THE ACOUSTIC DESIGN OF A MULTIPURPOSE HORSESHOE HALL AND A DRAMA HALL AT DRUSKININKAI CULTURE CENTER

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1  INTRODUCTION

This paper presents the acoustic design of a 1100-seat multifunctional horseshoe hall, a 500-seat drama hall at Druskininkai Culture center, in Lithuania. The culture house functions as a multipurpose event center for the Druskininkai community and arriving visitors.

The paper discusses the different aspects of acoustic design of the auditoria. The aspects covered are the design goals for acoustic qualities of the hall, the study of the geometry of the spaces and finally the suggestions of shapes and material types to achieve the design goals.

Figure 1. View of the Druskininkai Culture Center daytime
2 ACOUSTIC DESIGN OF THE MULTIPURPOSE HORSECHOE HALL

2.1 Background

Before the project design started it was discussed what concept of the hall could be chosen and which is more aligned with the city’s cultural life, forecasted events and multifunctionality.

Three types of the possible concepts were discussed:
- Hall for reinforced music;
- Opera house;
- Hall for acoustical music

After the discussions with the client, it was agreed to choose “Hall for reinforced music” concept, considering the fact that the city will supply all kinds of events for the multifunctional hall, with technical adjustments to control reverberation time (from 0.8 s to 2 s) according to the type of event is per-formed. Having the possibility to change the reverberation time and adjust hall acoustics to any type of event, we are designing the first concept further.

The basic layout of the hall itself is horseshoe, with the back and side balconies. The overall width of the hall is ~26 m and the maximum length from the stage front to the back wall is ~26 m.
2.2 Design goals

In this section acoustic requirements, principle building and room acoustic solutions for the Druskininkai Cultural Center are presented. Building acoustical structures are based on solutions and principles used in modern cinema/hall complexes and are implemented in the architectural and structural drawings. Chosen structural types are based on the architectural layout and the structural design.

2.2.1 2.1.1 Requirements

Sound insulation

In this paragraph airborne sound insulation and impact noise level requirements are presented. All airborne sound insulation requirements are given as either $R'_w$, that is in-situ measured values, or $R_w$ - laboratory values, in accordance with ISO 140-4 and ISO 717-1. Sound insulation requirements are set for both vertical and horizontal directions.

The sound insulation requirements are presented in table 1.

<table>
<thead>
<tr>
<th>Room</th>
<th>airborne sound insulation $R'_w$, dB</th>
<th>impact noise $L'_n,w$, dB</th>
<th>doors sound class $R_w$, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between main hall and corridor</td>
<td>75</td>
<td>49</td>
<td>2x44 dB</td>
</tr>
</tbody>
</table>

Table 1. Sound insulation requirements
Between cinema auditorium and corridor  70  49  2x44 dB
Between theatre hall and corridor  70  40  2x44 dB
Between auditoriums and evac. corridors  65  49  40 dB
Between main hall and offices  75  49  35 dB
Between offices  48  63  35 dB
Between rehearsal rooms  55  49  40 dB
Between rehearsal room and main hall  60/70  49  44 dB
Auditoriums roof construction  50  -  -

Sound insulation indexes of boundary structures describe the insulation of the barrier structure itself, which does not consider the transfer of the sound propagation and openings (ventilation ducts, electrical cables bushing) in constructions.

**Background noise levels**

Low background noise level is one of the main attributes of a high-class hall. For new halls, background noise levels of between 10 - 12 dB(A) are normally achieved, and 20 dB(A) is maximum allowed.

For background noise levels the requirements are set as Noise Criteria (NC) curves and the permissible noise levels are given in octave bands. The maximum background noise levels are presented in NC-curves.

**Table 2. NC-curves**

<table>
<thead>
<tr>
<th>31.5</th>
<th>63</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>8000</th>
<th>Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC15, dB</td>
<td>62</td>
<td>47</td>
<td>36</td>
<td>29</td>
<td>22</td>
<td>17</td>
<td>14</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>NC20, dB</td>
<td>69</td>
<td>51</td>
<td>40</td>
<td>33</td>
<td>26</td>
<td>22</td>
<td>19</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>NC25, dB</td>
<td>58</td>
<td>54</td>
<td>44</td>
<td>37</td>
<td>31</td>
<td>27</td>
<td>24</td>
<td>22</td>
<td>21</td>
</tr>
<tr>
<td>NC30, dB</td>
<td>61</td>
<td>57</td>
<td>48</td>
<td>41</td>
<td>35</td>
<td>31</td>
<td>29</td>
<td>28</td>
<td>27</td>
</tr>
<tr>
<td>NC35, dB</td>
<td>63</td>
<td>60</td>
<td>52</td>
<td>45</td>
<td>40</td>
<td>36</td>
<td>34</td>
<td>33</td>
<td>32</td>
</tr>
</tbody>
</table>

For auditoriums the acoustical requirements were set as follows:
1. Background noise levels (technical equipment and traffic noise);
2. Noise levels from adjacent cinema auditorium.

