC 651 type I specifications, while real time analysis are available on both input channels in octave or third octave spectra, from 20 Hz to 20 kHz conform to IEC1260 Type 0 specifications for digital filtering. Frequency weighting filters A, B, C and G are available and simultaneous recording of the input signal to the hard disk is a particular feature of "Symphonie" that enables post processing and further analysis. The "dBBATI32" is the software used to measure the acoustic indices in the buildings. If it is used with "Symphonie" measuring systems, dBBATI32 adds to the computer the facilities of a digital audio recorder, a Type 1 sound level meter, a frequency analyzer and an optimized system for measurements in buildings.

3.1 Measurements of the acoustic indexes

The procedures employed are those established in the ISO 3382-1 and IEC 60268-16 standards, and all measurements are accomplished in the unoccupied room. The environmental conditions were monitored during the measurements by a precision electronic thermo-hygrometer. The ranges of variation of the environmental conditions are 19.6– 20°C for the temperature, and 49–50% for the relative humidity, respectively. An emission of MLS signal have been used to determine the following parameters for each frequency band between 125 Hz to 4000 Hz and in all the 9 receiver positions of Fig. 2 in the lecture hall area: reverberation time (T30), and early decay time (EDT), for the evaluation of reverberation characteristics; clarity (C80), definition (D50). The MLS signal is generated by the 01dB-Stell Symphonie PCMCIA card and analyzed by the dBBATI32 software. The signal generated feeds the amplifier GdB to be later reproduced by the omnidirectional source A1 dodecahedral loudspeaker DO12 01-dB Stell, placed at a height of 2,00 m. Various microphones (with appropriate signal-conditioning amplifiers OPUS 01 dB-Stell) are used to obtain the various parameters.

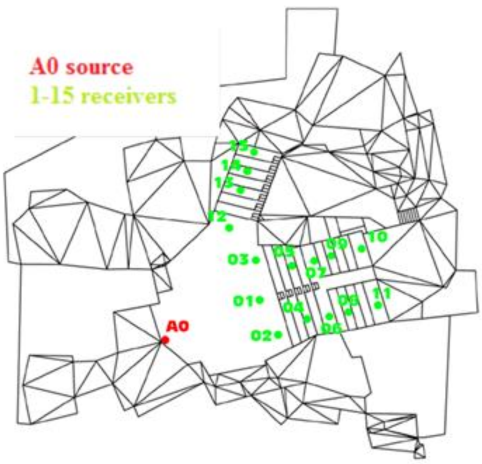

Figure 2 - ground plan with the n.15 receivers and A0 source position

They are all located at, 1.20 m from the floor, in predetermined positions in the hall seating area, see Figure 2.

The various acoustic parameters are spectrally averaged as specified in ISO 3382-1 standard. At least three measurements have been done consecutively in each position in order to be in accordance with ISO 3382-1.

3.2 Acoustic simulations

The measurements of the acoustic indexes were used for verification, validation and calibration of a ray tracing computer model (Catt-Acoustic) of the hall in order to determine the suitable interventions of acoustic correction to improve the acoustic quality.

The construction of a three-dimensional geometrical model of the room is the starting point towards reliable acoustical computer-aided simulations. Sound sources, receivers and the geometry of the room itself have been implemented into the model in such a way that they remain decipherable to the predicting software.

Consequently it was used Google SketchUp and Autocad to realize the three-dimensional geometrical model of the room

Acoustically characterizing surfaces into the computer model boils down to defining their capability to absorb and scatter energy from incident sound rays. Every entity in the model whose size shows an order of magnitude not comparable to the wavelength of the excitation signal was disregarded and then compensated by flat surfaces with accordingly-corrected scattering coefficients.

As for absorption coefficients, data from the extensive databases found in the literature are assumed for most of the materials of the space [3,4]

The iterative procedure for the validation of the virtual model is based on the steady adjustment of absorption coefficients for those materials of the enclosure in order to obtain that the simulated T30 differ by no more than 5% from this measured in situ in the space.

