AN OBJECTIVE INVESTIGATION OF THE ACOUSTICS IN THREE NEWLY BUILT CONCERT HALLS

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ABSTRACT

In the north of Sweden, three new concert halls have been built in the last few years. The three halls are; Studio Acusticum in Piteå (2007), Kulturens hus in Luleå (2007) and Norrlandsoperan in Umeå (2002). The Acoustics of the halls have been designed by Tunemalm Akustik. There are noticeable differences between the halls. Studio Acusticum is a multipurpose concert hall where the variable acoustics is realized by a height adjustable ceiling and absorbing curtains. Variable volume is an unusual solution, which permits good acoustics without many of the drawbacks normally associated with multipurpose halls. Kulturens hus is also a multipurpose hall, but here the variable acoustics is realized by variable absorption. The walls can be changed from reflective to absorptive by a system of motor driven panels. The acoustic properties of the ceiling can also be changed. To attain very short reverberation times, absorptive curtains can be lowered on the stage and side walls. Norrlandsoperan does not have any means of varying the acoustics during concerts. It is thus a “true” concert hall, built to fulfill the requirements of symphonic music. Good acoustics is thus achieved on the cost of versatility.

During the winter of 07/08, a thorough investigation of the acoustics in these halls has been made. The investigation showed that each hall has its own distinct character, making them more or less suitable for different music. The measurements were made in accordance with ISO 3382:1997, which describes the acoustic parameters used for objective concert hall evaluation. One of these parameters, Lateral Fraction (LF), was found to have reproducibility issues.

1. INTRODUCTION

Musical styles have different acoustical requirements. Historically, music has been composed and adapted for the music halls which were available. This fact makes music sound better, if it is performed in a hall which has acoustical properties characteristic for the time it was written. Therefore, an acoustician must design a concert hall with the most probable usage scenario in mind. Consequently, some music will sound better than other.

A good concert hall should give the listener a feeling that he/she is enveloped by the sound. It should also enhance the feeling of the apparent width of the source (the musicians). Listener envelopment and apparent source width are dependent on lateral sound, reflections from the side walls. It is an important indication of the acoustical quality of the concert hall [1].

1.1. Studio Acusticum, Piteå

Studio Acusticum was inaugurated in 2007 and seats 630 persons. Since the town of Piteå has a strong tradition of using wood for buildings, the construction consists mostly of wood. To receive good reflective properties, the wooden elements have received a special surface treatment. Studio Acusticum is a multipurpose hall where
the variable acoustics is realized by a height adjustable ceiling which permits a volume change of more than 30%. The volume change can also be combined with absorptive curtains. Three acoustic configurations of the hall were measured: High ceiling, low ceiling and low ceiling with curtains.

Image 1. Different acoustical configurations in Studio Acusticum, Piteå

1.2. Kulturens hus, Luleå

Kulturens hus was also inaugurated in 2007 and seats 950 persons. There is also a library and a smaller music hall in the same building. This requires good sound insulation, which is realized by dual concrete walls, where the inner one is covered with wooden panels. Kulturens hus is a multipurpose hall utilizing variable absorption. The surface of the walls can be changed from reflective to absorptive by a system of motor driven panels. The acoustical properties of the roof can be changed from diffusive to absorptive. Absorptive curtains can be lowered on the stage and side walls to achieve very short reverberation times, for a hall of this size.

Because of a technical error during the measurement, only one acoustic configuration could be measured in Kulturens hus. The roof was unfortunately stuck in “absorbing” mode. Everything else was set to maximum reverberation (reflecting walls, no curtains). Older measurements of the reverberation time with maximum and minimum T-60 are shown as reference.

Image 2. The concert hall in Kulturen hus, Luleå

1.3. Norrlandsoperan, Umeå

The concert hall at Norrlandsoperan was inaugurated in 2002. It is the smallest of the three, seating about 500 persons. In order to achieve necessary reverberation times in a small hall, the ceiling is quite high. The hall is made of concrete, to ensure a solid and rigid construction. There are no possibilities for variable acoustics, but since Umeå is a large city, there are other facilities to accommodate all purposes.
2. MEASUREMENTS

The following equipment was used for all acoustical measurements:

- Elton omnidirectional loudspeaker
- MILAB VIP-50 microphone with variable polar patterns
- HEAD Acoustics HMS III dummy head
- WinMLS 2004 acoustic software

A logarithmic sine sweep with the length of 12 sec was used. The measurements were stored in a laptop with a 24 bit, 48 kHz sound card. The number of measurements in each hall were 36 (Piteå), 32 (Luleå) and 24 (Umeå), see figure 1. All measurements were made in an empty hall, following the recommendations in ISO3382:1997. The only exception is loudness (G), which was calculated using the direct sound as reference.

![Figure 1. The measurement and source positions in Studio Acusticum, Kulturens hus and Norrlandsoperan](image)

The values of early Inter-Aural Cross Correlation (80 ms) are presented as 1-IACC in order to get a higher value for a “better” result. The values of $C_{80}$ and $1-IACC_{E3}$ are the average of the octave bands 500, 1000 and 2000 Hz. The values of $G_{mid}$ are the average of the octave bands 500 and 1000 Hz. Lateral fraction ($LF_{E4}$) is the average of the bands (125-1000 Hz). Measurements of reverberation time (T-60) are extrapolated from -5 dB to -35 dB.
3. RESULTS

A big advantage with the height adjustable ceiling is that a change in volume theoretically should affect all frequencies equally. This is confirmed by the measurements, as seen in figure 2. The change in volume results in an almost parallel movement of the reverberation curve. The curtains are apparently wisely designed, since they work well even at low frequencies.

