# ROOM ACOUSTICS IN THE SCENE II IN THE NEW OSLO OPERA AND THE RIDEHUSET - TWO VARIABLE ACOUSTICS COUPLED SPACE VENUES

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## 1 INTRODUCTION

Two coupled volume halls for music has been accomplished in Oslo the last year where we have been acoustical consultants. Scene II (two) is a 440 seat multi purpose hall in the new Oslo Opera. The ‘Ridehuset’ is a refurbishment of an old building to a rehearsal room and 230 seat concert hall for the Staff Band of the Norwegian Armed Forces (FSMK). Both auditoria have coupled volumes and variable absorption. In spite of being very different rooms and shapes, they share some acoustical properties we would like to address.

### 1.1 The Ridehuset

The Ridehuset was built for the ‘Norwegian king’s crew’ in 1824 at the Akershus fortress in Oslo. In 1981 it was refurbished as a rehearsal and performance venue for the Riksteateret (a theatre touring the whole Norway) until about 2003 and looked like what we see in Figure 1.

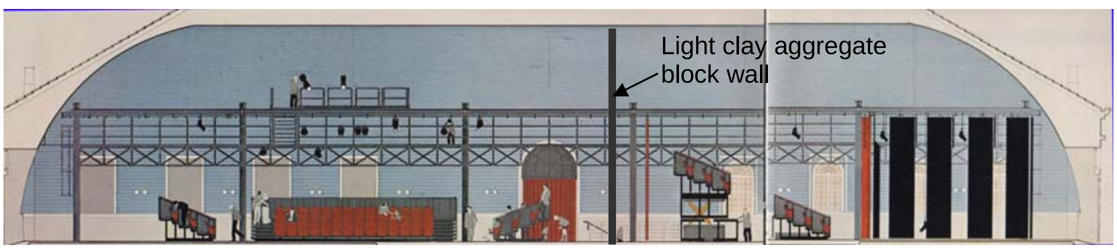



**Figure 1: The Ridehuset formerly housing a touring theatre from 1981-2003, was for a year used as a preliminary rehearsal and concert hall for the Staff Band of the Norwegian Armed Forces. [Based on a drawing by 4B arkitekter]**

The growing FSMK, being a military brass corps, needed a larger and less loud rehearsal space and started to use the former theatre for plenum rehearsals and concerts in 2003. But after just about a year, it was banned for use by the Work-environment authorities due to ‘improper working conditions’. It belongs to the story that they already had a noise level issue going. The military corps also was facing the threat of being removed from the military budgets and thus loosing their positions.

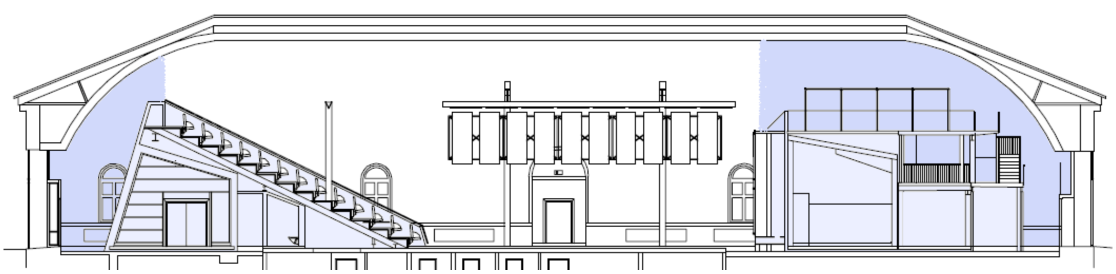


**Figure 2: The new Ridehuset concert- and rehearsal hall with 5 practice rooms as heavy floating boxes inside. Light blue shaded areas indicate the coupled room volumes. See Figure 11 for a plan drawing. [Based on a drawing by 4B arkitekter]**

However, a project planning new working facilities for the orchestra had been running since 2003. In 2005 the military orchestras finally got a governmental resolution saving their existence, practically for ever.

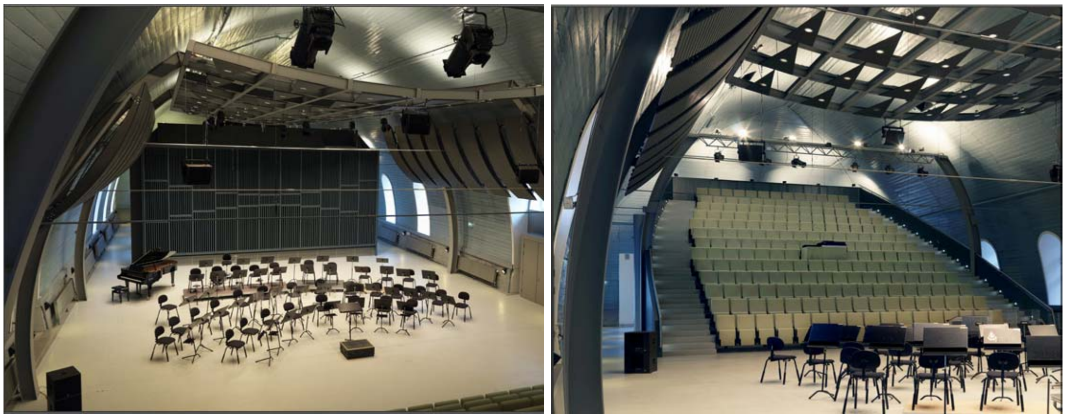


**Figure 3: The Ridehuset, scene and audience views [Photo: Jiri Havran, 4B arkitekter]**

The refurbishment project finally was founded, and in October 2007 the FSMK, with its 39 musicians, could move in to its new facilities. They have 30 light practice rooms in a connecting building, 4 heavy practice rooms for timpani and percussion, a plenum rehearsal room as well as a 200 (+35 loose) seats concert- and rehearsal hall for the orchestra. The budget was about 82 MNOK.

**Room dimensions:** L = 50,9m, $W_{max}$ = 16,7m, $H_{max}$ = 10,3m.
**Volume**: (Odeon global estimate): 6100m$^3$. Inner volume: 3700m$^3$. Total volume $\approx$ 4700 m$^3$
**Stage area:** L = 16,3m * $W_{max}$ = 16,7m = 272m$^2$ In practice they use the front 2-3 m of the scene for two rows of loose chairs so the occupied stage area is around 12*12m = 144m$^2$.
**Practical area per musician**: about 4m$^2$

## 1.2 The Scene II Oslo Opera

The user requirements for Scene II are for a very flexible room to house anything from baroque- and chamber-operas to modern contemporary music and operas, concert performances, rock operas, and so on. Use- and acoustics is supposed to be very variable. “The scene” can be in any direction, audience in the round, or more traditional. The room also will be used for dance. DNO&B emphasised that the room should be good for the singers.

**Figure 4: The Scene II with pit. [Photo: Statsbygg]**

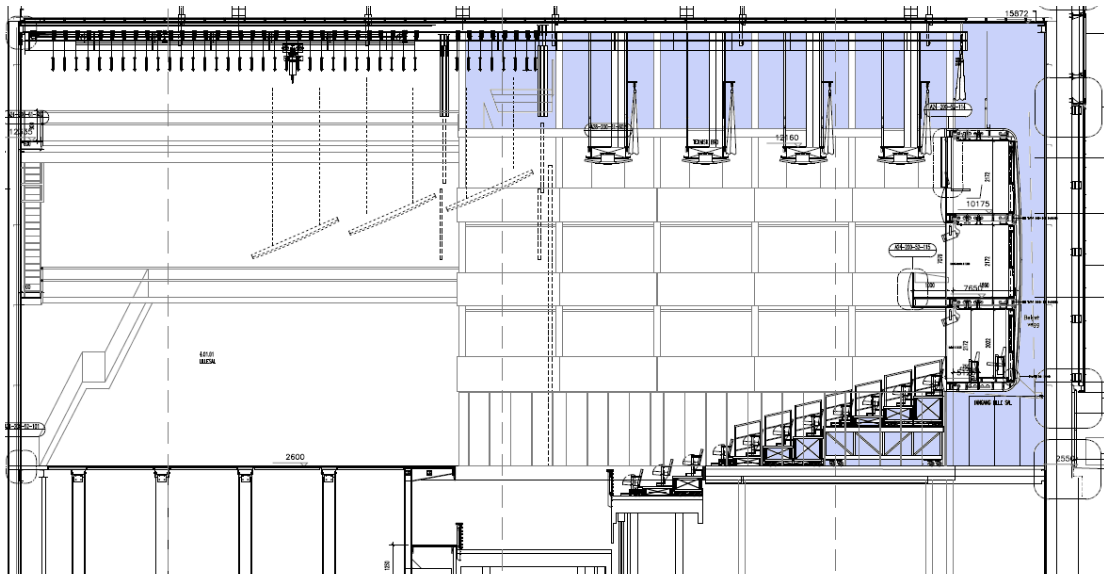


**Figure 5: Scene II section version with pit. Coupled volume is indicated with light blue color. The volume under the seats can be sealed off or opened by the doors as can be seen in Figure 6. [Based on a drawing by Snøhetta]**

