BUILDING ACOUSTICAL DESIGN OF THE EXTENSION OF THE CONCERT HALL AARHUS

Richard M. Ballinger

COWI A/S
Odensevej 95
5260 Odense S, Denmark
rmb@cowi.dk

ABSTRACT

The extension of the Concert Hall Aarhus (Musikhuset Aarhus), opened in September 2007, comprises of a new Symphonic Hall, Rhythmic- and Chamber Halls, a children's theatre and in excess of 100 other music rooms. The extension houses facilities for Aarhus Symphony Orchestra and the Royal Academy of Music.

Expectations have been high, despite the project being restricted on time, building area and funds.

Amongst the many challenges concerning the building acoustical aspects of the project; the fact that the whole building is enveloped with single skinned glass façade, has required a high level of planning in order to achieve acceptable results.
In addition to sound insulation requirements of 70-75 dB in all music rooms, special requirements where defined for the 63 and 100 Hz frequency bands. Calculations have been made using ISO 12354 to optimize structures and design.

The interplay of building- and room acoustical requirements has also been a main part of the design of the music rooms, where issues concerning the use of parallel wall elements has had to be resolved.
This paper describes the building acoustical requirements, challenges and results of the project, and a realistic view of what can be achieved in the building acoustical design of music rooms under restrictive conditions.

1. INTRODUCTION

The extension of The Concert Hall Aarhus 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 comprises chiefly of 2 fan-shaped halls for multipurpose use, the larger of which (Store Sal) 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 being, 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 and with very demanding sound insulation requirements.

5 teams of contractors, along with architects, engineers and acousticians competed to design and build 16,300 m² of music halls and rooms. All this was to be completed in a very short time span of 2 years and for a mere DKK 285 mill. (EUR 38 mill).

2. THE PROJECT

The project comprises of a 1200 seat Symphonic Hall, a 600 seat Rhythmic Hall, a 120 seat Chamber Hall, 12 large double storey rehearsal rooms, more than 25 large single storey rehearsal rooms, 4 recording studios, and approximately 75 practice rooms and teaching offices also sound insulated to above 70 dB.

The Rhythmic Hall is positioned above practise rooms and below sound sensitive areas such as the library with listening booths, and only 5 metres from the Symphonic Hall.

The Chamber Hall and the large double storey rehearsal rooms are enveloped at the façade with single skin lightweight elements. Recording studios are critically positioned under the Foyer and above parking areas on the lower ground floor.

In total the building has 6 storeys and a parking basement.

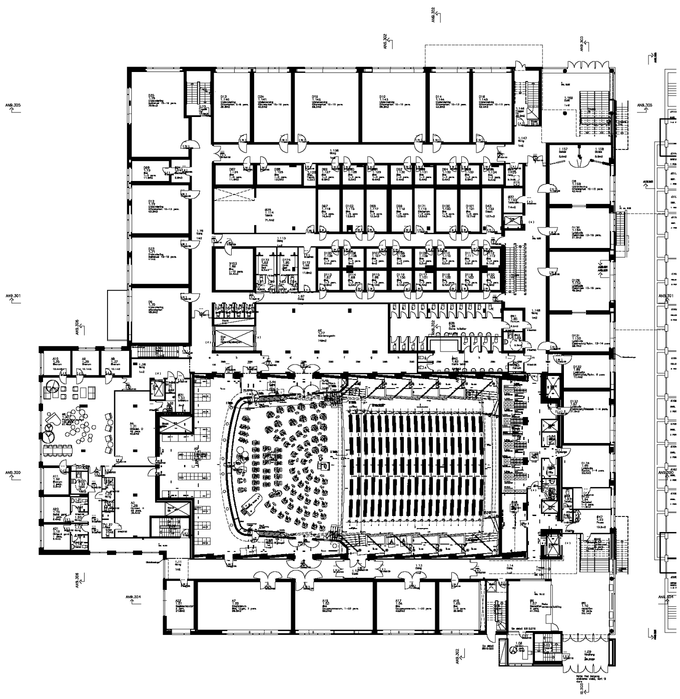

Figure 1. *Plan of the ground floor level - Symphonic Hall base level, smaller rehearsal and practice rooms and recording studios*

