MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Acoustical and Electroacoustical Process for Improving a Multi-purpose Sports Stadium

Lee, Yu-Ting [1]
Department of Architecture, National Cheng Kung University, Tainan, Taiwan
No. 1, Daxue Rd., East Dist., Tainan City 701, Taiwan (R.O.C.)

Tsay, Yaw-Shyan [2]
Department of Architecture, National Cheng Kung University, Tainan, Taiwan
No. 1, Daxue Rd., East Dist., Tainan City 701, Taiwan (R.O.C.)

ABSTRACT

Multi-purpose sports stadiums have become an efficient and cost-effective solution for accommodating both speeches and musical performances. Particularly at universities, stadiums tend to be used not only for sporting events but also for ceremonies and other extracurricular activities. However, the expansive space of stadiums often results in a long reverberation time and thus causes problems with acoustics.

In this study, we selected a university stadium to carry out a case study of a practical process for improving acoustics. We utilized field measurements to diagnose current performance and found that reverberation time was quite large. We performed a simulation with ODEON software and compared the results with the field measurements to verify the boundary conditions. Afterwards, we simulated design strategies based on both architectural acoustics and electroacoustics for evaluation. We found that a curve-shaped ceiling for MPP can reduce the reverberation time to approximately 2 seconds (unoccupied). Furthermore, various acoustic parameters, including SPL(A), C_{80}, and STI, were improved via the electroacoustics process. Both the uniformity and the clarity of sound distribution were expected to be significantly improved for speeches by arranging the position and angle of the speakers.

Keywords: Architectural acoustics, Multi-propose stadium, Public address system
I-INCE Classification of Subject Number: 51, 76

1. INTRODUCTION

Acoustical strategies have become an indispensable issue when dealing with multi-purpose spaces. Many studies on auditoriums have been carried out to analyze the various acoustic characteristics of different kinds of shapes, such as shoebox halls, fan-shaped halls, and rooms with balconies. In traditional auditoriums or lecture rooms, soft finishing materials are commonly adopted to prevent reflected sound.

---

[1] yutingedithxx2@gmail.com
[2] tsayys@mail.ncku.edu.tw

In recent years, multi-use spaces have become an ideal solution for public buildings, such as universities, whose demands vary from ceremonies to student events. In addition to auditoriums, stadiums are also very common in universities. They are even more accessible and can be flexibly used for a variety of causes due to their spaciousness. However, stadiums, are often designed with wooden floors, raw wall finishing, and steel roofs, which results in a relatively large reverberation time.

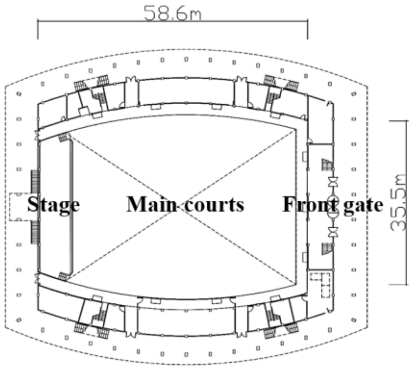
Unlike previous works, this case study is carried out to overcome the acoustical defects for speech and music in stadiums. The chosen stadium is located in National Cheng Kung University in Taiwan. In addition to sporting events, ceremonies and extracurricular activities are also held there, with acoustical qualities ranging from speech intelligibility to music clarity. Like any other stadium, it has a wooden floor for sports purposes, as well as steel, curved ceilings, which leads to approximately 5 seconds of T_{20}. The high reverberation time creates a serious problem even for simple communication during the course of fundamental uses.

2. OBJECTS OF THE CASE STUDY

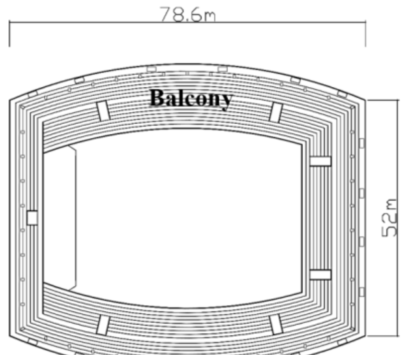
2.1. Room description

The stadium is symmetrical in an elliptical shape with two main parts, the court on the ground level for sports and the surrounding balcony for the audience members (Fig. 1). The total volume is about 55,000 m^3, and the total capacity is about 10,000 audience members, including 6,000 fixed plastic seats in the balcony section and 4,000 moveable seats on the court. The maximum length is over 75 meters, and the maximum height is more than 10 meters.

