Mapping the sound quality of halls for classical music

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ABSTRACT

For several years we have done an extensive measurement campaign in halls of different typologies and uses. Together with these measurements, we have also done assessment surveys to several general public and to a selection of experts who served as a control group. The analysis of the results has permitted to establish a model to classify a hall according to classical music performance, which depends on reverberation time (T30), lateral factor coefficient (LFC) and listener envelopment (LEV). Additionally, an optimum interval for the model has been established for classical music. From the measurements of these three quality parameters, quality maps for halls can be determined for classical music. In this paper, the maps for 6 halls are shown. These maps are a useful tool to visualize in a quick and clear way the locations of the hall where the quality criterion is met for classical music.

1 INTRODUCTION

Getting a criterion based on objective measures to assess the quality of a concert hall is one of the fundamental aims of room acoustics. Yet, it has recently been recognized that one of the most important missing elements in the room acoustics puzzle is the lack of preferred design criteria for each room acoustics parameter [1]. Since Clemens Wallace Sabine [2], whose initial discovery of the reverberation time as persistence of the sound in an enclosure constituted the most important parameter in the evaluation of the hall, new descriptors have been added in the following decades to analyze and evaluate existent halls, or design those in phase of construction.

No single definitive design parameter exists that can be said to correspond with perceived hall acoustic quality. However, it is clearly important for designers to have a model that enables objective measurements to be correlated with subjective responses. For this reason, different
authors have tried to find models that combine some of the studied acoustic parameters in order
to obtain an objective ranking that correlates with the subjective ranking.

One of the most important references for determining optimal values from psychoacoustic
studies can be found in the work by Ando [3, 4] on the preferred acoustical parameters for
different musical criteria, and especially in his theory of subjective preference. He used as
independent statistical parameters (variations in any of which do not affect the others):
Interaural Cross-Correlation Index (IACC); Early Decay Time (EDT); Strength Factor (G); and
the time between the first direct sound and the first reflection (ITDG).

Another important authority, Beranek, added two independent parameters to those of Ando:
Bass Ratio (BR) and Surface Diffusion Index (SDI). These parameters were used with a
modification of Ando’s theory to obtain an objective hall ranking method [5].

In [6, 7], objective parameters were used to obtain a mathematical expression that would
provide an objective hall ranking. In this regard, Ando [4] presented a complex method to predict
a subjective hall assessment. This procedure was studied and modified by Beranek [5], in line
with his own technical calculations, interpreting as weights the functions used by Ando. Similar
attempts at hall assessment by using acoustic parameters can also be found in Barron [8],
Higini [9], and in a previous study made by the present authors [10]. These references present a
mechanism that, with the aid of graphs, enables the assessment of hall parameters and
provides a global quality coefficient.

In previous studies [11, 12], the number of acoustic parameters was reduced statistically to an
orthogonal set of three factors by using factor analysis. One factor was interpreted as RT,
another as a spatiality factor correlated with lateral energy fraction (LFC); and the third one was
an envelopment factor correlated with listener envelopment (LEV according to [13]).

In [14], it was presented a linear combination of RT, LFC and LEV correlating with Ando
functions of preferred values. This allowed us to introduce an Ando-Beranek function fitted to
the experimental objective data that agrees with the assessment of the halls included in our
studies [15]. An optimal interval of the Ando-Beranek function was established too. In [14], the
graphics presented showed which measured data satisfy an optimal relation in a LFC-LEV
plane for the RT of the studied hall. However, this representation is not optimal to evaluate,
design or introduce modifications to improve the acoustic quality for classical music. In this
sense, we introduce a new representation based on the maps of the Ando-Beranek function
superimposed over the floor plan of the studied hall. Superiority and advantages of this
representation are showed using 6 halls of different sizes and uses.

2 ANDO-BERANEK MODEL

In this section we introduce an Ando-Beranek model inspired by the work of these two authors
[4, 5]. This model consists of a linear combination of the $S_i$ Ando functions [3] with additional
weights. In Beranek [5], it is said that from Ando studies we can deduce the relative weighting
evolved for each $S_i$ Ando functions. In previous works [14], we have introduced weights
constants as additional degrees of freedom. This enables us to obtain a linear combination $S_{AB}$
of the orthogonal factors [11, 12] that correlates with a linear weighted combination $S$ of $S_i$
functions. $S_{AB}$ was named Ando-Beranek model.

The general problem to be solved is the following: how to find the coefficients in (1) in such a
way that the correlation coefficient showed in (2) is maximum. As the functions of Ando are
related to the subjective response for large concert halls and classical music, we expect that the linear combination obtained will provide equivalent information.

\[ S_c = \sum_{i=1}^{5} \alpha_i S_i \]  

(1)

\[ r = \text{corr}(C + a \cdot \text{RT}_{\text{mid}} + b \cdot \text{LFCE}_4 + c \cdot \text{LEV}; S_c) \]  

(2)

In [14], it was found that the combination with the best correlation was the one shown in (3).

\[ S_{AB} = -1.49 + 0.36 \cdot \text{RT}_{\text{mid}} + 2.76 \cdot \text{LFCE}_4 - 0.19 \cdot \text{LEV} \quad (r = 0.97) \]  

(3)

With regard to our subjective hall assessment [15], the hall quality criterion with the \( S_{AB} \) parameter is presented in (4).

\[ -\frac{1}{3} \leq S_{AB} \leq 0 \]  

(4)

3 STUDIED ROOMS

This study includes results from 6 halls from Valencia (Spain) whose main purpose is to offer an accurate verbal or musical audition. We used \textit{WinMLS} program for measuring and analysis [16]. This program computes, from the recorded impulse response, the acoustical parameters in accordance with ISO 3382 norm [17] as well as other parameters not included in the norm.