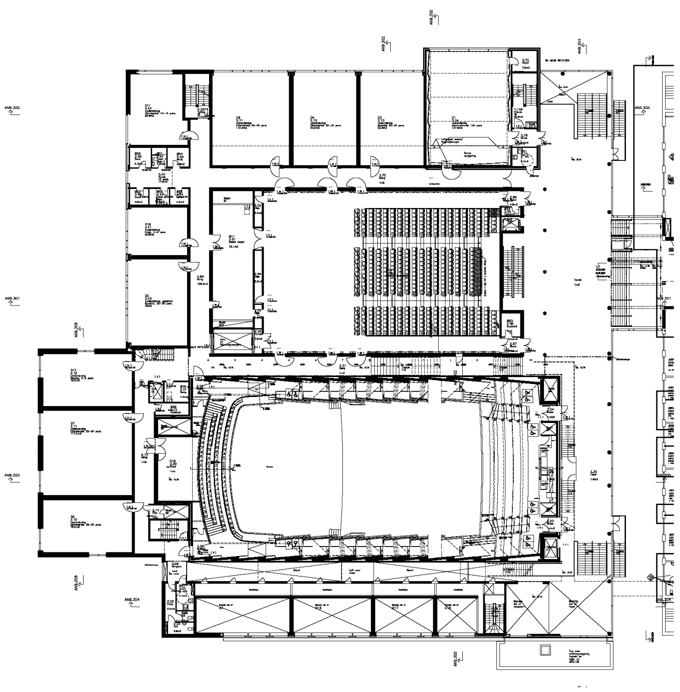

Figure 2. *Plan of the first floor level - Rhythmic and Chamber Halls, larger rehearsal rooms and foyer.*

3. CHALLENGES

3.1. Requirements

The specified requirements for all the Royal Academy of Music's rooms and halls - right down to offices for teaching staff and 1 person practice boxes - was at the outset R'_w 75 dB and R'_{63Hz} 50 dB. This would have required heavy wall constructions throughout, which would not at all have been feasible due to space and economic issues.

Requirements for the Symphony Orchestra rehearsal rooms where set more conservatively at R'_w 60-65 dB.

Requirements for impact noise where generally set at $L'_{n,w}$ 48 dB, which didn't propose the great challenge in achieving.

Background levels, although not further discussed in this paper, where NR 25 for the majority of the smaller rooms, NR 20 for larger rehearsal rooms and NR 15 for the Rhythmic and Symphonic Halls and recording studios. The largest challenge regarding background levels has been that the main ventilation plant room for the Symphonic Hall is positioned directly below the stage.

The requirements for the Music Academy's rooms where changed during contractual discussions to more realistic values of R'_w 75 dB/R'_{100Hz} 50 dB for most rooms larger and R'_w 70 dB for all smaller rooms (below 12 m²). This gave the opportunity of using lightweight walls for 70 dB divisions, and concrete walls with supplementary lightweight stud walling for the larger rooms.

A few rooms; Rhythmic Hall, 1 large rehearsal room for rhythmic music and 4 studios remained at R'_w 75 dB/R'_{63Hz} 50 dB.

Apart from physically having to achieve the requirements, another related challenge to the extra requirements at 63 Hz, was to obtain reliable values (measured or calculated) for building materials under 100 Hz.

3.2. Facades

The choice of façade is the Achilles heel of the project. Designed as single skinned aluminium profile/glass sections, spanning across adjacent rooms both horizontally and vertically - it was to be one the biggest challenges. Normally music rooms with these requirements are constructed as total box-in-box systems. In this case however, the room's inner box was to be integrated in the outer box at the facade.

3.3. Floor heights

Although not an issue at the outset, heights for floating floor constructions became an issue due to design errors combined with high cambers of precast hollow concrete floor slabs. This resulted in a revised design of wall/floor junctions.