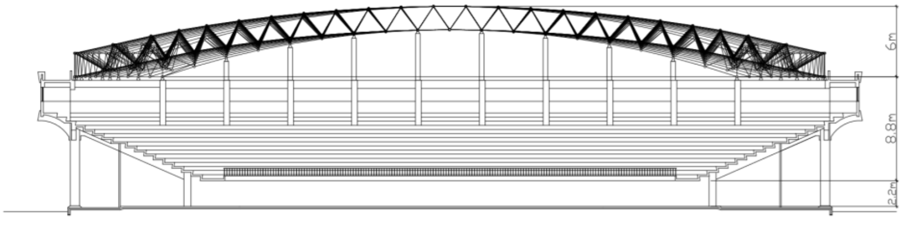
The background noise is about NC30-35 since the stadium is adjacent to the main traffic road. In addition to the typical sports use, band music, short dramas, and guitar performances are the other common uses of the space. Not equipped with any sort of public address system, this room apparently lacks an acoustical design for its deserved status.

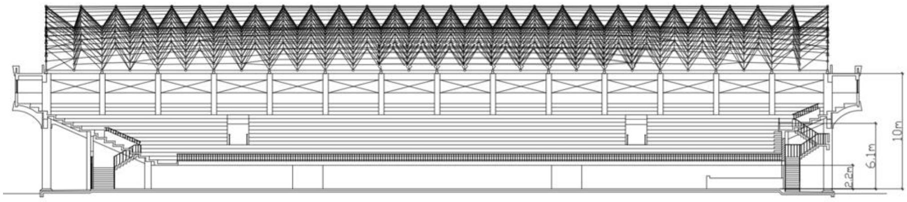


(a) Ground floor plan



(b) Second floor plan





(c) Longitudinal section

Fig. 1 Plans and sections of the stadium

2.2. Objectives and proposed target values

In this work, we aim to determine an acoustic strategy for the multi-purpose stadiums that can be generally applied. For both speech and music uses, the specific T_{20} is defined as 2.6-1.4 seconds as a function of volume (Wilson, 1989). STIPA are also considered to ensure the quality of speech with the assistance of public address systems, and C_{80} is measured to make sure that the space is suitable for the primary musical styles played in the stadium.

3. METHODOLOGY

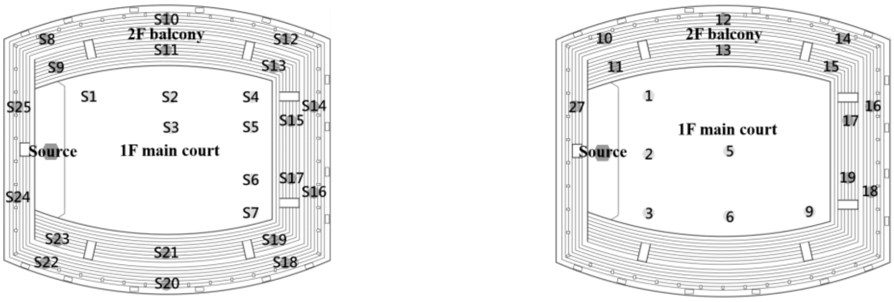
Field measurements and simulations are carried out to verify the accuracy of the treatments. In the first phase, we conducted field measurements to diagnose the acoustic condition of the unoccupied stadium. Based on the results, simulations are implemented to help with further analyses. Strategies are investigated to meet different demands.

3.1. Field measurements

We measured and calculated the acoustic indicators, T_{20} and STI, using the Dirac 5.0 software system. The MLS signal was chosen as a stimulus to diagnose the impulse response of the room. SPL was checked by a continuous white-noise signal, and data were collected using a B&K 2250 hand-held analyzer. An omni-directional speaker sound source was set at a height of 3 meters, while the receivers were set at 1.5 meters to represent a listener in a standing position (Fig. 2). During the measurement, the air temperature was 27.6 °C, and the relative humidity was 82.4% (a rainy day).

3.2. Numerical simulations

After the field measurement, we carried out a simulation using ODEON version 14 software. During this phase, the compatibility of the field measurements and simulation were verified. All the set materials came from the Odeon material library and references (Table 1). We further investigated strategies in the simulation based on the validations.



