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A new symphonic hall, Musikhuset Aarhus,Denmark

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During the past 3 years Musikhuset Aarhus in Denmark has been enlarged by an area of approximately 17,000 m^2 to a new total area of approximately 34,000 m^2.
The new part of the complex contains a symphonic concert hall for Aarhus Symphony orchestra with 1200 seats, a hall for rhythmic contemporary music with 600 seats and a hall for classical music with 160 seats. The new complex also houses the premises for the Royal Academy of Music.
Important design considerations for the symphonic hall will be highlighted in the paper and the results of the preliminary and final computer modelling of room acoustics will be presented using examples of auralisation.
In conclusion the room acoustic parameters (measured according to the ISO 3382-1 standard) will be discussed, also in respect of initial reaction from orchestral musicians.

1 Introduction

The Symphonic Hall in Aarhus is designed and built especially for Aarhus Symphony Orchestra and for symphonic music. That means the hall is rectangular with a limited width and with balconies like in other classical halls in Europe such as the Musicverein in Vienna and the Tonhalle in Zurich.

The actual size of the hall is height x width x length approx. 19.5 x 21.9 x 43.25 m. The volume of the hall is approx. 15,000 m^3, which was estimated to be enough to give a sufficient room reverberance with 1200 audience, a full choir and orchestra.

There is also a cavity behind the stage and the choir balcony designed to house an organ in the future.

The project was realised in a turnkey contract with the Danish Contractor A. Enggaard, the architect company C.F. Møller and COWI/ARTEC as acoustic consultants.

In order to create optimal acoustic for symphonic music, a number of room acoustical aspects and requirements had to be carefully examined and fulfilled. These inputs were given in the tender material and some of them will be discussed in the following sections.

2 General acoustical design aspects

The audience must experience high fullness of sound and a sufficiently long reverberation time together with a high clarity in order to clearly perceive tones and voices in the music played.

The hall shall have a good envelopment, which means the listener shall feel him or herself surrounded by sound and have the impression that the sound source is "broader" than the stage.

Also the sound pressure level shall be sufficiently high and the background level low enough in order to have a big dynamic range. The colouring shall have both depth without rumbling and have brilliance without sharpness.

On the stage the musicians shall be able to hear each other and to communicate in an optimal way. They shall experience sufficient support from the hall and the stage, so that they can play their instrument in a normal way without "forcing" it.

Unwanted acoustical phenomena like focusing, mislocalisation and flutter echoes must not occur.

The background noise levels from technical installations and from external noise sources i.e. from traffic shall not be audible.

The majority of these room acoustic qualities can be objectively evaluated by measuring the room acoustic parameters as described in the ISO 3382-1 standard.

The use of a room acoustic simulation program is strongly recommended during the whole design phases since this process is a highly iterative process between the users, engineers, architects and acousticians.

3 Some design aspects for the hall

3.1 The audience area

The surfaces of the hall have been designed with a mixture of heavy and light constructions.

Side wall elements are made of concrete which are angled and shaped in order to provide sufficient diffusion.

Other wall elements are made of curved multilayer gypsum panels..

Balcony fronts are made of gypsum boards covered with wood panels. They are irregularly shaped and tilted in order to create as many early reflections as possible towards the audience seating.

Roof elements are of concrete slabs with irregular surface mainly due to construction reasons and installations.

Floors on terraces and balconies are made of wood applied directly to heavy substructures.

All wooden elements are made of ash or veneered ash.

Concrete elements are painted.

Walls on second tier and third technical tier are provided with absorbing elements made by mineral wool covered with a fabric. They are hidden in pockets in the side wall and can be deployed independently in order to adjust the reverberation time in the hall when required by the actual music programme or special performances.

Adjustable curtains are placed in front of the back walls. These can also be operated individually depending on the performance.

Audience seating are chairs with absorbing front and seat while the back and underneath the seat are covered with hard surfaces.

Air inlets to the hall are placed under the seats and outlet are placed in the corners between the ceiling and the walls.

The overall visual impression of the hall as formulated by the architects should be: The Nordic Style with a light dominant colour.

3.2 The stage area

The stage is designed for up to 100 musicians - the normal number will be around 70.

The construction is a solid wooden floor with a 200 mm cavity in order to give resonance support to cellos and double basses. Extra raised podiums are used for terracing of the orchestra.

A reflector with 3 adjustable sections is placed over the stage.

At the rear of the stage is a raised balcony with 120 places in 4 levels, which can be used for singers or extra audience when not used by these.

At the rear wall an acoustic curtain can be deployed.

4 Layout of the hall

In Fig.1 and 2 a section and plan of the new hall is shown.