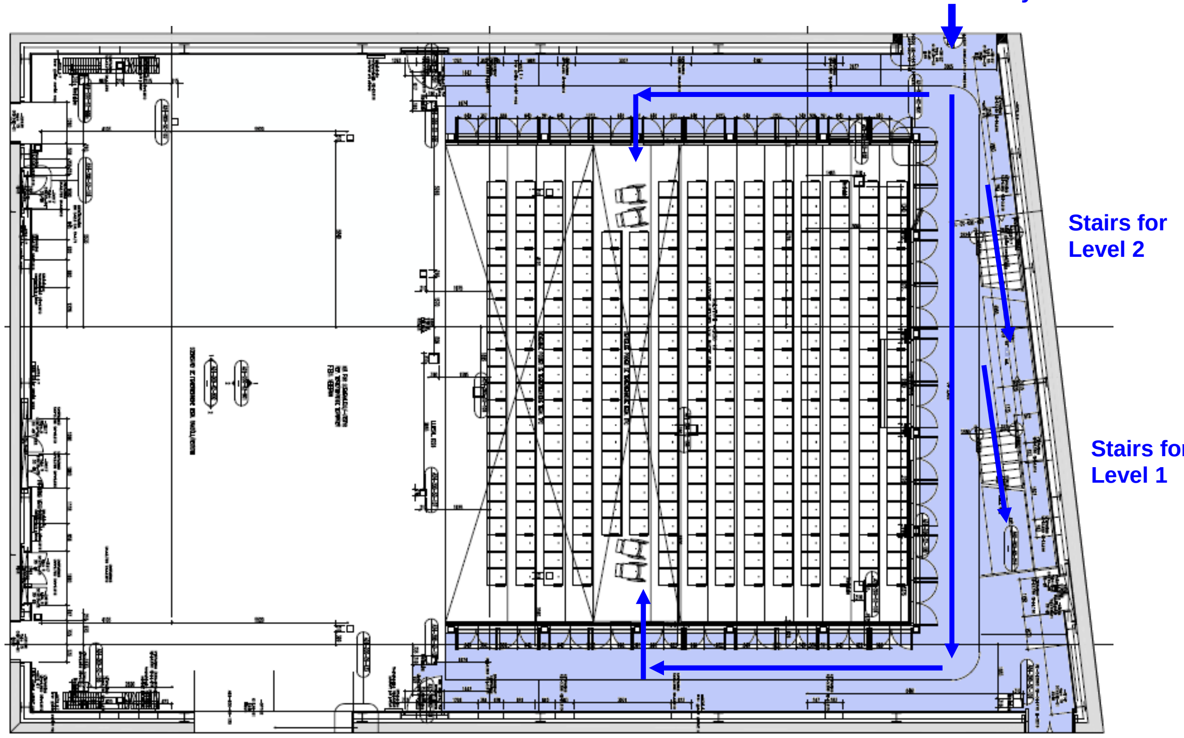



**Figure 6: Scene II Stalls level showing the outer and inner volume for which the coupled area can be increased by doors. Light blue shaded areas are the outer volume. [Based on a drawing by Snøhetta]**

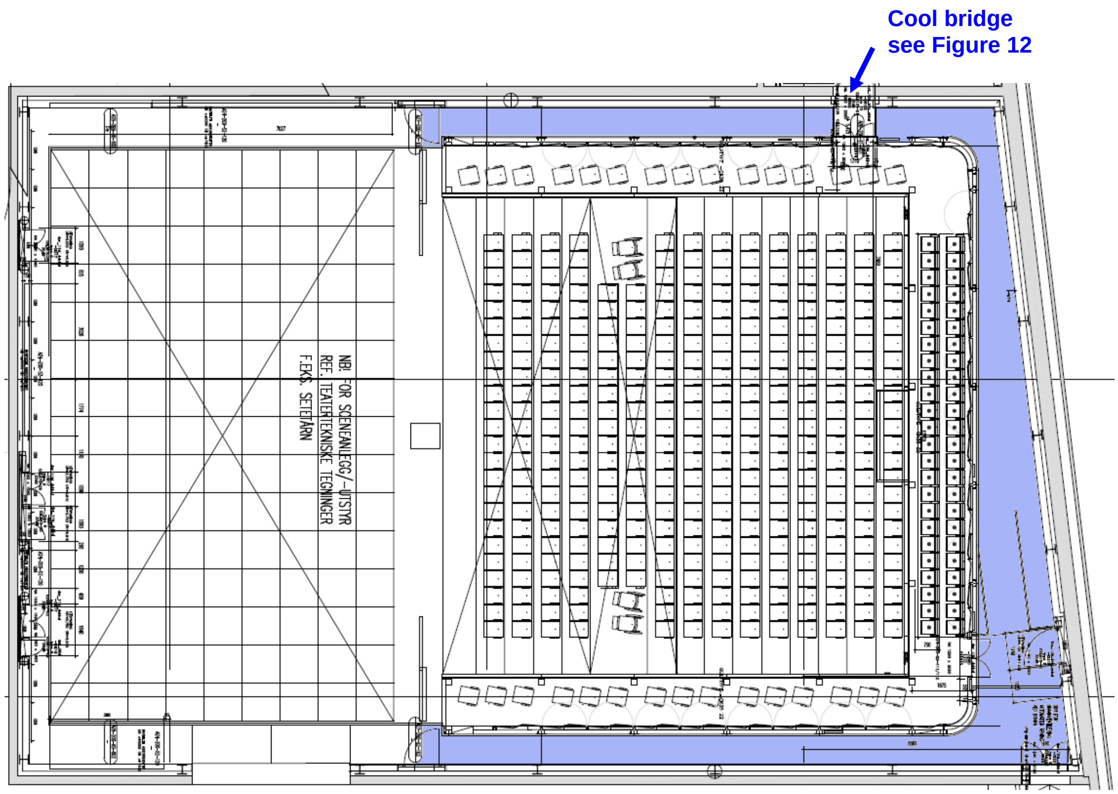



**Figure 7: Scene II level 1 without pit option. Coupled volume is indicated in light blue color. [Based on a drawing by Snøhetta]**

**Room dimensions:**
Outer box: L = 32,3m, W = 20,5m, $H_{max}$ = 13,7m.
Inner box: L = 29,9m, $W_{min}$ = 15m, $W_{max}$= 18,2m $H_{max}$ = 13,7m.
**Volume**: (Odeon global estimate): 6850m$^3$. Inner box volume: 7400m$^3$. Outer box volume: 9000m$^3$
**Stage area:** L = 13,3m * $W_{max}$ = 20,7m = 275m$^2$.
**Pit size:** W = 6,2 m * L = 15 m = 93 m$^2$ (Overhang: 1,4m).
**Practical area per musician in pit (dimensioned for 40)**: about 2,3 m$^2$ (1,8m$^2$ if overhang is not counted)

## 2 REQUIREMENTS

For the Ridehuset we made the requirements based on the experiences we and the orchestra had with that auditorium as a theatre and other rehearsal spaces. They had a long period where they moved around and played in available halls around Oslo. They were happy with the acoustics, and easy access to the stage, in 'Bærum Kulturhus' in which we did room acoustical measurements. We also had experience with their former facilities and had a complete set of measurements from the theatre while used as a preliminary rehearsal and concert hall.

The Scene II had a detailed building program provided from the contractor, Statsbygg, including an detailed acoustics chapter, written by Statsbyggs acoustician Tor Halmrast. The requirements were discussed in dialog with the Norwegian Opera and Ballet.

### 2.1 Room acoustical requirements for the Ridehuset

For the concert hall there was only a reverberation time requirement. “The RT should be placed around the values they have in ‘Bærum Kulturhus’ about 1.25 – 1.35 seconds with the musicians present”.

We also had a particular emphasis on the sound levels of the practice and rehearsal rooms because of the hearing damage and working conditions.

“The background noise levels should not exceed 30dBA and we should project for solutions capable of achieving 25 dBA”.

There were also sound insulation requirements, but they are not the topic here.

### 2.2 Room acoustical requirements for the Scene II

The building programme quotes these requirements for the acoustics of the Scene II:

- Reverberation time: T = 1,5-0,8 seconds
- Variable absorption: Very flexible
- Background noise HVAC: ≤ NR 17 (22 dBA)
- Noise requirement from technical equipment for the stage: 25-30dBA*

*Measured at closest audience seat. If there is a pure tone component in the noise the requirement is 5 dB stricter.

In a meeting with the acoustical reference group the summer 2001 there was agreement that the RT was the main parameter, but that the G-factor should not be too high.

## 3 PLANNING AND CALCULATIONS

Both halls were modelled using the Odeon software. Especially the Scene II went trough a series of different design changes. The requirements were also amended during the project, a work lead and written by one of the authors, Lars Strand.

### 3.1 The Ridehuset – Planning and background

Before starting the refurbishment project we had an Odeon model for the hall in its former theatre form. We also had a complete measurement set of IR’s done there with different amounts of wool drapes present in the room. We had initially also helped the FSMK with the necessary amount of drapes to mount in order not to make it too loud and to make it similar to the situation from when the theatre was present there.

