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Acoustic suitability for heritage-listed buildings using BRASS software: a case study of Armando Gonzaga Theatre, Rio de Janeiro, Brazil

Guilherme FAGERLANDE[1]; Maria Lygia NIEMEYER[2]; Julio Cesar Boscher TORRES[3]

[1, 2] Federal University of Rio de Janeiro, Brazil, Postgraduate Program in Architecture - PROARQ

[3] Federal University of Rio de Janeiro, Brazil, Urban Engineering Program, Polytechnic School

ABSTRACT

The Armando Gonzaga Theatre, located in Marechal Hermes, a low income neighborhood in Rio the Janeiro, is for the local inhabitants the single cultural facility in the spot, being used for different purposes, from plays to acoustic and amplified musical concerts. Although, since 1989, had been included in a list of artistic-cultural heritage buildings by INEPAC (State Institute of Cultural Heritage), is currently in very poor conditions by lack of maintenance. The aim of this paper is the use of BRASS software as tool to propose solutions to improve the acoustical performance in the Armando Gonzaga Theatre considering a compromise between speech and music in order to contemplate the variety of uses of the room and compatible with the heritage limitations required by the INEPAC. The methods used are the simulations of the current situation compared to the measurements in the place, and the simulations of situations with new interventions, using BRASS software (Brazilian Room Acoustic Simulator), developed in the Urban Engineering Program of the Federal University of Rio de Janeiro. The results show that it is possible to make these proposed adjustments, improving the acoustic performance of the building, but respecting its original characteristics.

Keywords: Room acoustics, Acoustic simulation, Heritage-listed buildings.

1. INTRODUCTION

The Armando Gonzaga Theatre, designed by the architect Affonso Eduardo Reidy is a perfect example of the Modern Architecture produced in Brazil in the 1950's. Deployed in the center of a square, the building was conceived from the intercession of two trapezoids which define its volumetric shape and the organization of the main spaces: foyer, audience, and stage (Figure 1) (1).

Located in Marechal Hermes, a low income district of Rio the Janeiro away from the urban central area, the 278-seat theatre was inaugurated in 1954 as an action which aimed to provide art and culture for peripheral neighborhoods. For the local population the Armando Gonzaga still remains as the single cultural facility in the spot, being used for different purposes, from drama or comedy plays to acoustic and amplified musical concerts.

Although, since 1989, the theatre had been included in a list of artistic-cultural heritage buildings by INEPAC (Institute of Cultural Heritage of Rio de Janeiro State), currently the building is in very poor conditions mostly by the lack of maintenance. In Figure 2 a set of photos taken by the author shows the actual conditions of the theatre, in the current situation.

The aim of this paper is the use of BRASS software as tool to propose solutions to improve the acoustical performance in the Armando Gonzaga Theatre considering a compromise between speech and music in order to contemplate the variety of uses of the room and compatible with the heritage limitations required by the INEPAC.

[1] guilhermefagerlande@gmail.com
[2] dobarulhoproarq@gmail.com
[3] julio@poli.ufrj.br

