PRELIMINARY ASSESSMENT OF THE ACOUSTICS OF THE GUAÍRA THEATER IN CURITIBA, STATE OF PARANÁ, BRAZIL

Paulo Henrique Trombetta Zannin*, Marcus Vinícius Manfrin de Oliveira Filho, Andressa Maria Coelho Ferreira, Cristiane Pulsides, Samuel Ansay and Bruno Portela

Laboratory of Environmental and Industrial Acoustics and Acoustic Comfort,
Federal University of Paraná – UFPR, Brazil
*Corresponding author

Résumé

Cet article présente une évaluation préliminaire de l'acoustique du Théâtre Guaira. Ce dernier est l'un des théâtres les plus importants du Brésil, dont l'espace est conçu pour les présentations de concerts symphoniques, des opéras, des ballets et des pièces de théâtre. L'acoustique de la salle principale du Théâtre Guaira a été évaluée sur la base des temps de réverbération calculées pour les conditions suivantes: 1) 1/3 de la capacité des sièges occupés, 2) 2/3 de la capacité des sièges occupés, et 3) tous les sièges occupés. En plus de ces calculs, les temps de réverbération ont également été mesurés en suivant les directives de la norme internationale ISO 3382-1: 2009.

Mots clefs: Guaíra Theater, le temps de réverbération, des mesures de temps de réverbération, l'acoustique des salles

Abstract

This paper presents a preliminary assessment of the acoustics of the Guaíra Theater. This is one of Brazil's most important theaters, whose space is designed for presentations of symphony concerts, operas, ballets and plays. The acoustics of the main auditorium of the Guaíra Theater was evaluated based on reverberation times calculated for the following conditions: 1) 1/3 of seat occupancy, 2) 2/3 of seat occupancy, and 3) full seat occupancy. In addition to these calculations, reverberation times were also measured following the guidelines of the ISO 3382-1: 2009 standard.

Keywords: Guaíra Theater, reverberation time, measurements of reverberation time, room acoustics

1 Introduction

The history of the Guaíra Theatre, located in the city of Curitiba, capital of Paraná, Brazil, began in the 19th century. However, although the theater – at that time called São Teodoro Theatre – was slated to open in September 1884, its inauguration was canceled due to political unrest in Brazil [1, 2]. A curious fact is that the facilities of this theater were used as a political prison at that time. After undergoing renovations, the theater was finally opened to the public in 1900, but then demolished in 1937 for safety reasons [1, 2].

The current Guaíra Theater complex comprises three auditoriums: 1) Bento Munhoz da Rocha Netto Auditorium, which is the largest of the three and is nicknamed "Guairão," with seating capacity for 2173 people; 2) Salvador de Ferrante Auditorium, with seating capacity for 504 people; and 3) Glauco Flores de Sá Brito Auditorium, with seating capacity for 104 people.

Work on Guairão Auditorium, the most popular of the three auditoriums, started in 1954 and its inauguration took place in 1974 (Figure 1).

Its 2173 seats are distributed as follows: 1) Orchestra – 1,156 seats, 2) Mezzanine – 539 seats, and 3) Balcony – 478 seats. The design of this auditorium, along with the calculations of reverberation time, were completed in 1955, and are the work of Engineer Rubens Meister [3]. Guaíra Theater is one of the largest and most important theaters in Brazil. However, little is known about its acoustics.

This paper presents calculations of reverberation times by the designer of the Guaíra Theater – "Guairão" Auditorium (Figure 2), Engineer Rubens Meister [3], as well as the reverberation times calculated by the authors of this article, using Sabine's reverberation formula [4]. In addition to the calculations, the reverberation time, RT, was measured according to ISO 3382:1-2009 – Acoustics – Measurement of room acoustic parameters. Part 1: Performance spaces [5] while the theater was unoccupied.

Figure 1: Inaugural poster of the activities of the Guaíra Theater.

*paulo.zannin@gmail.com

Figure 2: Front façade of the Guaíra Theater (main entrance).

