



The acoustic characteristics of heritage theaters in Quito-Ecuador

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Abstract

This work shows the results of the acoustical measurements that were done in some theaters into the architectural heritage in Ecuador. The selected theaters are Bolivar, Sucre, Capitol and Variedades. Bolivar and Sucre were considered theaters at the beginning of their function, they still have the structure as the original; on the other hand, Variedades and Capitol were cinemas at the beginning and then made them theaters with a modern structure. The theaters that were studied have different architectonical styles and represent differentials on plant and volume forms, in addition to a different structure. The results show the sensible difference in the acoustical parameters on each theater. This study makes a value about the more appropriate uses on the theaters according to the acoustical parameters.

Keywords: Theater acoustics, acoustical parameters, speech intelligibility.

1 Introduction

Theaters as spaces for cultural expression are part of the heritage value of humanity because they have an artistic-architectural heritage that is currently being the subject of various studies, both at an architectural and acoustic level. For this reason, this research will study the acoustic conditions of the theaters considered as heritage assets, most representative of the city of Quito.

For the acoustic study of the selected theaters, two conditioning factors are presented, the first derived from the diversity of geometric shapes typical of the stylistic influences of the architecture of that historical period in which they were built and the second is the form of intervention and modification of uses of theaters over time, so the current acoustics differ from their original state.

2 The theaters studied

The theaters considered for this study represent the most varied typologies of these venues between the 19th and 20th centuries. Of the existing theaters, four venues have been selected, in two cases, their current state has not changed substantially with respect to their original structure and the remaining two have undergone a comprehensive reform, which is far from their original state. The characteristics of the theaters are briefly described below, arranged in chronological order.

2.1 Sucre National Theater

Design: Francisco Schmidt

Construction: 1877-1886

Characteristics: The Sucre National Theater is a patrimonial architectural landmark in Quito, which expresses the neoclassical character, which was built at the end of the 19th century. It's located in the Plaza del Teatro,

between Guayaquil & Quito avenues. In 1877 its construction began by the German architect Schmidt who used part of existing constructions such as wide adobe, walls and a sequence of arches on which he designed the structure similar to the European opera houses of the time. The neoclassical facade occupied by the entire block, predominantly horizontality and symmetry, is composed of a basement of semicircular arches on solid pillars on which the highest body rests; in the central part is the entrance that advances towards the square and preserves the greater formal treatment with columns of Ionic capitals and fluted shafts crowned by a tympanum with gilded reliefs. The theater, despite being small, has in its interior the majesty and functionality of the theater of the time. [1]. It has a sober, slightly oval space, which is defined by three levels of the box and galleries. The lunette surrounded by two levels of boxes and the upper lunette.

After several minor restorations throughout its history, in 2003 its original splendor was recovered. The dressing rooms, stage, stage machinery and sound equipment were modernized and the original seats from the beginning of the 20th century were restored.

Capacity: 795

2.2 Capitol Theater

Design: Giacomo Radiconcini

Construction: 1910

Characteristics: Built by the Italian architect Radiconcini, who was an introducer of the Neo-Renaissance language when building this type of palaces or villas with Renaissance and eclectic styles. The theater was originally conceived as a palace belonging to the Samaniego family, which has an attractive facade in front of Gran Colombia avenue, designed with a neoclassical language and neo-Renaissance details, it has a style called "Italianate", which consists of on the ground floor there are arches and on the upper floor there is an architrave on Doric columns and a Moorish balustrade.

The palace was remodeled twenty years later and inaugurated as the Cadena Theater in 1937, which would later be called the Capitol Theater, which had part in the formation of the modern city of Quito, offering cinema performances. In its design, the exterior access is through an elegant lobby that gathers and leads the audience to the theater's main stalls and a block of stairs that lead to the foyer and the second-floor balcony. [2].

The municipality of Quito in 2010 undertook a proposal for the recovery and renovation of the building, to restore its use as a theater, which completely modified the interior of the building.