(a) Positions for SPL

(b) Positions for the T_{20} and STI

Fig. 2 Positions of field measurements

Table 1 Main absorption coefficients in simulation settings

Material	Frequency bands (Hz)							
	63	125	250	500	1k	2k	4k	8k
Floor （Parquet fixed on concrete）[1]	0.04	0.04	0.04	0.07	0.06	0.06	0.07	0.07
Audience （Unoccupied plastic chairs）[2]	0.06	0.06	0.10	0.10	0.20	0.30	0.20	0.20
Roof/Ceiling （steel trapeze profile）[3]	0.40	0.35	0.20	0.15	0.11	0.09	0.10	0.10
Wall （smooth concrete, painted）[3]	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
Window/Door（glass）[3]	0.35	0.35	0.25	0.18	0.12	0.07	0.04	0.04
Micro-perforated panel [4]	0.42	0.42	0.76	0.61	0.58	0.52	0.27	0.27
A standing person [4]	0.05	0.05	0.07	0.11	0.21	0.35	0.43	0.43
A seated person in a wooden chair [4]	0.06	0.06	0.06	0.14	0.20	0.29	0.34	0.34

(1) M. David Egan, "Architectural Acoustics"
(2) Michael Vorländer, "Auralization：fundamentals of acoustics, modelling, simulation, algorithms and acoustic virtual reality"
(3) Christensen, C. L.., "ODEON room acoustics program version 6.0 user manual, industrial, auditorium and combined editions." Lyngby：Oersted Plads.
(4) Architectural Acoustic lab., NCKU

4. ACOUSTICAL DESIGNS

4.1. Architectural geometry renovation

To achieve suitable absorption with geometry, increasing the effective absorption area in the stadium becomes the top priority. We focused on the ceiling since it spans the entire space and has almost half the potential absorption surface. Based on this point of view, the original steel-kind ceiling were masked with acoustic micro-perforated panels (MPP) as the first step.

The ceiling was covered in MPP with a 0.25-meter air borne space. The panel was 25-mm thick with a layer of non-woven fabric attached beneath it, which absorbed the mid- and high-frequency bands, and the structure of the 250-mm air borne area helped to reduce the energy of the low-frequency bands.

Table 2 Validation cases, unoccupied

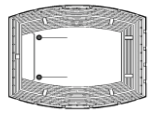
Case	Description
A0	The original measurement conditions.
A1	The original simulation conditions.
A2	The ceiling-renovation simulation conditions.

4.2. Electroacoustical strategies

To establish a compromise between multiple uses, the specific T_{20} value can certainly not satisfy every condition for speech and music. Instead, it can only reach a moderate value to meet mutual demands. Therefore, electroacoustic systems were installed. In this work, we studied line-array speakers in several cases. The detailed arrangements of the speakers are shown below (Table 3).

In this phase, simulations were carried out with 60% audience capacities, which is the most common capacity for most uses. The 100% occupied condition only occurs at such significant events as graduation ceremonies.

Table 3 Cases of line-array speakers

Case	Audience	Height(m)[1]	Transducers(°)[2]	Diagram	
B0	unoccupied	7	0 0 -2 0 -2 -4 -6 -10		
B1	60% occupied				
B2			0 0 -10 -10 -10 -10 -10 -10		
B3		10			

(1) Standing type (from the botten of the array to the floor).
(2) The frequency range of each transducer is 55Hz- 19kHz.

5. RESULTS

In the first phase, we verified the compatibility of the field measurements and simulations. Figure 3 displays a high correlation between the measured and simulated T20. Case A1 demonstrates an 11% decrease from case A0 at 500Hz, while at 125Hz, the lowest deviation appears to be about 7%. The simulation case may tend to underestimate the mean T20 due to overestimating the ceiling absorption. Secondly, the propagation of SPL is demonstrated in Figure 4. It shows that the distances between the positions and the direction of the speaker play a major role in the distribution of SPL.

Overall, the simulation results coincide closely with the measured results. Case A0 shows a relatively high T20, surpassing the target value by about 3 seconds (Fig. 3).

5.1. Architectural renovation results

The MPP worked as an effective absorber to achieve an acceptable T20 (Fig. 3). Case A2 showed a 55% decrease compared to case A1 at 500Hz. However, the absorption of the MPP did not work well with low-frequencies bands. The air gap between the MPP and the ceiling may be adjusted to obtain better absorption of low frequency bands.