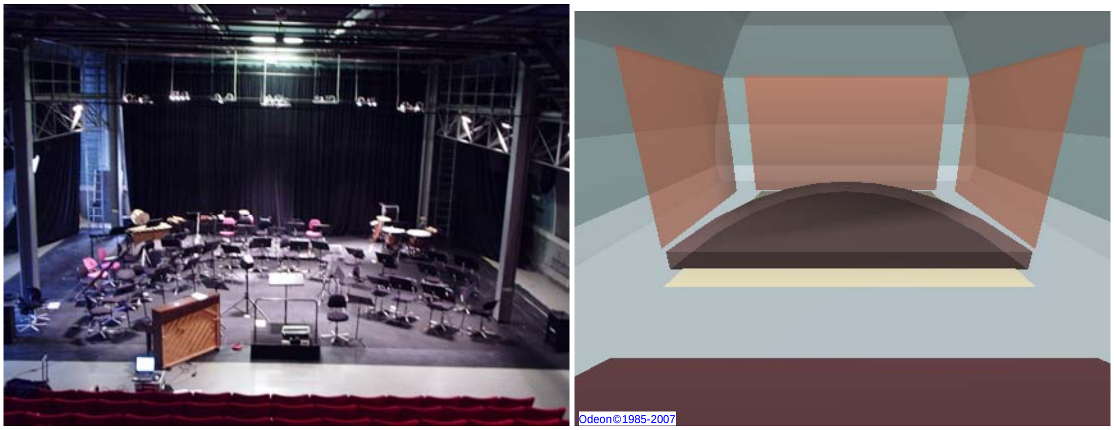



**Figure 8: The former rehearsal and concert setup initially had wool drapes all around the stage. The practice gravitated towards the frontal side drapes being pulled up just leaving the drapes behind and in the rearmost corners. [Photo: Anders Buen]**

The users had experiences with the room for about a year, also after the addition of extra sound absorbing and sound level damping drapes.

We adapted the practice DNO's orchestra was using in their former rehearsal space, 'the Tempelet' (an Oslo Salvation Army Auditorium) where they used 'Swedish felt' on the marble floor in order to 'round off' floor reflections a bit. We also got a positive experience report from Gunnar Ihlen in the DNO orchestra from a rehearsal they conducted in the Ridehuset[6].

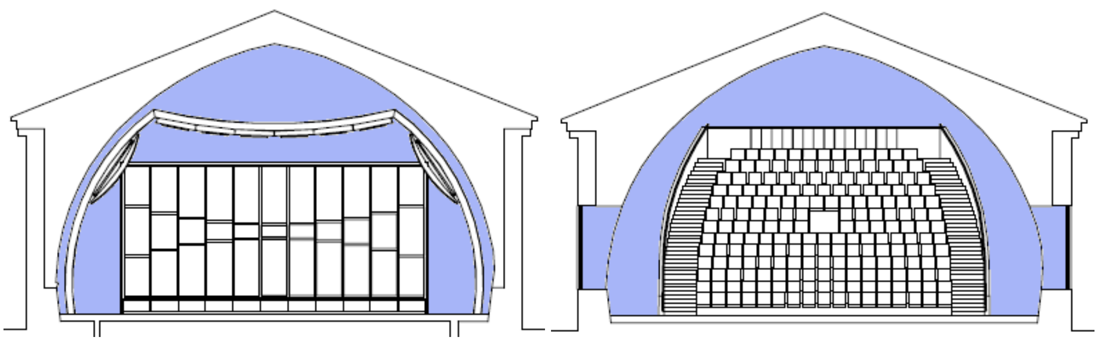


**Figure 9: The acoustically challenging 'Tunnel' shape was counteracted using opposite curved shapes and a transparent reflector array diffusing the sound. Light blue is the coupled volume area. [Based on drawings by 4B arkitekter]**

Our background material and user experiences thus were very good. But the shape of the hall was a challenge. We were not allowed to attach anything to the existing structure, of preservation causes. So a steel rig was mounted inside the shell for fixture of a large reflector array and inward curving reflectors at the sides. The problem of hearing musicians close to the side walls from the behind was resolved.

The 'anti focus design' was developed by looking at the distribution of 'sound balls' in Odeon compared to a shoe box hall of comparable dimensions. Sound distribution from a side source with and without the cylinder reflectors are shown in Figure 10 pictured at 80ms. The better distribution with the cylinder sections in was similar to the shoe box model, except for a much better diffused sound. As you may see in Figure 10, there is no trace of wave fronts. In the shoe box the wave fronts are still visible after 80ms indicating a lack of diffusion.

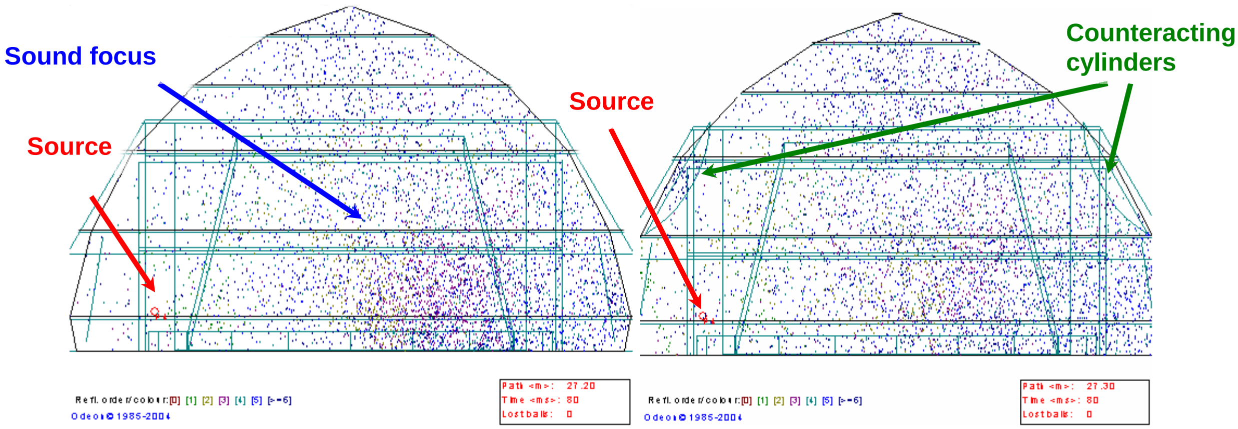



**Figure 10: Cross sections of the Ridehuset with billiard balls distributed from a left source pictured at 80ms. Left: Original room shape. Right: With counteracting cylinders.**

Values for the G factor and stage support, $ST_{Early}$ were calculated using pencil and paper following the diffuse sound formula G = 10*log(T/V) + 45 dB and Gades empirical regression function $ST_{Early}$ = -7.62*log($V_{Scene}$) -12dB from his work on concert hall stages.

The aim was to achieve a G below 10dB for the hall.

The only added absorption to the room was a wool drape behind the 'scene grid' which may be pulled in and out by hand, see Figure 11. Figure 3 show the slatted panel behind the stage that the wool drape is hidden behind. Behind the slatted panels there is a sound diffusing wall.

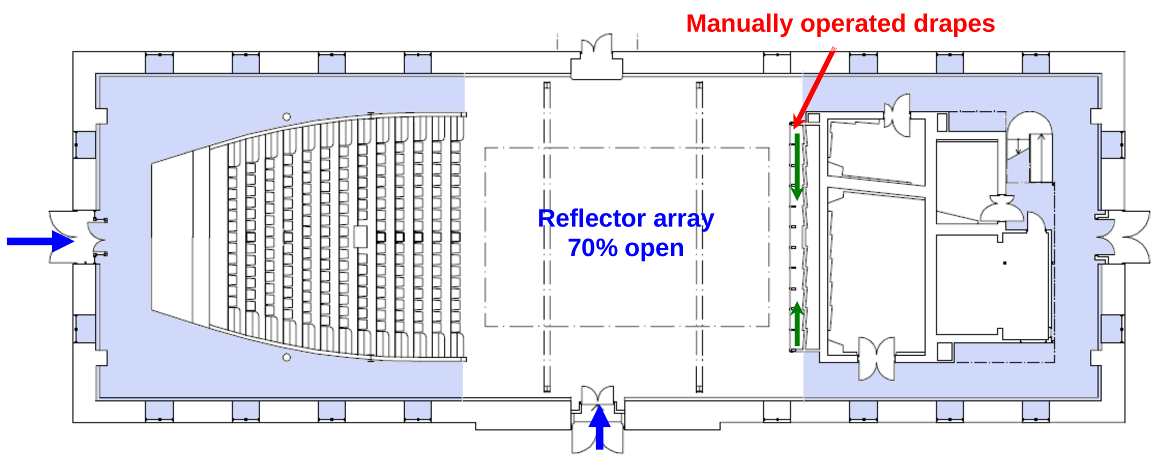



**Figure 11: The Ridehuset in plan. There is significant volume behind and around the seating as well as behind the scene which couple to the larger scene volume (light blue). Blue arrows indicate audience entrances. [Based on a drawing by 4B arkitekter]**

## 3.2 The Scene II – Planning and background

For the DNO one of the main concerns has been the reverberation time, the conditions for the singers, and the sound levels in the pit.

The stage textiles were delivered in a separate project and budget 'The user equipment project'. We were hired for judgement of the acoustical qualities of the textiles. DNO&B asked for this service. Thus we could influence the choice of possible several hundred $m^2$ Sabine that initially was not under our control.

### 3.2.1 The Scene II - The “Object”

The auditorium went through a series of different designs. Central for the architects was the idea that the Scene II should be a very different experience from the Scene I and Foyer. The room dimensions also were enormous! Acoustically the room was too wide, some 20,5m. The program called for balconies on three levels. Soon the inner box became a closed box, the so called “Object”.

**Figure 12: Scene II model picture of the “Object” and staircase up to the first balcony level. This is the first you see of the room while entering it. The right is fire escape doors at level 2. [Left illustration: Snøhetta, right photo: Statsbygg]**

One design was as a ‘glowing’ opaque glass object ‘levitating’ over your head. As you may have guessed, the design was too expensive and complicated. The ‘spacious idea’ was modulated into a more practical and affordable compromise - a ‘fast machine’, still levitating, a Ferrarri red passive lighted object as you can see in Figure 12.

