SUBJECTIVE EVALUATION OF THE BEIJING NATIONAL GRAND THEATRE OF CHINA

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1 INTRODUCTION

Paul Andreu and AdPi won the international competition to create the National Grand Theatre of China in Beijing. The complex includes three halls including an Opera House (2400 seats), a Concert Hall (2000 seats) and a Chinese Theatre (1100 seats) which are placed under a glass and titanium dome. The acoustics of these three halls has been designed by CSTB1.

This paper focuses on the subjective evaluation of the Concert Hall. It has been done during a test concert before the opening with an audience composed of around 2000 people. The audience was composed of a wide range of people from untrained listeners to professional acousticians. 507 questionnaires have been returned on which this study is based. The analysis of the results is done for the entire hall first and then for the hall divided in seating areas so as to reach a finer analysis. A comparison with objectives measures in the hall is also done.

2 DESCRIPTION OF THE CONCERT HALL

This 2000-seats hall has been especially designed for the international symphonic repertoire. Therefore the acoustics has been fixed and dedicated to classical or romantic pieces, including organ play, soloist or with orchestra. The Concert Hall has a basic shoebox shape, slightly curved, including an organ at the rear orchestra platform (see Fig.1). It has two galleries, the first starting from main floor and surrounding the orchestra platform, the second starting from the organ wall and turning all around the hall. The ceiling is horizontal and corrugated for giving diffused reflections everywhere in the hall, and a reflector above the orchestra platform has been installed.

The main characteristics of the Concert Hall are:

- Number of seats: 2000; Volume: 22500 m³
- Max width: 34 m; Max length upper level: 50 m
- Ceiling height above the orchestra: 18 m; Mean ceiling height: 16.5 m
- Max distance of the farthest seat from central stage: 38 m

Figure 1. View of the NGTC Concert Hall from stage (a) and from the balcony (b)
3 QUESTIONNAIRE & AUDIENCE CHARACTERISTICS

3.1 Questionnaire design

A specific psychoacoustic questionnaire has been designed (see Fig. 2) and a translated version into Chinese language has been distributed to the audience. The questionnaire includes specific questions about acoustics and also allows to assess the global sensation of comfort of each person (visibility of the orchestra, comfort in the chair...).

A large number of questionnaires have been filled in for the Concert Hall (507) what gives representative results and allows us to have a fine analysis of the Concert Hall acoustics and especially permits to focus on several different parts.

![Figure 2. English version of the distributed questionnaire (front and back view)](image)

1. General questions have been first asked to qualify the overall comfort into the Concert Hall. Those are located in the first part of the questionnaire and people have been asked to rated the global factors from "Very Poor" to "Very Good", with a "Don't know" possible choice:

<table>
<thead>
<tr>
<th></th>
<th>Very Good</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
<th>Very Poor</th>
<th>DK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

2. Five acoustic parameters have been assessed by the audience: reverberance, clarity, liveness, warmth and intimacy. People have been asked to rated these on a free scale as following. The free scale allows people to rate a parameter just as the impression they
have. For the processing of data this scale as been rated from 0 (left of the scale) to 10 (right of the scale).

These 5 parameters have been described in the questionnaire as following:

- Reverberance: persistence of the sound, superimposition of the different sounds
- Clarity: perception of musical details
- Liveness (brilliance): richness and persistence of high sounds
- Warmth: low sounds distinguished rich and clearly
- Intimacy: the music gives the impression of being in a small enclosure

3. The questionnaire has been designed to be filled in by the audience and the musicians alike. For this reason the questionnaire has been separated into two groups: the first one for the musicians and the second for all. Unfortunately it was impossible to poll the musicians: only the second part has been analysed.

4. Other questions have been asked about Personal Data (age, number of concert in the last year, etc.) to be able to distinguish untrained and trained listeners.

5. Questions about the overall acoustics of the Concert Hall have been asked with the same scale as for overall comfort questions. These questions allow us to have the global impression of the audience on the Concert Hall acoustics.

6. Finally, a box for free comments and remarks has been integrated in the questionnaire.

### 3.2 Audience characteristics

The age of the audience ranged from under 18 to above 65 with 81.4 % above 30 (see Fig.3).