5.2. Electroacoustical strategies results

Regarding speech intelligibility and increased flexibility of the room to meet various demands, an active audio strategy was put into practice. We implemented a public address system in the room in different cases (Table 3). T20, SPL, and SITPA (STI value customized for PA systems) were employed, and the results are shown below.

T20 is displayed in Figures 5 and 6. In case B1, the mean T20 shows a 4% decrease at 1kHz and 11% decrease at 2kHz when compared to case B0. The audience provided mid- and high-frequency absorption. At the center of the room, case B1 appears 29% higher than case B0 at 500Hz but indicates a 15% and 27% decrease at 1kHz and 2kHz, respectively.

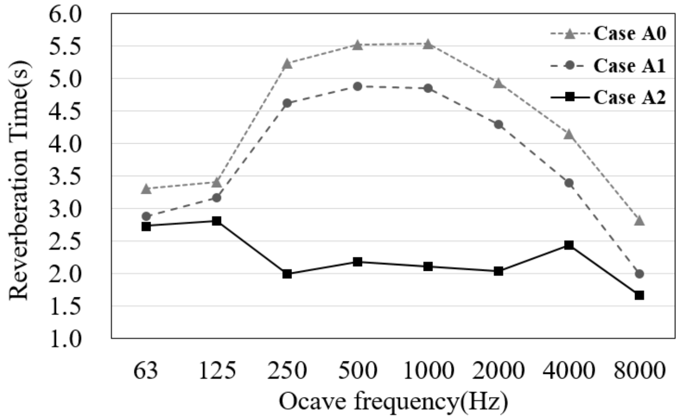


Fig. 3 The mean value of T20

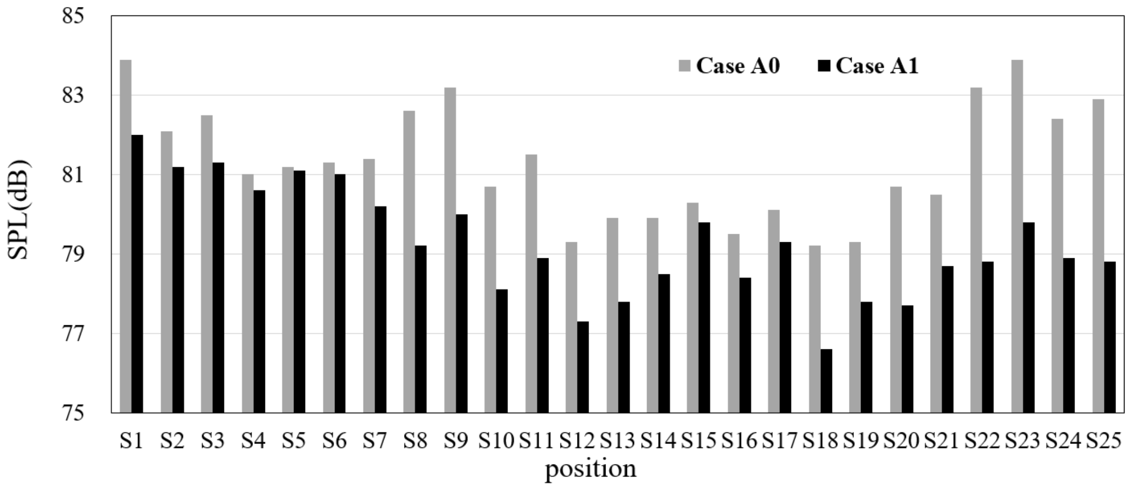


Fig. 4 The distribution of SPL

In case B1, the sound focal effect seems to be amplified, causing a relatively irregular sound field within the stadium. In Figure 6, compared to case B0, both case B2 and case B3 have a 20% and 17%, respectively, lower value at 500Hz. However, case B3 indicates a 13% and 5% increase at 1kHz and 2kHz, respectively, whereas case B2 decreases at both frequency bands. The speaker's height may be influence this phenomenon because the closer a speaker is to the ceiling, the stronger and faster the energy reflects off from the ceiling.

Regarding speech intelligibility, we investigated STIPA. On the ground floor, case B1 and case B2 indicated a "Good" level on the STIPA scale (IEC 60268-16), with case B1 being the best. As for case B3, the energy reflected by the ceiling may explain the low values. Furthermore, the STIPA on the balconies all reach a "Fair" (or higher) level.