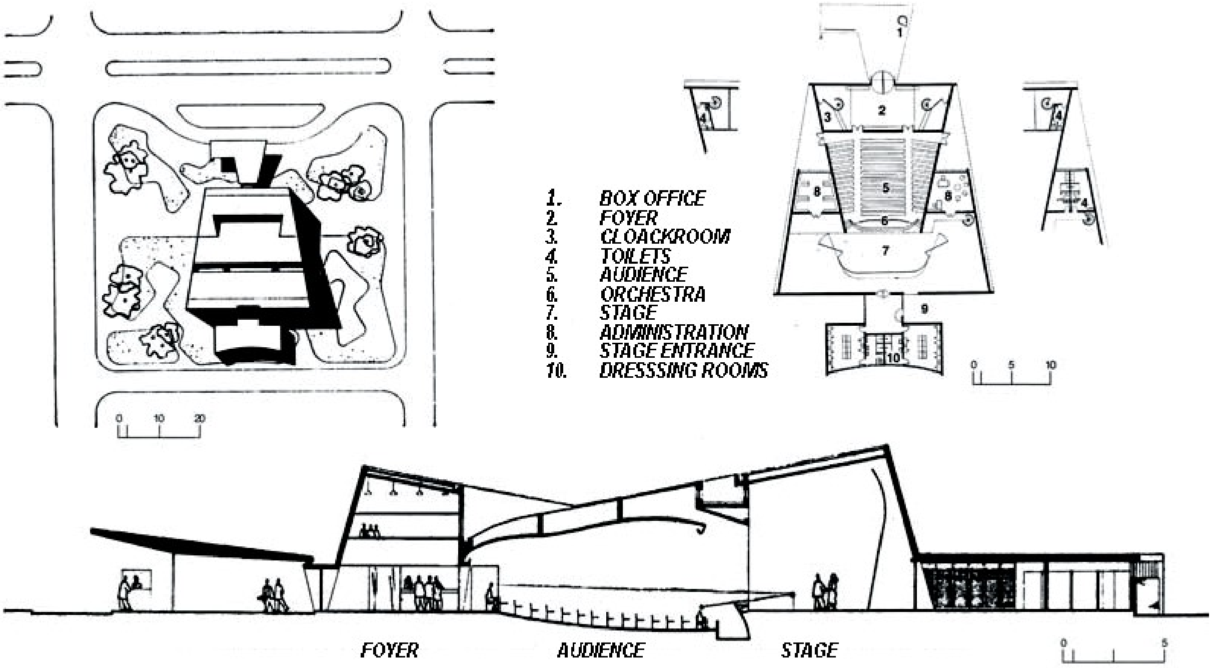


Figure 1 – Armando Gonzaga Theatre by Affonso Eduardo Reidy (1)

Figure 2 – Actual theatre situation (2018)

2. ROOM ACOUSTIC SIMULATIONS: BRASS

In the method of acoustic numerical simulation of ray tracing, the modeling of the sound wave follows the assumptions of geometric acoustics, with straight acoustic rays emitted from the sound source, where each ray has the source power information, and its path is influenced by air viscosity and room geometry, as well as the phenomena of absorption, specular reflection and diffuse reflection. The method of ray tracing is not suitable for simulations that consider scattering, because in this phenomenon a ray that affects one surface is reflected in several other new rays. This method is restricted to the calculation of specular reflections by adding to them all the energy associated with the diffuse reflections. Relevant to this method are the total energy emitted by the sound source, the number of rays emitted by the source, the directionality of the source through spherical coordinates, the air absorption coefficient, the distance traveled by the rays and the absorption coefficients of the surfaces. The disadvantages of the ray tracing method are the need for a large number of rays for the simulation (2, 3).

BRASS (Brazilian Room Acoustic Simulator) uses the ray-tracing method to obtain mono and binaural impulsive responses in the receivers, and allows obtaining the main quality acoustic parameters of the room, with auralization. The ray tracing belongs to the group of geometric acoustic methods, where there is an energetic approach to the propagation of sound. In this case, wave phenomena such as interference are not considered since only energy is used. When using BRASS in rooms, the energy captured by the receiver depends on the number of rays emitted by the source, the distance between source and receiver, the radius of influence of the receiver, the geometry of the room as well as the acoustic characteristics of the surfaces (absorption, scattering and transmission) (4).

3. METHODOLOGY

The methods used are the simulations of the current situation compared to the measurements made in the place, and the simulations of situations with future interventions, using the software BRASS.

The first step of the study is to create a three-dimensional model of the room in CAD software, separating the layers according to the existent materials in the room, and then export it to BRASS. After exporting, the absorption coefficients of each layer are inserted in 9 octave-bands, from 63 Hz to 16 kHz, following the tables in the Brazilian Standard 12.179 (5), or other references and catalogues. The sound source is inserted in the model with the coordinate system, as well as the receiver. The source can be an anechoic sound of an instrument or voice, in which is set the power in watts. Then it is possible to generate the simulation together with the acoustic parameters by receiver and the auralization. The adjustments of the model are made by comparing the measurements took in place and adapting the shapes of the room or the absorption coefficients of the materials (6).