Capacity: 850

2.3 Variedades Ernesto Albán Theater

Design: Giacomo Radiconcini

Construction: 1913-1914

Characteristics: Built since 1913 by order of the Quito businessman Jorge Cordovez, the art nouveau building project was in charge of the Italian architect Giacomo Radiconcini, and it was inaugurated on April 12th 1914 with screenings of silent films. Located in the Plaza del Teatro on Flores Avenue. During 1940-1994 it passed into the hands of the Mantilla cinema chain, operating exclusively as a movie theater.

Regarding its architecture, the theater is delimited by a square and two sections of the facade. One section is of homogeneous architectural value, the other section on the square reiterates its character of entrance. The colorful facade with neo-Renaissance features and an eclectic appearance in front of the square, generate a space of architectural enhancement. Its entrance is made up of an atrium with spaces for circulation. Its inner composition with seats in the stalls and two levels of balconies allows spectators to maintain closeness with the stage and the artists, while the café-concert format allows it to become a meeting place. [3].

After a comprehensive remodeling in 2006, the FONSAL reopens the space under the name of "Teatro Variedades Ernesto Albán".

Capacity: 250

2.4 Bolívar Theater

Design: Augusto Ridder, Hoffman & Henon

Construction: 1931-1933

Characteristics: One of the most iconic theaters in the city of Quito begins in the minds of the Mantilla brothers after founding their company of Theaters and Hotels of Quito C.A., they commissioned the design to a famous firm of Architects of Philadelphia Hoffman & Henon, recognized in several countries, and at the head the Architect Augusto Ridder who later would carry out several works in the city.

It was inaugurated on April 15th, 1933, with a capacity for 2,200 spectators, making it shortly thereafter the first stage for large-scale events on the entire Pacific coast.

In the Bolívar Theater, it isolates the external reality from the interior environment, through architectural resources of an eclectic proposal where several trends converge, among which are evidenced as art deco, neoclassicism. It is located on Espejo Avenue, between Guayaquil and Flores, in the Historic Center of the city of Quito. It opened its doors as a cultural center for the performing and cinematographic arts. It was positioned as a social and cultural reference during the decades of the 30's to the 70's. The original intention of the designers of the great palaces of cinema and the performing arts was to inspire fantasy. The entrance is made through a wide hall with six decorated columns of quadrangular section, from there you access an anteroom and two stairs to the mezzanine. The main hall of the theater, with lowered arches, ends in a ceiling with Baroque decoration. Two side rooms, emergency exits, underground parking, as well as bar-cafeteria services on the upper floor. Lunettes and boxes are distributed over two floors, it consists of a large stage and dressing rooms. The structure is made of brick walls, a mezzanine with iron and wood beams, as well as the stairs and carpentry. [4].

After a fire affected the theater facilities to a great extent, in 2002 a private foundation was created for the restoration and recovery of this building, which today is in operation, accommodating in its room with 963 seats, restaurant, cafeteria, room for artistic-cultural events, cultural center, and a museum.

