STAVANGER CONCERT HALL, ACOUSTIC DESIGN AND MEASUREMENT RESULTS

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1 INTRODUCTION

September 2012 saw the opening of a new concert hall in Stavanger, Norway. The 1,500-seat *Fartein Valen Hall* has been critically acclaimed and is considered by musicians as well as critical listeners as one of the most successful recent concert halls.

The acoustic design includes geometrically optimized surfaces for early reflection direction to all seats, a variable height ceiling, overstage acoustic reflectors and free-hanging side balconies. A full set of acoustic measurements has been performed in the hall in 2013 and results of the measurements are presented. The acoustic quality of the hall combines a long reverberation time, in excess of 2 seconds, with high clarity and very high lateral efficiency.

The project acoustic design was developed as a partnership of three acoustic consulting companies, Sinus AS (Norway) was responsible for building acoustics, Akukon Oy (Finland) was responsible for the acoustic design of the flexible hall, and Kahle Acoustics (Belgium) was responsible for the acoustic design of the Fartein Valen concert hall discussed here.

2 FROM THE BRIEF TO THE FINAL DESIGN

The project for a new concert hall in Stavanger (Nytt Konserthus i Stavanger) was first defined in a rather detailed architectural and acoustic brief, by Tor Halmrast. For the main symphony hall, the client and the users asked for a 1500-seat shoebox concert hall with three balconies. An occupied reverberation time of at least 2.1s was requested, as well as a high amount of early reflection to ensure uncompromised musical clarity.

The Stavanger Symphony Orchestra (SSO) has a repertoire comprising both main symphonic works and baroque music. Excellent acoustics was thus required for chamber music ensembles as well as large symphony orchestras. During the international architectural competition, the question of whether the hall should have a movable ceiling of variable height or reverberation chambers as a mean of variable volume was left open and to the discretion of the architects. The winning design by Medplan Arkitekter (now Ratio Arkitekter, from Oslo) showed that both solutions could be accommodated within their proposed architectural design. After the end of the architectural competition, but still prior to the selection of the acoustical consultant, a decision was taken against reverberation chambers and for a movable ceiling.

When Kahle Acoustics came into the project, two main design changes were implemented in collaboration with the architects, with the aim to strongly enhance the visual and acoustic intimacy of the hall as well as the general acoustic quality. Firstly, the initial design by Medplan / Ratio had a hall width of 26m. While appropriate for a large-scale concert hall we considered this excessive for an intimate concert hall. The size of the main parterre was reduced, inscribing a smaller parterre (in both length and width) inside a bigger volume on the balcony levels. In addition, balcony overhangs were minimised for the rear balconies.

Secondly, the side balconies were detached from the walls, creating an additional acoustic volume behind floating balconies while reducing the width between the balcony fronts and getting the audience members on the side balconies closer to the centreline of the room. Downstand surfaces located under the balcony soffits were integrated into the design in order to create strong lateral reflections to all audience members, both in the parterre and on the balconies, as well as strong reflections back to the musicians. The height of each level of side balconies was later adjusted to ensure the optimal acoustic efficiency of these corner reflections. The coupled volumes created behind the floating side balconies differ from the usual reverberation chambers in the fact that they are not intended as a variable acoustic device (no variable closure is provided) but rather as a way to enhance the spaciousness of perceived reverberation.

The movable ceiling was maintained, and overstage acoustic reflectors were added to the design. Those were hung freely from the movable ceiling in order to allow for an independent tuning of acoustic volume and stage support. Acoustic curtains were installed on motorised curtain tracks along the side walls of the concert hall, in the additional coupled volumes. They can be totally hidden in curtain boxes located on the four corners of the hall. When deployed, these curtains allow for a lower reverberation time for amplified events and brass band concerts. A vertically foldable rehearsal curtain was also installed in a curtain box integrated in the movable ceiling, above the rear rows of the parterre. When deployed during rehearsals, it is used to simulate the acoustic absorption of a full audience.