Finally the architectural interventions can be done in the CAD 3D model by adapting the shapes and the materials, and exporting it to BRASS to generate the new results, repeating the method until the acoustic parameters needed are achieved.

3.1 Room information

The drawings and sections of the room were not found in *dwg* format, but images were obtained in references (1). From a survey done at the place where distance measurements were taken, the three-dimensional model was made in CAD software from the dimensions measured together with the proportions of the drawings.

3.2 Room measurements

Acoustic measurements were made of internal background noise, as well as the Room Reverberation Time, with the meter Instrutemp ITDEC-4080, class 2.

The acoustic measurements of background noise inside the auditorium followed the steps of the Brazilian Standard 10.152 (7), using the *slow* mode, with measures during 5 minutes. There were 2 measures with the air conditioning on and other 2 measures with the air conditioning off.

To obtain the Reverberation Time RT_{60} inside the room it was followed the Brazilian Standard 12.179 (5), using *fast* mode, with measures during 30 seconds. The measurement of the RT_{60} used a balloon pop in the middle of the stage and the acoustic meter in the middle of the auditorium.

It is important to highlight that all of these measurements were taken in empty room.

3.3 Three-dimensional model in CAD software

In the CAD software, the internal elements of the current situation were designed, such as walls, floor, ceiling, stage and acoustic panels (Figure 3a). The model was only worked with plans made from the *3dpolyline* command, associating with the law of Ampère, where all the faces should be turned inside the enclosure. The sender and the receiver were inserted as dots in CAD.

3.4 Simulation of the current situation in BRASS

The *dxf* file was imported into the BRASS software and converted into a *txt* file. Within this *txt* file the absorption coefficients were inserted into each material in each frequency range, following the tables of references (5, 8). These tables provide the absorption coefficients from 250Hz to 4000Hz, so for the frequencies of 63Hz the frequencies of 125Hz were repeated, and for frequencies of 8kHz and 16kHz the frequencies of 4kHz were repeated. Table 1 presents the materials and coefficients used in the model. As the measurements were made in empty room, the simulation of the current situation also did not consider spectators in the auditorium.

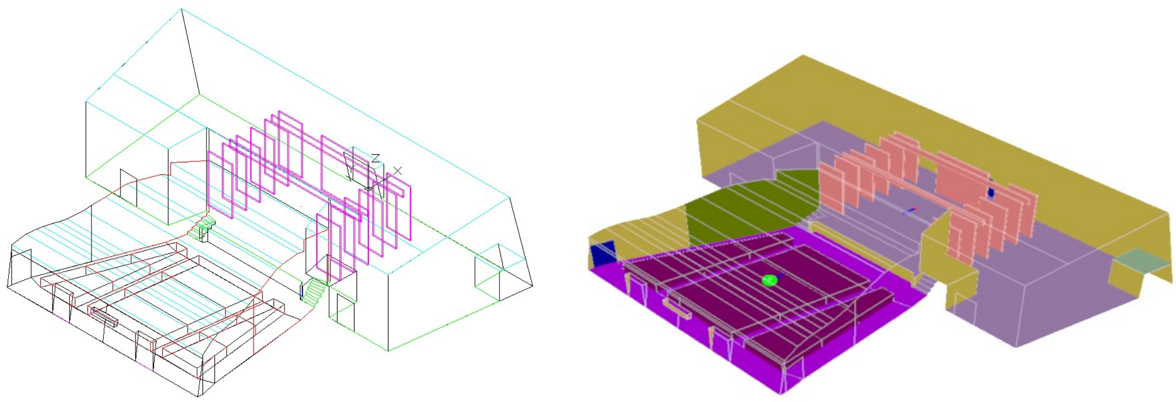
Figure 3b shows the imported model for the Brass software with the sound source (red dot) and the receiver (green dot), inserted at the measurement site, according to the Cartesian plane, at the x, y, z coordinates value of the CAD quotas. For the receiver a binaural virtual head was used in stereophonic mode. The transmitter was configured by emitting 100,000 rays at the sound source with 80dB energy, with the maximum of 10 reflections per ray. The elements outside the inner room do not influence the computational acoustic simulation, so they were not modeled. Other data should be entered into the software, such as temperature (20°C), pressure (1Pa) and humidity (40%).