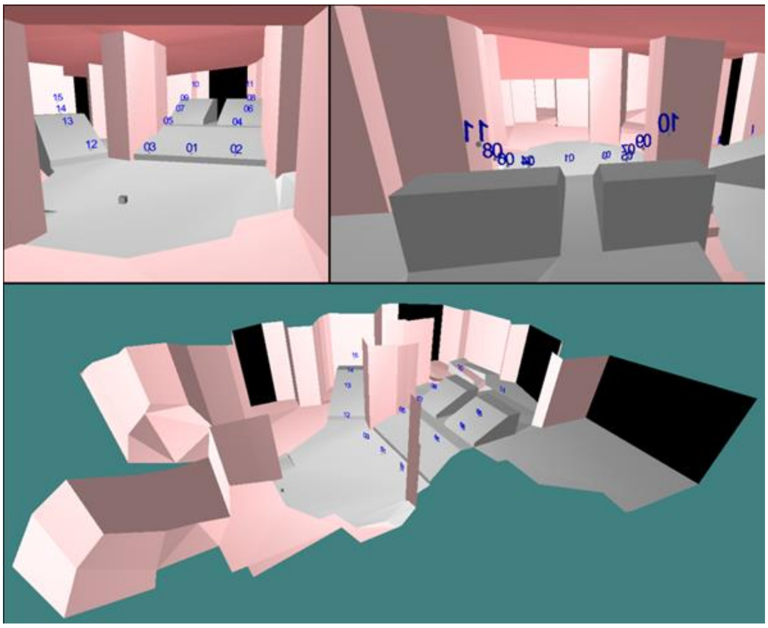

Figure 3- Catt-acoustic model

3.3 Results and discussion

The results of the measurements allow us to expose some considerations on the acoustic behavior of the theater.

There is a clear difference between the central and lateral bleachers : the values of all indices are worse in the lateral bleachers. This is probably due to the angle of lateral deviation of the bleachers , which is excessively tilted with respect to the focal point of the stage. Furthermore , the distance from the rock walls is such as to create an excess of reverberation and consequently flutter echo.

The values of reverberation times , as well as those of the early decay time , are too high compared to those required for prose and music : sound-absorbing materials should be introduced to reduce reflection and focusing of the sound energy in early reflections.

At first reflections are clearly related C80 and D50 definition .

The values obtained are not acceptable for the frequency range between 125 Hz and 1 kHz . Infact it is pointed out a strong overlap between the reflections of the second and third order and the direct sound and early reflections, compromising the transparency and clarity of both music and speech. The optimization of these indices is consequential to the improvement acoustic quality of the theatre.

The comparison between the values for the various acoustic parameters given by in situ measures and computer simulations constitutes the following step after the calibration procedure.

The figure 5 which presents results for T30 and EDT as a function of octave-band central frequencies, after individual values from all the receivers have been spatially averaged [5].

According to the outcomes, for the T30 parameter the discrepancies between experimental and simulated values appear at high frequencies, with a deviation at 2000 Hz. However, simulated and experimentally measured do not differ from one another by more than five percent.

As concerns the EDT parameter, discrepancies between experimental and simulated values mainly appear at l25 and at 2000 Hz. However, there is a fairly close match between the overall results from computer simulation and those resulting from experimental measurements [7].

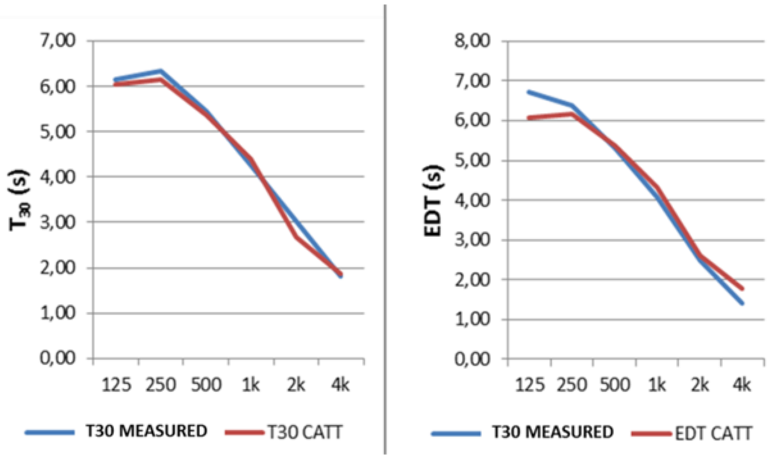

Figure 4 -.Measured and simulated values of T30 and EDT

4. Acoustic corrections

One of the main practical applications emanating from the calibration and validation of geometrical models is the possibility to study the effect of suitable interventions of acoustic correction, in order to improve the acoustic quality. Different possible interventions were considered:

- Solution 1: treatment of the stage with wooden platform
- Solution 2: sound absorbing curtains
- Solution 3: Acoustic panels on the roof
- Solution 4: Sound absorbing panels on the walls

The first proposed solution consists of installing a wooden platform on the floor in white cement constituting the stage, below which is placed a layer of 15 mm rockwool.