Capacity: 2200

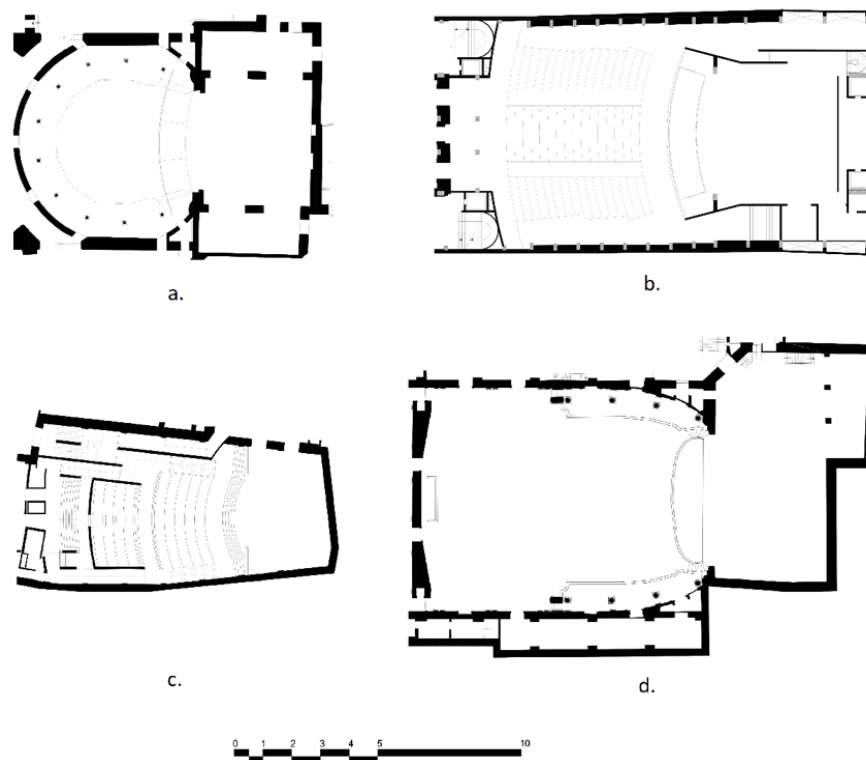


Figure 1- Plan graph of the theaters studied, in their current state.

Table 1 – Characteristics of the theaters

Theaters	Hall Volume m ³	Max. Dim. M (LxWxH)	Audience area m ²	Number of seats
a. Sucre	3283,03	15,17 x 20,02 x 10,81	303,70	795
b. Capitol	8953,70	19,20 x 23,66 x 19,71	454,27	850
c. Variedades	1930,38	09,40 x 13,60 x 15,10	127,84	250
d. Bolívar	9055,94	27,48 x 22,51 x 14,64	618,57	2200



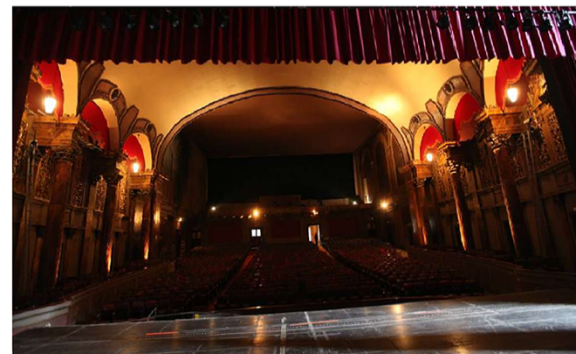
a.



b.



c.



d.

Figure 2- Interior view of the theaters studied, in their current state.

3 Methodology and measurement equipment

The acoustic measurements and subsequent calculations have been carried out under the criteria of the ISO 3382:2009-1 standard [5]. As an excitation signal to obtain the impulsive responses, the sound of a 40 cm diameter balloon exploding was used. ProTools software was used to record the sound signals and a Beyerdynamic Order # 449.350 microphone was used as a receiver. The processing of the signals and the extraction of the acoustic parameters has been carried out using the Dirac 6.0 software.

Three sound source positions were selected in each theater, which were located in the central part of the stage and near it. The microphone positions were located throughout the audience area, in such a way that they cover the largest useful surface and supervising that they do not follow a uniform pattern. The number of microphone positions varied depending on the size of each theater.

To ensure good precision in the determination of reverberation times, ISO 3382-1 requires that the level of the sound source be at least 45 dB above the background noise in all frequency bands of interest if is going to calculate the T_{30} , and at least 35 dB to calculate the T_{20} . Given the emission limitations of the sound source used, the first of the requirements has not been met in some cases, especially in the low-frequency bands and

for the microphone positions furthest from the sound source. The second requirement has been met in all cases except for some microphone positions of Variedades theater. For this reason, the parameters used in this work to describe the reverberation time are EDT and T_{20} .

