THE ACOUSTICS OF THE NEW SYMPHONIC HALL IN AARHUS, DENMARK

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1 INTRODUCTION

The new 1200 seat Symphonic Hall in Aarhus opened in September 2007 is the new home of the Aarhus Symphony Orchestra. The design of the hall is a modern interpretation of the shoebox, with 2 main balconies and includes seating for 120 part choir behind stage. Variable acoustics include a 3 part height adjustable reflector spanning the whole platform area and sliding absorbers on a large proportion of the side walls.

The project has been a co-operation with Artec Consultants who have been employed as responsible for the acoustical design. Computer modelling has been used as a tool to ensure that the requirements of acoustical parameters would be achieved and that the planned variable elements would create the proposed effect. In addition, structural and volume issues have given challenges to the success of the hall.

This paper will describe the acoustic requirements, design and constructional issues, results and achievements using computer modelling and finally the measurements results achieved in the finished hall.

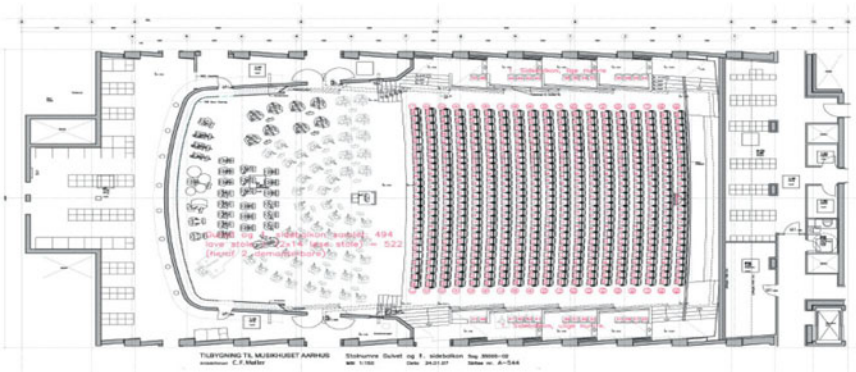

Figure 1. Plan of the new symphonic hall in Aarhus

The extension Aarhus Musikhus is the result of a long standing need for a new hall designed for symphonic music for the Aarhus Symphony Orchestra. The existing concert hall earlier used by the Symphony Orchestra, has a rather low reverberation time of about 1.5 seconds and unsatisfying values for other room acoustical parameters such as lateral energy fraction.

The project of building a new hall and other facilities has been under way for a while, and plans where drawn up for a suggested new building on the car park at the rear of the existing building. The plans where then assessed and accepted by the council planning office. At a very late stage, the Royal Academy of Music (Det Jyske Musikkonservatorium) - who had their facilities spread out at various addresses in the town - where given the possibility of joining the project. The idea of music students being under the same roof as the working professionals was welcomed by all parts. The only problem was that there was no time to change the plans for the building's area and heights. The new project was now to include many more rooms.

2 ACOUSTIC REQUIREMENTS

2.1 The hall's use and dimensions

In the tender document, the vision for the new concert hall is described in this way: "It is the primary demand, regarding the creation of the new concert hall for Aarhus Symphonic orchestra, to achieve excellent acoustics for symphonic music."

Further it is specified that, "the outer shape of the Hall should be rectangular with a limited width and balconies as in the classical European concert halls, for example Musikverein in Vienna and that room acoustical aspects should be brought to perfection for the purpose. The audience should experience a large sonority and suitable reverberation time and at the same time be able to distinguish between single notes by high clarity. The hall should also have a good spaciousness, so the audience feels surrounded by the music and perceive the sound source as wider than the stage. The sound level should be high enough to suppress the background noise in a suitable way. The timbre should have both depth without rumble and brilliance without sharpness.
The musicians should be able to hear each other in an optimal way regarding precision of the ensemble, and they should have appropriate support from the reverberance of the hall."
Some specifications of dimensions were also given.

2.2 Reverberation time

In the tender documents only one parameter was used to make a general characterization of the acoustical needs of the symphonic hall, namely the reverberation time. The reverberation time with fully occupied hall should be at least 2.2 seconds in the middle frequencies - to more than 2.5 seconds at 125 Hz. Without an audience the reverberation time in the hall should not increase more than 0.1 second.