It is common knowledge that in typical music rooms, after 3 or 4 reflections, the main energy propagation becomes diffused, that is, it is dispersed (9).

Once all the information has been entered in the *txt* file, the simulation that generates a *txt* file for the receiver is presented, showing the acoustic parameters found. Until the RT_{60} global is not achieved, the thickness of the materials can be adjusted according to the specifications in the current situation.

Table 1 – Existent materials, their placement and absorption coefficients per octave frequency bands

Material	Place	63	125	250	500	1k	2k	4k	8k	16k(Hz)
Cork 8mm	Walls	0,09	0,09	0,08	0,06	0,14	0,21	0,22	0,22	0,22
Curtain	Stage	0,25	0,25	0,33	0,40	0,50	0,60	0,60	0,60	0,60
Plaster	Walls/ceiling	0,02	0,02	0,02	0,02	0,02	0,03	0,06	0,06	0,06
Wooden stage	Stage	0,40	0,40	0,30	0,20	0,17	0,15	0,10	0,10	0,10
Rubber mat	Aud. floor	0,04	0,04	0,04	0,08	0,12	0,03	0,10	0,10	0,10
Leather armchairs	Seats	0,13	0,13	0,14	0,15	0,11	0,07	0,07	0,07	0,07
Wooden door	Aud./stage	0,14	0,14	0,10	0,06	0,08	0,10	0,10	0,10	0,10
Glass	Auditorium	0,20	0,15	0,10	0,15	0,20	0,25	0,30	0,32	0,35



(a) CAD model (b) BRASS model

Figures 3a and 3b – Three-dimensional model in (a) CAD software and (b) BRASS software (2019)

3.5 Simulation of the interventions

The Armando Gonzaga Theatre is used for speech, acoustic and amplified concerts, so the interventions in BRASS aimed to reach better acoustic performance for these multiple uses of the room. As the measurements were taken in empty room, the simulation of the interventions must consider the room with 2/3 of occupation to approach the reality.

4. RESULTS

4.1 Acoustic measurements

The acoustic measurements of background noise inside the room were made in two places of the auditorium, with the system of air conditioning on, and with the system off. The measurements are compared to the Brazilian Standard 10.152 (7) on Table 2. With the air conditioning system on, the values are much over the limits of the standard, and without the system on, the values are still above the limits. That would require a better insulation of the room, especially in the gaps of the doors. It is remarkable that the *high wall* air conditioning system must change to a ducted system with an acoustically isolated machine room, considering also the insulation for the vibration of the machines.

The broadband measured RT_{60} in the auditorium is 2.0 seconds. These measurements were taken in empty room, and it is necessary to make the simulation of the interventions with 2/3 of the auditorium occupied. This room with 2,500 m3 should have the RT_{60} of 0.97s for speech and of 1.37 for concert music.

Table 2 – Acoustical measurements of background noise inside the theatre

Point	Air conditioning	Measurements in dB(A)	NBR 10.152 (7) in dB(A)
5	Off	36.0	30-35
5	On	58.4	30-35
6	Off	37.7	30-35
6	On	58.4	30-35

4.2 Acoustic simulation of the current situation

The simulation of the current situation in the software BRASS gave the results shown in Table 3, extracted from the software. The global T_{60} reached 1.98s, presenting a margin of error of 1%.

Table 3 – Results of the simulation of the current situation in receiver R1

R1	63	125	250	500	1k	2k	4k	8k	16k(Hz)	Global
T_{20}	1.79	2.04	2.11	1.93	1.70	1.56	1.24	0.84	0.55	1.60
T_{30}	2.07	2.09	2.10	2.05	1.80	1.65	1.28	0.90	0.61	1.74
T_{60}	2.18	2.22	2.15	2.07	1.93	1.75	1.45	1.04	0.68	1.98
EDT	1.62	1.74	1.66	1.59	1.61	1.42	1.07	0.60	0.49	1.20
C_{80}	-2.17	-1.16	1.74	1.61	0.81	1.59	4.24	8.24	12.91	4.09
D_{50}	21.34	27.65	35.38	30.71	32.76	39.40	51.51	71.31	84.96	52.82
CT	162.9	162.2	143.5	141.4	140.1	126.1	97.9	68.1	49.4	104.6
SPL	51.68	52.18	55.46	58.05	59.69	61.44	62.50	62.60	58.43	68.99
SPL(A)	25.48	36.08	46.86	54.85	59.69	62.64	63.50	61.50	51.83	68.41

