THE DESIGN OF VARIABLE ACOUSTICS AT THE NEW CONCERTHALL OF THE “MUZIEKGEBOUW AAN ‘T IJ” IN AMSTERDAM (NL).

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1 INTRODUCTION

The “Muziekgebouw at the IJ” in Amsterdam (NL), opened in june 2005, contains a fully equiped flexible 730 seat concerthall. It caters for a broad range of music performances, from small chamber music to middle size orchestra’s and choirs with symphonic, classical and contemporary music.

This paper describes the principal features of the acoustic design of this hall with particular emphasis on the design of a variable acoustics system that adjusts conditions to suit different types of performance. The development of the design with the help of an acoustic scale model is discussed and the results achieved in the completed hall are presented.

2 THE BRIEF

The brief describes the hall as a multi-purpose performance venue with the following main issues:
- “traditional” chamber music, from soloist up to orchestras of ca. 55 musicians;
- “modern” ensemble music in traditional and special seating arrangements;
- types of amplified, electronic and computer music;
- types of music with spatially variable performance arrangements and double choir. The hall has to stimulate such experiments;
- music(theatre)pieces specially written for this hall;
- musictheatre and opera without stage tower or orchestra pit.

A number of 800 seats with comfortable leg space is required. The ground floor has to be flexible in height to adapt the floorprofile to the type of performance, for instance either a flat floor, a raked floor or enlargement of the stage. Ground floor seats therefore have to be removable. Maximum allowable background noise level has to fulfill 15 dB(A), partly because the hall will also be used for recordings.

3 ACOUSTICAL DESIGN OF THE HALL

3.1 Key requirements & acoustic variability

Peutz contributed in a very early stage to the acoustic demands set in the brief as follows:
The acoustics should be suitable for all different types of music mentioned above and should therefore be adaptable. Both variable in volume, related to the size of the orchestra, as well as in reverberation time, related to the type of music. Only natural (not electronically) variable acoustics are aloud. A variation of reverberation time between 1,5 and 2,5 s. (fully occupied) has to be aimed for. With extra absorption (theatre drapes) a further reduction to 1.2 seconds should be possible.
To set clear directions for the architect specific suggestions for size dimensions are also set in the brief as follows: The largest room volume should be at least 10.000 m3 (12.5 m3 per seat) and the smallest volume 6.000 m3 (7.5 m3 per seat). With a movable ceiling surface of for instance 500 m2 this would imply a height variation between 12 and 20m.
Because the acoustics for natural music prevail above those for reinforced music the hall has to have all positive characteristics of a good concert hall. Such as sufficient reverberance, an even sound distribution, sufficient lateral reflections, sufficient support on stage, good clarity, adequate diffusion of large flat surfaces, and a wide dynamic range requiring sufficient gain and a very quiet background.

3.2 Auditorium shape & volumes

In an early design stage a rectangular shoebox shape was chosen, to ensure optimal acoustic conditions (even sound distribution, lateral reflections). In figure 1 and 2 two sections through the concerthall are given, in which the red line indicates the (light) inner box structure and blue the outer (concrete) box.

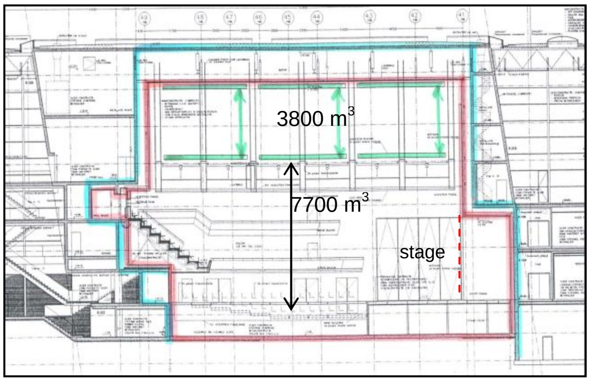

Figure 1. Section through concerthall

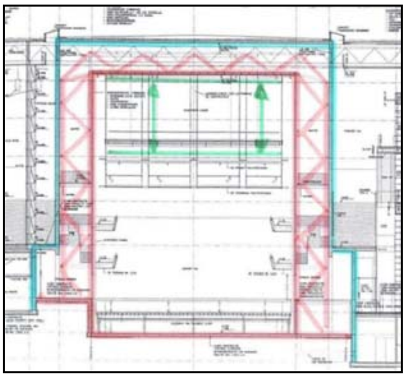

Figure 2. Cross-section

The overall width of the hall is limited to 19.5 m, with a length on floor level of 30m, including 10m for the stage. On ground level the floor surface is 590m² including 200m² main stage. The main stage is positioned within the main volume of the hall, in order to optimize the acoustic coupling towards the audience. For the enlargement of the acoustic volume a large space directly above the lighting grid was designed and implemented, to ensure sufficient acoustic coupling towards the main volume. This space was given roughly similar dimensions as the hall itself (32x19.5x10m (lxwxh)) and its height is adjustable using movable ceilings above the lighting bridges.
For underlying concerthall one main balcony in the rear of the hall was considered the maximum, in order to ensure optimal acoustic conditions on this balcony and to limit the amount of seats under balconies. The depth under this main balcony is limited to 4m (3m height), the depth of the balcony itself set at 8m. For additional seats one side balcony was originally designed, but a second side balcony on both sides was added in the final design stage to gain more seats. Both side balconies were acoustically favored because they break up the large sidewalls and thus add additional sound diffusion.
Finally the total number of seats is 729 (494 ground floor, 161 balcony, 74 side balconies), which is below the number of 800 aimed for, mainly due to the demand for comfortable (leg)space (100 cm row distance, seat width 59 cm).