The platform functions as a vibrating panel which damps the sound waves at low frequency.

The materials used for the platform are:

- fir wooden planks of 3 cm thick, with a density per unit area of 12.60 kg/m2;
- •rockwool of density 45.00 kg/m3, with flow resistivity of 14152 rayls / m.

The second solution has the objective to exclude all the entire niche, used as backstage, adjacent to the stage, reducing the path of late reflections .

This type of treatment is performed using a porous sound-absorbing curtain (model of MERMET ACOUSTIS ® 50), installed on the roof and it will used during the theatrical performances.

Table 1-Absorption coefficient of ACOUSTIS® 50

125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
0.10	0.20	0.45	0.60	0.78	0.80

The third solution concerns the installation of absorbent panels on the ceiling that is the cause of the largest number of reflections.

Considering the peculiarity of the environment, the panels are hanging on the rock so in this way they are easy to install and low invasive.

The idea is to use the same fabric used for the curtains. The panels are made in the shape of right isosceles triangle, with the short sides respectively of 2.50 mt and 3.50 m

The frame of the panels to which is fastened the textile is made of wooden beam with a circular section of a diameter of 2.5 cm .

The panels are arranged in even number on the top of the stage and the central and lateral bleachers: each couple of panels is characterized by an inclination of ± 10 ° to avoid specular reflections and diffuse better the reflected rays.

The panels are suspended at 4,00 m from the ceiling above the stage and at 2.50m from the ceiling above the bleachers .

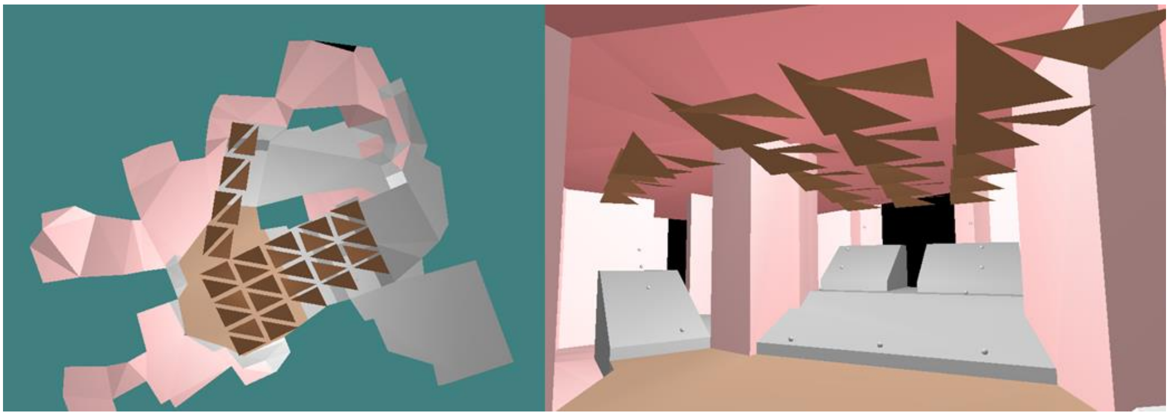

Figure 6 - Arrangement of panels (plan) - Arrangement of panels (stage view)

The fourth solution of intervention concerns the treatment of the surfaces of the rock walls .

The choice of the walls to be treated is carried out according to the data output of Catt simulations, choosing the surface that are most affected by sound beams. In the figure n. are highlighted in red the treated walls.

In particular are treated the walls behind the lateral bleachers because they are a critical points for the reflections which fall within the area of the stage.

The acoustic panels designed consist of wooden planks, width 8.0 cm and thickness 1.0 cm, gap of 1 cm between them. Behind the panels it is placed a layer of 15.0 cm of rock-wool and an air gap of 10.0 cm

The absorption coefficients of the panels were calculated using the software ZORBA considering the geometrical and physical characteristics.