It was specified that it should be possible to reduce the reverberation time to approximately 1.6 seconds, e.g. if loudspeaker systems are going to be an option in the concert hall.

2.3 Other parameters

Design values for other acoustical parameters in the unoccupied hall were given after selection of the winning project. The primary ones are shown in table 1.

Parameter (ISO 3382-1) in unoccupied hall	**Target Value**
Reverberation Time, T_{30} [s] $_{250\text{-}2000\ Hz}$	2.3
Early Decay time, EDT [s] $_{250\text{-}2000\ Hz}$	2.1
Clarity, C_{80} [dB] $_{250\text{-}2000\ Hz}$	-1
Strength, G [dB] $_{250\text{-}2000\ Hz}$	5
Lateral Energy Fraction, $LF_{80\ 125\text{-}1000\ Hz}$	0.24
Early Decay Time on stage, EDT [s] $_{250\text{-}2000\ Hz}$	1.6
Support, ST_{early} [dB] $_{250\text{-}2000\ Hz}$	-12

Table 1. Design values

3 DESIGN AND CONSTRUCTUAL ISSUES

3.1 Volume and height

A challenge in the design phase was to meet the requirement concerning the volume of the hall. The area and height of the building, which was accepted by the council planning office, could not be changed; consequently it was not possible to raise the height of the building to increase the volume of the hall. At the same time the subsoil conditions set a limit for how deep it was possible to go, and, as mentioned earlier, the project had to include many more rooms than first intended, since the Royal Academy of Music joined the project at a very late stage, in that way there was also restriction to the length and the width of the hall.

The compromise that was finally reached implied, among other things, that the project was granted an exemption from the council planning office allowing for the beams in the roof construction to be visible from the outside above the original height limit; raising the height limit by 30 cm. Another consequence of the limited space was that the hoisting apparatus for the reflectors was placed inside the hall and not on a technique floor over the hall.

The dimensions of the final solution are given in table 2 along with the required dimensions and the dimensions of the reference hall Musikvereinssaal in Vienna.

	Required dimensions according to tender document	**Dimensions of Musikvereinssaal[1]**	**Dimensions of final solution**
Volume [m^3]	17,000	15,000	15,000
Seats	1200	1680	1200
Length [m]	45	52.6	43.25
Width [m]	22	19.6	21.9
Height [m]	18	17.7	18.7
T_{30} occupied [s]	min. 2.2	2.0	2.3

Table 2. Comparison between dimension of Musikverein and the new symphonic hall in Aarhus

The volume of the new hall differs significantly from the specified 17,000 m^3, but it is still comparable with the volume of the reference hall Musikverein in Vienna, which is among the best concert halls in the world.

3.2 Balcony depth and height

Due to the dimensional restrictions of the hall as described above, compromises where made with the balcony design in order to ensure the required 1200 seats in the hall. According to the requirements, it should be possible to see at least 50% of the ceiling which is also in keeping with the accepted guidelines [2] of balcony depths being shorter than their heights.

In addition to the balconies being deeper than the optimal, the problems where exaggerated due to the supporting beams being extremely high, thus reducing the height locally at the balcony's front edge. This resulted in the balcony height/depth ratio being as much as 1:1.6, and one is therefore unable to see the ceiling at all from the rear seats.

Calculations of parameters such as strength were, as expected, much lower than what can be expected due to distance alone. Measurements in the unoccupied hall have later shown that the calculations where a little pessimistic (underestimations of about 1 dB) and therefore the results are acceptable considering the shallow balconies.

In the Vienna Musikvereinssaal most side balcony seats behind the front row have restricted view of the stage and the seats towards the back of the flat floor suffer from a lack of brilliance[1].

3.3 Organ box

The hall design includes a large concrete box for later addition of an organ. Visually screened off from the rest of the hall with open wooden panelling, the concrete box is still experienced as a supplementary reverberation chamber. In order to simulate the absorption of an organ, standard theatrical cloth was hung in 80% of the opening area. Calculations of this absorption compared well with absorption measurements made of an organ in conjunction with a previous project.

4 RESULTS AND ACHIVEMENTS USING COMPUTER MODELLING

Computer modelling was used as a tool to ensure that the requirements of acoustical parameters would be achieved and that the planned variable elements would create the proposed effect.