All of the 507 persons did not answered to all the questions, nevertheless 154 persons (30.4 %) had attended at least one music performance in the previous year, up to 5 or 6 concerts for 28 persons (5.5 %). 251 persons on 404 (49.5 %) had attended one musical performance in the previous 6 months. These results allow us to assume that the audience is composed of not very frequent concert-goers.
4 OBJECTIVE MEASUREMENTS

Objective measurements in the occupied hall have been done just before the opening of the National Grand Theatre. An omnidirectional loudspeaker with a maximum acoustic power of 103 dB(A) has been used. It was placed at the centre of stage, close to the conductor location. A Sennheiser multi directional MKH80 microphone has been used in the omnidirectional directivity and placed in 10 positions (see Fig. 4). The results are shown in Table 1.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT 30 (s)</td>
<td>2.6</td>
<td>2.2</td>
<td>2.3</td>
<td>2.2</td>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>EDT (s)</td>
<td>2.2</td>
<td>1.8</td>
<td>1.6</td>
<td>1.7</td>
<td>1.6</td>
<td>1.3</td>
</tr>
<tr>
<td>Definition 50 (%)</td>
<td>21.4</td>
<td>36.6</td>
<td>45.5</td>
<td>48.0</td>
<td>46.6</td>
<td>48.4</td>
</tr>
<tr>
<td>Clarity 80 (dB)</td>
<td>-3.0</td>
<td>0.2</td>
<td>1.7</td>
<td>1.8</td>
<td>1.8</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table 1. Measured criteria of the occupied Concert Hall

5 SUBJECTIVE EVALUATION RESULTS

The data have been processed and statistically analyzed using SPAD v5.6.0 software. All percentages given exclude data where no reply was given.

5.1 Mean results in the entire Concert Hall

5.1.1 Overall comfort

In this first section, we focus on general parameters about the acoustics of the Concert Hall and about the feeling of comfort as for the listeners.

The comfort in the chair is good or very good for most of the people: 63.5%. The visibility of the orchestra is good or very good for 88.0% of the audience. The architecture and the decoration of the hall are considered to be good or very good for 81.3%. These results show that the audience feels comfortable in the Concert Hall, even if the comfort of the chair seems less appreciated than the other parameter. Thus, we can assume that the acoustic perception of the audience is not disturbed by these other factors. This is confirmed by the matrix correlation in Table 2 which shows that there is no linear relation between the acoustic judgment and these factors (weak correlation values around 0.3).

<table>
<thead>
<tr>
<th>Overall acoustic quality impression</th>
<th>Degree of silence in the hall</th>
<th>0.28</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Visibility of the orchestra</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>The comfort of the chair</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>Architecture &amp; decoration</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Overall impression</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2. Correlation coefficients between overall impression and disturbing factors
5.1.2 Detailed acoustic perception

The results of the five assessed acoustic parameters are shown in Table 3.

<table>
<thead>
<tr>
<th>Subjective criterion</th>
<th>0-------------10</th>
<th>Mean value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reveberance</td>
<td>Restrained</td>
<td>Spacious</td>
</tr>
<tr>
<td>Clarity</td>
<td>Blurred</td>
<td>Very clear</td>
</tr>
<tr>
<td>Liveness, brilliance</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Warmth</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Intimacy</td>
<td>Close</td>
<td>Remote</td>
</tr>
</tbody>
</table>

Table 3. Mean values for the 507 filled questionnaires in the Concert Hall.

Reveberance: the audience has perceived a high reverberance (7.6/10). This global impression of spacious sound is in accordance with the measured criteria RT30 (=2.0s) and EDT (=1.7s) at mid frequencies.

Clarity: the sound in the hall has been found very clear by the entire audience (8/10). The questionnaire also shows that the sounds of the different instruments are distinguished clearly or very clearly for 89.5% of the audience, and the soloist is distinguished clearly or very clearly for 90.1%. These subjective results are well related with the measured high value of the Clarity criterion in the occupied hall at mid frequencies (C80mid = 1.8 dB).

Warmth: the audience found the sound of the hall very warm (7.6/10). This subjective impression can be compared with two acoustic criteria calculated from the acoustic measurements: the Bass Ratio (BR) and the Bass Strength (Glow(125,250))3. BR = 1.05 and Glow = 3.7 dB. These values show that the bass sounds (low frequencies) are clearly audible when the full orchestra is playing. This explains why people judge the sound to be very warm in the hall.