Due to the demand of free view from the main balcony towards a possible orchestra-position in the middle of the hall, the main balcony is relatively steep for a concerthall (32 degrees), and sets a height demand of 7.5m including 2.5m free height above the floor of the highest row. Together with 3m free height under this balcony this accounts for the actual lighting bridge position of 10.5m+ as well for the increase of the lowest ceiling height, that became 13.3m+. Increasing the building height could have compensated this. Raising the fixed height of the ceiling (20.2m+) or the outer roof during the design to allow higher ceiling adjustments was however not an option due to financial reasons. The highest position of the movable ceiling was therefore limited to 19.4m+ (80 cm for structure of movable ceiling) and the actual height variation of the ceiling became 6.1m, which is significantly lower than 8m as originally aimed for. Due to the larger ceiling surface (630 instead of 500 m²) however the additional volume of 3800 m³ almost met the goal set (4000 m³).
Based on the lowest ceiling height of 13.3m+ the final minimal acoustical volume of the hall in concertarrangement (stage walls closed) became 7700 m³ instead of 6000 m³ aimed for. Together with the smaller number of seats of 729 compared with the 800 aimed for, the volume per seat increased with 40% from 7.5 m³ to 10,5 m³. It could therefore be doubted whether the lowest RT of 1,5 s aimed for could be achieved. The maximum acoustical volume in concert arrangement (sloped

floor, stage walls closed) finally became 11500 m³ instead of 10000 m³ aimed for, leading to a 25% increase of volume per seat of 15.8 m³ instead of 12.5 m³. It could be expected therefore that the highest RT desired of 2.5 sec, based on 12.5 m³ per seat, would be easy to achieve or even exceeded. The maximum volume change has become 150%, slightly below the 166% aimed for, which will influence the variation of T30 values achievable. In chapter 4 the final results based on measurements are discussed.

3.3 Lighting grid & moving ceilings

Within the whole hall a regular grid of fixed lighting bridges is applied, sketched in figure 3. In order to limit the acoustic obstruction towards the (movable) ceilings above this grid, the grid is made as open as possible, and grid floors are as small as possible (60 cm), with open steel mesh floors.

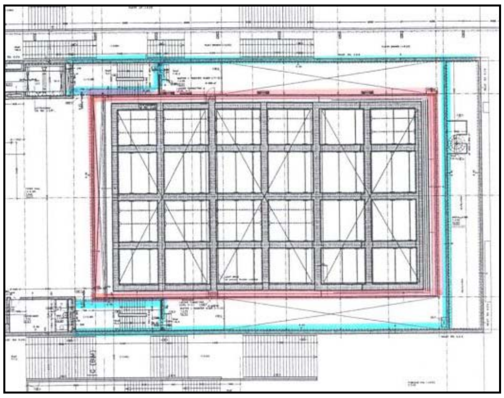

Figure 3. Plan on lighting-grid level

Figure 4. Photo of lighting bridge

Above this grid sufficient height and volume had to be created to obtain the required volume change. During the design the height of the lighting bridges above stagelevel gradually increased from 9.5 up to 10.3m+. Also the height required for railing with point-hoists (see figure 4 and 5) and safe walking on the lighting-bridges, determining the lowest ceiling position, increased from 2m up to 2.8m. Both aspects contributed to an increase of lowest ceiling height (13.3m+) and increase of the minimal acoustic volume (7700 m³).
The amount of additional volume can be gradually regulated using three independently adjustable moving ceiling elements of 150 m2 (9 x 17 m) each, 450 m² in total. See also figure 1. Three ceiling parts were chosen instead of one to add some additional variability to the acoustics. The actual height of the three ceilings can be chosen independently, according to the musician’s experience or taste. For instance above stage the ceiling could be lowered and above the audience both other ceilings could be high (indicated as “HHL”). All three ceiling are counterbalanced by heavy weights in the buffer zone next to the hall, and are electrically operated and adjustable within few mm.

Figure 5. View on bridge level towards lowered ceiling and technical equipment

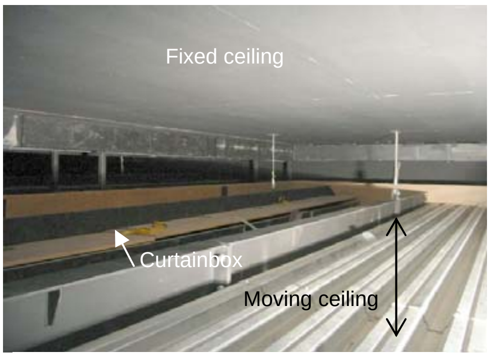

Figure 6. View above ceiling in high position, curtain box closed.

The acoustic requirement set of at least 20 kg/m² for the surface mass of the (movable) ceiling is met by applying 24 mm thick wood (multiplex 14,5 kg/m²) against the bottom of the profiled steelplates (>8 kg/m²), lying on steel bearingstructures, see figure 6. Due to height differences between the flat ceiling parts and the bottom of the curtain boxes some diffusion of the ceiling elements was obtained, see figure 5.
In the highest position of 19.4m+ the edges of the ceilings connect to the roof, closing off the void above the ceilings to prevent unwanted absorption, and adding 3800 m³ beneath the ceilings to the hall volume (HHH). Above the movable ceilings variable absorption is applied using 1000 m² (9 rows of 6x17m) of acoustic curtains, see figure 7.These curtains are separately operated. When the ceilings are in a lowered position these curtains can be retracted out of their storage box hidden in

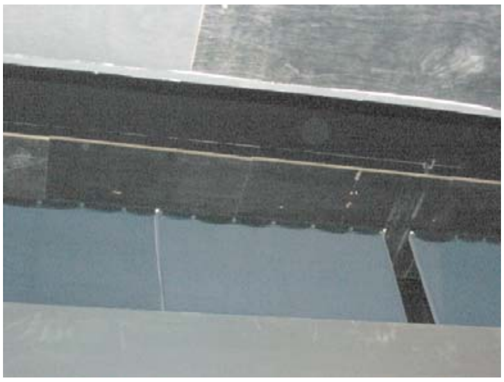

Figure 7. View through gap between ceiling towards curtains being retracted out of box.

the ceilings, into the void to deaden it. They can also remain stored in their storage box within of the movable ceiling (figure 6) to make them acoustically ineffective in order to couple the volume of the void to the auditorium. Based on scale model research a large gap of 1-1.5m around every ceiling element is applied (see figure 7). This is done to achieve either additional absorption in low ceiling positions if the void is deadened by the curtains or to increase coupling of the void to the hall in low ceiling positions if the curtains remain in their storage box.

3.4 The flexible stage walls

To enable special performance arrangements, theatrical events and sufficient routing space and preparing space for musicians around the stage, an additional floorsurface of 230 m² was designed using rear and side stages with a height of 8m and a depth of 5 meters, see figure 8. The side stages are separated from the main stage by four rotating wallpanels of 8m height and 2.5m wide on each side, see figure 9.