3.4. Loyalty

A very important issue to be considered as a practicing acoustics consultant; is that on the one hand you want to retain a high level of professional respect from the client, whilst on the other hand your contract is with a builder who is building a high class building for a relatively small amount of funds.

4. SOLUTIONS

4.1. Box-in-box design

The majority of all floor panels in the music rooms comprises of 225 mm hollow concrete slabs. Floating floors were originally planned as 100 mm concrete on 50 mm hard mineral wool; these were though drastically reduced to in some places 50-60 mm concrete on 30 mm mineral wool.

Ceilings comprise of 2 layer 12.5 mm gypsum boarding hung on elastic supports with a 200 mm cavity insulated with 100 mm mineral wool.

Walls for 70 dB partitions comprise solely of lightweight elements; 3 layers of 12.5 mm gypsum on each side of an almost fully insulated 300 mm cavity. Walls between music rooms and corridors are 2 layer 12.5 mm gypsum boarding on each side of a 220 mm cavity insulated with 190 mm mineral wool. Doors in these walls are tandem doors (one in each side of the wall), graded respectively 30 and 35 dB.

4.2. Façade junction

The facades are aluminium boxed elements with sound insulating glass (dimensioned according to external noise levels). Façade elements with direct contact to the room are isolated from heavy core building elements (outer box) using specially designed mounting brackets. The mounting brackets isolate from direct contact using polyurethane elastomeric pads. The area, thickness and elasticity of the pads are chosen according to the relevant loads (static and wind) and adjusted accordingly to ensure damping in the relevant frequency range.

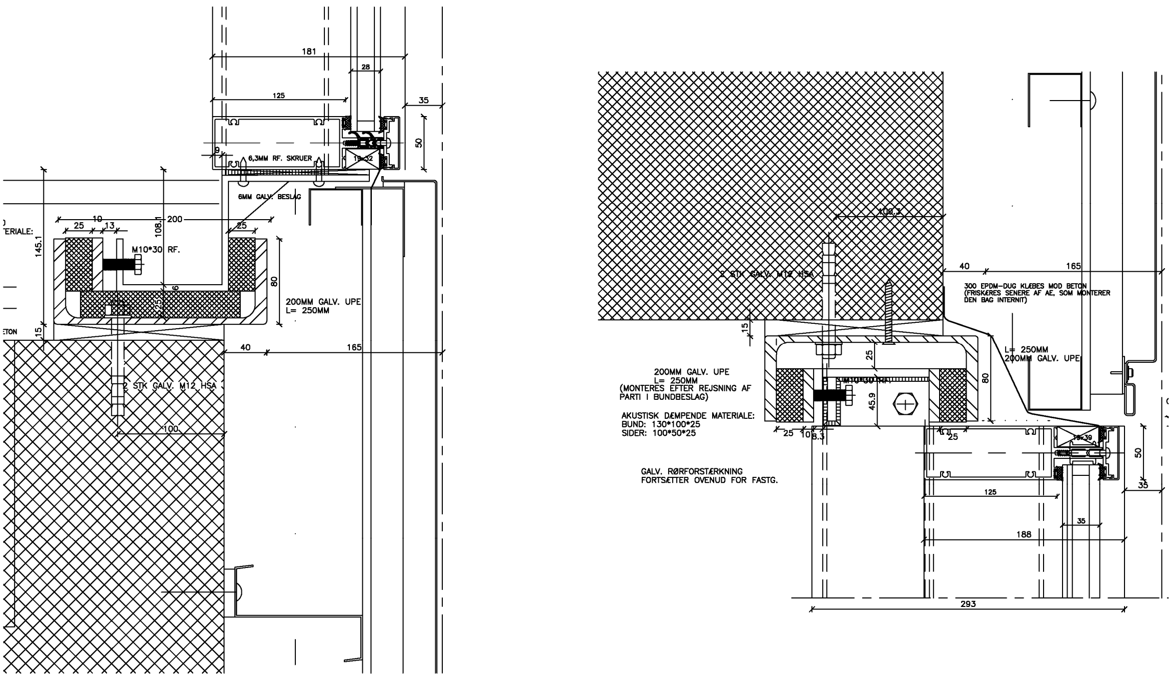

Figure 3. *Section drawings of façade mounting brackets used for isolation from the outer box.*