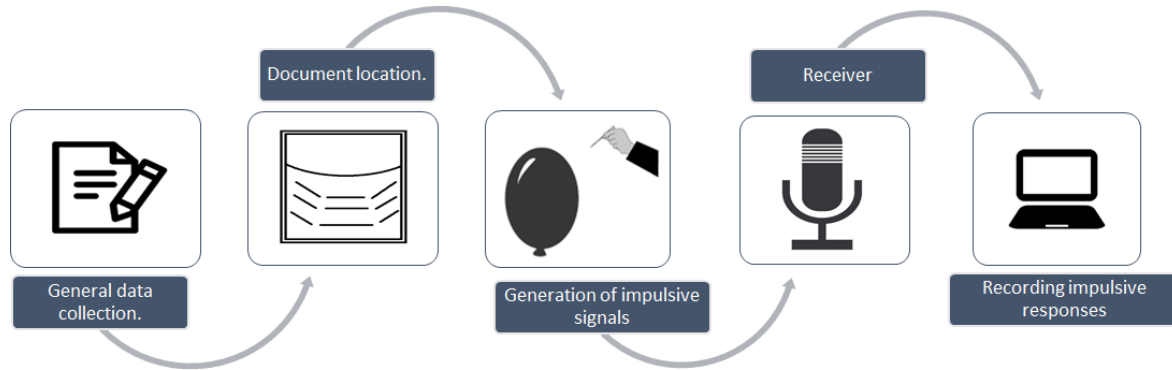


Figure 3- Outline of the measurement procedure.

4 Results

4.1 Reverberation time

Tables 2 and 3 show the average and standard deviation of the EDT and T_{20} values, respectively, obtained in each of the evaluated theaters. The values in the 1/1 octave bands with center frequencies between 125 Hz and 8 kHz are presented, as well as the value at mid frequencies, calculated as the average of the values in the 500 Hz and 1 kHz bands. For T_{20} , the Bass Ratio (BR) and Brilliance (Br) values are also calculated according to the following equations:

$$BR = \frac{T_{20}(125 \text{ Hz}) + T_{20}(250 \text{ Hz})}{T_{20}(500 \text{ Hz}) + T_{20}(1 \text{ kHz})} \quad (1)$$

$$Br = \frac{T_{20}(2 \text{ kHz}) + T_{20}(4 \text{ kHz})}{T_{20}(500 \text{ Hz}) + T_{20}(1 \text{ kHz})} \quad (2)$$

Table 2 – EDT [s]

Frequency Hz	Sucre		Capitol		Variedades		Bolívar	
	Aver.	SD	Aver.	SD	Aver.	SD	Aver.	SD
125	1,56	0,26	1,94	0,57	1,38	0,27	2,86	0,53
250	1,28	0,21	1,25	0,36	1,30	0,18	2,52	0,43
500	1,06	0,21	0,70	0,18	1,25	0,13	2,28	0,49
1000	0,99	0,19	0,51	0,20	1,17	0,11	2,00	0,51
2000	1,01	0,17	0,57	0,26	1,13	0,14	1,98	0,66
4000	0,88	0,21	0,57	0,30	0,99	0,16	1,71	0,75
8000	0,68	0,18	0,41	0,20	0,77	0,16	0,89	0,55
EDT _{mid}	1,03		0,61		1,21		2,14	

Table 3 – T₂₀ [s]

Frequency Hz	Sucre		Capitol		Variedades		Bolívar	
	Aver.	SD	Aver.	SD	Aver.	SD	Aver.	SD
125	1,60	0,17	3,38	1,24	1,35	0,11	2,56	0,21
250	1,31	0,10	2,26	0,39	1,29	0,08	2,37	0,17
500	1,09	0,07	1,58	0,36	1,26	0,06	2,28	0,17
1000	1,07	0,08	0,93	0,21	1,24	0,04	2,04	0,13
2000	1,05	0,08	0,87	0,10	1,19	0,04	1,93	0,09
4000	0,97	0,06	0,85	0,09	1,06	0,04	1,74	0,10
8000	0,80	0,05	0,69	0,09	0,88	0,03	1,28	0,08
T _{20 mid}	1,08		1,26		1,25		2,16	
BR	1,35		2,25		1,06		1,14	
Br	0,94		0,68		0,90		0,85	

4.2 Energy Parameters

As descriptors of the relationship between early acoustic energy and late energy, Clarity C₈₀, Definition D₅₀ and Central Time T_S have been calculated. Average values and standard deviations for each frequency band, as well as values for mid-frequencies, are shown in the following tables.