Intimacy: the acoustic field has been judged neither intimate nor remote by the general audience (5.5/10). Nevertheless the intimacy is judged better if we only consider answers of the most frequent concert-goers. It is possible to compare this impression of intimacy (subjective parameter) with the Initial Time Delay Gap, ITDG (measured parameter) which is considered to be an appropriate measure of a hall intimacy if measured for seats in the middle of the hall. On measurement point n°3 (see Fig. 4) ITDG is equal to 32ms which corresponds to a good intimacy. These two different results between audience impression and measures can be explained by the untrained musical perception of many people of the audience.

Overall acoustic assessment

The degree of silence in the hall has been considered to be good or very good for 80.0% of the audience (469 answers to the related question). A general question has been finally asked to assess the overall acoustics of Concert Hall. 88.3% of the people felt satisfied with this acoustics – 42.6% good and 45.7% very good.

5.2 Results considering seating areas in the Concert Hall

The Concert Hall of the National Grand Theatre of China has been divided into 20 areas so as to carry out a finer analysis of the subjective evaluation of the acoustics (see Fig.4). This division has been chosen to have homogenous seating areas in the hall even if this does not give exactly the same number of persons inside each area with 22 persons per area in average (see Fig.5). To make the reading of graphs easier all the following figures and graphs correspond in colours.
In this section two assessed parameters (reverberance, and clarity) are analysed on the 449 questionnaires filled with a seating location.
We can notice on Fig. 6 that symmetrical areas – which should have the same acoustics – have not been judged to have the same acoustic properties. This is well illustrated with different results for symmetrical areas n° 4 and 6, and symmetrical areas n° 18 and 19.

The results on Fig. 6 give us the deviation of the assessed criteria:
- the mean value for Reverberance is 7.6/10 and the standard deviation $\sigma_{\text{rev}} = 0.61$.
- the mean value for Clarity is 8.0/10 and the standard deviation $\sigma_{\text{clar}} = 0.74$.

These deviations are small since they are less than 1 over 10.

The measurement points (MP) are then averaged in groups to allow comparisons with selected seating areas and to minimize measurement errors. The Table 4 gives EDT, RT30, and C80 values for MP groups with corresponding seating areas. The localisation of the measurement points and the seating areas can be seen on Fig. 4.

<table>
<thead>
<tr>
<th>Seating areas</th>
<th>RT30 (s)</th>
<th>EDT (s)</th>
<th>C80 (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1.77</td>
<td>1.84</td>
<td>2.48</td>
</tr>
<tr>
<td>5, 6</td>
<td>1.90</td>
<td>1.84</td>
<td>2.42</td>
</tr>
<tr>
<td>8, 9</td>
<td>1.69</td>
<td>1.54</td>
<td>6.02</td>
</tr>
<tr>
<td>14, 15</td>
<td>1.81</td>
<td>1.49</td>
<td>2.72</td>
</tr>
<tr>
<td>20</td>
<td>1.75</td>
<td>1.51</td>
<td>4.37</td>
</tr>
</tbody>
</table>

Table 4. Average values of RT30, EDT and C80 for measurement points groups in the occupied hall with corresponding seating areas.
Reverberance:
EDT is compared to the assessed reverberance on Fig. 7. Except for the area n°3 in the front stalls where the reverberance has been found higher, the measured EDT (green bars) has the same trend as the reverberance. This means that the whole audience was able to give a judgement well related the real acoustic field in the Concert Hall for our measurement points.

Clarity:
The assessed clarity is compared to the C80 criterion on Fig. 8 (C80 is plotted on a logarithmic scale because it is measured in dB). There are more differences between assessments and measurements result for this criterion. For the seating areas in front stalls (3, 5, 6) the assessed clarity have the same trend as the measured one, but assessments do not correspond to measures very well. Two factors cause these differences: the C80 measurements have a high deviation, and the clarity subjective parameter appears to be more difficult to assess than the sensation of reverberance for the audience.

6 CONCLUSION
A subjective assessment of the new NGTC Concert Hall has been done just before the opening. 507 questionnaires have been computed and analysed so as to have a feedback of the audience about the hall acoustics, with a lot of untrained spectators in acoustics. These results have been then compared to objective measurements, both for the entire hall and for more precise areas. The division of the hall into 20 seating areas allowed us to compare measurement and assessment results directly. The acoustics of the Concert Hall of the Beijing National Grand theatre of China has been judged to be very good, with a spacious reverberance, a good clarity and a warm sound.

7 ACKNOWLEDGMENTS
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8 REFERENCES

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