The room geometry was refined and optimised until the very end of the design phase with the aim of providing abundant early lateral reflections to all audience areas, including not only the parterre but also the rear and side balconies. The angle in plan and the vertical tilt of many surfaces in the concert hall, including the balcony fronts, downstands and control room walls were defined for that purpose.

Figure 1: Picture taken during the first rehearsal in the new Stavanger Concert Hall

The final dimensions of the concert hall are the following: Width of the hall, parterre: 18.7m (slightly reverse fan), to downstands (i.e. to end of corridor behind side balcony seats): 21.7m, to structural walls: 25.5m. Length of hall, stage edge to last row parterre: 19.6m, stage edge to rear wall: 29.4m, max: 43.5m. Height of hall, variable ceiling in lowest position: ~ 17m, variable ceiling in lowest position: ~22m. Volume of hall, with low ceiling: ~16,000m³, 10.5 m³/person, with high ceiling: ~20,000m³, 13.3 m³/person.

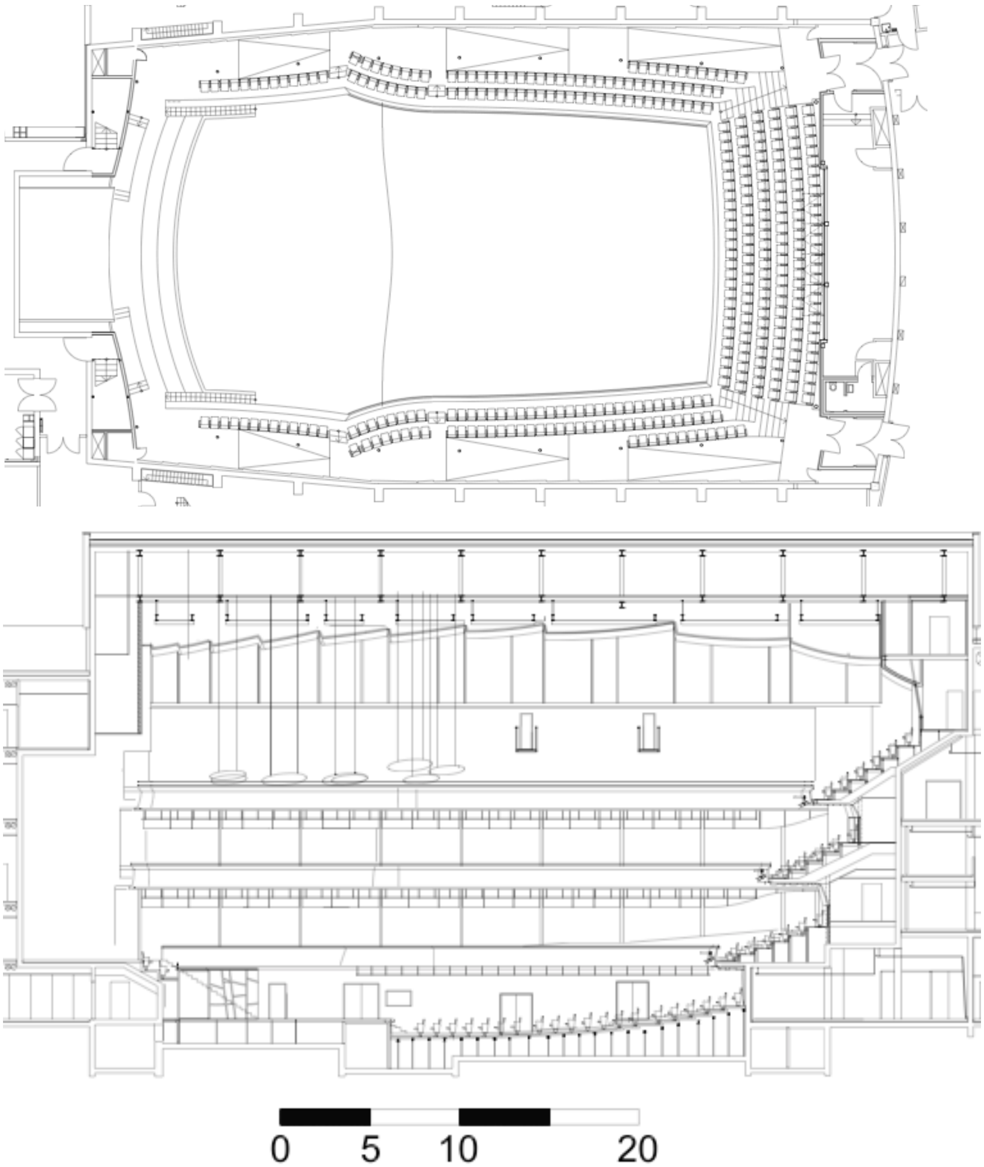

Figure 2: First balcony plan and long section of Fartein Valen hall

3 SCALE MODEL STUDY

In order to evaluate in detail the value of the acoustic design for Fartein Valen hall, it was decided to build an acoustic scale model at 1:25 scale.

The main purpose of the scale model study was to investigate the acoustical effect of the floating side balconies and to confirm that the coupled volumes had the intended acoustic behaviour. While computer simulations using both CATT-Acoustic and Odeon software were also used to guide the acoustic design, the diffraction and coupling phenomena involved could not be simulated with a sufficient level of accuracy. The client-side acoustic consultant on the project, Tor Halmrast from Statsbygg, consequently advised to proceed with this scale model study in order to assess the acoustic superiority of the design over any of the other design options relative to floating or non-floating side balconies, and have full confidence with this innovative design option.

Figure 3: Picture of the 1:25 scale model in its main configuration

3.1 Measurement equipment