The principle is that measured noise level cannot exceed NC-curve on any octave band.

The noise levels from the ventilation systems for main hall and theatre hall (and other technical equipment in the building) and traffic noise cannot exceed levels of NC20 curve, for cinema auditorium can-not exceed levels of NC30 curve.

During low frequency sound effects (such as explosions) higher sound levels are not permitted in adjacent auditoriums.

**Reverberation time requirements**

In table 3 requirements for reverberation time is given for different room types.

**Table 3. Average values for reverberation time T (s)**

<table>
<thead>
<tr>
<th>Room</th>
<th>Reverberation time T, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cinema auditorium</td>
<td>0.4 – 0.6</td>
</tr>
<tr>
<td>Corridor/Lobby/Bar</td>
<td>0.6 – 0.8</td>
</tr>
<tr>
<td>Stairway</td>
<td>1.0 – 1.3</td>
</tr>
<tr>
<td>Main hall</td>
<td>0.9 – 1.0</td>
</tr>
<tr>
<td>Theatre hall</td>
<td>0.8 – 1.0</td>
</tr>
<tr>
<td>Rehearsal room</td>
<td>0.8 – 1.0</td>
</tr>
</tbody>
</table>
All wall claddings from the cinema auditorium side are covered with room acoustical treatment. Acoustical treatment on sidewalls is up to 170 mm thick, on front wall 100 mm and on rear wall 250 mm.

### 2.3 Room acoustic design

The reflections from side and rear walls as well as the reflections from the ceiling were studied and the designs were adjusted accordingly, to prevent focusing or other unwanted acoustic phenomena. Reflections from the balconies, ceiling and rear walls were studied, according to that study sound insulation and diffusing materials were used to prevent any unwanted reflections.

Example of these studies can be seen in figures 3 – 5.

**Figure 3** Reflections from the ceiling

**Figure 4** Reflections from the side balconies and sidewalls

**Figure 5** Reflections from the rear wall

In this paragraph, surface materials of the multipurpose hall are presented.

#### 2.3.1 Ceiling

Ceiling is a suspended ceiling with laminated 12 mm thick plywood boards with a large cavity, filled with mineral wool. Half of the ceiling is absorbing construction, where perforated boards are used,
2.3.2 Walls

The rear wall is acoustically mostly absorbing surface with some surface structures to provide reflections and some surface structures to ensure sufficient diffusion. The rear wall is covered with perforated laminated 12 mm thick plywood boards with a 200 mm cavity behind them, filled with mineral wool, perforation area is 18%; 60% of back wall surfaces are absorbing and 40% diffusing. The surfaces are divided evenly.

The sidewalls are acoustically partly reflective and partly absorbing surfaces, with some surface structures to ensure sufficient diffusion. The sidewalls are covered with laminated building boards with 100-300 mm cavities behind them, filled with mineral wool. In addition, the sidewalls are angled, to provide early reflections for parterre and balconies, between 2 m – 4.5 m and 6.4 m – 9.5 m, angles are between 6-11 degrees. Different thickness of boards are used, between 8 mm and 16 mm boards, are divided evenly. Reflective surface is 30% of the overall surface area, 70% absorbing. The surfaces are divided evenly.

2.3.3 Floor

The floor surface is a hard surface, with good durability. The floor surface is a wood parquet or on wooden joists. Wooden joist pace is 300/400/500 mm and randomly changed, to ensure different sound absorption on lower frequencies.

2.3.4 Stage

Stage ceiling and wall surfaces are very absorbing. Walls are covered with perforated wall panels to protect the absorbing material. Material thickness is 100 mm, and 50% of the surface area is covered.

2.3.5 Seating

The chairs have upholstered seats, which fold up. The back rests are upholstered but the backs of the chairs are hard. The bottom of the seat is perforated, to ensure better absorption when unoccupied. The upholstering on the seat is 50 mm thick and the upholstering on the back rest 40 mm thick. The perforation of the seat bottom reaches all the way through the structures.

2.3.6 Orchestra pit

The wall elements in the orchestra pit are absorbing, diffusing and reflective surfaces, orchestra pit elements are removable and connected on the walls with hooks. Reflective surface is 30% of the overall surface area, 50% absorbing and 20% diffusing.
2.4 Modelling results of the multifunctional hall

The main hall has been modelled with the ODEON 14.01 acoustic simulation software. Several different configurations have been tested, mainly to investigate the influence of different audience seats and the effects of geometrical changes of the ceiling and side walls.