4.3 Acoustic simulation of the architectural proposals

The global RT_{60} of 2 seconds measured in the room is very high for the uses. The first thing before starting the simulation of the current situation in the software BRASS was to decrease the volume of the room by using curtains around the stage, where actors and musicians can go in and out through it, creating a sound barrier avoiding the reverberation in the backstage areas. In the stage background it was proposed a wood panel to reflect the sound to the stage as well as to the auditorium.

With this guideline the volume of the room changed from 2,500m³ to 1,138m³, the appropriate global RT_{60} for speech changed to 0.9s and the appropriate global RT_{60} for concert music changed to 1.3s.

Being a heritage-listed building, it is not possible to change certain architectonic elements of the auditorium, as the concrete rippled ceiling and the lateral cork panels in both sides near the stage. The floor of rubber mat was kept as a good material for maintenance of the room. As extremely necessary, the plaster walls in the back of the auditorium were covered with absorbing materials in independent structures.

A baffle system was proposed in the back of the auditorium fixed to the ceiling by struts. This system is very efficient for having two faces of absorption, and was very convenient to the building because the curved ceiling designed by the architect will still be visible, but the acoustic reflections and focus in the background of the auditorium could be mitigated.

Absorptive panels were inserted in the cork walls near the stage to minimize the RT_{60}, as the ceiling and floor suffered no interventions in the front of the auditorium. Those panels were spaced enough so the cork walls designed by the architect could still be present in a harmonic way.

The model in BRASS with these interventions is showed in Figure 4, where the sound source S1 is represented as a red spot, and receiver R1 as a green spot. Table 4 presents the existent and new materials used in the intervention.

With these project decisions the simulation presented a satisfactory acoustic performance for speech and music compared to the existent parameters, as showed in Table 5. Table 6 presents the comparison of the global acoustic parameters between the current situation and the proposal intervention. Only global (full band) parameters were compared due to the measurement equipment restrictions. It is possible to see that Reverberation Time (RT_{60}) decreased from 1.98 to 1.11s, Early Decay Time (EDT) decreased from 1.20s to 0.39s, Central Time (CT) decreased from 104.6s to 58.0s, Clarity (C_{80}) increased from 4.09 to 12.18, Definition (D_{50}) increased from 52.82% to 84.56%. The Sound Pressure Level (SPL and SPL (A)) remained practically the same, there being no perceptible decrease of the sound level in the receiver.

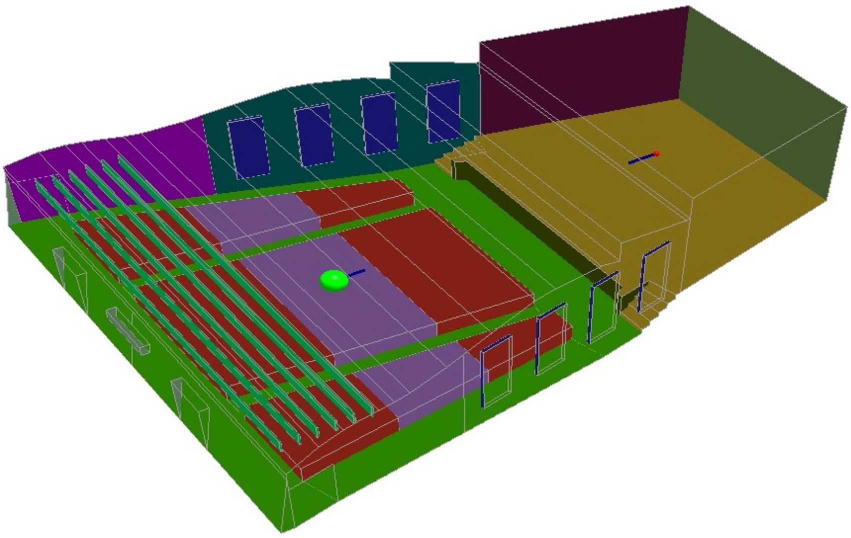


Figure 4 – Model of the intervention in BRASS (2019)