The impulse response of the halls was obtained by sinusoidal logarithmic sweep tests because of the advantages this type of signal has over others. ISO 3382 norm has been followed when working with an adequate signal/noise ratio. All measurements were made in empty halls and the source was situated at the center of the stage.

The mapped halls in this study are:

1. Castellon Auditorium (H1). It is used for conferences, congresses, concerts of all types, opera and dance. It was built in 2004 and it has 1200 seats. Its volume is 14850 m\(^3\) and has a RT of 2.43 s. The volume/seat is 12.4 m\(^3\). We measured at 51 different points.

2. Ribarroja Auditorium (H2). This auditorium is a rectangular room used for theatre, opera, dance and concerts. It opened in 1994. It has 783 seats, a volume of 7830 m\(^3\) and a reverberation time of 1.79 s. The volume per seat relation is 10 m\(^3\). We have studied 39 points.

3. Principal Theater of Valencia (H3). It is an Italian-style theater, with a horseshoe shape and boxes on different floors. It is used for theatrical representations, orchestra and soloist concerts, opera, chorus, and dance. It was built in 1832 (reformed at 1991). It has 1224 seats, a volume of 6986 m\(^3\), an RT at mid frequencies of 1.5 s and a V/seat of 5.7 m\(^3\). We measured 53 points.

4. Torrent Auditorium (H4). Its floor plan has an irregular hexagonal shape (fan shaped +inverted fan shaped). It is an auditorium used for conferences, congresses, concerts of all
types, opera and dance. It opened in 1997. It has 606 seats, a volume of 6430 m$^3$, a reverberation time of 1.87 s, and a V/seat of 10.6 m$^3$. We measured at 48 points.

(5) Paranimf UPV (H5). It is a rectangular shaped hall used for conferences, congresses, and soloist concerts, chamber orchestras and chorus. It was built in 1978 with 385 seats, a volume of 2700 m$^3$, an RT at mid frequencies of 1.3 s, and a V/seat of 7 m$^3$. We measured 24 points.

(6) ETSII Assembly Hall, UPV (H6). It is a rectangular shaped small room, used for conferences, congresses and soloist musician recitals. It was built in 1978. It has 142 seats, a volume of 434 m$^3$, a RT of 0.68 s and a V/seat of 3 m$^3$. We measured at 16 points.

4 QUALITY MAPS: RESULTS AND DISCUSSION

The objective parameters for the studied halls are shown in Table 1. To determine the quality maps, we applied the Kriging method [18]. Figure 1 shows the acoustic quality maps over the floor plans of each of the studied rooms. The graphic approach used was as follows: if the $S_{AB}$ parameter is less than -0.33, that point in the map is shown in blue. If it is greater than 0, it is shown in red. In the locations where relation (4) it's satisfied, colors are scaled between blue ($S_{AB} < -0.3$) and red ($S_{AB} > 0$). In the first halls, $S_{AB} < -0.3$ and, in general, the reason is that LEV is very high. This means, broadly speaking, an excess of late energy, and could be related to the overpowering phenomenon discussed in [5]. In the cases where $S_{AB} > 0$, the cause is often a low LEV, usually negative, which is associated with a poor sense of envelopment [19].

According to the criterion established by the expression (4), the subjective perception and the exposed color rule, we have:

(1) In rooms H2 and H6 the parameter $S_{AB}$ is less than -0.3 in most of the ground audience area, i.e. there is an excess of late energy.

(2) In room H5, the same occurs in most of the ground area. In this case, however, the values for $S_{AB}$ are in the appropriate range in the farthest part from the stage. The clear part that appears in these rooms is close to the entrance doors.

(3) Rooms H1, H3 and H4 have a similar behavior. In the maps, the three areas of interest can be distinguished: blue, red and color-scaled. In these cases, the blue zone is in the vicinity of the stage. The optimum values are located in the central area of the ground, while in the farthest part from the stage there is a lack of LEV.

As a general conclusion, we have observed that the $S_{AB}$ parameter quality maps [14] can provide an immediate impression of the quality of a hall for orchestral classical music. It also shows the places where the condition (4) is best satisfied. Additionally, it can be used as a diagnosis system to detect acoustic problems within the room. These problems tend to be the consequence of an excess or lack of LEV (more or less late energy, following [13]).

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Table 1: Objective parameters for studied halls (mean values). Halls are ordered descending by $S_{AB}$.

<table>
<thead>
<tr>
<th>Hall</th>
<th>LFC$_{E4}$</th>
<th>$RT_{mid}$ (s)</th>
<th>LEV</th>
<th>$S_{AB}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>H3</td>
<td>0.19</td>
<td>1.50</td>
<td>-2.44</td>
<td>0.04</td>
</tr>
<tr>
<td>H4</td>
<td>0.25</td>
<td>1.87</td>
<td>0.08</td>
<td>-0.15</td>
</tr>
<tr>
<td>H1</td>
<td>0.26</td>
<td>2.43</td>
<td>1.43</td>
<td>-0.16</td>
</tr>
<tr>
<td>H5</td>
<td>0.35</td>
<td>1.30</td>
<td>1.79</td>
<td>-0.41</td>
</tr>
<tr>
<td>H6</td>
<td>0.29</td>
<td>0.68</td>
<td>0.36</td>
<td>-0.51</td>
</tr>
<tr>
<td>H2</td>
<td>0.25</td>
<td>1.80</td>
<td>2.20</td>
<td>-0.57</td>
</tr>
</tbody>
</table>

Figure 1: Quality maps of studied halls: $S_{AB}$ parameter is mapped. Dark blue corresponds to $S_{AB} < -0.33$. Red means $S_{AB} > 0$. Scaled light colors represent values in the range $-1/3 < S_{AB} < 0$. 
REFERENCES