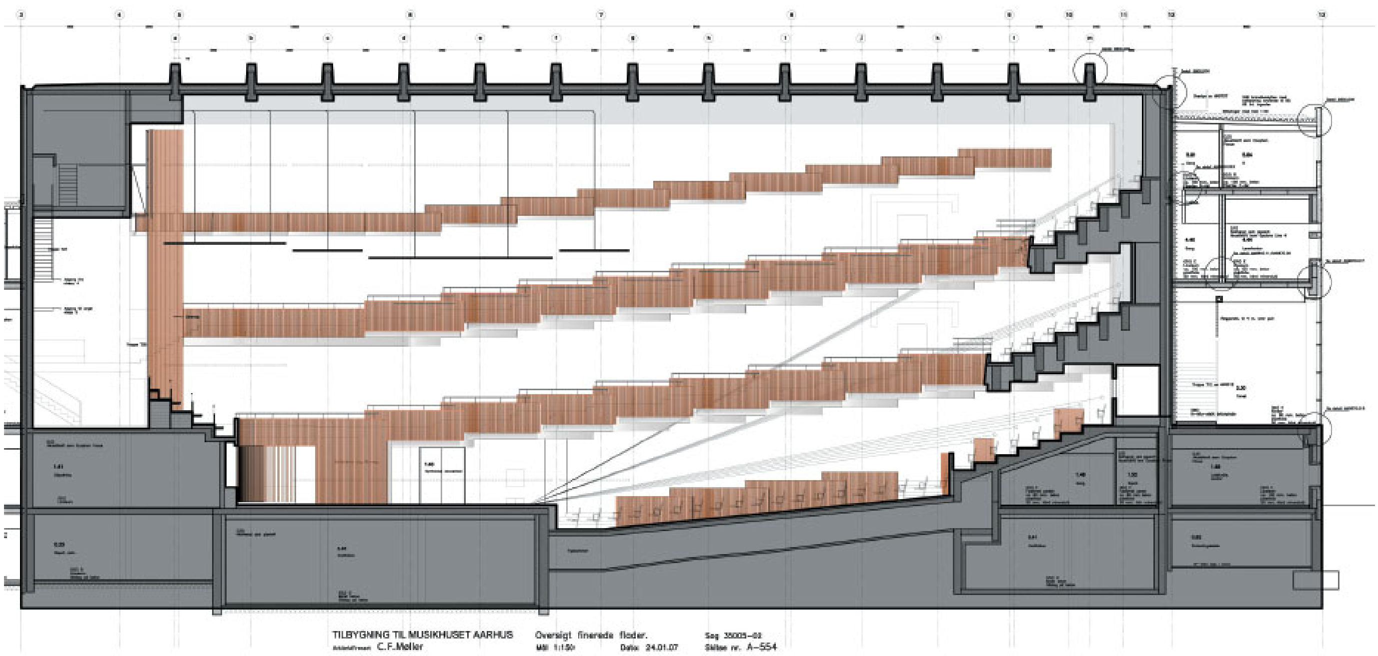

Fig. 1 Section of the new symphony hall

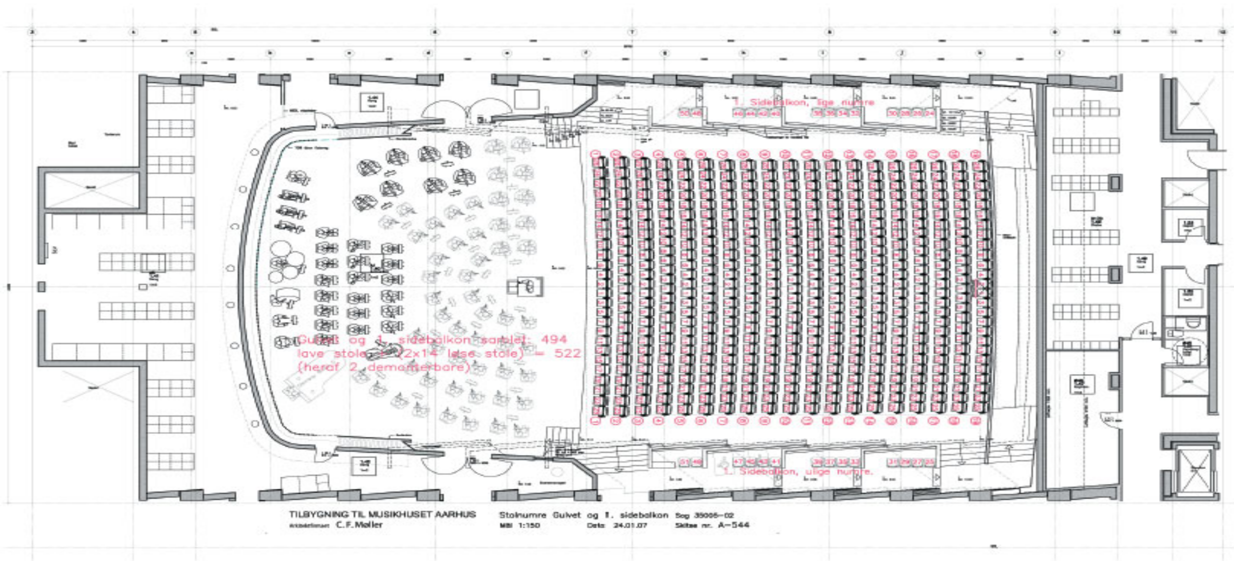

Fig. 2 Plan of the parterre in the new symphony hall

In Fig. 3 and 4 pictures of the final hall is shown.