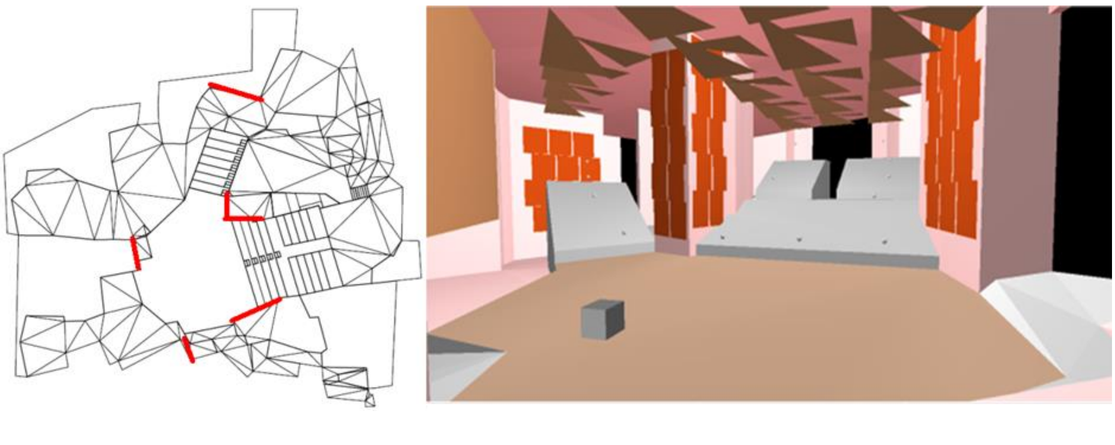

Figure 7 -Arrangement of sound-absorbing panels (plan) - Arrangement of panels on the walls

(stage view)

Tale2 - Absorption coefficients of sound-absorbing panels calculated by Zorba

125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
0.85	0.85	0.80	0.65	0.45	0.25

The following figures illustrate the results of the combination of the different contributions for the improvement of the acoustic quality of the hall for T30, C80 and D.