2 Method

Reverberation times can be determined from mathematical formulas and measurements using appropriate instrumentation [4, 5]. The reverberation time can be calculated by the well-known Sabine Formula [4], since the average ambient sound absorption coefficient is less than 0.3. This is the case of the theater considered here. Therefore, the Sabine formula was used for the calculations presented in the next section using absorption coefficients (α) listed in Table 1.

$$RT = \frac{0.163.V}{A+4mV} [s] \qquad [1]$$

where:

V is the volume of the room under analysis [m^3],

A is the equivalent sound absorption, $A = \sum_{i=1}^{n} \alpha_i \cdot S_i$,

where S_i is the area of the materials that make up the room, and α_i is the sound absorption coefficient of these materials,

$4mV$ corresponds to air sound absorption, expressed in [m^2], and m is the energy attenuation coefficient of air, expressed in [10^{-3} m^{-1}].

According to ISO 3382-1:2009 [5], reverberation time can be measured by the interrupted noise method and the integrated impulse response method. These two methods were employed in this study.

Measurement of the RT by the interrupted noise method consisted of exciting the room with a pseudo-random pink noise and calculating the RT from the room's response to this excitation [5].

The measurements were taken using the following devices: 1) B&K 4296 dodecahedron loudspeaker; 2) B&K 2716 audio power amplifier; 3) B&K 2260 real-time sound analyzer; 4) Brüel & Kjaer Qualifier Type 7830 room acoustics software.

Table 1: Summary of the absorption coefficients of the materials used by Meister to calculate the RT of Guaíra Theater [3].

Materials	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Gypsum [6]	0.016	0.032	0.039	0.050	0.030	0.028
Plaster on masonry walls [3]	0.02	0.02	0.02	0.02	0.03	0.06
Perforated gypsum panels [3]	0.04	0.06	0.08	0.10	0.06	0.06
Wood paneling [3]	0.020	0.02	0.02	0.02	0.02	0.02
Varnished wood [6]	0.05	0.03	0.03	0.035	0.03	0.02
Eucatex hardboard [6]	0.05	0.03	0.03	0.035	0.03	0.02
Wood (flooring) [6]	0.15	0.10	0.10	0.10	0.10	0.10
Carpeting [6]	0.10	0.15	0.25	0.35	0.40	0.45
Seats [6]	0.30	0.30	0.30	0.30	0.30	0.30
Air conditioning grills [6]	0.30	0.40	0.50	0.55	0.50	0.33
Curtains and drapes [6]	0.08	0.29	0.44	0.50	0.40	0.35
Glass [6]	0.03	0.03	0.03	0.02	0.02	0.01

RT measured by the integrated impulse response method is similar to the previous method, but the room's response is given by an integrated impulse response. As in the previous measurement, the room is excited with a sound signal, but in this case a sine sweep signal. The difference lies in the way this signal is captured, transformed into an impulse, and the RT extrapolated from the decay of this impulse [5]. This mode of measuring is less biased by background noise than the previous one [4, 7]. Dirac 3.1 software was used to take this measurement and process the data [7]. The equipment consisted of: 1) a omnidirectional source, 2) a sound amplifier, 3) audio interface, 4) a sound level meter (receives the room's response), and 5) a portable computer with Dirac 3.1 software. Changes were made in the wavelength, number of repetitions and intensity of the signal in order to obtain a more accurate measurement of the RT. This precision is observed by means of the signal-to-noise ratio, which, according to the ISO 3382-1 standard [5], should be higher than 35 dB to calculate T20 and higher than 45 dB to calculate T30. If these signal-to-noise ratios are not reached, parameters T20 and T30 are considered inaccurate [5]. In the present study, it was assured a signal-to-noise ratio higher than 45 dB in all measurements.

The measurements presented here are part of a preliminary study of the acoustics of the Guaíra Theater.

The RT was measured by the interrupted noise method (ISO 3382-1) at the seven points indicated in Figure 3, and the results are described in Table 5. Sound source positions were used for the measurements by the integrated impulse response (ISO 3382-1) and the results of those measurements are given in Table 5. These measurements were taken at 11 points (see Figure 4). Figure 4 shows the interior of the Guaíra Theater.