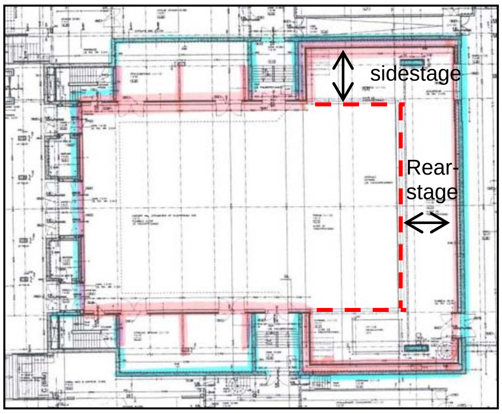

Figure 8. Plan of concerthall on stage-floor level.

Figure 9. Photo of side stage walls in open position and closed rear wall, both with led-lighting implemented.

The wall between stage and rear stage, sized 20m width and 10.5m height, can be raised over a height of 8m in order to connect the rear stage over its full height with the hall, see figure 10.

Figure 10. Photo during concert with choir with open rear and side stage

Figure 11. View from behind to the movable backstage wall with tilted wooden paneling

On all of these movable walls a similar open wooden- lath structure is attached as on the auditorium walls (see paragraph 3.6), with build-in led-lights (figure 9). The closed paneling behind it is lighter and consists of 24 mm thick tilted plywood paneling with irregular-profile for additional diffusion, see fig. 11. Based on measurements and listening experience it is recommended to keep these walls closed if optimal acoustic conditions for musicians and audience are demanded. This because the side- and rear-stage are not acoustically controlled and their backwalls are not diffusive. If these movable walls are open valuable (early) sound will leak away towards the side and rear stage and will be lost for the audience. For events where theatrical conditions however are more important or if more space is required these side panels are now and then being used in open position, see figure 10.

3.5 Seating and movable floor

A flexible ground floor with removable seating is applied to enable different arrangements for audience or performers, such as with orchestra in the middle of the hall and seats on stage, or a standing audience. The floor of the auditorium is segmented into 10 parts (2x20m) that can be vertically moved over 1.2m height. A 3m high basement has been build for this equipment under the floor, which gives additional storage under the stage floor. This enables either a fully flat floor level with the stage, or a sloped floor with better sightlines towards the orchestra, or with intermediate settings.
The movable wooden floor consists of 3 layers of 15 mm wood (45mm), so with a mass of 32 kg/m2 it fulfills the acoustic demands. Gaps in between the floor elements and with the wall have been kept as small as possible (<10mm), for acoustic as well as safety reasons. The total number of seats finally has become 729, with comfortable size (100cm row distance, seat width 59 cm). All 494 seats on the ground floor can be easily removed using sets of 4 chairs on wheels. Storage space is available in the buffer zone next to the hall.

The acoustic absorption of the chairs was carefully specified to ensure that the highest RT value of 2.5 s occupied was met and that the change in RT between occupied and unoccupied conditions was minimized. Therefore additional perforation of the seat bottom was applied. As usual for Peutz the seats were tested both occupied and unoccupied in a reverberation chamber using standard procedures. Additionally they were also measured covered with special cloth, as a simulation for audience-occupation to be used for measurements in the real hall. Absorption values measured are NRC=0,5 unoccupied and NRC=0,65 occupied.

3.6 Diffusion & build-up of concert hall walls

Because of the large surface of the auditorium and stage walls diffusion was considered necessary to smoothen its reflections. At the same time too much absorption had to be prevented. The Danish architects (3xNielsen) proposed for all the visual walls below lighting bridge level an open horizontal wooden lath structure consisting of 40 x 32 mm (HxD) laths in a regular pattern, to be placed at 15 cm distance of the closed wall itself. Using lighting in the space between could give the desired lighting-effects. Although previous applications of this type of wall finish (open laths) in concert halls were not known and seemed to be quite uncommon for concert halls and not without any risks, Peutz investigated it seriously with laboratory measurements and listening tests. An very high degree of sound diffusion of this lath-structure was already observed, especially in horizontal directions (parallel to the laths), and a few adaptations were proposed that were implemented in the design:

- the pattern should preferably be at least 50% open;
- irregular distances between adjacent laths were demanded to prevent risk of sound-coloration through interference effects;
- the wooden laths should be painted at least once (transparent) to reduce high frequent absorption;
- the closed wall behind the laths (back layer) should be irregular and diffusive as well, but not as fine as the laths, and have a mass of at least 20 kg/m^2.
- a mock-up of the final assembly had to be tested on sound insulation and sound diffusion.

A proposal of the architect for the back layer of thin plaster on a thick layer polystyrene was rejected because after measurements it appeared that its sound absorption measured in the reverberation chamber was too high and had an uneven frequency-distribution (NRC=0,3). Finally a heavier build up was chosen with 20-30 mm plaster on an irregular stone-steel mesh with variable depth, with a total mass of 30 kg/m^2. This finish was applied in front of the structural wall, consisting of 15 mm gypsum plate screwed on 60 mm thick sandwich (steel-rock wool-steel) paneling. See figure 12.

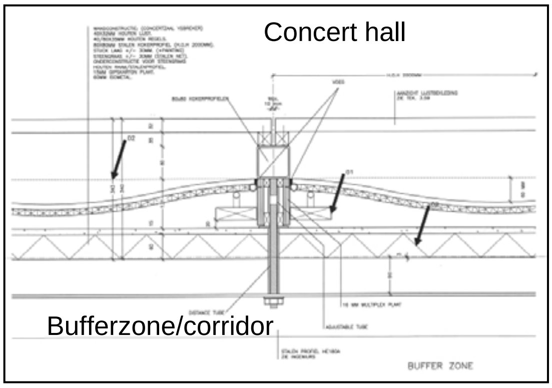

Figure 12. Horizotal section through wall of concert hall.

Figure 13. View of irregular plastered-wall before wooden laths are placed

With this method a irregular, bubbling wall surface was obtained that would give the additional diffusion desired (see figure 13). Finally the wooden lath-structure with selfsupporting steel bearings was applied on the innerside (figure 14), making up for the total wall thickness of 350 mm.