Table 4 – Existent and new materials, their placement and absorption coefficients per octave frequency bands

Material	Place	63	125	250	500	1k	2k	4k	8k	16k(Hz)
Cork 8mm	Walls	0,09	0,09	0,08	0,06	0,14	0,21	0,22	0,22	0,22
Curtain	Stage	0,25	0,25	0,33	0,40	0,50	0,60	0,60	0,60	0,60
Plaster	Walls/ceiling	0,02	0,02	0,02	0,02	0,02	0,03	0,06	0,06	0,06
Wooden stage	Stage	0,40	0,40	0,30	0,20	0,17	0,15	0,10	0,10	0,10
Rubber mat	Aud. floor	0,04	0,04	0,04	0,08	0,12	0,03	0,10	0,10	0,10
Leather armchairs	Seats	0,13	0,13	0,14	0,15	0,11	0,07	0,07	0,07	0,07
Occupied armchairs	Seats	0,33	0,33	0,39	0,44	0,45	0,46	0,46	0,46	0,46
Absorptive panel 1	Walls/Baffle	0,15	0,15	0,45	0,69	0,95	0,94	0,98	0,98	0,98
Absorptive panel 2	Back of Aud	0,23	0,23	0,68	0,98	1,04	0,97	0,99	0,99	0,99
Glass	Auditorium	0,20	0,15	0,10	0,15	0,20	0,25	0,30	0,32	0,35

Table 5 – Results of the simulation in receiver R1 with the intervention

R1	63	125	250	500	1k	2k	4k	8k	16k(Hz)	Global
T_{20}	1.15	0.98	0.84	0.59	0.52	0.50	0.47	0.37	0.23	0.62
T_{30}	1.23	1.25	0.86	0.69	0.59	0.56	0.48	0.41	0.30	0.78
T_{60}	1.30	1.27	1.04	0.79	0.74	0.72	0.64	0.50	0.37	1.11
EDT	0.82	0.68	0.55	0.55	0.48	0.39	0.30	0.24	0.23	0.39
C_{80}	2.98	6.26	9.85	9.52	10.52	12.51	14.29	17.54	22.08	12.18
D_{50}	36.68	56.34	66.80	72.54	78.90	82.10	88.75	93.68	96.76	84.56
CT	104.7	88.8	75.1	72.3	63.2	58.7	53.3	48.3	43.9	58.0
SPL	52.10	53.81	56.31	57.41	58.08	60.40	62.11	62.66	58.91	68.67
SPL(A)	25.90	37.71	47.71	54.21	58.08	61.60	63.11	61.56	52.31	67.83

Table 6 – Broadband acoustic parameter comparison between current situation and proposal intervention

Global	T_{20}	T_{30}	T_{60}	EDT	C_{80}	D_{50}	CT	SPL	SPL(A)
Current situation	1.60	1.74	1.98	1.20	4.09	52.82	104.6	68.99	68.41
Intervention	0.62	0.78	1.11	0.39	12.18	84.56	58.0	68.67	67.83

5. CONCLUSIONS

Considering the state of the art of acoustics research, acoustic performance simulation should be considered essential tool for the design of auditorium and spectacle rooms. These software provide cost reductions, quickness of modelling and remodeling the architectural space, with simultaneous results. These benefits increase in developing countries with cost constraints.

In heritage-listed buildings this methodology is fundamental because it makes possible the experiment with different materials and their placements, so the acoustic performance can be coupled with suitable design that respect the original characteristics of the building.

BRASS is a tool in development that can be a very good instrument for acoustic simulations, presenting diversified parameters as well as audio files that describe the room´s “sound” very close to reality.

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