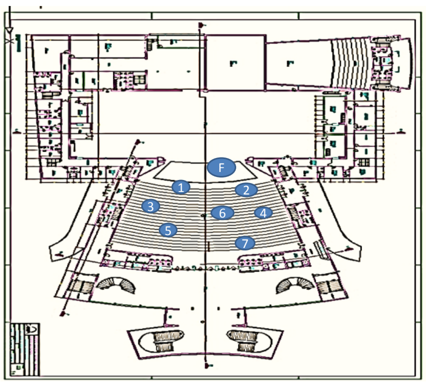

Figure 3: Measuring points at the audience seats and position of the dodecahedron loudspeaker: F = Source.

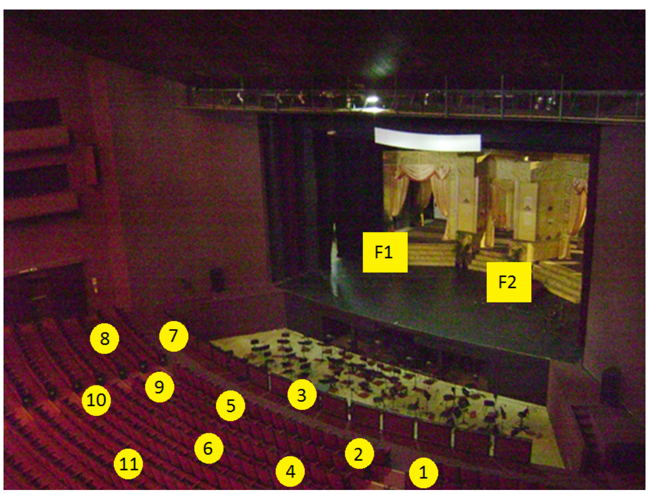

Figure 4: View of audience seats, orchestra pit and stage – Guaíra Theater. F1 = Sound source position 1; F2 = Sound source position 2.

3. Results and Discussion

Tables 2, 3 and 4 list the reverberation times, RT, of the main auditorium of the Guaíra Theater, Guairão, with 1/3 of seat occupancy, 2) 2/3 of seat occupancy, and 3) full seat occupancy, respectively, determined by the authors of this study and by the original designer of the theater, Engineer Rubens Meister [3].

Table 2: Calculated reverberation time (RT) of the theater with 1/3 of seat occupancy

Frequency [Hz]	Calculated in this study RT (s)	Calculated in 1955 by Rubens Meister [3] RT (s)
125	2.08	2.26
250	2.46	2.07
500	2.08	1.87
1000	1.95	1.78
2000	1.89	1.93
4000	1.84	1.87
Average RT	**2.05**	**1.96**

Table 3: Calculated reverberation time (RT) of the theater with 2/3 of seat occupancy.

Frequency [Hz]	Calculated in this study RT (s)	Calculated in 1955 by Rubens Meister RT (s) [3]
125	1.73	2.22
250	2.35	1.96
500	1.93	1.72
1000	1.79	1.63
2000	1.74	1.75
4000	1.71	1.71
Average RT	**1.87**	**1.83**

Table 4: Calculated reverberation time (RT) of the theater with full seat occupancy

Frequency [Hz]	Calculated in this study RT (s)	Calculated in 1955 by Rubens Meister [3] RT (s)
125	1.48	2.18
250	2.25	1.90
500	1.79	1.59
1000	1.66	1.50
2000	1.61	1.60
4000	1.59	1.57
Average RT	**1.73**	**1.72**

Despite the reforms that took place during the years, the original RT value calculated by Meister was kept, as shown in Tables 2, 3 and 4. This fact is explained by the RT calculations made in the present work, which are very similar to the original ones of the Guaíra Theater project.

Table 5 shows the results of the RT calculated in this work and the RT measured by the interrupted noise and integrated impulse response methods, according to ISO 3382-1, considering the fully unoccupied theater (no seat occupied).

The calculated RT values listed in Table 5 are based on the sound absorption coefficients used in the original design of the theater and considering unoccupied seats [3].

The original design of the theater indicated a sound absorption coefficient of α = 0.3 (broadband) for unoccupied seats; this coefficient was used for the unoccupied RT evaluation described herein [3].

Table 5: Calculated and measured reverberation time (RT) considering the unoccupied theater.