One of the architects also was dreaming of a 50ties American camping cabin. There are some elements left of that round corner cabin and the glow is sort of kept in the aluminium silvery balcony fronts, see Figure 4.

### 3.2.2 Free hanging textiles – absorption data

One of the problems we faced was: How do we model the 485$m^2$ of scene textiles which are freely suspended? What absorption coefficients should we use? Would we get absorption from both sides? Could such freely suspended absorber be more effective than if hung close to a wall? How should we handle the sound that hits the textiles? Surely it cannot be looked as a tight barrier!

There was no available absorption data in the Odeon or the Catt database for the purpose. A figure presented in Mike Barrons Auditorium acoustics book was just about all we had[1].

The project financed laboratory absorption measurements of freely suspended sound absorbing drapes. The data also became basis for the requirements for all the *drape based’ variable absorption in the entire Opera project, including the Main scene. Best practical ‘economic’ effect per square meter was achieved by a double layer of wool textile of about 550$kg/m^2$. We also found that the freely suspended banner is a more effective absorber than when hung close to a wall, at least in the fully diffuse lab[2].

**Figure 13: Reverberation lab measurements at SINTEF 'Byggforsk' Oslo. Left: Drape hung 250mm from wall. Right: Same drape 'freely suspended'. [Photo: Anders Buen]**

During the project we also had a master student at NTNU Trondheim that worked on the problem doing absorption, transmission, airflow resistance and other physical property measurements of smaller test samples. Impedance tube absorption data also was collected. He presented three theoretical models for predicting the free banner absorption and made a program for the purpose[3]. His program 'AbsTex' can be downloaded from the website http://www.ognedal.com/content/view/69/138/. 'AbsTex' also contains the measured absorption and transmission data from the measured smaller drapes.

### 3.2.3 The Scene II - Coupled volume outside the 'Object'

The volume outside the 'object' is roughly 1600m$^3$ and the floor area under it is the public entrance to the hall, see Figure 6 and 12. Would we benefit from that coupled volume in the inner hall? Could it serve as a variable absorption resource? Would the 'corridor' under the 'Ferrari camping cab' sound too reverberant for the small talking audience?

The rooms were decoupled in the room acoustics model to investigate any coupling effects. The only effect we could see was a slight increase in $T_{30}$ in the mid frequency region of about 0,1s.

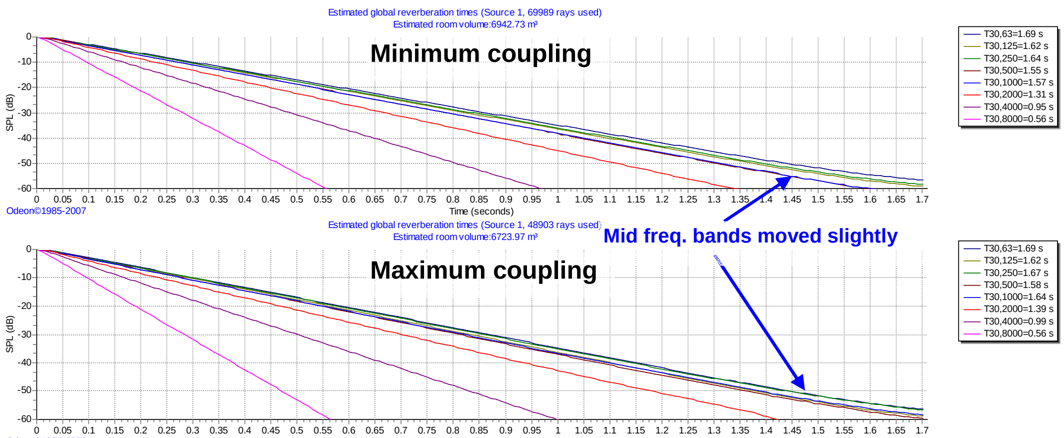



**Figure 14: The Scene II global estimate for RT, wet room in max and minimum coupling.**

A source and receiver outside the object in the model indicated that the acoustics would be good and damped there. However, it would sound more reverberant if the source was outside the object, e.g. on the scene or in the pit.

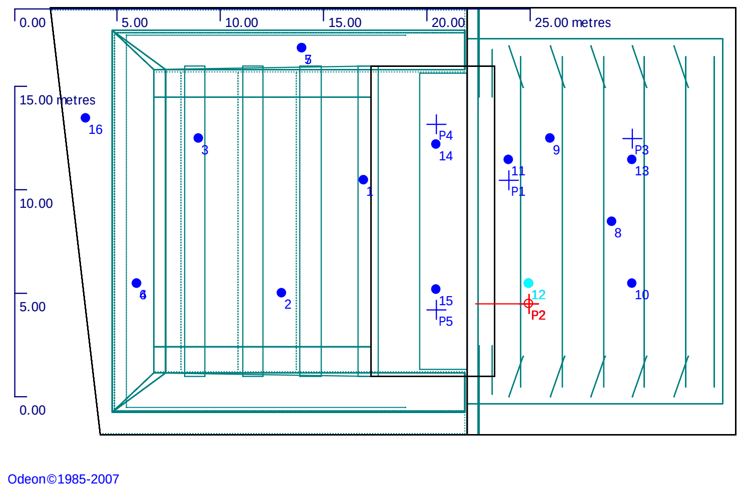



**Figure 15: The Scene II room acoustical model. Scene textiles are included.**

## 3.2.4 The Scene II - Variable absorption

The variable acoustics is supported with a motorized drape following the shape of the object, almost closing off the outside volume. There are manually operated drapes behind the light bridges and acoustic doors with a reflective/diffusive and absorptive side are all around the balconies above the seats, see Figure 17. The motorized drapes can be stored in 'reflective pockets' at each side.

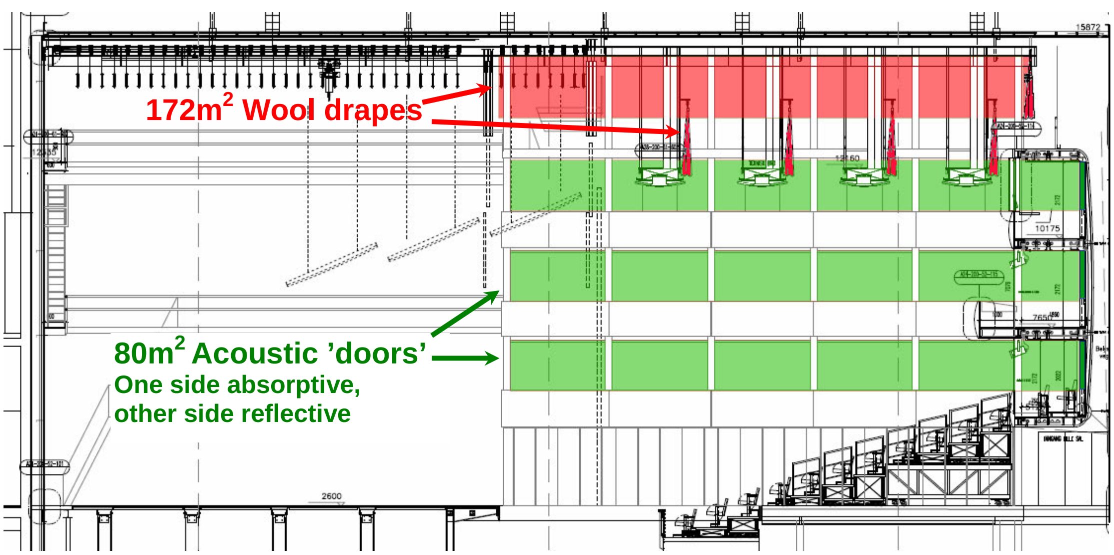



**Figure 16: Scene II - Variable absorption. [Based on a drawing by Snøhetta]**

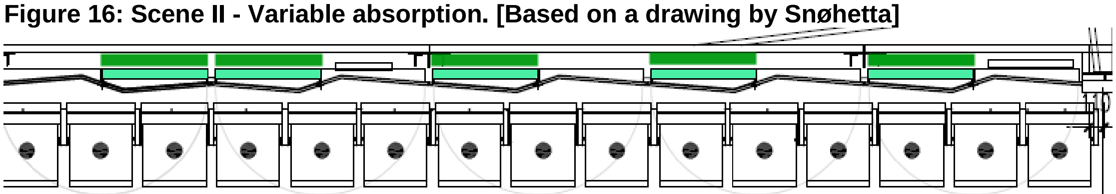


**Figure 17: The Scene II, acoustic doors with a reflective and an absorptive side. The thicknesses of the mineral wool absorption panels are different for the outer and inner layer to provide some variation. The absorber is covered with a air open protective glass fiber textile. [Based on a drawing by Snøhetta]**

# 4 MEASUREMENTS

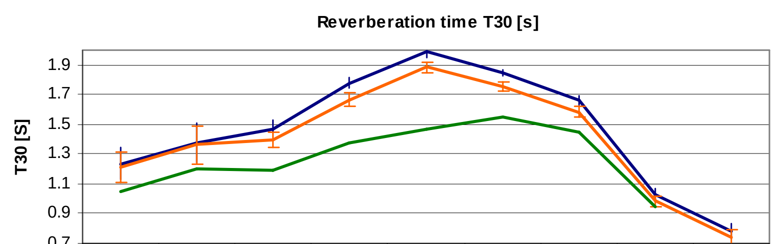
Both halls were measured using WinMLS 2004 with a Digigram VX Pocket PCMCIA soundcard, a studio microphone from B&K and a custom built microphone amplifier. The system is calibrated for G-factor measurements at NTNU's anechoic chamber in Trondheim. Measurement (and calculation) positions were following the scheme as proposed and used by Anders C. Gade[4].