The curves in figure 3, showing maximum and minimum possible reverberation times corresponds to measurements made by Tunemalm Akustik in 2007. Even in the most reverberating configuration, the reverberation time can be a little too short for certain types of classical music. On the other hand, when the hall is in short reverberation mode, it is an excellent choice for modern amplified music. The slope of the audience
is rather steep. This permits good sight-lines and higher absorption of direct sound, which is a desirable feature for modern amplified music.

![Figure 4. Reverberation times in Norrlandsoperan, Umeå](image)

The reverberation time in Norrlandsoperan is currently a little too long at low frequencies. Future measures will be made with purpose to absorb low frequencies more, in order to “straighten out” the curve a little. This will hopefully increase the clarity of musical performances.

The results from the measurements are presented in table 1.

<table>
<thead>
<tr>
<th>Hall</th>
<th>Configuration</th>
<th>$C_{60}$ (dB)</th>
<th>$G_{md}$ (dB)</th>
<th>1-IACC$_{E3}$</th>
<th>LF$_{E4}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA, Piteå</td>
<td>High ceiling</td>
<td>-1,2</td>
<td>9,0</td>
<td>0,58</td>
<td>0,42</td>
</tr>
<tr>
<td>SA, Piteå</td>
<td>Low ceiling</td>
<td>0,6</td>
<td>8,9</td>
<td>0,60</td>
<td>0,40</td>
</tr>
<tr>
<td>SA, Piteå</td>
<td>Low ceiling + curtains</td>
<td>3,0</td>
<td>6,5</td>
<td>0,51</td>
<td>0,29</td>
</tr>
<tr>
<td>KH, Luleå</td>
<td>Absorbing ceiling</td>
<td>2,1</td>
<td>6,2</td>
<td>0,68</td>
<td>0,49</td>
</tr>
<tr>
<td>NO, Umeå</td>
<td>-</td>
<td>-0,8</td>
<td>8,6</td>
<td>0,70</td>
<td>0,29</td>
</tr>
</tbody>
</table>

Table 1. Acoustical parameters measured in the concert halls.

Another interesting feature of Studio Acusticum is that the volume change has little effect on other parameters than reverberation time. Loudness, IACC and lateral fraction is not affected. Since clarity is dependent on reverberation time, it is the only parameter that varies. When absorbing curtains are added on the stage and side walls, a decrease in lateral sound (IACC and LF) are noticeable. Also, the loudness value goes down. This is a natural consequence of added absorption.

The degree of clarity is high in Kulturens hus. This is a bit unexpected, considering it is the largest hall of the three. Loudness is lowest, a natural property of a large hall. The measurements indicate good lateral sound. Bearing in mind that the roof was stuck in absorbing mode, the values of LF and IACC are probably a little bit too high. An absorbing roof increases the lateral energy compared to the total energy.

Norrlandsoperan is the smallest of the three. This, in combination with low absorption, gives it a high value of loudness. The value of 1-IACC$_{E3}$ is high, probably because there always are reflecting surfaces in the vicinity in a small hall. Lateral fraction on the other hand, is rather low. This might be caused by the microphone...
orientation. The null in the polar pattern shall point at the sound source, as illustrated in figure 5. In a small hall like Norrlandsoperan, this can lead to large offset angles close to the stage and awkward results.

![Figure 5. Microphone orientation while measuring lateral fraction](image)

During the measurements, doubts arose regarding LF. The recommendation is to use a high-quality studio microphone, with switchable polar patterns. But what does the polar pattern really look like? To answer this question, the polar patterns of the microphone used (MILAB VIP-50) was measured in an anechoic chamber with a turntable. The results of these measurements are presented in figure 6.
Figure 6. MILAB VIP-50 polar patterns, 125-4000 Hz, 10 dB/div
The omnidirectional polar patterns look reasonable, but in bidirectional mode the results are questionable, at best. At higher frequencies the bidirectional pattern is distorted. The pattern is skewed, which gives a different result if the microphone is rotated 180°. The patterns are not gain-matched either. An investigation by Farina, [2], gave similar results. The skewness might be caused by a mismatch in the microphone membranes. These problems lead to reproducibility issues. Hall to hall comparisons are only meaningful, if the measurement equipment used is identical.

Also, the value of LF is usually presented as an average over the frequency bands 125-1000 Hz, but human directional hearing is better at higher frequencies. Therefore, it could be more interesting to analyze the lateral energy at higher frequencies but this is not possible with current studio-microphones.

4. CONCLUSIONS

This work has shown that variable volume is a good way to design a multipurpose-hall, since it has many advantages over the more traditional variable absorption approach. Reverberation time and clarity can be varied without affecting other acoustical properties, such as the important lateral sound.

Some drawbacks with LF were found, but it is not a useless parameter. As long as the same measurement equipment is used, it will reveal relative differences between halls. Lateral fraction could be improved by specifying the polar pattern of the measurement microphone in ISO3382, in the same way as the sound source is described. Usage of studio-grade microphones is not ideal.

5. REFERENCES