4.3. Revised floor/wall junction

Originally the inner box - excluding façade elements and ceiling constructions - was to be supported by the floating floor (proposed 100 mm concrete on 50 mm mineral wool). This was revised due to height issues, and then the floor - reduced in thickness - couldn't support the loads.
An alternative junction was designed, where lightweight walls where supported on the precast hollow slab flooring with an interlayer of hard mineral wool. The dynamic stiffness for both types of mineral wool; support for floating floor and support for walls, where determined to ensure appropriate damping according to the relative loads.
Due to the change in the floor/wall junction, the corridor walls where now not stable enough to support the doors; the wall giving excess lateral movement when the doors where open and shut. Connecting the 2 door frames with a joint casing gave problems with transmission both of impact and airborne noise. Various measurements were made to determine how much connection could be maintained without the values of sound insulation being drastically affected. Finally thin panel pins were used to connect the casings, giving enough fixture, and only reducing values for R'w about 1-2 dB and increasing L'n,w up to 8 dB, but nevertheless still fulfilling the requirements.

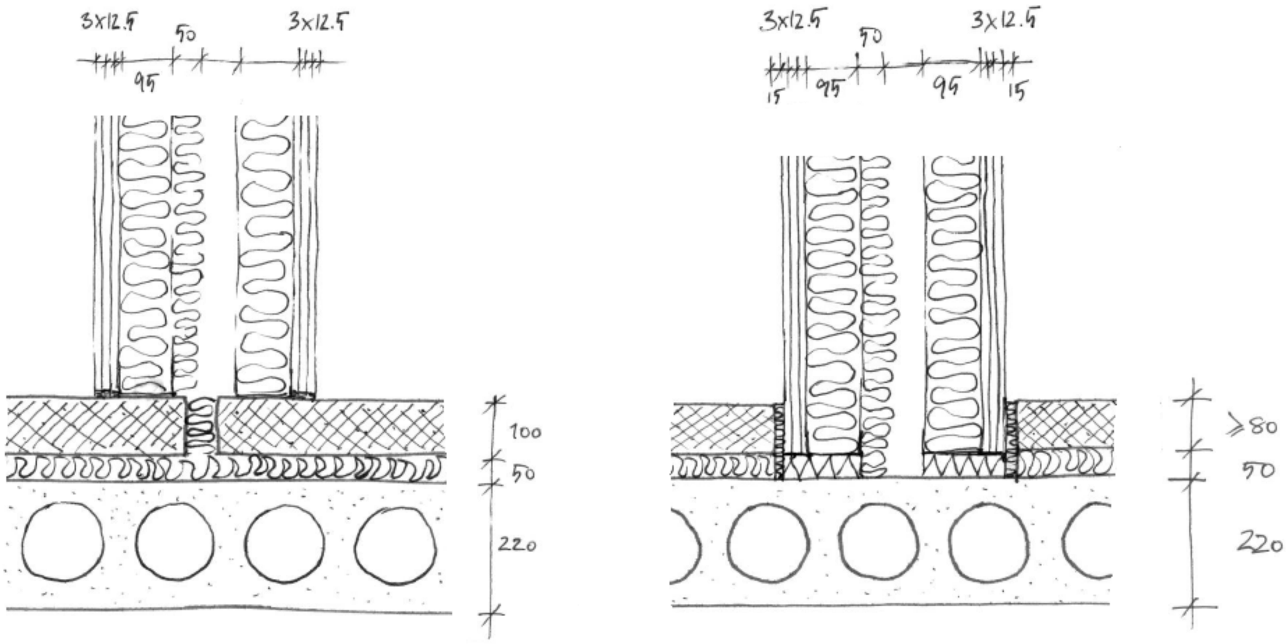

Figure 4. *Sketches of the revision of the wall/floor junction due to reduced available heights. Sketch on the right shows the floating floor and wall are positioned on two different types of insulation.*

4.4. Sound insulating ceilings

All sound insulating ceilings, comprising of 2 layer gypsum boarding and elastically supported from the precast concrete floor slab above, were dimensioned to support an acoustic system ceiling and installations. The sound insulating ceiling was therefore one continuous plate without penetration.