Impulse responses were measured using an omnidirectional sound source consisting in a tetrahedral arrangement of four piezoelectric capsules. Two omnidirectional microphones were used as receivers. Swept sine was used as a test signal, allowing for acoustic parameter measurements in octave bands centred on frequencies between 3125 and 50,000 Hz (125 to 2000 Hz in real scale). Temperature, humidity and barometric pressure were also measured in order to allow for a correction of the frequency-dependant air attenuation.

3.2 Measurement procedure

An Oslo-based model builder, Modellfabrikken, built the scale-model. Its testing was conducted by Kahle Acoustics and LIMSI-CNRS. 3 source positions, 22 receiver positions and 9 different configuration of the scale model were measured and analysed. Five of these room configurations were chosen specifically in order to assess the effect of the floating side balconies and coupled volumes.

For all of those five configurations, the movable ceiling was set at its highest position and the stage reflectors were set at an average height of 14m above stage floor. The first configuration, named "DWST" is representative of the intended and finally built design, with floating side balconies, downstand reflective surfaces, and coupled side volumes. For the configuration named "noDWST", the downstand surfaces located underneath the balcony soffits were removed. For the configuration "sides closed", side volumes were taken out by adding vertical side walls just behind the side balconies. This configuration simulates a classic shoebox design with narrow side balconies attached to the side walls. The configuration named "interm_DWST" was similar to "DWST", but with intermediate floors added in the additional side volumes at each balcony level, fastening the side balconies to the side walls. Finally, the configuration named "interm_noDWST" was the same as "interm_DWST" but without the downstand reflective surfaces.

All measurements correspond to fully occupied conditions. Audience members were modelled with 9mm thick acoustic foam glued onto a 1mm thick plastic panel, and wooden beads to simulate the heads.

3.3 Measurement results

Table 1 provides a summary of the global results obtained from the scale model measurements for 6 traditional room acoustic parameters[1] at mid frequencies (frequency averaging according to ISO 3382, receiver locations closer than 10m excluded).

Table 1: Measurement results for 5 configurations of the scale model.