The predominant C_{80} of case B1 ranges from 3 to 6 dB or above (Fig. 9), which indicates that percussive-instrument music styles with strong tempos, such as rock bands, piano, and electronic instruments, are a better fit for the stadium, which corresponds to the majority of musical styles in extracurricular events for students.

6. DISSCUSSION AND CONCLUSION

We have discussed architectural and audio acoustics in this work to determine a relatively suitable method that can be applied to more flexible uses. We first carried out field measurements to diagnose the phenomenon of the original acoustics and then conducted a simulation for further analysis. Since the current interior surfaces.

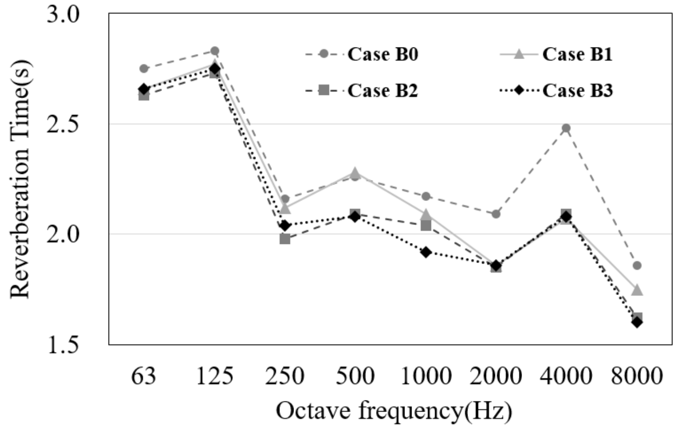


Fig. 5 The mean value of T20

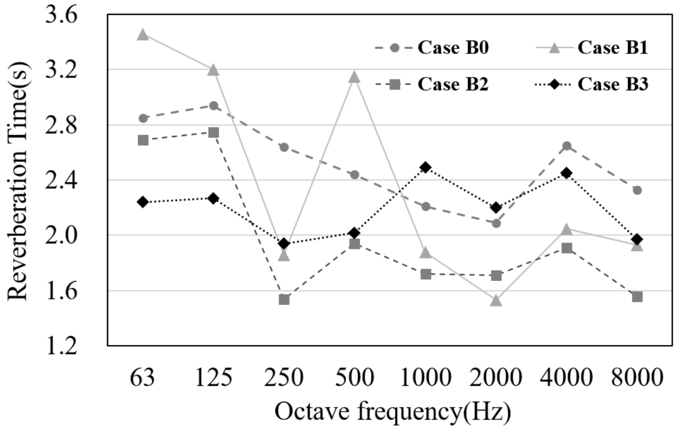


Fig. 6 T20, center of the court

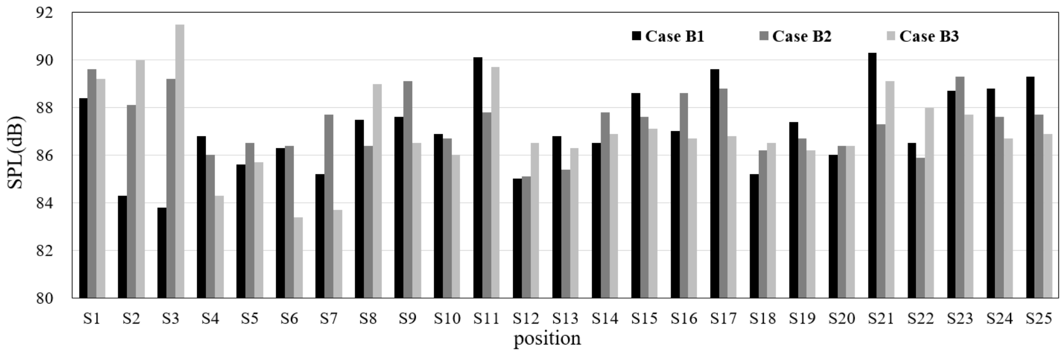
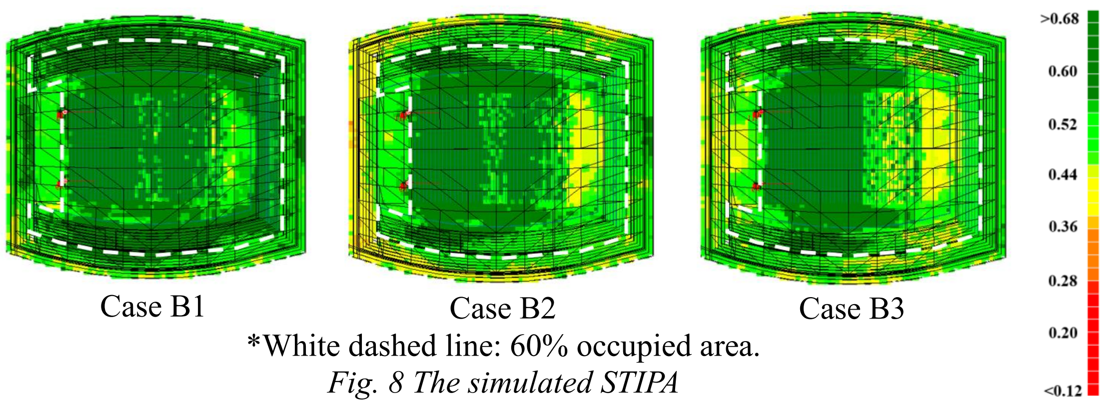