## 4.1 The Ridehuset – Room acoustical data

In the Ridehuset a set of three source- and four receiver positions in the audience area and four receiver positions on the stage was measured along with stage support values in 'dry' and 'live' versions. The conductor- and sound engineer's positions are also included.

### 4.1.1 The Ridehuset - Reverberation times

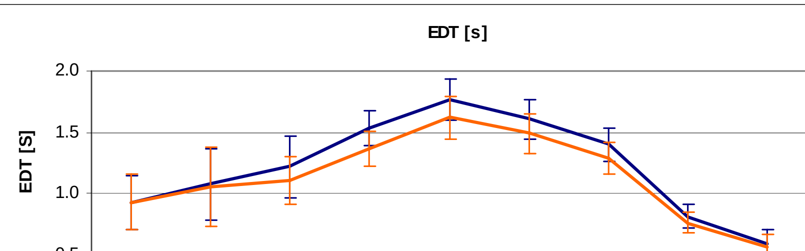
The room sounds bright. The RT has a low bass ratio, BR, due to the preserved existing inner shell of the hall, se Figure 18. This room should work well for amplified music when it comes to the short RT in the bass. The audience also will balance out the curve a bit.




| | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | 16000 |
|---|---|---|---|---|---|---|---|---|---|
| T30[s] scene og sal | 1.2 | 1.4 | 1.5 | 1.8 | 2.0 | 1.8 | 1.7 | 1.0 | 0.8 |
| T30[s] scene og sal dempet | 1.2 | 1.4 | 1.4 | 1.7 | 1.9 | 1.8 | 1.6 | 1.0 | 0.7 |
| Expected T30 w orch vabs in | 1.0 | 1.2 | 1.2 | 1.4 | 1.5 | 1.5 | 1.4 | 0.9 | |

**Figure 18: The Ridehuset RT. Green curve is calculated RT with the orchestra present. The seats are unoccupied.**

We see that the effect of the wool drape behind the orchestra is about 0.1s on the reverberation times, which is pretty much, the large volume taken into account.




| | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | 16000 |
|---|---|---|---|---|---|---|---|---|---|
| EDT[s] scene og sal | 0.9 | 1.1 | 1.2 | 1.5 | 1.8 | 1.6 | 1.4 | 0.8 | 0.6 |
| EDT[s] scene og sal dempet | 0.9 | 1.1 | 1.1 | 1.4 | 1.6 | 1.5 | 1.3 | 0.8 | 0.6 |

**Figure 19: The Ridehuset EDT [s] with and without the variable absorption. No orchestra and unoccupied seats.**

### 4.1.2 The Ridehuset - Clarity and G-factor

The musical clarity is high, especially in the bass. The values are some 1-2dB higher at the stage than in the audience areas. This supports the comments about the acoustics of the hall as if the source is very ‘close’.

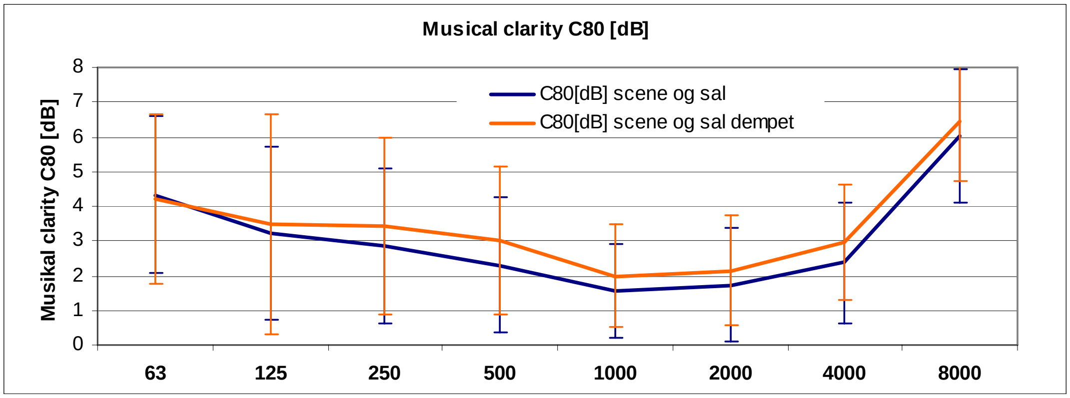



**Figure 20: The Ridehuset, musical clarity C80 averaged over all receivers with variable abs (orange) and without (blue).**

The average G factor is about 13 dB at the stage and about 8dB in the audience areas. The overall average is about 10dB as we see in Figure 21. This agrees fairly well with the predicted 11dB from using the diffuse field model. The effect of the variable absorption is about 1 dB. The level is stronger in the 2-4kHz region, a property which should support e.g. violin and singers formants.

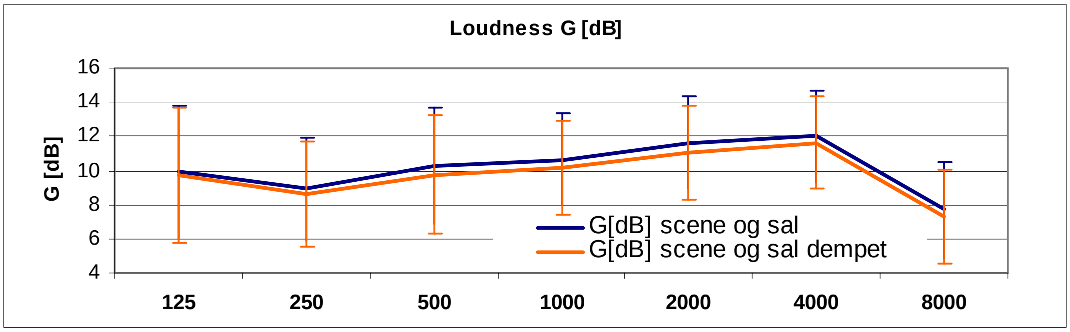



**Figure 21: The Ridehuset, average G-factors for scene and audience receivers with variable absorbers (orange) and without (blue). One standard deviation is given as error bars.**

### 4.1.3 The Ridehuset - Stage support

Figure 22 show the measured early support values with and without the drape in. The net effect of the drape is about 1dB and the values are fairly high, but as recommended for chamber music halls[5] (>12dB). The levels tend to decrease towards the audience so if the orchestra wants to decrease the sound levels a bit, they may move a bit forwards on the stage.

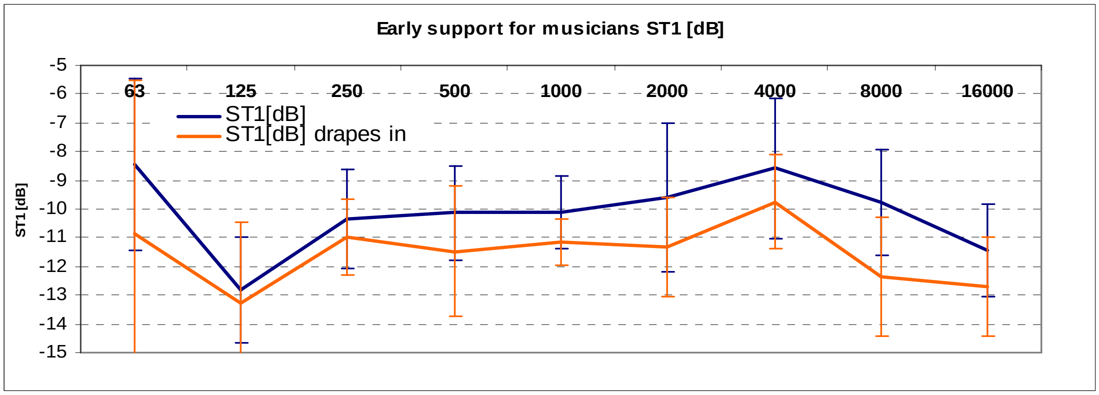



**Figure 22: Ridehuset, stage support $ST_{Early}$ with drapes in (orange) and without (blue)**

### 4.1.4 The Ridehuset – Effects of the coupled volume

We have done calculations of the impulse response in behind the audience area from three source positions as shown in Figure 23. We see that the EDT is much higher outside, see also Figure 24 where the distribution over the entire floor area is given.

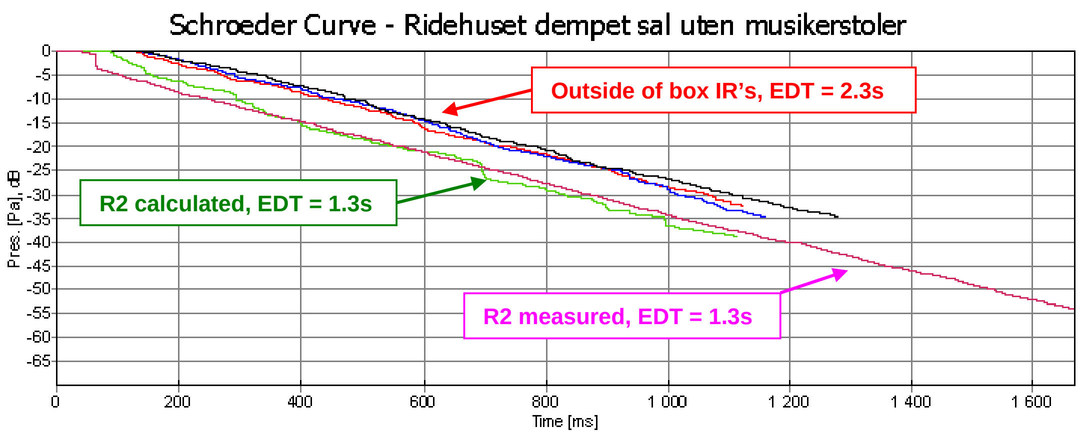



**Figure 23: The Ridehuset, variable absorption in. Calculated IR's behind the seat structure (red, blue and black) compared to an IR in the audience seat R2 from the same source (green).**

The entrance to the concert hall is from behind the audience structure, so the more reverberant, and thus less clear, sound there will be heard by latecomers or when entering the room while it is used for rehearsals.