	DWST	noDWST	sides closed	interm_DWST	interm_noDWST
T30 (s)	2.32	2.31	2.22	2.34	2.31
EDT (s)	2.06	2.06	1.99	1.96	1.95
G80-∞ (dB)	0.68	0.97	0.63	0.50	0.48
G0-80 (dB)	-1.16	-1.34	-0.91	-0.97	-1.50
G (dB)	3.00	3.08	3.04	2.95	2.74
C80 (dB)	-1.85	-2.31	-1.55	-1.46	-1.99

Variations of acoustic parameters are small and often inferior to just noticeable differences (JND), but some consistent results emerge. Firstly, configuration “DWST” provides an increase in early energy parameters (G0-80 and C80) compared to configuration “noDWST”, confirming an increased efficiency of the design in terms of early reflections. Even higher amounts of early energy are obtained with the classic shoebox design (“sides closed”), but at the expense of reduced acoustic volume and reverberation time.

Secondly, the additional side volumes are shown to be efficient in prolonging the reverberation of the hall. The scale model measurements show a 0.1 second increase of T30 when these side volumes are open to the main volume, T30 being virtually identical for all the configurations in which these side volumes are open (fluctuations inferior to measurements uncertainties).

Thirdly, the addition of intermediate floors is found to reduce the energy of the reverberant field (G80-∞) as well as EDT. On the contrary, the widest opening towards the side volumes obtained in configuration “noDWST” increases the amount of late energy.

The last two observations confirm that the finally built design (configuration “DWST”) creates a slightly longer reverberation than a classic narrow shoebox design (configuration “sides closed”) while providing a similar amount of energy for the late field. Late energy is made to arrive at the listeners’ ears slightly later, which is thought to increase the feeling of reverberation with no detriment to musical clarity. On the contrary, configuration “noDWST” provided the highest amount of late energy, but no increase of reverberation time with respect to the final design.

Acoustic parameter variations over the different audience seats were also studied with some interesting results. Confirmation was found the side volumes acted as “acoustic chimneys”[2], conveying late energy towards the audience members on the 2nd and 3rd balcony levels from either lateral or rear directions, and slightly reducing the “overhang effect” (typical decrease of sound levels under balcony overhangs).

The scale model measurements were successful in providing sufficient confidence in the floating balcony design as developed. In addition, global results were very encouraging, with all acoustic parameters being within the desired ranges. The scale model was also used to detect and rectify a few architectural and acoustic details that required further improvement. In particular, all details regarding acoustic finishes and surface roughness for acoustic diffusion were decided based on the results of the scale model study.

4 MEASUREMENTS IN THE BUILT HALL

Following the successful opening of the concert hall in September 2012, a full set of acoustic measurements of the completed Fartein Valen hall was carried out. The intention was both to objectively confirm the outstanding acoustic quality unanimously perceived during the first rehearsals and concerts, as well as provide a final acoustic instruction manual for the users. The various acoustic settings of the concert hall suggested in the user manual were defined based on both critical listening of several concerts and rehearsals during the first year, and on the results of acoustic measurements conducted in may 2013 by the LIMSI-CNRS, Kahle Acoustics, and Sinus AS.

4.1 Measurement equipment

Impulse responses were measured using several omnidirectional loudspeakers as sources (large dodecahedron source for low and mid frequencies, small dodecahedron for mid and high frequencies) and several types of microphones as receivers: omnidirectional microphones for main acoustic parameters, figure-of-eight microphone for measurement of lateral energy fraction, and an acoustic dummy head for measurement of Inter-Aural Cross Correlation coefficient IACC). Swept sine was used as a test signal.

4.2 Measurement procedure

3 source positions, 16 receiver positions and 6 different configuration of the concert hall were measured and analysed. Only the results for the main acoustic configuration, intended for symphony orchestras, are presented here. In this configuration, the movable ceiling was set at its highest position, overhung stage reflectors were set at a height of 15m above stage floor, and no acoustic curtain was deployed.

All measurements were conducted under unoccupied conditions. In addition, several impulse responses were measured during a test concert in may 2012, with a slightly lower setting of the movable ceiling and some details of the interior wood cladding not being entirely completed. An estimated occupied value for reverberation time T30 was obtained through extrapolation of these two measurement conditions.