Frequency [Hz]	RT calculated in this study RT [s]	RT measured by the Interrupted Noise Method RT [s]	RT measured by the Integrated Impulse Response Method RT [s]
125	2.60	2.50	1.84
250	2.60	1.72	1.57
500	2.26	1.47	1.50
1000	2.14	1.37	1.45
2000	2.06	1.32	1.38
4000	2.00	1.26	1.25
Average RT [s]	**2.27**	**1.56**	**1.50**

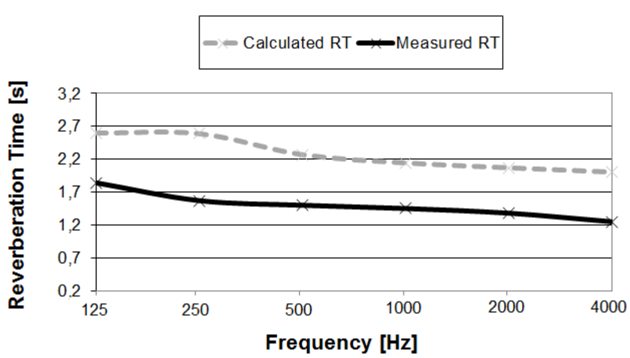

Figure 5: Comparison of measured RT per integrate impulse response method and calculated RT.

On the other hand, in his highly relevant book Concert Halls and Opera Houses, page 640, Appendix 3, Leo Beranek [8] lists the following values for the sound absorption coefficient for unoccupied seats – medium and heavily upholstered seats, see Table 6.

Table 6: Absorption coefficients for unoccupied seats, according to Beranek [8]

Frequency [Hz]	Sound absorption coefficient (α) for unoccupied seats medium-upholstered seats [8]	Sound absorption coefficient (α) for unoccupied seats heavily upholstered seats [8]
125	0.54	0.70
250	0.62	0.76
500	0.68	0.81
1000	0.70	0.84
2000	0.68	0.84
4000	0.66	0.81

Considering these absorption coefficients [8], for medium-upholstered and heavily-upholstered unoccupied seats, Figure 6 and Figure 7 compares the calculated RT values against the RT values measured by the integrated impulse response method.

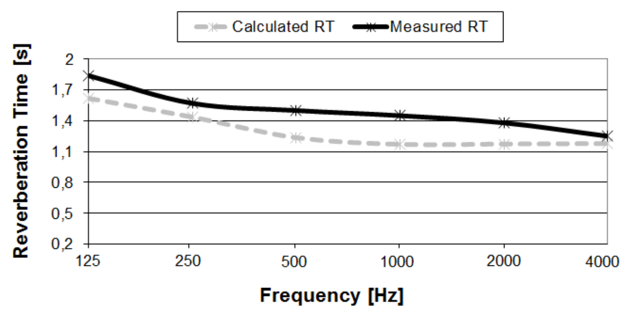

Figure 6: Comparison of measured RT as per integrated impulse response and calculated RT, considering the unoccupied theater with medium-upholstered seats [8].

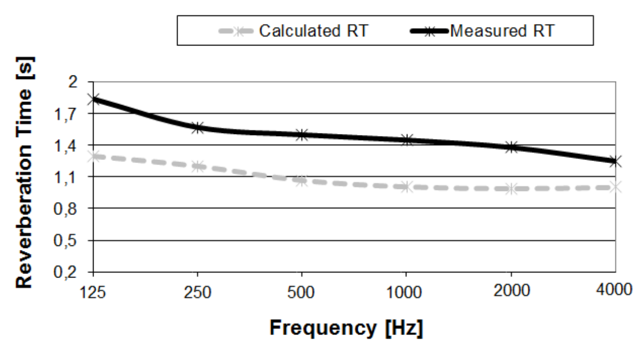

Figure 7: Comparison of measured RT as per integrated impulse response and calculated RT, considering the unoccupied theater with heavily-upholstered seats [8].

The seats in this theater today are practically the same as the original ones, except for minor renovations. In order to determine the correct sound absorption coefficient for these seats, their sound absorption coefficient should be measured in a reverberation chamber.