Figure 14. View of wall detail with wooden laths and closed panel

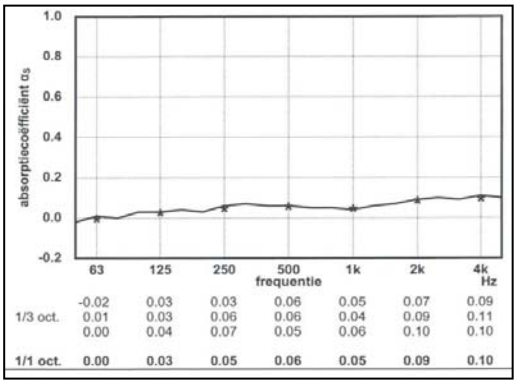

Figure 15. Sound absorption measured of laths structure.

In the laboratory the wall assembly measured on sound insulation and resonance effects. With Rw=54 dB sufficient sound insulation was obtained. The sound absorption of the final lath structure, painted once and placed on 20 cm distance of a concrete floor, was measured in Peutz' reverberation chamber to be between 5-10% which was judged as acceptable.
For the moveable walls instead of plaster on stone-mesh a build up of 2x22 mm-thick tilted plywood paneling was applied.

Additionally all the wooden laths walls below bridgelevel (10.5m) have integrated computer-controlled led-lighting that makes it possible to give any colour combination to the walls and adapt the atmosphere of the wall to the performance.

3.7 Noise control

The site is situated in an urban area, right at the borderline of the old heart of the city of Amsterdam and the newly-developed banks of the IJ, and a few hundred of meters away from Amsterdam Central Station. Right next door is the Bimhuis, build simultaneously, with a 200 seat hall for jazz and improvisation. The main concerthall of the Muziekgebouw was built as a complete box-in-box to prevent outside noise intrusion (large cruise vessels pass at 30 metres, trains at 100 metres) and to obtain studio quality.
The outer structure (blue line in sections in figure 1,2 and 8) has 35 cm thick concrete walls and 25 cm thick concrete roof. The inner box (red line in sections) is a “light” construction and is completely separated from the outer walls and roof and has its own concrete floor (basement) with its own piles, completely separated from other building structures. The fixed inner ceiling consists of 2x12.5 gypsumplates, the inner walls are already described in the previous paragraph. The buffer zone between the walls and roofs of the boxes is 3m deep, and is used for the steel structures, ventilation ducts, silencers, storage space, staircases etc. The movable ceiling is not essential for sound insulation purposes because of its large gaps.
Since the hall will be used often as a studio, a very low noise level of the ventilation system was required, less than 15 dB(A). On the main balcony air supply under the seats was applied, but in the stalls this was not possible due to the movable floor and removable seats. Therefore induction nozzles are build in the all four side balconies edges to supply fresh air to the audience in the stalls. The design of the system was made in very close co-operation with Peutz in order to guarantee sufficient low velocities and low noise levels. The essential parts were tested in Peutz laboratories, like the comfort and noise properties of the air induction nozzles, and lead to specific adaptations to the Krantz' nozzles. As done previously in the Royal Albert Hall project Peutz performed 3-dimensional computational fluid dynamics studies to check for the comfort aspects (temperature, air velocity) of the total system. After completion of the building the background noise level of the main hall was measured at 9 – 10 dB(A) or NR-2.

4 ACOUSTIC MODELLING

In the early stage of the design the hall has been studied in the Peutz laboratories on a physical 1:16 scale model to make sure the concept would work in every respect. In this scale model study a large number of variables were studied, like ceiling settings, width of light bridges, area of ceiling parts, balcony design, additional absorption above the ceilings, movable stage side walls. A standard impulse modelling technique was used with a special sound source on two source positions and small microphones on 12 measuring positions. The absorption coefficients of the relevant elements were verified using Peutz' 1:16 reverberation chamber. An impression of the scale model interior compared with the real hall is given in figure 16 and 17.
The scale model study showed that:
- lowering the movable ceilings leads to increased early sound energy and reduced late reverbarance, with clarity (CL-80) increasing with 4-5 dB (@1kHz);
- If a technical grid with closed floors (figure 16) would be applied the maximum Clarity-80 change between high and low ceiling positions of +4 dB would be seriously reduced depending

on the amount of closed bridge surfaces under the moving ceiling. This reduction was measured to be 0-1 dB at 20 cm gridwidth, 1,5-2 dB for 60 cm width and 3 dB for 80 cm width. Based on these results the early option for a closed grid with steel nets in between was abandoned and proper lighting bridges with open mesh floors were designed, with a floor width as small as practically possible (60 cm). This is illustrated in figure 4 and 17 with photos in the real hall (1:1).