Interestingly we get a sort of 'inversion' of the sound field by placing the source in that outer volume, see Figure 25. The EDT is sort of inverted in relation to the situation with the source at the stage area in Figure 24. A similar effect is seen with the source in the right coupled volume too, e.g. on top of the box just behind the stage. This could be utilized in concerts and productions to achieve some interesting sound effects.

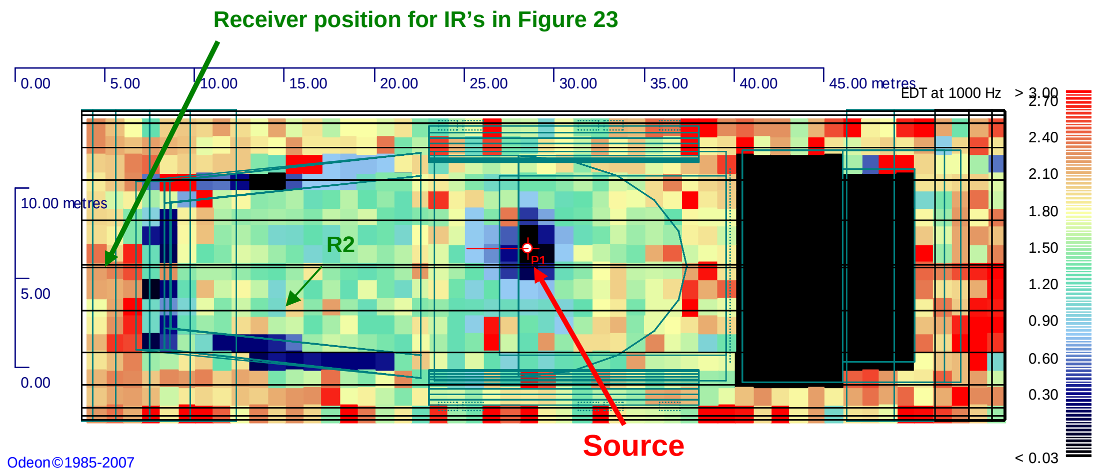



**Figure 24: Ridehuset, EDT @ 1 kHz distributed over the floor, audience and the orchestra. EDT is generally higher in the outside volume.**

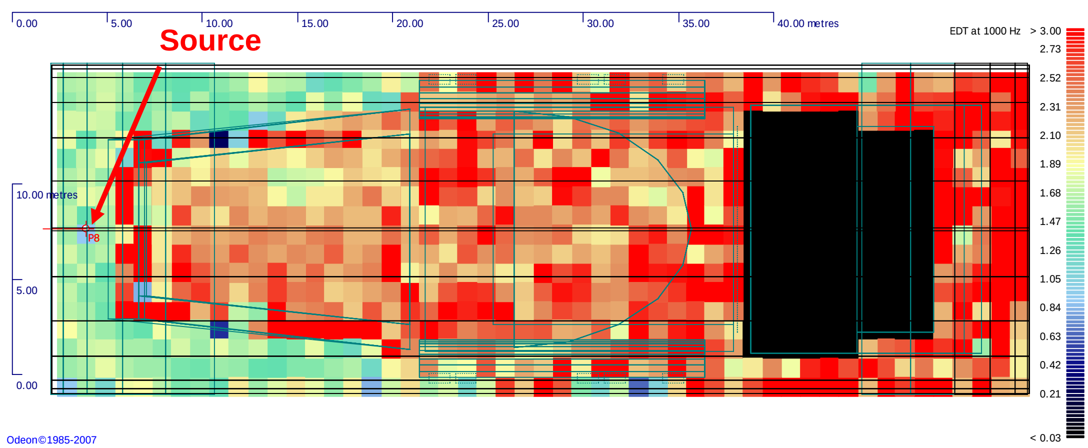



**Figure 25: Ridehuset, EDT @ 1 kHz with the source behind the audience structure.**

In Figure 26 we see the entire IR set measured at the Ridehuset both with and without the variable absorption in (the drape behind the stage). We see straight and fine Schroeder curves with no indication of a double slope.

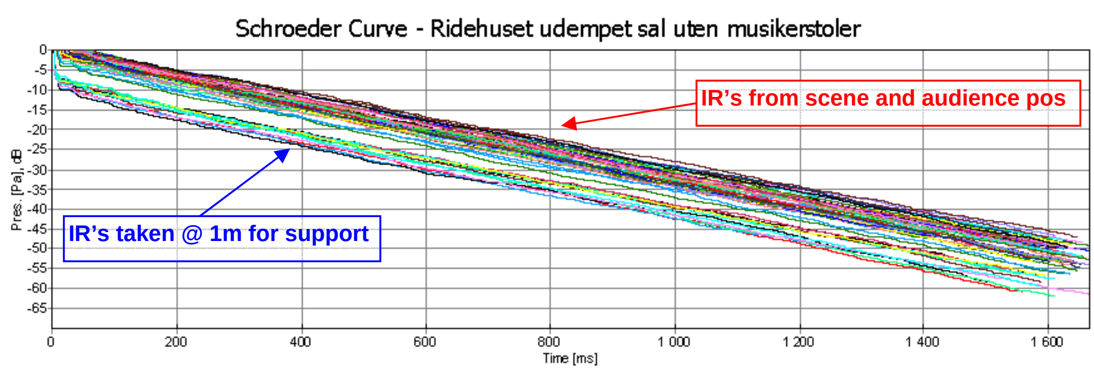



**Figure 26: Ridehuset, the complete set of IR's from scene and audience positions with and without variable absorption. There is no trace of double slopes. The early falloff for IR's taken @ 1 m is typical for such close up stage support measurements.**

## 4.2 The Scene II - Room acoustical data

In Scene II we measured using only one source position on the stage and one in the pit. Support values are taken from three source positions at the stage and two in the pit.

### 4.2.1 The Scene II - Reverberation times

The measured EDT in Scene II is shown in Figure 27 for both 'wet' and 'dry' room. We see that the EDT tends to be higher in the upper part of the room where the receiver is closer to the coupling space outside the 'Object'. We also see that the variable absorption as indicated in Figure 16 has a good effect in the stalls area.

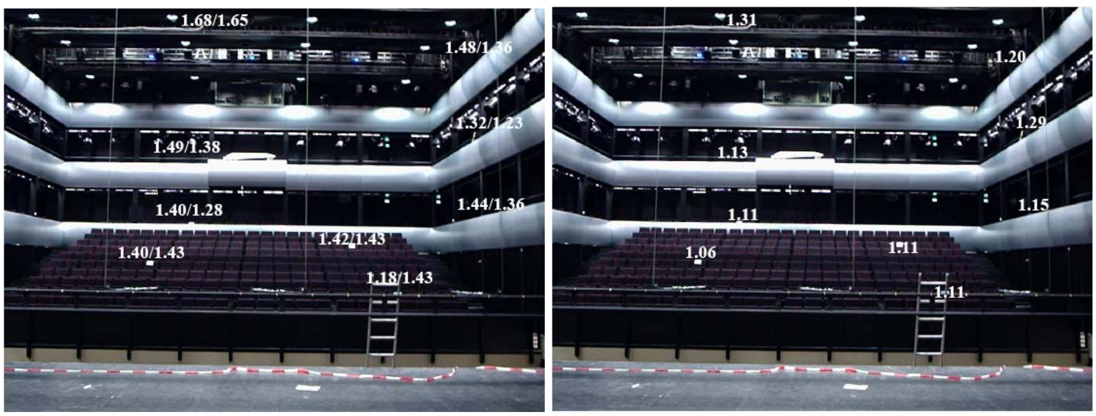
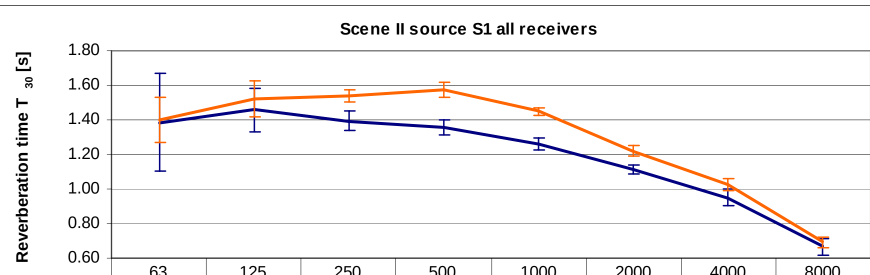



**Figure 27: The Scene II mid frequency EDT from stage and pit sources. Right: EDT from stage source in 'dry' version.**

The reverberation curve is moderate in the bass as can be seen in Figure 28 and the effect of all the variable absorption is about 0,2 s in the mid frequency region. To achieve more, the scene textiles will have to be changed from the 80% reflective drapes to wool textiles. They have some 500m$^2$ to play with.