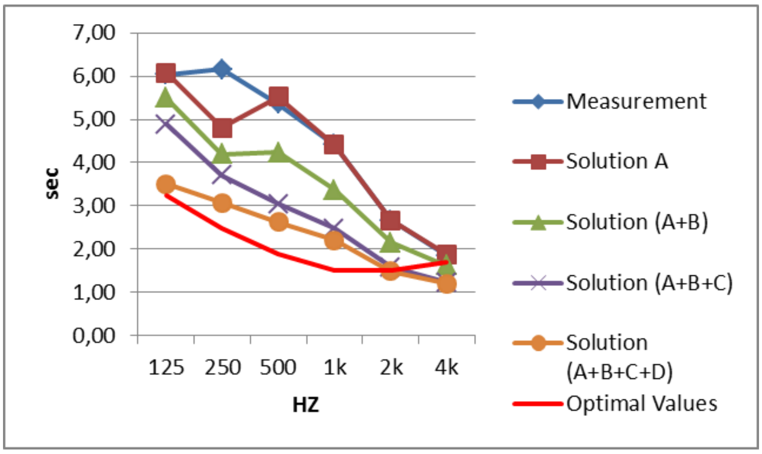

Figure 4 - acoustic behavior of T30 for different solutions

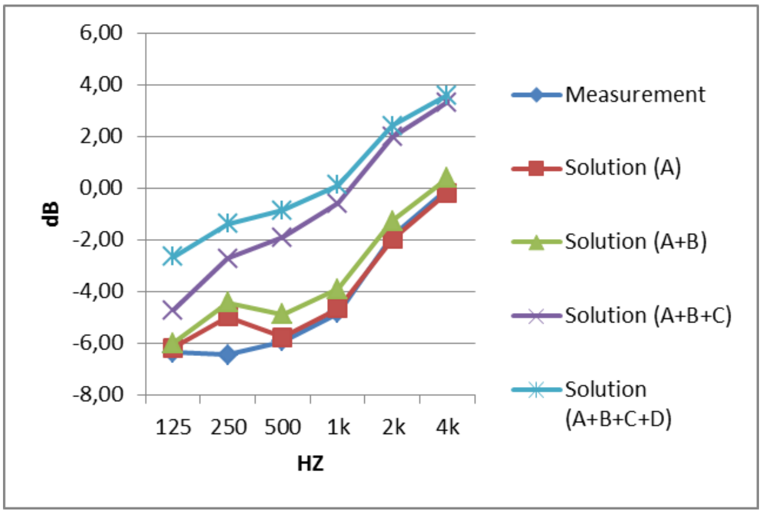

Figure 5 - acoustic behavior of C80 for different solutions

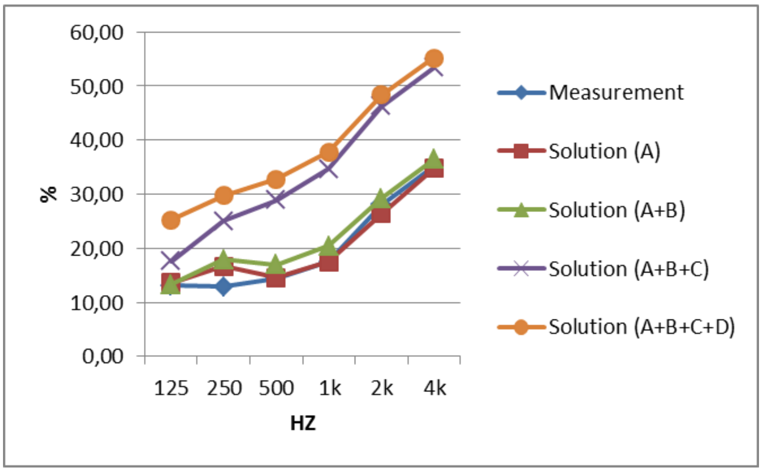

Figure 6 - acoustic behavior of D50 for different solutions

After the treatments, all indices of sound quality, according to the calculations of the software CATT, give rise to a significant improvement in the quality of room acoustics.

The sound pressure level, or SPL, decreases in the area of the bleachers, because there is less overlap between the direct sound and reflections.

The reverberation time is the parameter that undergoes the most important improvement, because of the strong reduction of late reflections, which leads to have values very close to the optimal values. The clarity index as well as the definition index assumed optimal values for musical performances, a bit ' less for prose, which, however, they can be performed with the aid of a sound systems, focusing on the direct component of the sound in the bleachers.

The analysis of the acoustic comfort inside the Latomia has suggested the following considerations:

- Reverberation time: currently the room is very reverberant ,T30=4,50 s at 500Hz. Instead after the correction T-30 medium is less of 1.90 s , considered as the average of frequencies in the range 250 Hz - 2 kHz.
- Early Decay Time: the values are closely linked to those of the reverberation time , are non-linear and non- coherently scattered with respect to the optimal (1.80 ÷ 2.60 s).
- Clarity: currently the values are not acceptable in the entire frequency band. After the correction the values are acceptable, with regard for the music, in the frequency bands from 1 kHz to 4 kHz. In the low frequencies, however, the values are too low compared to the ideal speech ($-4.0 \leq C80 \leq 2.0$ dB for music, $C80 \geq 3.0$ dB for speech). After the correction the values of C80 are higher than 3.0 dB, that is the suggested value for speech.
- Definition: currently the values are not acceptable in the entire frequency band. After the correction the values are all acceptable with regard for the music, but too low for prose ($D50 \leq 0.50$ the music, prose $D50 \geq 0.50$).

5. Conclusions

This study investigates the acoustic behavior of a theatrical space set up in a restored Latomia in Ragusa Iblea through instrumental techniques and acoustic models in order to propose possible solutions applicable to similar structures. The theatrical space was modelled through the software Catt Acoustic, and the model was calibrated against the experimental values. Then, four typology of acoustic corrections were proposed to improve the acoustic quality of the room, and the effectiveness of such interventions was tested through simulations. In particular, the area most affected by the sound rays was identified; the amount of the reflection rays coming from the bleachers and floor was decreases with the help of absorbent panels, so as to reduce the sound pressure level due to the late reflections, on the whole frequency spectrum. Finally, the vertical walls were treated with a specific amount of absorbing surface, without exceeding, therefore avoiding drastic culling of reverberation time that can make the hall " dumb".

The right combination of the proposed acoustic corrections allows to improve significantly the acoustic response of this theatrical space

In conclusion, this paper has offered the possibility to identify not only the necessary actions to improve the acoustic quality of theatrical space, but also to highlight an optimization process in the selection of interventions to be implemented .In a following step, the room was modelled on the software Catt Acoustic, and the model was calibrated against the experimental values. Then, some interventions were proposed to improve the acoustic quality of the room, and the effectiveness of such interventions was tested through simulations. In particular, the area most affected by the sound rays was identified; the amount of the reflection rays coming from bleachers and floor was decreases with the help of absorbent panels, so as to reduce the sound pressure level due to the late reflections, on the whole frequency spectrum. Finally, the vertical walls were treated with a specific amount of absorbing surface, without exceeding, therefore avoiding drastic culling of reverberation time that can make the hall " dumb" .

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