2.4.1 Reverberation time

As the room will be equipped with a constellation system, the reverberation time should not be more than 1 s at mid frequencies and should be more or less equal for all frequencies. In particular, it is essential that the reverberation time at low frequencies should be short and that reverberation time at high frequencies should not be too low, to ensure good speech intelligibility.

The simulation shows that the reverberation time and early decay time are within the acceptable range.

Calculated average reverberation time is 1.0 s in mid frequencies and have slight increase in the bass frequencies.

In all simulations, the EDT is lower than the RT, this shows that no unusual reflections or effects in the hall, this is good for speech intelligibility. This shows enough early reflections in the hall, due to the shaping of the front walls and partly to the ceiling construction.

2.4.2 Clarity and strength

The parameters calculated from energy fractions, analysed from the impulse responses, are presented in this section. The values for clarity (C80 and C50) are presented.

The values for both C80 and C50, changes somewhat with the source-receiver distance. However, the change is actually smaller than could be expected. The average C80 is 7.0 dB and the average C50 is ~4dB dB at mid frequencies.

2.4.3 Speech intelligibility

Speech intelligibility is expressed with a parameter called Speech Transmission Index (STI) or Rapid Speech Transmission Index (RASTI). STI is calculated for all octave bands from 125 Hz to 8000 Hz whereas RASTI is calculated only for the 500 Hz and 2000 Hz octave bands.

For rooms intended for drama performance, the STI/RASTI value should be “GOOD” in accordance to the subjective scale presented in Table 1.

<table>
<thead>
<tr>
<th>Subjective scale</th>
<th>STI/RASTI value (accordingly to IEC 60268-16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bad</td>
<td>0,00 – 0,30</td>
</tr>
<tr>
<td>Poor</td>
<td>0,30 – 0,45</td>
</tr>
<tr>
<td>Fair</td>
<td>0,45 – 0,60</td>
</tr>
<tr>
<td>Good</td>
<td>0,60 – 0,75</td>
</tr>
<tr>
<td>Excellent</td>
<td>0,75 – 1,00</td>
</tr>
</tbody>
</table>

Speech intelligibility depends on many factors – reverberation time, background noise, level and direction of the reflections etc.
The calculation showed that both the STI and the RASTI parameters are between 0.55 to 0.8 for all measurement points. The biggest change in STI is noticeable between the position of the source on the stage, and sources further back on the stage giving the smallest STI/RASTI values.

Speech intelligibility was estimated by calculating the C50 early-late energy ratio as well as the Speech Intelligibility parameter, STI.

2.4.4 Lateral reflections

Calculated LF80 in mid frequencies is ~25%, this is suitable.

3 ACOUSTIC DESIGN OF THE THEATRE HALL

3.1 Background

In this paragraph the room acoustic design of the theatre hall is presented. Theatre hall seating is a tel-escape system, both flat and rising floor is a possibility. Theatre has balconies. Recommended reverberation time for empty room should be 0.8 seconds at the frequency range of 125-4000 Hz. The suggestions presented in this report should be worked into the final design solutions with cooperation between the architect and the acoustician.

Theatre hall is 513 seat drama hall. The basic layout of the hall itself is ellipse shaped, but the inner part is more or less shoebox shaped with parallel side walls. The overall width of the hall is ~17 m and the maximum length from the stage front to the back wall is ~22 m. The stage dimensions are 11x17 m.

![Figure 7 Layout of the theatre hall](image)

3.2 Room acoustic design of the theatre hall

The actual ceiling is sloping from the stage backwards, however there are a series of reflectors hanging underneath the ceiling surface to provide a more even distribution of ceiling reflections. Several different configurations have been tested, mainly to investigate the influence of different materials used on the ceiling and side walls.
Just one chapter about the reflection studies and the pictures:

### 3.2.1 Sidewalls

![Figure 8 Reflections from the sidewalls](image1)

As can be seen in Figure 8. Reflections from the sidewalls, second picture, the sidewalls provide sufficient reflections to the seating area. The sound from the stage reflects back from the end of the side walls. Since this is unwanted, the back part of the wall needs to be absorbing.

### Rear wall

The ellipse shape of the rear wall produces focusing effect on the last row middle seating and more disturbingly in the open control room at the back (visible in the Figure 9). This means sufficient diffusion needs to be used to eliminate the focusing.