The requirement for the wet room was met, while we have not measured the fully damped room yet.




| | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
|---|---|---|---|---|---|---|---|---|
| T30[s] S1 alle pos dempet | 1.38 | 1.46 | 1.39 | 1.36 | 1.26 | 1.11 | 0.95 | 0.67 |
| T30[s] S1 alle pos klangfull | 1.40 | 1.52 | 1.54 | 1.57 | 1.45 | 1.22 | 1.03 | 0.69 |

**Figure 28: The Scene II average reverberation times T30 [s] for wet and dry room.**

### 4.2.2 The Scene II – Musical and vocal clarity

Mid frequency (500Hz-2kHz) musical clarity from the pit source and definition for the stage source are shown in Figure 29 for the ‘wet’ room. The values are fairly high and will increase when the audience is present.

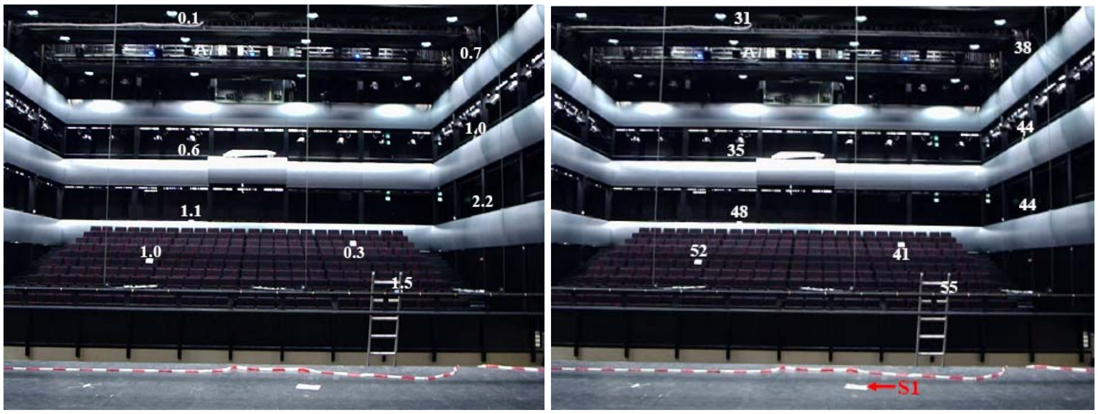



**Figure 29: Musical clarity, $C_{80}$ from pit source and definition D50 values stage sources in wet room.**

### 4.2.3 The Scene II – G factors and Balance

The balance is slightly in favour of the scene in the wet room, see Figure 30.

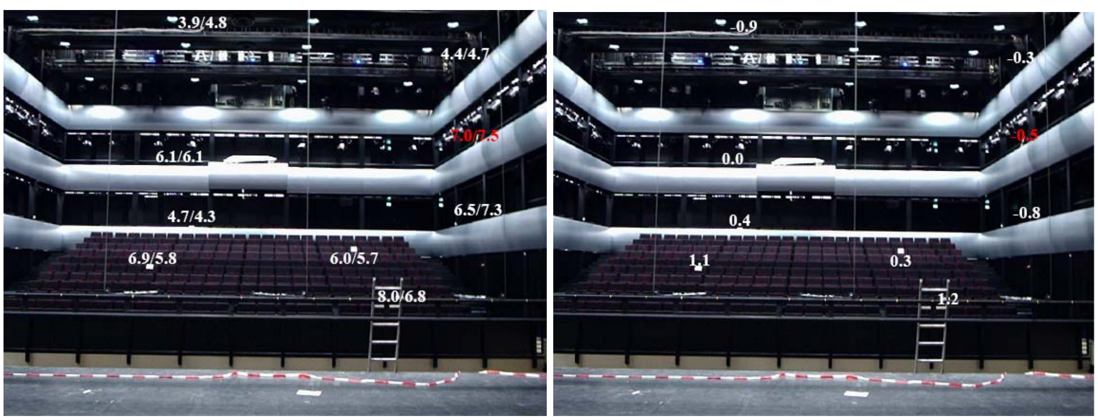



**Figure 30: Mid frequency G-factors for stage and pit source respectively. Right: Balance $G_{Scene}$ - $G_{Pit}$ in wet room.**

### 4.2.4 The Scene II - Stage and Pit support

The stage support values are even at the stage and fairly close to what the DNO&B's singers had of support in their former theatre Folketeateret with a similar stage set[9,10]. The support values do not seem to be influenced much by the variable absorption.


**Figure 31: Stage support $ST_{Early}/ST_{Late}$ [dB]. Elements from the orchestra shell were used on the stage as a set.**

The early support values in the pit are strong. The pit is now mounted with slatted panels, porous and textile based drapes so the pit is somewhat less sound reflective. This was done after complaints from the orchestra in the first tests which were done before the variable absorption in the pit was mounted.

### 4.2.5 The Scene II – Effects of the coupled volume

In Figure 32 we see the measured IR's from Scene II. One position is measured behind the 'Object' at stalls level, see Figure 15 (receiver 16) in both 'dry' and 'wet' version of the room. The EDT is higher than inside the 'Object', and the Scroeder curve have a initial almost flat region before converging towards a straight line lying above the other Schroeder curves of the IR's.

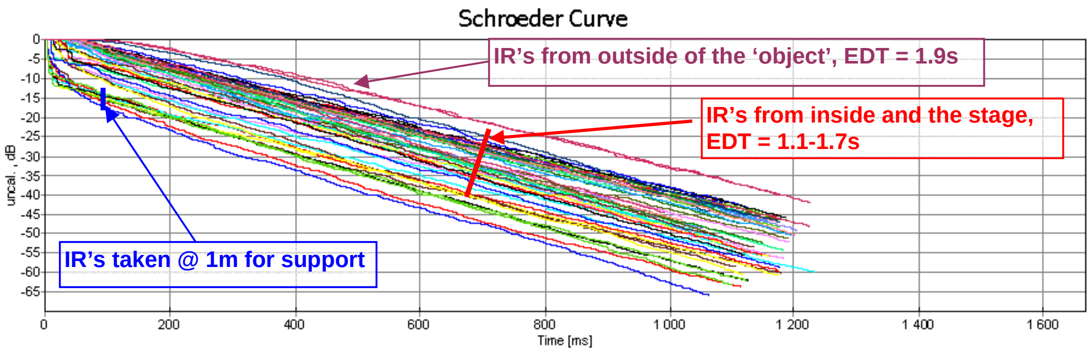



**Figure 32: Scene II, complete set of IR's from stage and pit sources as well as from the support measurements. There are data from both 'dry' and 'wet' version of the room.**

We also see that the inside box Schroeder curves are more or less straight and that they do not show a double slope, except for IR's for the support measurements.
In Figure 33 we see how the EDT is distributed over the floor and audience areas. In the outer volume the EDT is higher.

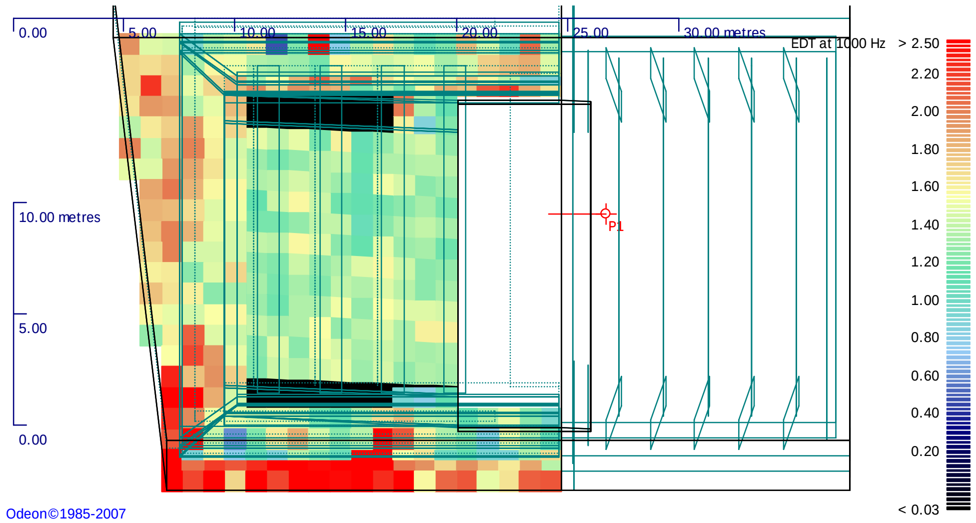



**Figure 33: The Scene II, EDT [s] from stage source showing that the values tend to be higher in the "reverberation chamber".**

Figure 34 show the EDT with the source in the outer volume, giving an inverse effect on the EDT. This effect could be investigated more in practical use. Can this effect add some usable acoustical and dramatic possibilities to the hall? There are several possible source positions that can be utilized, bridges, stairs, but also on top of the object, maybe the light bridges. The sources could be moving as well.