The Guaíra Theater is an important Brazilian cultural center designed for presentations of symphony concerts, operas, ballets and plays, i.e., for multiple purposes. Its dimensions of 13760 m^3 and its 2173 seats are comparable to those of other concert halls and opera halls around the world. To exemplify, we can cite the following concert and opera halls:

Table 7: Concert Halls and Opera Halls [4]

Place	Volume [m^3]	Seats	RT [s] (full occupancy)
Metropolitan Opera House in New York [4]	30500	3800	1.8
Colon Theatre in Buenos Aires [4]	20550	2500	1.7
War Memorial Opera House in San Francisco [4]	20900	2070	1.6
Neues Festspielhaus in Salzburg [4]	14000	2160	1.4
Opera de la Bastille in Paris [4]	21000	2700	1.5
Symphony Hall in Boston [4]	18800	2630	1.8
Concertgebouw in Amsterdam [4]	18800	2210	2.0
Barbican Concert Hall in London [4]	17750	2030	1.7
Liederhalle in Stuttgart [4]	1600	2000	1.7

4 Conclusions

The present work is a tribute to Professor Rubens Meister, who made the necessary acoustical calculations for the design and construction of this great theater. The measured RT values show that Guaíra Theater has a high acoustic performance, being suitable for theater plays, speech and opera. Very different types of artistic presentations take place in the Guairão Auditorium, such as ballets, symphony concerts, operas, chamber music and semi-classical concerts, choral groups, plays and bands using sound system. Therefore, the Guaíra Theatre is a place for general purpose activities which demands compromise among the acoustic parameters values and the type of activity, i.e., a space for speech and a space for music [9].

Acknowledgments

The authors gratefully acknowledge the financial support of the Brazilian Government, through the National Council for Scientific and Technological Development – CNPq, and the German Government, through the German Academic Exchange Service – DAAD, which enabled the purchase of the equipment and software used in this study. The authors also wish to thank the peer reviewers for their careful assessment and invaluable suggestions. The authors would like to thank the collaboration of the architect Sérgio Izidoro, technical manager at Teatro Guaíra, in providing relevant technical information about the Theatre. The authors would also like to thank the Foundation Teatro Guaíra for allowing this study to be conducted.

References

[1]<http:pt.wikipedia.or/wiki/Centro_Cultural_Teatro_Guaíra>, Accessed on 12 Dec 2011 (in Portuguese)

[2] <http://www.tguaira.pr.gov.br>, Accessed on 12 Dec 2011 (in Portuguese)

[3] Meister, R. Arquivo Histórico do Teatro Guaíra - Cálculo do tempo de reverberação – Teatro Guaíra [Historical Archive of Guaíra Theater – Calculation of reverberation time] (Large Auditorium), 1955 (in Portuguese).

[4] Fasold W, Veres E. Schallschutz and Raumakustik. Verlag für Bauwesen – Berlin, 1998 (in German).

[5] International Organization for Standardization. ISO 3382-1:2009 Acoustics - Measurement of room acoustic parameters. Part 1: Performance spaces. Switzerland, 2009.

[6] Knudsen V. O., Harris C. M. Acoustical Designing in Architecture, 1950. Published for The Acoustical Society of America by the American Institute of Physics. Fifth Printing, 1988.

[7] Instruction manual Dirac room acoustics sofare type 7841. Denmark: Brüel&Kjaer Sound & Vibration Measurements, 2003.

[8] Beranek L. Concert Halls and Opera Houses. Springer-Verlag – New York, Berlin and Heidelberg, 2004.

[9] Cavanaugh W.J., Tocci G.C., Wilkes A.J. Architectural Acoustics – Principles and Practice. John Wiley & Sons, Inc. Second Edition, 2010.


WE CAN MAKE WHATEVER YOU MAKE
BETTER.
SAFER.
QUIETER.
The blueprint of good sound control starts with ROXUL® Core Solutions (OEM) insulation. Made from basalt rock, our insulation provides excellent acoustical dampening and fire resistant properties. So whether you're designing a car muffler, music studio or modular office – our team of experts will work with you before, during and after fabrication to create the custom sound solution you're looking for. Visit us at roxul.com/oem
ROXUL®
The Better Insulation™

STUDY OF CAVITY MODAL DAMPING: A NUMERICAL METHODOLOGY FOR ACOUSTIC EVALUATION USING THE FINITE ELEMENT METHOD IN VEHICLE BODIES BASED ON EXPERIMENTAL TESTS.