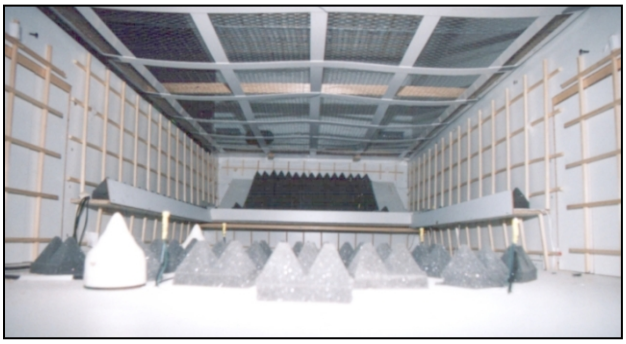

Figure 16. View in scale model towards balcony

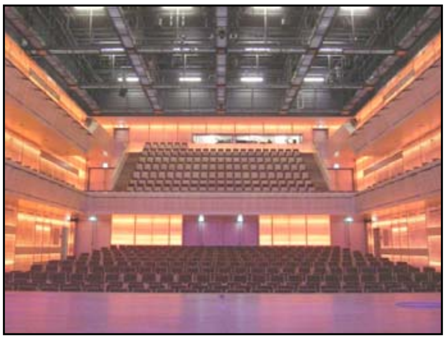

Figure 17. View in real hall towards main balcony

- Relatively wide gaps between the ceilings of 1-1,5 m would be necessary to obtain sufficient acoustic coupling towards the void behind the ceilings. In that way a late secondary reverberation tail could be obtained with the ceilings low and the void reverberant;
- Curtains above the ceiling are sufficiently effective to deaden the void if the ceilings are lowered, and add additional absorption to the main volume because the surface of the gaps becomes absorbent.
- The variable curtain-absorption on the ceiling effects only the late reflections (300-800 ms, reverberance) and not the early reflections (0-100 ms);
- The desired variation of reverberation times between 1,5 s (LLL) and 2,5 s (HHH) could be achieved, based on a height difference of 8m for the moving ceilings (in the scale model this height difference was possible because in this early stage the grid level was still low at 9.5m+ and height-obstructing theatrical-technical limitations discovered in the building phase were not yet known);
- Opening the rear stage wall leads to loss of early energy and a slight increase of reverberance (if rear stage is empty) and thus a lower CL-80 value;
- Adding theatre-drapes on stage with all ceilings low (LLL) will reduce T30 to 1,2 seconds;
- No concentrated or disturbing late reflections were measured, mainly due to the shoebox shape, as long as a minimal amount of diffusion on all the walls and the ceiling is applied. In the early design phase the diffusion in the scale model consisted of wooden laths (size 6x6 mm (1:16); 96x96 mm (1:1)) in a rectangular mesh (size 100x100 mm (1:16) ; 1.6x1.6m (1:1)), see figure 16.
- The large amount of variability of the different (acoustic) provisions (3 independent ceilings, acoustic ceiling curtains, theatre-drapes, variable stagewalls) will require an significant period of testing and experimenting after completion and should for practical reasons preferably result in a limited number of fixed settings.

All recommendations based on the scale model study have been implemented in the further design. Based on the positive conclusions of the scale model study with respect to the variable acoustics achieved the design process was proceeded.

5 RESULTS ACHIEVED

5.1 Description of measurements and listening experience

Measurements of the reverberation times have been performed several times during the final stages of construction in order to control the development of its acoustics during the finishing process and to gain information about the contribution of separate elements to the total absorption. This process is however usually quite chaotic and during the building phase acoustic provisions like the movable ceilings or curtains were not yet functional, which made comparison and interpretation of subsequent results rather difficult. As soon as the wall and ceiling surfaces were fully closed and the floor was finished a reverberation time of 4,4 s in the empty hall (no chairs) was measured. Based on this result final judgement has been made on the choice and detailing of the chairs that had to be delivered a few months later.

As soon as the hall was almost finished (February 2005) several listening tests have been performed during test sessions with several orchestras and soon afterwards during regular concerts. These concerts have lead to enthusiastic first reactions, from the initiator, the musicians and the public, as well as in the press, from “an acoustic miracle” to “an amazing acoustic quality”. One year later these impressions are still similar. Its acoustics are surprisingly clear, transparent and diffusive, with a high definition, envelopment, support and uniformity, which is in our view mainly due to its shoe box shape, proper dimensions, two slim side balconies and the carefully selected diffusivity and texture of the walls.
In between the busy booking schedule one day has yet been available to perform acoustic measurements. On 23 may 2005 measurements of the impulsresponse have been performed between similar positions as in the scale model, using two different noise sources (fig. 18,19). These are used to evalute energy-time curves as well as for auralisation purposes. Also seperate reverberation measurements have been done (using an alarmgun). Using a large amount of specific cloth and helping hands, all chairs were covered with cloth, see figure 18 and 19. With this method Peutz was able to measure the hall in a simulated occupied condition, indicated as “occupied”.

Figure 18. Interior of concerthall during measurements using “dodecahedron” soundsource, with simulated occupation.

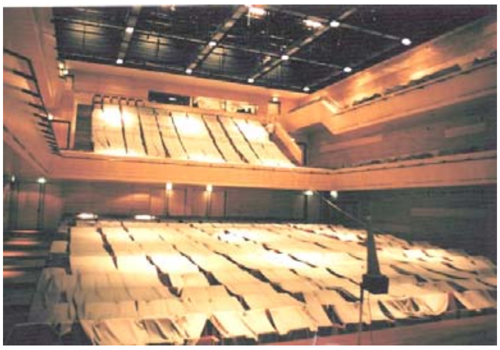

Figure 19. Interior of concerthall during measurements using “noise cone” point-soundsource.

Because a negative effect of theatre-drapes on the halls natural acoustics was expected and already observed during several concerts where these were not (fully) removed, the influence of 400 m^2 of theatre-drapes was also measured, both on the impulsresponses as on the reverberation times. Several variants were measurements with different positions of the theatre-drapes. Hanging on stage in front of all of the stage walls (0-10m+), see figure 20, or pulled up as high as possible above bridge level (10-20m+). In this case the theatre-drapes are almost out of sight but still within the acoustic volume of the hall (see figure 21), depending on the height of the moving-ceiling. This could only have been improved if a stage height of 30m was designed instead of 20m. Alternatively also a variant is measured where all theatre-drapes are fully removed out of the hall.

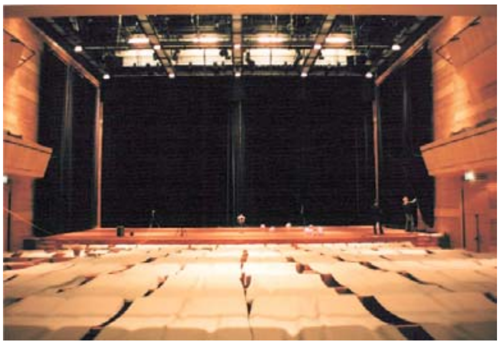

Figure 20. Theatre-drapes on stage.

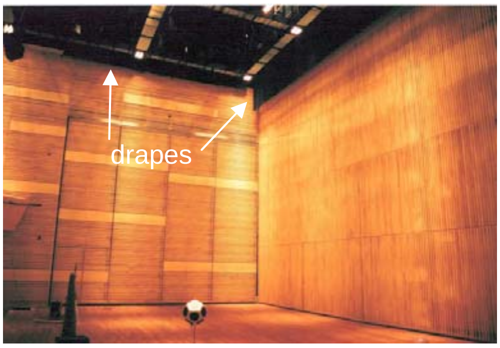

Figure 21. Theatre-drapes pulled up

Additionally the reverberation time was also measured during a specific concert on July 7th 2005 with full cooperation of the performers and the audience, whereby 2 different ceiling settings have been measured, unoccupied as well as with full occupation of audience and orchestra.