An exception to this was the ceiling construction in the Rhythmic Hall. The floor slab above this hall - due to the span - was designed as combined beam/floor (TTD) elements, with a plate thickness of only 50-60 mm concrete. Although the sound insulating ceiling could be mounted just below the bottom of the beams, it had to be penetrated many places to make room for ventilation diffusers. The ventilation diffusers are connected to large pressure regulating boxes which were each specially reinforced and elastically detached from the room's outer shell.

Figure 5. *Photo of the sound insulating ceiling used in the Rhythmic Hall with supplementary measures for incorporating ventilation diffusers.*

4.5. Room acoustical issues

It is normally preferred to angle walls of music practice rooms a few degrees (and in some cases also ceilings). This removes parallel surfaces, reducing problems with amplified Eigen frequencies and flutter-echo. However, again due to space and economic issues, it was chosen to try to achieve good results using right-angled walls, combined with modular angled wall adjustable wall absorbers on at least two walls in each room.

4.6. Building acoustical calculations

Calculations of the major part of all the music room types have been conducted using Bastian vers. 2.2. Despite ISO 12354's limitations for calculating lightweight constructions, results have been relatively precise in frequency areas where reliable data was known for respective constructions. Data for frequencies below 100 Hz has been difficult to obtain.

The sound insulation calculation program Insul, based on theory by B.H. Sharp and Cremer, has been used to calculate construction types where measured data hasn't been available. The correct choice of coupling in double constructions is very critical, and when using Insul, it would be apt if correction values were possible for the standard connection systems included. Calculation of floating floor constructions isn't really an option in Insul.

Notwithstanding Insul has been useful as a general guideline, when measurements of similar constructions have been available to compare with.

Calculation of the resilient supports in the façade mounting brackets has be achieved using the supplier's (Getzner) own calculation program FreqCalc.

The most critical input to the calculations has been the flanking transmission of façade constructions. Apart from the calculations of each mounting bracket to ensure no coupling, measurements of flanking transmission through similar façade element constructions [3] were used as input in ISO 12354 calculations.

5. MEASUREMENTS AND RESULTS

After the building's completion, an extensive series of measurements where carried out to ensure that constructions fulfilled the requirements. In total, more than 110 measurements of sound insulation and impact noise where made. The measurement programme was a joint venture between us, the contractor's acoustic consultant, and the client's advisor, Anders Christian Gade.

5.1. Choice of method, airborne sound insulation

A normal ISO 140-4 setup using a pink noise sound source was used for sound insulation measurements. This was used despite high levels of background noise (the ventilation system couldn't be turned off and wasn't adjusted properly at this stage) and the need to measure accurately below 100 Hz.

The reason for this choice was simply a matter of time. Measurements using alternative methods such as sinus-sweep, MLS and intensity would be less sensitive to background noise problems, but require more time. It was decided that if it could be established that the requirements were fulfilled, then extra time wouldn't be used to find exact values.

This of course is unfortunate in an academic point of view, where more exact values in all frequency bands could be used to compare the projected calculated values.

The measurement setup was the following:

- Speakers: 01dB dodecahedron loudspeaker & HK Audio Pro18S sub-bass
- Amplifier: Norsonic NOR280 amplifier incl. noise generator.
- Tapping machine: Brüel & Kjær 3204
- Recording/Analyse: Brüel & Kjær 2260 and 01dB Symphonie

5.2. Measurements below 100 Hz

According to the first set of measurements, there were a couple of places where the special requirements at 63 Hz where not fulfilled. Therefore further measurements where made to try to determine where the high transmission of low frequency noise was dominating.
Our preferred method for these studies would have been sound intensity measurements, but due to last minute technical problems (defect cable to probe) this choice had to be deferred.
Instead, although not giving us the possibility to correctly determine the source of the problem, measurements where made according to ISO 140-4. Although this time using are a very comprehensive set of microphone positions, and thereby ensuring a much lower level of uncertainty.
The spread in values of 63 Hz was in excess of 13-15 dB. To reduce the measurements' uncertainty, microphones where placed in at least twice as many positions compared to the maximum spread in dB of the measured values. The results of these measurements showed an increase of the actual values at 63 Hz of up to 6 dB, and resulted in coming within a couple of dB from the required 50 dB.