Ferreira, S. Tiago *[1], Magalhães, A. Pedro †[1] , Moura, l., Frederico‡[2] et Ferreira, S. Timoteo§[2]

[1] Pontifical University Catholic, Department of Mechanical Engineering, Av. Dom José Gaspar, 500, Belo Horizonte, Brazil.

[2] Federal University of Minas Gerais, Department of Mechanical Engineering, Av. Antônio Carlos, 6627 – Pampulha, Belo Horizonte, Brazil

Résumé

Ce travail se concentre sur la recherche d'une solution numérique pour les études acoustiques du véhicule et l'amélioration de l'utilité des paramètres numériques "expérimentaux" pour la phase de développement d'un nouveau projet automobile. Plus précisément, cette recherche porte sur l'importance de la cavité d'amortissement modal pour véhicule exerce pendant les études numériques. Cette recherche vise alors à suggérer les valeurs de paramètres normalisés de la cavité d'amortissement modal dans les études acoustiques des véhicules.

Cette valeur normalisée de modal cavité d'amortissement est d'une grande importance pour l'étude de l'acoustique des véhicules dans l'industrie automobile, car elle permettrait à l'industrie de commencer des études de la performance acoustique d'un véhicule neuf au début de la phase de conception avec une estimation fiable qui serait proche de la valeur finale mesurée dans la phase de conception. Il est commun pour l'industrie automobile à atteindre de bons niveaux de corrélation numérique-expérimentale dans les études acoustiques après la phase de prototypage parce que cette phase peut être étudiée par les commentaires de la simulation et les paramètres modaux expérimentaux.

Ainsi, cette recherche suggère des valeurs de cavité amortissement modal, qui sont divisés en deux parties en raison de leur comportement: celui qui va jusqu'à 100 Hz, et un autre au-dessus de cette valeur.

La séquence de cette étude montre comment nous sommes arrivés à ces valeurs.

Mots clefs : Méthode des éléments finis. Contrôle acoustique. véhicule entier. Corrélation expérimentale numérique. Amortissement modal.

Abstract

This work focuses on finding a numerical solution for vehicle acoustic studies and improving the usefulness of the “Numerical experimental” parameters for the development stage of a new automotive project. Specifically, this research addresses the importance of cavity modal damping for vehicle exerts during numerical studies. This research then seeks to suggest standardized parameter values of modal cavity damping in vehicular acoustic studies.

This standardized value of modal damping cavity is of great importance for the study of vehicular acoustics in the automotive industry because it would allow the industry to begin studies of the acoustic performance of a new vehicle early in the conception phase with a reliable estimation that would be close to the final value measured in the design phase. It is common for the automotive industry to achieve good levels of numerical-experimental correlation in acoustic studies after the prototyping phase because this phase can be studied with feedback from the simulation and experimental modal parameters.

Thus, this research suggests values for cavity modal damping, which are divided into two parts due to their behavior: one that goes up to 100Hz, and another above this value.

The sequence of this study shows how we arrived at these values.

Keywords: Finite Element Methods. Acoustic Control. Trimmed body. Numerical Experimental Correlation. Modal Damping.

1 Introduction

This study has been motivated by the conflict during the final stages of the development of a vehicle, as well as by the comparison between the results generated by the simulation team with those acquired from the experimental team.

For an appropriate correlation, it is always necessary to acquire cavity modal damping data originated from prototypes and subsequently assign them to the numerical model. In this manner, the phase of refinement of the numerical results requires a prototype, and this slows the progress of work and research.

With respect to the simulation methods used today, the finite element method (FEM), as described by Braess et al [1] proposes a quite different situation. Ever-increasing demands for greater comfort have elevated the dynamic design criteria as the primary elements of modern body engineering.

* tiago.simao@ifmg.edu.br

† paamj@oi.com.br

‡ frediluiz@yahoo.com.br

§ timoteo_ferreira@yahoo.com.br