5.2 Reverberation times (T30) measured

Reverberation times (T30) calculated based on the decays measured in most relevant settings are summarized in table 1, all averaged over at least 6 decays at random positions through the auditorium. "LLL" means all ceilings low (including extracted ceiling curtains unless otherwise mentioned) and "HHH" means all ceilings maximum height. Three values for T30 are given, the 500 Hz octave value, and values averaged over the octaves from 125 Hz to 2 kHz resp. up to 4 kHz. Variations of T30 over different positions in auditorium are within 0,1 s (125Hz–4kHz). In figures 22-25 several results are given as a function of frequency.

Table 1 Measured reverberation times (23 May 2005 (no.1-10), 7 July 2005 (no.11-14)) in different settings

No	Setting ceilings/ occupation seats	Other specifications	T30 (seconds):			Figure
			500 Hz	125 Hz - 2kHz	125 Hz - 4kHz	
1	LLL, empty	theatre drapes high	1,86	1,90	1,83	25
2	LLL,"occupied"	theatre drapes high	1,65	1,69	1,63	23,25
3	LLL,"occupied"	theatre drapes low	1,24	1,37	1,32	22,23
4	HHH,"occupied"	theatre drapes high	2,1	2,08	2,0	23,25
5	HHH, "occupied"	theatre drapes removed	2,51	2,50	2,40	22,24
8	LLL,"occupied"	theatre drapes removed	1,8	1,82	1,75	22,24
9	LLL,"occupied"	theatre drapes removed, ceiling curtains in box.	2,33	2,21	2,12	24
10	HHL,"occupied"	theatre drapes high	2,06	2,04	1,96	-
11	HHH, unoccupied	100 m2 theatre drapes, side stagewalls open	2,6	2,56	2,66	-
12	as 11: with full audience and orchestra		2,40	2,32	2,40	-
13	Ceilings half high, unoccupied	100 m2 theatre drapes, side stagewalls open, ceiling curtains in box.	2,45	2,31	2,40	-
14	as 11: with full audience and orchestra		2,22	2,10	2,18	-

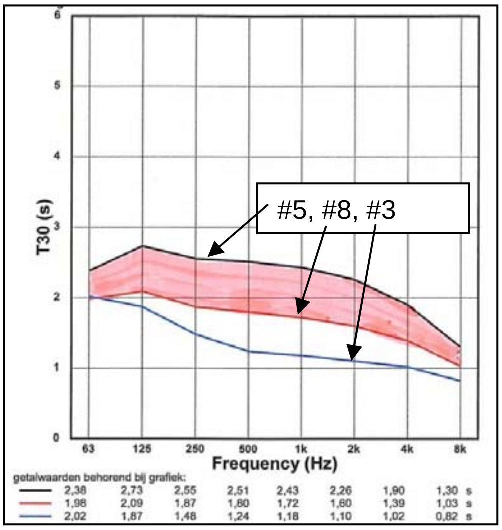

Figure 22. T30 measured in variant #5, #8 and #3. Red area indicates influence of moving ceilings (including ceiling curtains).

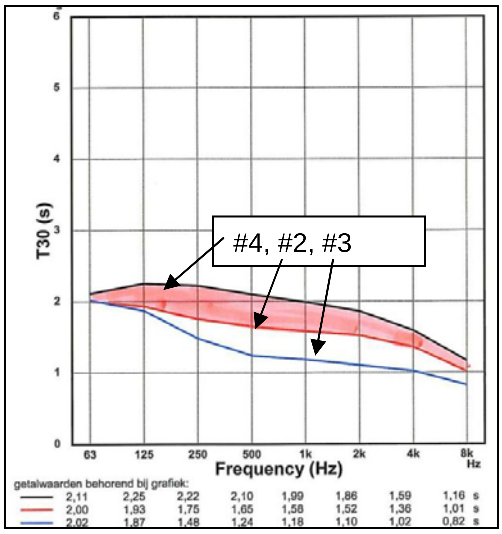

Figure 23. T30 measured in variant #4, #2 and #3. Red area indicates influence of moving ceilings, limited through presence of theatre drapes.

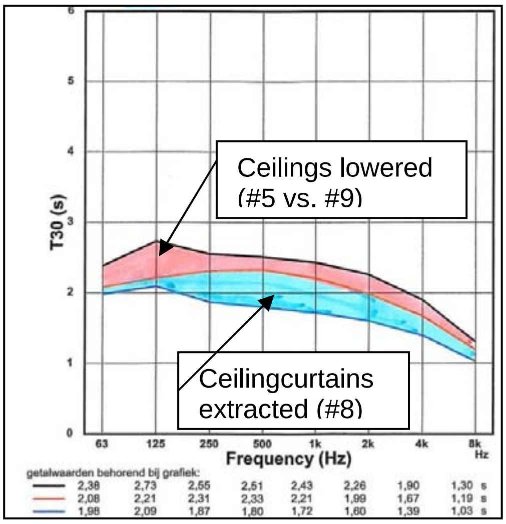

Figure 24.. T30 measured in variant #5, #9 and #8. Seperated effect of lowering ceilings (red) and extracting ceilingcurtains (blue)

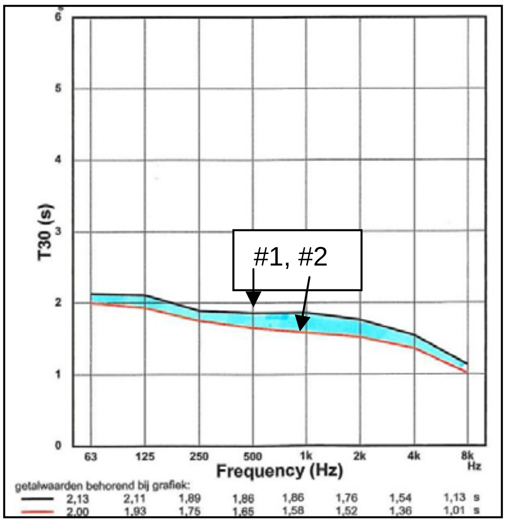

Figure 25. T30 measured in variant #1 and #2. Influence of (simulated) occupation on all 730 chairs (blue).