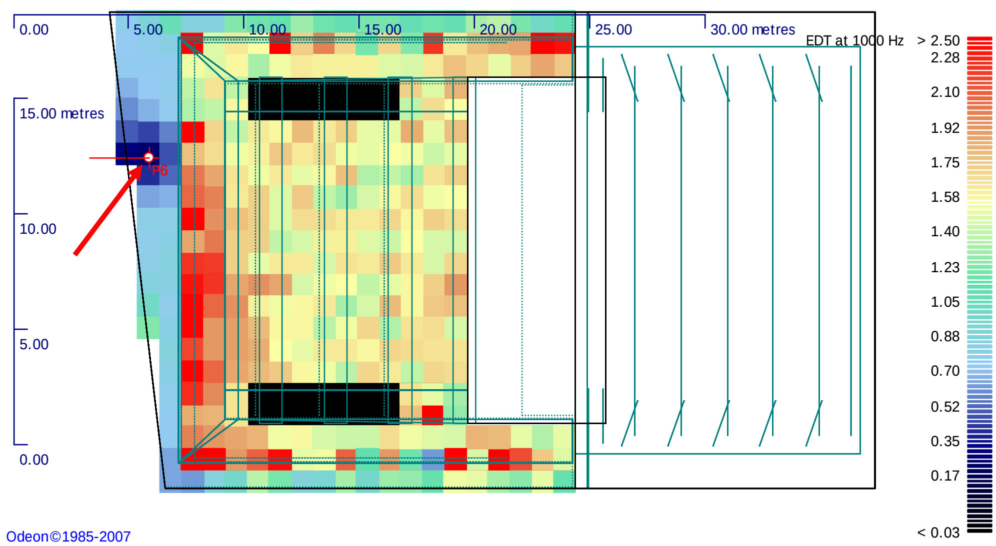



**Figure 34: The Scene II EDT [s] from an omnidirectional source in the outer volume showing that the EDT becomes higher in the inner volume inverting the situation in relation to Figure 33.**

### 4.2.6 The Scene II – Subjective assessments of the acoustics

Subjective assessments of the room acoustical conditions were collected from a group of acousticians, singers, musicians, the client (Statsbygg) and a few from the architect team. Tests were conducted with a 50 person orchestra in the pit, as well as a separate test with singers and a piano on the stage.

We used the same assessment sheet for the tests in the main stage. Most respondents had attended the tests in both halls (Main scene and Scene II). Subjective scores were from 0-10 and the average results are shown in Figure 35 and 36. The Scene II was judged to be somewhat louder, less reverberant and with a slightly lower envelopment for the orchestra, but higher for the singers. However the tonal quality, warmth, brilliance, clarities and the overall impression are judged to be equal.

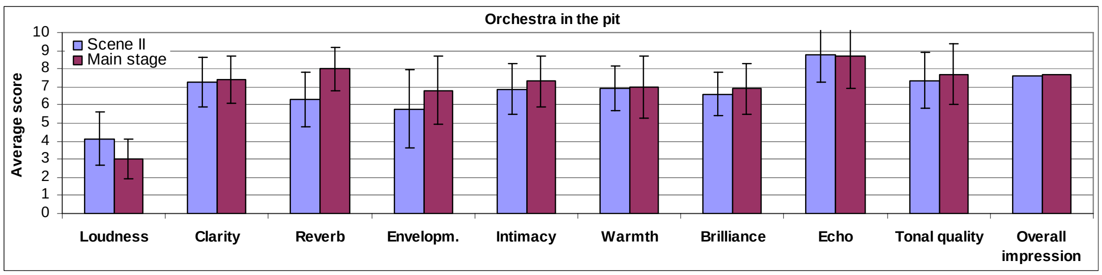



**Figure 35: The Scene II: subjective responses from the test with the orchestra in the pit. Blue is Scene II and violet is from a comparable test in the Main scene, but wit a larger orchestra. The number of responses was 117-131 for the Scene II and 106-123 for the Main scene. Error bars are ± one standard deviation.**

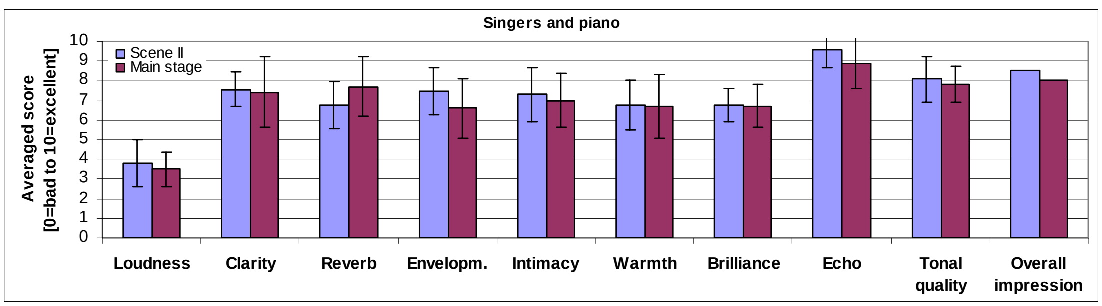



**Figure 36: The Scene II: Subjective responses from the test with singers and piano at the stage. Blue is Scene II and violet is from the same test in the Main scene. The number of responses was 30-34 for Scene II and 22-31 for the Main scene. Error bars are ± one standard deviation**

## 4.3 Summary and discussion

Table 1 and 2 show some key numbers for the acoustical parameters of the two auditoria compared to Leo Beranek and A. C .Gades recommendations for chamber music halls.

The Ridehuset seem to have data closer to the recommendations by Beranek, while the fully damped Scene II has values closer to the recommendations for chamber music as given by the contemporary acoustician Anders Gade. Beranek seem to prefer a more reverberant, loud and somewhat less clear acoustics.

**Table 1: Some acoustics key numbers for the Ridehuset and the Scene II. Beranek and Gades preferred values for chamber music halls are given as reference. Volume: inner/outer.**

| Hall | N seats +mus | Volume [$m^3$] | V/N [$m^3$] | Vabs. [$m^2$] | $T30_{0.5\text{-}1kHz}$ [s] | $EDT_{0.5\text{-}1kHz}$ [s] | $C80_{0.5\text{-}1kHz}$ [dB] |
|---|---|---|---|---|---|---|---|
| Ridehuset wet | 235+40 | 3600/4700 | 13/17 | 57 | 1,9 | 1,7 | 1,4 |
| Ridehuset dry | | | | | 1,8 | 1,5 | 2,1 |
| Scene II wet | 440+10 | 7400/9000 | 16/20 | 252 | 1,5 | 1,4 | 1,7 |
| Scene II dry | | | | | 1,3 | 1,2 | 2,7 |
| Beraneks rec. for chamber music halls < 700 seats[5] | | | | | 1,6-1,8* | 1,9-2,3 | -2 – 2 |
| Gades rec. for chamber music (2500$m^3$ 300 seats)[8] | | | | | 1,4 | 1,3 | 3,0 |

* Occupied data

**Table 2: Strength, Bass ratio (BR = $T_{125\text{-}250Hz}/T_{500\text{-}1kHz}$), stage support, ST1, and some absorption data along with Beranek and Gades recommendations for chamber music halls.**

| Hall | $G_{125Hz}$ [dB] | $G_{0.5\text{-}1kHz}$ [dB] | BR | $ST1_{250\text{-}4kHz}$ [dB] | $A_{0.5\text{-}1kHz}$ [$m^2$ Sabine] | Effective abs fact for vabs $\alpha_{0.5\text{-}1kHz}$ |
|---|---|---|---|---|---|---|
| Ridehuset wet | 7,4 | 8,2 | 0,7 | -9.8 | 308 | - |
| Ridehuset dry | 7,2 | 7,6 | 0,7 | -10.9 | 326 | 0,31 |
| Scene II wet | 4,7 | 5,9 | 1,0 | -13.8/-7.9* | 815 | - |
| Scene II dry | 3,1 | 3,8 | 1,1 | -13.8/-8.3* | 940 | 0,50 |
| Beranek rec.[5] | 9-13 | 9-13 | - | > -12 | - | |
| Gade rec.[8] | - | 10 | 1,0 | - | | |

* Pit values

The Ridehuset has a low bass ratio and a high clarity in the bass region. To attend concerts with amplified music here might be a good way to assess that property. Talking to the sound engineers hired in here also might be useful. The G factors do, however, not seem to be weak in the bass here.

Both halls are less loud than the recommendations given by Gade and Beranek. They have been planned to take high sound levels, which may be damped even more with variable absorption. The effective absorption coefficient for the project with the free hanging absorbers is higher. But more measurements are needed to separate the effect of the different drapes, hung across the rooms, cutting off the outer space, and the net effect of the acoustical doors. In the Ridehuset the drapes were partly hidden behind fairly deep slats that may have reduced the effect of the drape somewhat.

# 5 CONCLUSIONS

The coupled volumes in these two projects were both an architectural and acoustical feature that has been assessed using computer modelling. The volumes turned out to be useful to achieve an extra 0.2s, and 0,1s in the mid frequency reverberation time respectively for the Ridehuset and the Scene II. The measured Schroeder curves from the inside volumes in the halls are straight and do not show double slopes. However in the outer volume the slope is starting off almost horizontal and then fall off after a while showing 'opposite' double slopes.

The measurements confirm the predicted high EDT and lower clarity outside the inner active volume and the effect is clearly audible when you arrives the rooms while music is played in them. The outer volume might also be used for special sound effects. With the source in the outer volume the EDT on the audience seats and at the stage will be higher than when the source is played e.g. in the pit or at the stage. Could this be utilized for some interesting sound effects in performances?

The volume per seat key number for early room acoustics planning taken from concert hall literature (10-12m$^3$ per seat) does not seem to be sufficient for such halls with a fair amount of scene textiles and variable acoustics present in the room. Also the seats are more upholstered than in more traditional old concert halls. We need to collect more data from such halls and create new early planning key values.

The shape of the Ridehuset does resemble the apparently successful 'Tent shaped' concert halls, much used in North America[7]. It is a shape that would follow the Norwegian building tradition well. Maybe we should look a bit more into its properties and try it for new projects as well?

# 6 ACKNOWLEDGEMENTS

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