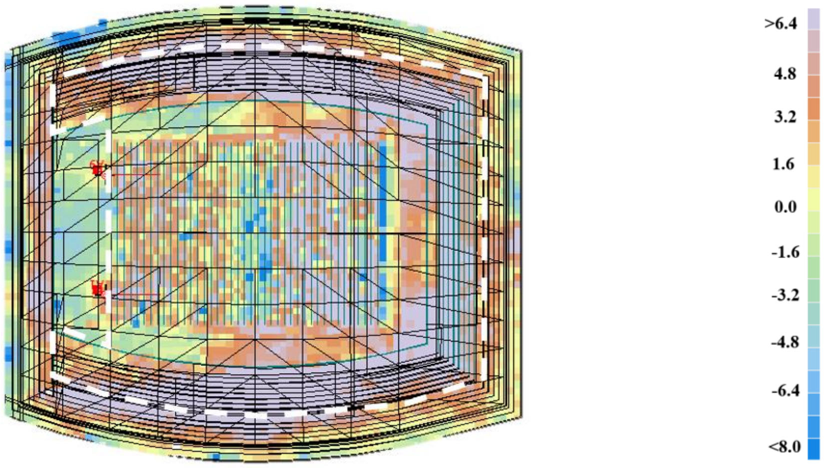
Fig. 7 The distribution of SPL



Case B1 Case B2 Case B3

*White dashed line: 60% occupied area.

Fig. 8 The simulated STIPA



*White dashed line: 60% occupied area

Fig. 9 C_{80} at 1kHz of case B1

were high reflective materials, we performed a renovation to increase the absorption in the stadium by installing MPP under the steel ceiling. Having successfully reduced T_{20}, we implemented electroacoustical strategies to support better multi-purpose uses. We studied three line-array-speaker cases to find a suitable case for the stadium. The results indicated that case B1 can provide the best acoustic environment in the STIPA conditions, especially with extra diffusers to overcome the focal regions.

Certain constraints still need to be overcome. Seats located in the rear balcony are supposed to get a better STIPA, which can be achieved by adding spot-speakers at the rear walls. Furthermore, all the measurements and simulations mentioned herein were conducted in a non-HVAC system condition. When the old HVAC system is turned on, the background noise approaches NC45. Future research should solve for a better acoustic environment.

7. ACKNOWLEDGEMENTS

The authors would like to thank Wang, Yang and Ma for help with the measurements and simulation and NCKU for its financial support.

8. REFERENCES

1. Maria Cairoli, "*Architectural customized design for variable acoustics in a Multipurpose Auditorium*", Italy (2018)
2. Mike Barron and Sven Kissner, "*A possible acoustic design approach for multi-purpose auditoria suitable for both speech and music*", the UK (2017)
3. Ahmed AliElkhateeb, "*The acoustical design of the new lecture auditorium, Faculty of Law, Ain Shams University*", Egypt (2012)
4. Francesco Martellotta, Michele D'alba and Sabrina Della Crociata, "*Laboratory measurement of sound absorption of occupied pews and standing audiences*", Italy (2011)
5. Eugene T. Patronis, Jr. Stadiums and Outdoor Venues, "*Handbook of sound engineers*", the UK (2008)
6. Wilson, C. E., *"Noise Control: Measurement, Analysis, and control of sound and vibration"*, the USA (1989)