Based on these measurements several conclusions have been drawn, the most relevant being:

- In occupied condition with all ceilings high (HHH) the maximum T30 of 2.5s aimed for is just realized (#5), provided all theatre-drapes are removed (as should be usual in a concerthall). See figure 25. This is realized despite the 25% higher volume per seat (15.8 m^3 instead of 12.5 m^3). This means that apart from seats and audience other elements in the hall cause a higher soundabsorption than usual in concerthalls, but that this is however just within the allowable limits. Most likely elements are expected to be the laths-on-walls (with a high amount of wood-surface (ca. 2200 m2)), and all moving elements (floor, stage walls, ceilings) with their gaps and slots involved.

- Lowering the ceilings to the minimum height (LLL) reduces T30 with 0,7 s. to 1.8s. (#8), so the aimed value of 1.5s is not fully realized and exceeded with 20%, see figure 25. This is mainly caused by the large volume per seat of 10,5 m³, that is 40% higher than aimed for (7.5 m³). Lower T30 values of 1.7 sec will occur if theatre-drapes are hung high (#2, see fig. 21,23)) or down to 1.3 sec if all theatre-drapes lowered on stage (#3, figure 20,22,23).
- The ceiling curtains in the void above the lowered ceilings prove to be essential for a reduction of the reverberation within the hall. Lowering the ceilings reduces T30 from 2.5s to 2.3s (#5, #9), but further reduction of T30 to 1.8s only occurs when all ceilingcurtains are pulled out of their box (#8). This effect is spectrally illustrated in figure 24.
- Theatre-drapes, also if they are retracted high above stage and apparantly out of sight (fig. 21), have a reducing effect on the variation of reverberation times because the drapes remain within the acoustic volume of the hall. The variation reduces from 0,7 s. to 0,4 s. Maximum T30 reduces from 2.5s (#5) to 2.1s (#4), and with ceilings low from 1.8s (#8) to 1.7s (#2). Spectrally the difference can be seen comparing figure difference figure 22 and 23. Also the gain and loudness of the hall is effected, which should be avoided for unamplified music, both for audience and for performers.
- Reduction of T30 due to occupation of all 729 seats is around 0,2s (see #2,#1,#11-#14). Spectrally the difference is displayed in figure 25.
- Values of Bass Ratio are determined to be 1.07 (HHH) or 1.12 (LLL).

5.3 Impulsresponses

On 23 may 2005 measurements of the impulsresponses have been performed using a standard Maximum Length Sequence method (MLS) between comparable source and microphone positions as in the scale model, using two different noise sources (fig. 18,19). These are used to evaluate energy-time curves as well as for auralisation purposes.
Based on the measured impulsresponses for 24 source-microphone combinations the Energy Time Curves (ETC) have been calculated. For interpretation a 20 ms filtered version is usually applied to simulate the time-filtering effect of the human ear. If several ETC's of the same source-microphone combination but from different variants are combined in one graph, one can judge the difference in sound level and time. In figure 27 combined ETC's (1kHz) are given between rear stage and 2nd side balcony for variant #2 and #4. Clearly the increased early sound causes by lowering the ceilings can be observed, as well as the reduced reverbarant sound level. This difference could have been higher, which is illustrated in figure 26, in which the reduction of soundlevel due to remaining theatre-drapes ("stage-curtains high") can be judged.

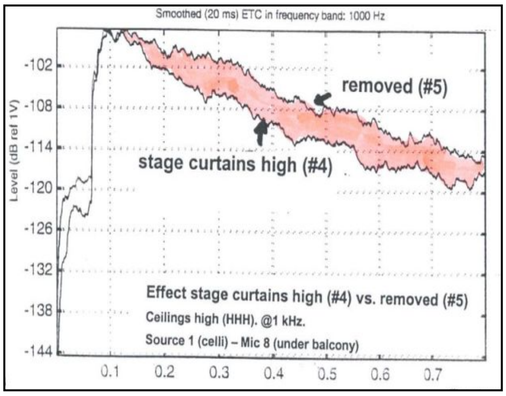

Figure 26. Combined ETC (1kHz) for #5 and #4.

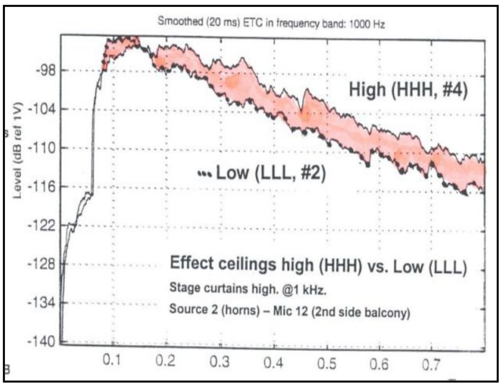

Figure 27. Combined ETC (1kHz) for #2 and #4.

5.4 CL-80 values

From the measured impulse-responses several acoustic parameters have been calculated. Such as Dir/reverb-ratio, C50, C80, D50, D80, ST1, ST2, EEB, Tcenter, EDT, T30, S/N. An example of the graphical presentation is given for the Clarity C-80 @1kHz in figure 28 and 29. It can be concluded than a significant effect on CL-80 is obtained through lowering the ceilings (and extracting ceiling curtains), especially for positions from 10m and further from the source (number 7 and higher).

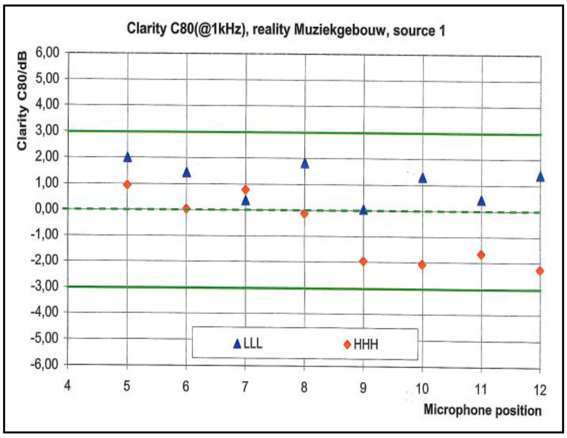

Figure 28. C-80 value for different micro-phone positions through the hall (#5 vs. #2). Source front stage.