4.1 Adjustable reflector

One of the variable elements is the reflector. The hall is equipped with a 3 part height adjustable reflector spanning the whole platform area. The 3 parts are named: rear, centre and doughnut according to figure 2.

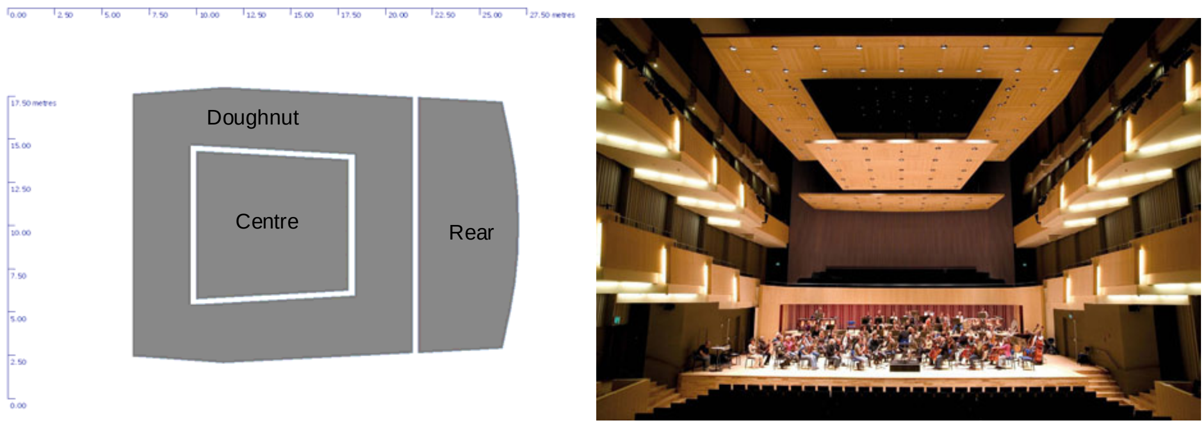

Figure 2. The adjustable reflector

The effect of different settings of the reflector was studied in the computer model. Calculations for three settings were carried out. The results are shown in table 3 below. The values are obtained with specific source positions and as an average over the hall.

Rear	**Doughnut**	**Centre**	**G** (250-2000 Hz)	**C80** (250-2000 Hz)	**LF** (125-1000 Hz)	**STearly** (250-2000 Hz)	**EDT stage** (250-2000 Hz)
12 m	10 m	8.5 m	4.5 dB	-0.5 dB	0.24	-12.8 dB	1.9
12 m	10.5 m	10.5 m	4.6 dB	-0.3 dB	0.24	-13 dB	2.0
10 m	8.5 m	8.5 m	4.5 dB	-0.6 dB	0.25	-12.6 dB	1.8

Table 3. Calculated results for different reflector settings

With the chosen source positions there is no significant difference between the calculated values.

Artec Consultants managed the adjustment of the reflector settings under the initial testing of the hall. The reflector settings can influence the experienced balance between the instruments on certain seats in the hall. Measurements of the reflector setting's influence on the objective parameters in the hall have not been carried out so far.

4.2 Sliding sound absorbing panels

Another variable element in the hall is the sliding sound absorbing panels on large proportions of the side walls. Computer simulation was used to predict the influence of the absorbing panels.

The calculated reverberation time with and without variable sound absorption is shown in table 4.

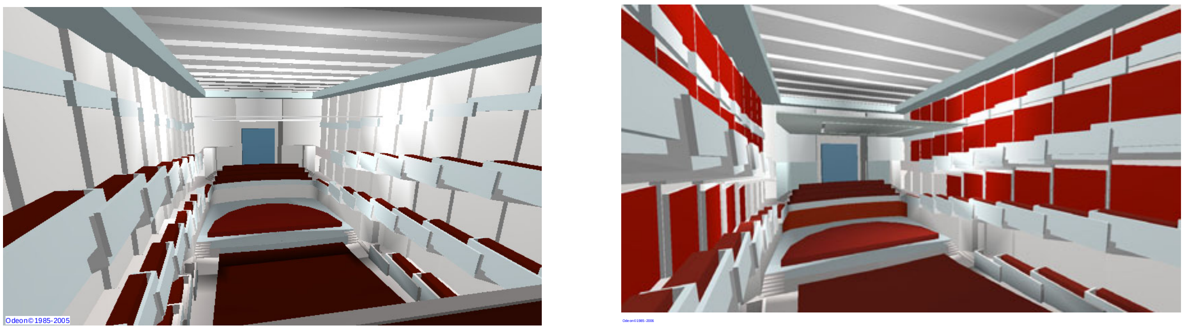

Figure 3. Plot from computer model without and with variable sound absorption.