Table 4 – C₈₀ [dB]

Frequency Hz	Sucre		Capitol		Variedades		Bolívar	
	Aver.	SD	Aver.	SD	Aver.	SD	Aver.	SD
125	1,90	2,68	2,36	1,96	2,27	1,91	-0,16	3,54
250	2,14	2,35	5,08	2,08	1,93	1,58	-1,12	3,77
500	4,09	2,59	7,93	1,95	2,40	1,28	0,95	3,63
1000	4,83	2,97	11,48	2,83	3,50	1,15	4,20	3,52
2000	4,27	2,70	10,25	2,73	3,77	1,66	4,13	3,71
4000	5,36	2,66	9,91	2,89	4,44	1,88	5,21	3,88
8000	7,03	2,74	12,05	3,27	6,20	1,92	8,13	3,84
C _{80 mid}	4,46		9,70		2,95		2,57	

Table 5 – D₅₀

Frequency Hz	Sucre		Capitol		Variedades		Bolívar	
	Aver.	SD	Aver.	SD	Aver.	SD	Aver.	SD
125	0,42	0,16	0,39	0,31	0,42	0,13	0,16	1,15
250	0,43	0,15	0,70	0,68	0,41	0,12	0,24	0,61
500	0,57	0,14	0,83	0,69	0,45	0,10	0,47	0,21
1000	0,62	0,16	0,98	0,83	0,55	0,08	0,76	0,73
2000	0,60	0,15	0,90	0,52	0,57	0,10	0,71	0,49
4000	0,65	0,14	0,89	0,49	0,60	0,11	0,84	0,98
8000	0,71	0,13	0,95	0,56	0,68	0,10	0,88	0,57
D _{50 mid}	0,59		0,90		0,50		0,61	

Table 6 – T_s [s]

Frequency Hz	Sucre		Capitol		Variedades		Bolívar	
	Aver.	SD	Aver.	SD	Aver.	SD	Aver.	SD
125	125	29	144	31	113	18	206	61
250	102	22	86	17	104	15	189	57
500	74	20	51	12	93	11	147	51
1000	63	22	28	12	78	10	98	43
2000	64	20	30	12	71	13	92	39
4000	55	20	30	15	63	13	68	33
8000	43	17	23	13	47	11	39	22
$T_{S\ mid}$	68		40		86		122	

4.3 Speech Intelligibility

From the impulsive responses the Modulation Transfer Function can be obtained [6], and, consequently, the Speech Transmission Index (STI) parameter. Since the type of sound source used does not have an emission level comparable to that of the human voice, the measured STI values mainly reflect the dependence of speech intelligibility on the effect of reverberation and to a lesser extent on the Signal ratio. /Noise. Table 7 shows the STI values applying the Male and Female filters according to the IEC 60268–16 standard [7].

Table 7 – STI

Theater	STI Female				STI Male			
	Avr.	Max.	Min.	SD	Avr.	Max.	Min.	SD
Sucre	0,63	0,70	0,50	0,05	0,63	0,69	0,50	0,05
Capitol	0,75	0,85	0,59	0,06	0,74	0,83	0,59	0,05
Variedades	0,60	0,70	0,54	0,03	0,59	0,68	0,53	0,03
Bolívar	0,59	0,82	0,40	0,09	0,58	0,80	0,40	0,09

5 Discussion

The results of the measurements show marked differences between the acoustic characteristics of the different theaters studied. Attending, in first instance, to the reverberation time, we can identify two theaters (Sucre and Variedades) with T_{20} values that oscillate, approximately, between 1s and 1.5s in all frequency bands, which a priori makes them appropriate for applications where correct intelligibility of the spoken signal is important. At the opposite extreme is the Bolívar Theater, with significantly higher reverberation times. Finally, the Capitol Theater presents an unusual frequency distribution of reverberation times. While in mid and high frequencies the T_{20} values are lower than those of any of the other theaters, below the 1kHz band there is a gradual increase in the T_{20} values that can exceed 3 s in the 125 Hz. All this can be seen clearly in figure 5.