4.3 Measurement results

Table 2 sums up the global results obtained from the scale model measurements for 10 traditional room acoustic parameters[1] at mid frequencies (frequency averaging according to ISO 3382, receiver locations closer than 10m excluded).

Table 2: Measurement results in the built hall

Occupancy	Acoustic parameter	Average value measured	Standard deviation
Fully occupied	T30 (s)	2.18	-
Unoccupied	T30 (s)	2.58	0.02
	EDT (s)	2.40	0.19
	G80-∞ (dB)	1.9	0.9
	G0-80 (dB)	0.3	1.2
	G (dB)	4.2	0.8
	C80 (dB)	-1.6	1.19
	1-IACC early	0.65	0.05
	1-IACC late	0.86	0.02
	LF	0.30	0.05
	ST1 (dB)	-12.1	0.6

The values obtained are globally consistent with those of the scale model measurements, configuration “DWST” being the closest to the completed hall. A direct comparison is however not possible on most of the parameters due to different absorption/occupancy conditions. The occupied value obtained for T30 is 6% smaller than in the scale model, which can be attributed to slight differences in material properties and the absence of surface roughness in the scale model. More surprisingly, the average value of C80 measured in the real hall under empty conditions is slightly higher than that measured in the scale model in fully occupied conditions. This is related to the early response (G0-80), which was 1.5 dB stronger in the real hall than in the scale model.

As required by the acoustic brief, fully occupied reverberation time in *Fartein Valen* hall is significantly longer than in most symphony halls. Unoccupied EDT is however quite similar to the values found in the literature[3] for famous shoebox symphony halls such as Boston Symphony Hall, Amsterdam Concertgebouw and Berlin Konzerthaus. And the C80 average value measured in Fartein Valen hall is 1 to 2dB higher than in those classic shoebox concert halls. Those observations confirm the special acoustic character of the new Stavanger concert hall: its acoustics is both highly reverberant and very clear. Perceived musical clarity is in fact even higher than what could be assumed from the EDT and C80 values, which the authors attribute to the spatial response of the hall characterised by an enveloping reverberation, spatially separated from the direction of the stage.

Fartein Valen hall has a well balanced sound strength (G): The sound is stronger than in many large-scale modern symphony, but still not as strong as in smaller-sized historic halls such as Vienna Musikverein (G = 6.3dB with similar source calibration method[4]), that can lead to uncomfortably high sound levels for large symphony orchestras. In this respect, the values obtained in Fartein Valen are perfectly suited to the needs of this concert hall. The lowest measured value for G parameter, corresponding to the quietest seat in the hall on the top balcony, and to a sound source located at the side of the stage, was 2.0dB.

The values obtained for 1-IACC_early and LF are very high. 1-IACC_early is similar to the highest values for famous historic shoebox symphony halls: according to the literature[3] Vienna Musikverein, Boston Symphony Hall, Berlin Konzerthaus, Zurich Tonhalle and Basel Stadt-Casino all have 1-IACC_early values between 0.61 and 0.65 (all within a just noticeable difference of 0.05). LF is actually even larger here than in those historic shoebox halls, and larger than the usually recommended values by about a just noticeable difference (0.05). This correctly corresponds to the very spacious sound perceived in this concert hall.