![Figure 9 Reflections from the sidewalls](image2)

### 3.2.2 Ceiling

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Suspended ceiling provides reflections for all the seats of the audience, with several small gaps in the reflection pattern, reflectors are slightly convex, with a big radius to offer even reflections to the seating area, without gap.

3.2.3 Sightlines

In this paragraph, the surface materials for the theatre hall are presented. Guidelines for all the surfaces were given, to reach the design goals.

3.2.4 Ceiling

Under the actual ceiling, suspended ceiling elements are designed, made of laminated building boards with a large cavity. On top of the boards, mineral wool (100 mm) is used. Approximately 50% of the surface is perforated, with a perforation of 12%, perforated areas are placed evenly over the whole ceiling surface. Ceiling above the suspended ceiling elements is covered with coated mineral wool plates (minimum thickness 50 mm), to ensure no reflections above.

3.2.5 Rear wall

The rear wall is acoustically absorbing and diffusing surface. The rear wall is covered with perforated laminated 12 mm thick building boards with a 100 mm cavity, filled with mineral wool, perforation area is 18%, angled boards are used. Absorbing surface is 60% of the overall surface area and 40% diffusing. Surfaces are divided evenly.

3.2.6 Sidewalls

The sidewalls are acoustically reflective and absorbing surfaces, with some surface structures to ensure sufficient diffusion. Sidewalls are covered with perforated plywood boards with different cavities, filled with mineral wool. Approximately 40% of the surface is perforated, with a perforation of 12%. Perforated areas follow the ceiling board line. Diffusion is added on the side walls, by tilting the side wall boards. All boards on sidewalls are with minimum 100 mm cavity which is filled with mineral wool.

3.2.7 Floor

The floor surface is hard, with good durability, the floor surface is a wood on wooden joists. Wooden joist pace is 300/400/500 mm and randomly changed, to ensure different sound absorption of lower frequencies. The same applies to wall and ceiling frame pace.

3.2.8 Seating

The chairs have upholstered seats, which fold up. The back rests are upholstered but the backs of the chairs are hard. The bottom of the seat is perforated, to ensure better absorption when unoccupied. The upholstering on the seat is 50 mm thick and the upholstering on the back rest 40 mm thick. The perforation of the seat bottom reach all the way through the structures.

3.2.9 Stage

Stage ceiling and wall surfaces are very absorbing. Walls are covered with perforated wall panels to protect the absorbing material. The stage floor is plywood or other durable surface, Wisa-Trans multilayer plywood, with a thickness of 45 mm, the floor has 50 mm mineral wool backing for noise control.
3.2.10 Curtains

In the situation when the telescope grand stand is driven in, the absorption of the grand stand will have to be replaced. Therefore, curtains are planned for all three walls – sidewalls and rear wall. Sound absorption coefficient of the curtains is between 0.8–0.9. The curtains are wool and have a weight 350 g/m².

3.3 Modelling results of the theatre hall

3.3.1 Reverberation time

Reverberation time should not be more than 0.8 s at mid frequencies and should be more or less equal for all frequencies between 125-4000 Hz. In particular it is essential that the reverberation time at low frequencies should be short and that reverberation time at high frequencies should not be too short to ensure good speech intelligibility. The calculated average RT is 0.7-0.8 seconds in the mid frequencies, which fulfils the requirement. EDT is 0.2 seconds lower.

3.3.2 Clarity

In order to evaluate the speech intelligibility and determine how well the space will work for drama and speech presentations, the clarity parameters as well as Speech Transmission Index (STI) has been simulated. The average C50 is 2.4 dB at mid frequencies and the average C80 it is 6.9 dB at mid frequencies. Both values are as can be expected from the simulated reverberation time and confirms that the hall has very clear acoustics.

3.3.3 Speech intelligibility

High clarity indicates good speech intelligibility. The simulations revealed that the STI and RASTI support this finding. Both the STI and the RASTI averaged parameters are between 0.62 to 0.65 for all calculated points, meaning that the speech intelligibility is good. In this hall the effect of the distance for these values is relatively small.

3.3.4 Lateral reflections

Calculated LF80 is 25%, what is suitable.

4 CONCLUSION

The Main hall is hoped to serve as a platform for very different types of performances: from business conferences to Opera and Drama, from symphony orchestra concerts to reinforced music gigs. Since the demands set by very different uses are close to impossible to achieve with traditional means of adjustable acoustics, the acoustic design of the multifunctional hall focuses on providing suitable acoustic conditions for reinforced sound and an electroacoustic enhancement system. For the smaller hall, the goal of the acoustic design was to provide the space with room acoustics suitable for drama theatre as well as conferences and events with reinforced music.

5 REFERENCES

2. ISO 3382-1:2009 Acoustic Measurement of room acoustic parameters