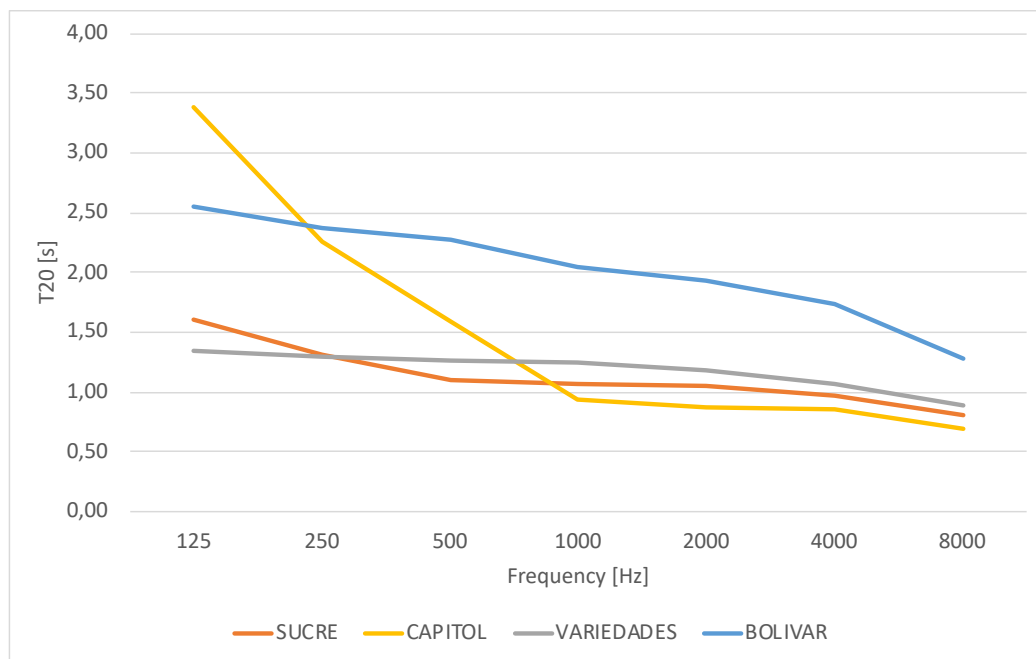


Figure 5 - Comparison of T_{20} values as a function of frequency for the theaters studied.

Next, we will try to determine what type of use is the most appropriate for each of the theaters based on their acoustic characteristics. To do this, from the different published criteria regarding the recommended values of the acoustic parameters depending on the use of the room, we will use those proposed by Higini Arau [8], collected in table 8. These criteria cannot be applied in a strict way to the theaters analyzed, mainly because they are defined for full rooms and the measurements were made with empty theaters.

The comparison of the values of the acoustic parameters obtained in the measurements and the optimal values for each type of use indicates that the Bolívar Theater presents adequate acoustic characteristics for symphonic music. The Sucre theater shows ideal conditions for applications where the signal emitted is the voice, both spoken (theater, conferences, etc.), and sung (opera). The Variedades Theater is shown as a multipurpose room, in which both musical and spoken voice activities can be programmed. With respect to the Capitol theater, the irregularity of the acoustic behavior in the different frequency bands means that its acoustic characteristics do not fully fit in with any of the usual applications of this type of theater.

Table 8 –Optimal values of the acoustic parameters depending on the use of the room according to Arau. [8].