5.3. Measurement results

The following is an overview of the results for the various construction types. The values for $R'_{63\,Hz}$ and R'_{100Hz} are measured using a standard ISO 140-4 setup, i.e. without supplementary microphone positions.

Airborne sound insulation, R'_w:

Floors between box-in-box rooms (typically 220 mm precast hollow concrete slab, 30-50 mm mineral wool 50-80 mm floating concrete slab - ceiling beneath 2 layers gypsum with 200 mm cavity insulated with 100 mm mineral wool):

- all measurements estimated to comply with requirement of $R'_w > 75$ dB
- some R'_w measurements in excess of 83 dB
- $R'_{63\,Hz}$ average 45.5 dB, median 44.2 dB
- $R'_{100\,Hz}$ average 56.5 dB, median 55.9 dB

Walls with concrete core between box-in-box rooms (typically 180-200 mm concrete with stud walls of 2 layer gypsum, 120 mm cavity with 70 mm mineral wool on each side):

- all measurements estimated to comply with requirement of $R'_w > 75$ dB
- some R'_w measurements in excess of 78 dB
- $R'_{63\,Hz}$ average 40.5 dB, median 41.1 dB
- $R'_{100\,Hz}$ average 54.7 dB, median 55.5 dB

Lightweight walls between box-in-box rooms (3 layers gypsum on each side, 300 mm cavity with 250 mm mineral wool):

- all measurements estimated to comply with requirement of 70 dB
- some R'_w measurements as high as 76 dB (2 rooms back to back)
- $R'_{63\,Hz}$ average 37.8 dB, median 36.8 dB
- $R'_{100\,Hz}$ average 46.0 dB, median 46.1 dB

Impact noise levels, $L'_{n,w}$:

Floating concrete floors (50-80 mm) on mineral wool (30-50 mm) between box-in-box rooms and from corridors, (varying supplementary padding under floor coverings):

- all measurements comply with requirement of $L'_{n,w} < 48$ dB
- some $L'_{n,w}$ measurements as low as 16 dB
- $L'_{n,w}$ horizontal, average 30.5 dB, median 28.5 dB
- $L'_{n,w}$ vertical, average 27.1 dB, median 29.0 dB

6. CONCLUSIONS

The new extension to the concert hall, in addition to the very successful room acoustics in the Symphonic and Rhythmic Halls, also includes a host of well sound insulated music rooms using very limited space and funds.

Traditional use of double façade constructions hasn't been applied. Although managing to obtain relatively high values of sound insulation - using what looks like a normal office type façade - it has been very challenging and with risk of failure if any of the proposed solutions were not applied correctly.

Impact sound levels of 48 dB were not problematic to achieve in box-in-box constructions - the floating floor constructions needed for airborne sound insulation combined with additional impact sound reducing materials under floor coverings has resulted in impact levels as low as 16 dB.

Airborne sound insulation of double lightweight constructions could easily achieve values of the required 70 dB - measurements of between 70-76 dB for a 375 mm double gypsum wall. Requirements of R'_w>75 dB were also obtainable using lightweight single skinned façade constructions with room divisions using 200 mm concrete and an inner box of insulated stud walling. Special requirements of 50 dB at 63 Hz were partly successful - here double heavy constructions are required as stud walling have little or even negative sound insulation at 63 Hz.

Although it's always good with a challenge, a combination of limited space, time and funds isn't an ideal cocktail for buildings with high sound insulation ambitions.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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