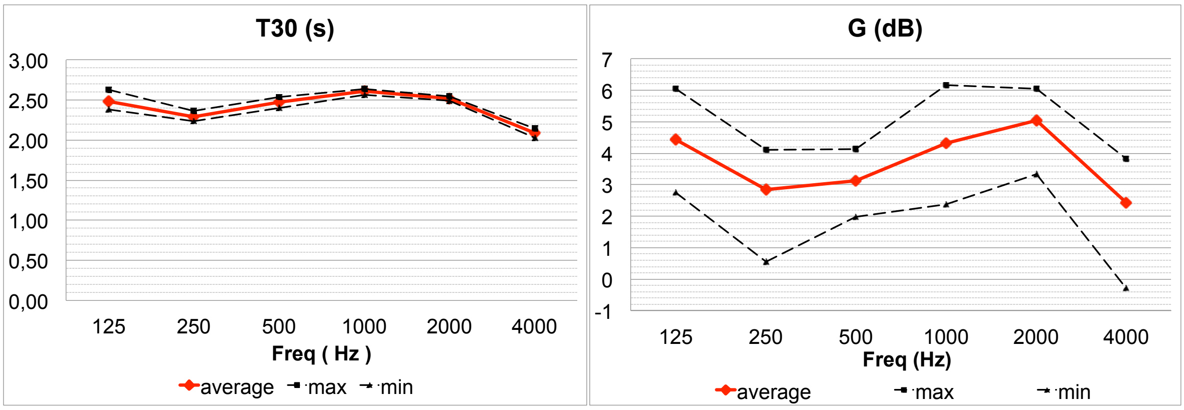

Figure 4: Measurement results summary for T30 and G parameters as a function of frequency

Another particular acoustic feature to Fartein Valen hall is a slight decrease in reverberation time at low frequencies (see Figure 4). A rise of reverberation time towards the bass frequencies is often recommended as it is sometimes linked to the goal of “good bass”. This design guide is in contradiction to observations in Stavanger concert hall where no one ever complained about a lack of bass. A similar drop-off is observed on the sound strength measurements (G). An open question for further investigation is whether the decrease in bass frequency acoustic response may be linked to the strong and beneficial vibration of the lightweight wood floors and seats in the parterre and balconies[5]. However, the average G value measured in the 125Hz octave band is 4.1dB, which – according to the work of L. Beranek[3] – places Fartein Valen hall among the concert halls with a very good bass response.

5 SUBJECTIVE FEEDBACK

First rehearsals of the Stavanger Symphony Orchestra in the new concert hall took place in May 2012. It was a success from the very first minute, with the first words of musical director Steven

Sloane being: “"Wow… The first thing you hear is… quality!” Musicians were all ecstatic about the acoustics of their new home[6].

The new concert hall finally opened to the public on 15th September 2012, with enthusiastic reactions from the press, music critics and acoustics specialists[7]. Since then, invited musicians and conductor consistently express high praise for the acoustics of Stavanger new concert hall. Two main quotations are the following. Danish conductor Thomas Søndergård after conducting the SSO, Bruckner’s 6th symphony on 7th November 2013: “One of the best halls in the world. Go to Stavanger as soon as you can! The hall has a presence both in the depth and in the higher frequency. The house is filled with love. It is unique what the little city of Stavanger has been able to do”. Piano soloist Leif Ove Andsnes after playing Beethoven’s 2nd piano concerto with SSO on 17th January 2013: “the best hall I have ever played in”.

6 CONCLUSION

The analysis of the measurement results confirms the acoustic success of this new concert hall in Stavanger and its very good place in the list of the most successful recent concert halls.

The acoustic characteristics that make the sound of Fartein Valen hall unique and recognizable are the following: 1 – Very generous reverberation providing richness to the orchestra sound and enveloping the listeners in a truly surround spatial response. 2 – Excellent musical clarity with no compromise on the strength of the reverberant sound, offering the opportunity to listen specifically to each instrument within the orchestra from any seat in the hall. 3 – Strong bass response associated with very distinct high frequency brilliance in the reverberation, enriching the timbre of musical instruments and enhancing musical dynamics[8]. 4 – Very high amount of early lateral reflections creating an impressive feeling of spaciousness and acoustic proximity of the listeners to the stage. 5 – Homogeneous acoustic conditions throughout the hall, low decrease of G over distance. 6 – Excellent acoustic conditions on stage characterized by a homogeneous acoustic behaviour of the stage platform, a high amount of early reflections and a well-balanced late feedback from the room. 7 – Comprehensive set of variable acoustic features to adapt the acoustics to the various types of events to be housed as well as to fine-tune the room response to the orchestral forces or the repertoire.

7 REFERENCES

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