Parameter	Symphonic Music	Chamber Music	Opera	Theater	
T_{mid}	Max	$0,6000 \cdot V^{0,1325}$	$0,5123 \cdot V^{0,1328}$	$0,509 \cdot V^{0,1325}$	$0,368 \cdot V^{0,1505}$
	Min	$0,5125 \cdot V^{0,1328}$	$0,4245 \cdot V^{0,1331}$	$0,396 \cdot V^{0,1273}$	$0,264 \cdot V^{0,1394}$
BR	$\approx 1,2$			$[0,9 - 1,1]$	
Br	$\geq 0,8$				
EDT_{mid}	$[0,9 \cdot T_{mid} - 1,0 \cdot T_{mid}]$		$[0,75 \cdot T_{mid} - 1,0 \cdot T_{mid}]$	$[0,6 \cdot T_{mid} - 0,75 \cdot T_{mid}]$	
D_{50}	$< 0,5$		$[0,5 - 0,6]$	$> 0,7$	
$C8_0$	$[-2 \text{ dB} - +4\text{dB}]$		$[+2 \text{ dB} - +6 \text{ dB}]$	$> +6 \text{ dB}$	
T_s	$130 \text{ ms} \pm 20 \text{ ms}$			-	

As a representative example of these evaluations, Figure 6 shows the comparison of the reverberation times at mid frequencies measured in the different theaters, with the optimal reverberation times, as a function of volume, for the different possible uses.

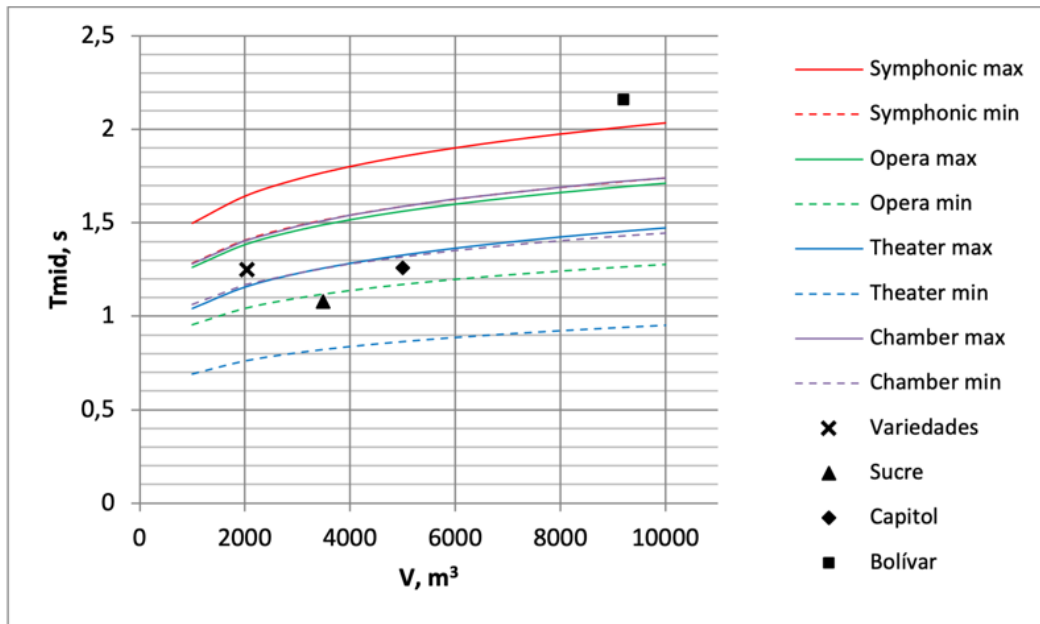


Figure 6 - $T_{20 \text{ mid}}$ values of the studied theaters compared with the optimal reverberation time values according to Arau [8].

6 Conclusions

The heritage theaters of the city of Quito constitute a cultural heritage that must be recognized and preserved and of which its acoustic characteristics are fundamental elements.

In this work, acoustic measurements have been made of four of the most important theatres, dating from the end of the 19th century and the beginning of the 20th. These theaters have always been, and still are, very important elements in the social and cultural life of the city.

The results of the measurements show a diversity of acoustic behavior in the halls, which makes the theaters studied more suitable for some uses than for others. Of the four theaters analyzed, the Bolívar theater is especially suitable for symphonic concerts, the Sucre theater works well as a theater hall and an opera hall, and the Variedades theater is shown as a multifunctional hall that can host different types of sound programs. The Capitol Theater has peculiar acoustic characteristics, with a noticeable imbalance between the reverberation times of the high frequencies and those of the low frequencies.

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