Fig. 3 View towards the stage

Fig. 4 View from 2. balcony

5 Computer simulations in ODEON

In the design we have intensively used computer simulations to create and examine different models and layouts of the symphony hall in order to fulfill the requirements from the building programme.

The hall has been designed by the architects using an AutoCAD 3D-model and that model was imported into the ODEON Room Acoustic Program.

From the model it is possible to calculate the reverberation time and other acoustical parameters according to the ISO/DIS 3382-1 standard: Acoustics - Measurements of room acoustics parameters - Part 1: Performance rooms.

5.1 Requirements and targets

The required reverberation time T_{30} for the occupied hall is at least 2.2 s at mid-frequencies (250 Hz - 2000 Hz) with 2.5 s at 125 Hz.

When the hall is unoccupied, the reverberation time must only increase a maximum of 0.1 s compared to the values mentioned above.

For productions using loudspeakers, it should be possible to reduce the reverberation time in the occupied hall to 1.6 s.

For the other room acoustical parameters related to the unoccupied hall the target values are presented in table 1 and 2 shown opposite.

5.2 Some results of the calculations

The model has been developed during the design. Many of the preliminary results have been examined and improvement to the design suggested to the architects and the users in order to fulfill the targets.

The final calculations presented here were carried out for the following settings:

- Surface properties as described in section 3.1
- Unoccupied hall
- Canopy setting: rear 12.0 m, donut 10.5 m and centre 10.5 m
- No acoustical panel in use
- No wall curtains in use

Absorption coefficients for the audience seats were implemented based on laboratory measurements. Our own measured values for a typical organ surface were used since the organ would probably not be installed before the opening of the hall.

The scattering coefficients used in this setting were 0.05 for most of the hard surfaces and 0.65 for the seating area.

The model was used to carefully examine and avoid echo and flutter problems. This resulted for example in adding some diffusing elements at the back wall behind the second balcony.

Furthermore auralization examples were created and presented to the users.

The results of the calculations are shown in the following tables 1 and 2.

Parameter (ISO 3382-1) measured *in audience area* unoccupied hall	**Mean value 568 receivers and 1 source**	**Target Value**
Reverberation Time T_{30} [s] $_{250\text{-}2000\ Hz}$	2.7	2.3
Early Decay time EDT [s] $_{250\text{-}2000\ Hz}$	2.4	2.1
Clarity C_{80} [dB] $_{250\text{-}2000\ Hz}$	-0.6	-1
Strength G [dB] $_{250\text{-}2000\ Hz}$	5.6	5
Lateral Energy Fraction $LF_{80\ 125\text{-}1000\ Hz}$	0.25	0.24
RASTI (RT = 1,6 s) RASTI $_{500\text{-}2000\ Hz}$	Not included	0.55 (sound system)

Table1 Target values acoustical parameters in auditorium

According to the calculations, with the absorption coefficients for the specific audience seats, the reverberation time T_{30} and EDT in the hall is 0.3 – 0.4 dB longer than specified in the project programme.

The mean value for clarity C_{80} in the hall is 0.4 dB higher than specified and the mean value for the strength G in the hall is 0.6 dB higher than specified.

The mean value for LF_{80} in the hall is close to the target value with some variations over the hall.

From these results, with the given design, it can be expected that the hall will be more reverberant in the unoccupied situation than programmed.

Parameter (ISO 3382-1) measured *on stage* unoccupied hall	**Mean value 5 receivers and 5 sources**	**Target Value**
Early Decay time EDT [s] $_{250\text{-}2000\ Hz}$	2.4 Sec.	1.6 Sec.
Support ST_{early} [dB] $_{250\text{-}2000\ Hz}$	-12.9 dB	-12 dB

Table 2 Target values for acoustical parameters on stage

The calculated mean value of EDT on stage is higher than specified. The simulations indicate some wave fronts travelling between the side walls on the stage in the time range 80-200 ms, which might cause this higher EDT.

Furthermore the ODEON chairs on the stage are modelled as a horizontal surface which can result in a shorter EDT.

The calculated mean value of support, ST_{early} on stage is 0.9 dB higher than specified.

From these results in the unoccupied situation and with the given design, it can be expected that the condition on the stage will be more reverberant than programmed but the support will be satisfactory.