The difference between occupied and unoccupied hall, without variable sound absorption was also examined in the computer model the results are likewise given in table 4.

Computer model **Mean value 568 receivers** **and 1 source**	**Reverberation time** **in the unoccupied hall** T_{30} [s] 250-2000 Hz	**Reverberation time** **in the occupied hall** T_{30} [s] 250-2000 Hz
Maximum absorption with all variable sound absorption in use	1.5 sec	-
Minimum absorption without variable sound absorption	2.7 sec	2.2 sec

Table 4. Calculated reverberation time with and without variable absorption and in occupied and unoccupied hall.

According to these calculations the required reverberation time spanning 1.7 - 2.3 seconds is obtainable in the unoccupied hall

It can be mentioned that the acoustic designer of the hall, Artec Consultants, did not agree with the goal of minimizing the difference between the empty and occupied reverberation time values, this affected the choice of chairs. The chairs that were chosen are unupholstered underneath the seat and the absorption consequently differs more from the absorption of the occupied seat, then it would have done if chairs with upholstered bottoms were chosen.

5 MEASUREMENTS RESULTS ACHIVED IN THE HALL AFTER CONSTRUCTION

A selection of acoustical parameters was measured in the hall after construction to determine to which degree the requirements were achieved.

The values in table 5 are the results of simulated and measured parameters in the unoccupied hall without any of the variable absorbers in use.

For the reverberation time, the calculated and measured result is also given for the case where all variable absorbers are in use, to illustrate the span within which the reverberation can be varied.

Parameter (ISO 3382-1) in unoccupied hall a) with all variable absorbers b) without all variable absorbers	**Computer model**	**Measured in the hall after construction**	**Target value**
Reverberation Time, T_{30} [s] $_{250\text{-}2000\ Hz}$	1.5 a) - 2.7 b)	1.7 a) - 2.8 b)	>2.3
Early Decay time, EDT [s] $_{250\text{-}2000\ Hz}$	2.4	2.6	2.1
Clarity, C_{80} [dB] $_{250\text{-}2000\ Hz}$	-0.6	-2	-1
Strength, G [dB] $_{250\text{-}2000\ Hz}$	5.6	5	5
Lateral Energy Fraction, $LF_{80\ 125\text{-}1000\ Hz}$	0.25	not measured	0.24
Early Decay time on stage, EDT [s] $_{250\text{-}2000\ Hz}$	2.4	2	1.6
Support, ST_{early} [dB] $_{250\text{-}2000\ Hz}$	-12.9	-13	-12

Table 5. Comparison between calculated and measured values

The conclusion of this comparison is that the computer model produces reliable results.

6 CONCLUSION

The reverberation time with the fully occupied hall should be at least 2.2 seconds in the middle frequencies. This was achieved even with the reduced volume of the hall, since the reverberation time without absorbing panels in the fully occupied hall was measured to 2.3 seconds. Without an audience the reverberation time in the hall should not increase more than 0.1 second. Because of the deliberate choice of chairs with wooden bottoms the difference between the full and empty hall exceeds 0.1 seconds, but using the sound absorbing panels it is possible to achieve the requirement anyway.

It should be possible to reduce the reverberation time to approximately 1.6 seconds, e.g. if loudspeaker systems are going to be an option in the concert hall. In the unoccupied hall the reverberation time with all variable absorption in use was measured to 1.7 seconds, which indicates, that in the occupied hall, the required 1.6 seconds can easily be reached.

It was possible to archive the required reverberation in the hall with the reduced volume. This was shown in the computer model and proven in the actual hall.

7 REFERENCES

1. M Barron, Auditorium acoustics and architectural design, published by E & FN Spon and imprint of Chapman & Hall, first edition 1993

2. L Beranek, Concert and Opera Halls How They Sound, AIP Press, USA, 1996