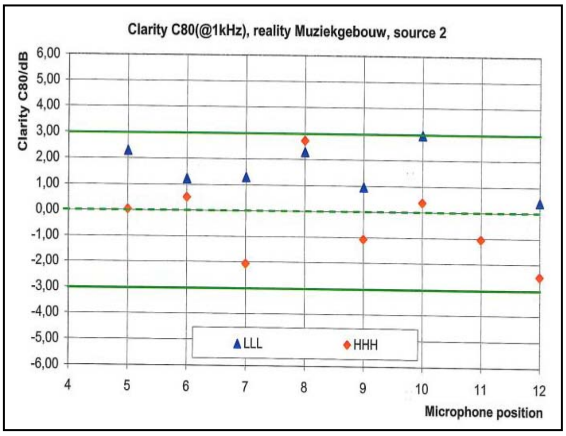

Figure 29. C-80 value for different microphone positions through the hall (#5 vs. #2). Source rear stage

5.5 Decrease with distance

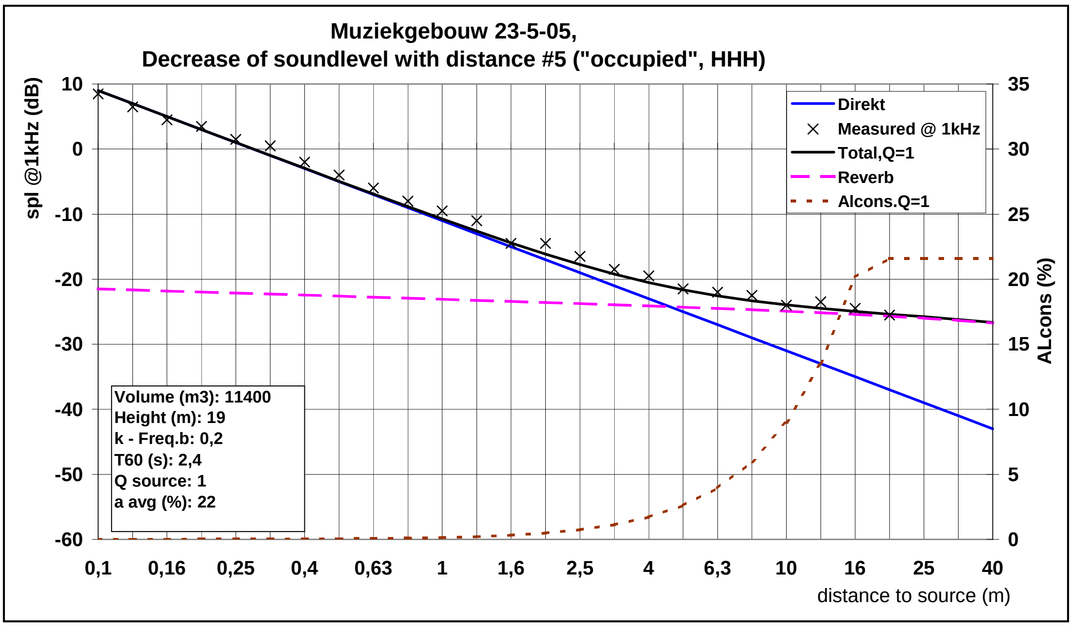

Figure 30. Decrease of soundlevel (@1kHz) with distance in variant #5.

Using a standard point source (Bose 102 with "nose-cone") placed on stage the decrease of sound level with increasing distance into the auditorium has been measured for several variants. Using the standard Peutz equations[1] for this decrease with distance this method is suitable to match the theoretical curves to the measurements and determine relevant parameters like the acoustical volume of the room and the average absorption. An example of the result for variant #5 (HHH) is

given in figure 30. An average absorption of 22% is deduced as well as an acoustical volume of 11400m^3. This volume fits well with the actual maximum volume based on the drawings.
The average absorption of 22% (summed surfaces ca. 3200 m^2) can roughly be divided in two main contributions: Assuming an average absorption for the occupied seats (490 m2 surface) of 70% (@1kHz (based on laboratory measurements) a preliminary deduction for the average absorption for the summed other surfaces (floor, walls and ceilings of 2600 m^2) of 14% is deduced. Though this is significantly higher than compared with figure 15 (laboratorymeasurement of the absorption of the laths), the contribution of absorption of the plastered wall behind the laths, and all gaps, slots, theatre-technical equipment etc. is excluded in this assumption. A lower average absorption than 14% for the walls and ceilings may therefore be expected. Nevertheless, assuming a total nett surface of wood of more than 4200 m^2 inside the hall a slight change in absorption due to microporous effects (like less sealant paint/lac, or dust) may cause a significant effect. In that respect the summed amount of horizontal woodsurfaces in de lath-structure of the wall may be considered sensitive for accumulation of dust and may therefore require regular cleaning. Feed-back about practical experience may be gathered in near future.

6 CONCLUSION

Measurements as well as listening experience have shown that the concerthall of the new “Muziekgebouw aan ‘t IJ” in Amsterdam (NL) has significantly variable acoustics, using moving ceilings. Its acoustics are surprisingly clear, transparent and diffusive, with a high definition, envelopment, support and uniformity, which is largely due to its shoe box shape and proper dimensioning, the two slim side balconies and the carefully chosen diffusivity and texture of the walls and ceilings. In practical use attention should be given to eliminate the residual absorption effects of theatre-drapes.
In short time the Muziekgebouw-building has created an already widely appreciated meeting place for musicians, music-lovers and music organisations and an additional hot spot to the cultural daily life in Amsterdam.


Figure 31. Exterior of the “Muziekgebouw aan ‘t IJ” in Amsterdam

7 PROJECTTEAM

Client	Municipality of Amsterdam
Architect	Nielsen, Nielsen & Nielsen (Denmark)
Acoustics/buildingphysics	Peutz (Netherlands) www.peutz.nl
Buildingcosts	30M€ (Muziekgebouw & Bimhuis)

8 REFERENCES

1. J. van der Werff, Behaviour of loudspeaker sound in autotunnels, Proc. 90th AES, 1991, Paris (1991).