This might indicate that some of the acoustic panels should be used during rehearsals.

The effect of the different settings of the canopy was limited in the model and was examined in more detail after the opening of the hall.

The calculations with and without the curtains and acoustical panels for the occupied and unoccupied hall are shown in Fig. 5.

From the results it is shown that the total area of the absorbing panels should be approximately 540 m^2 in order to reach the target value of 1.6 s in the occupied situation.

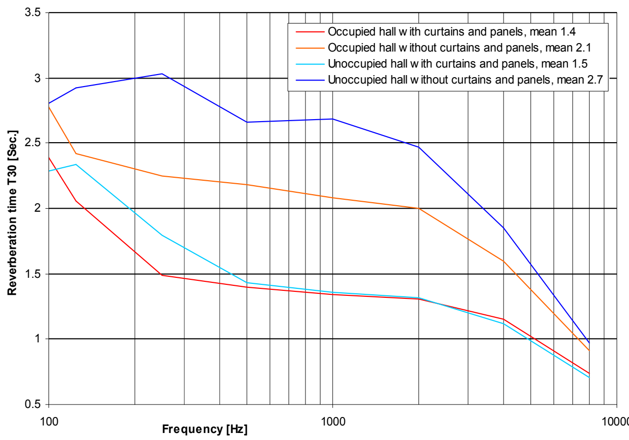

Fig. 5 T_{30} calculated for 4 different settings in the hall

In the occupied hall the reverberation time will vary between 1.4 and 2.1 s. When the hall is unoccupied, the reverberation time will vary between 1.5 and 2.7 s.

For some of the other acoustical parameters was found:

- The mean value for clarity C_{80}, in the hall is 0.4 dB higher than specified but with a fairly constant value throughout the hall
- The mean value for strength, G, in the hall is 0.6 dB higher than specified. The simulation indicates a shadowing effect with decreasing G under the rear balconies due to the overhang, which is determined by structural issues
- The mean value for LF_{80} in the hall is close to the target value with some variations throughout the hall

5.3 Concluding remarks on the modelling results

Overall, the results from the modelling shows, that the reverberation time T_{30} and EDT in the hall is 0.3 – 0.4 s longer than specified in the building programme which means, a slightly excessive reverberant hall should be expected - at least in the unoccupied situation.

This is however in accordance to the philosophies of the acoustic designer, who prefers to minimize these differences between the unoccupied and occupied situation using the many variable acoustical elements in the hall.

A comprehensive control measurement program and post-opening work with the orchestra was planned and is almost completed at this time. Therefore we will have the possibility to compare some of the results from the acoustic model with the results from the measurements.

In the next section some conclusions from this work is shown.

6 Comparisons with measurements

The results for the measured reverberation time T_{30} is shown in Fig. 6.

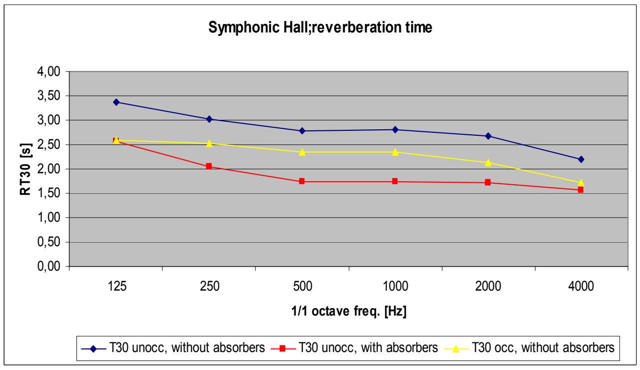

Fig. 6 T_{30} measured for 3 different settings in the hall

The results in Fig. 5 and 6 show that the model gives lower values than measured for the T_{30} for all settings, which could be due to differences between input data for the surfaces and how they are constructed or the setting of scattering coefficients in the model.

The measured mean value of the support ST_{early} on stage is 0.9 dB higher (around - 13 dB) than calculated which is quite acceptable.

The measured mean value of the EDT on stage is 2 s which is lower than calculated 2.4 s. This indicates that some of the mentioned other effects might have an important influence on the calculations.

7 Subjective evaluations

Two opening concerts were held in September 2007 and the enthusiasm was high both, among the audience and the musicians.

Some critics had a very positive subjective impression, and praised both the esthetics of "the Nordic Look" and the acoustics:

"The warmness of the total sound when the orchestra played was remarkable" and "everything stood extremely brilliant so one could hear every detail in the music even in the pianissimo parts". One concluded: "The new symphony hall has both reverberance and response".

The conductor, the musicians and the soloist were asked to give there their impressions, and the following three characteristics were emphasized:

- The outstanding brilliance
- The warm and round reverberance
- The response from the hall - no strain needed

And to conclude with the authors own overall impression:

- The hall breathes and holds the attention of the audience and the performers