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From acoustic brief to acoustic reality;

experiences from advising clients on recently built concert halls in Scandinavia

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ABSTRACT

This paper describes the author's experiences as acoustic advisor for the client in four concert hall projects in Scandinavia. For each of the projects, content of the acoustic brief, challenges in the process of realization and to which degree the acoustic specifications were fulfilled in the finished halls are presented. It is discussed how not only the content of the brief such as specifying the desired hall shape and reverberation time but also many other factors like economy, project management structure and attitude towards the press and public opinion can influence the process as well as the result.

Keywords: Concert halls, Room acoustic Design, Client advisor strategies

1. INTRODUCTION

Acousticians responsible for ensuring that the acoustic qualities of a new concert hall meet the client's expectations have to translate the client's – often ill articulated – acoustic preferences into words and figures, write them down in the acoustic brief and afterwards oversee or check that these specifications are fulfilled in the realized hall. Now, how important is this function and what determines whether the hall becomes a success or not?

The degree to which the client wishes to enforce that the acoustic brief is fulfilled might vary from cases where it is carefully checked that a certain set of acoustic parameters (as defined in ISO 3382) fall within narrow intervals to other cases where the client or acoustic designer show almost no interest in objective criteria at all (– often cases where the client simply relied on the reputation of a chosen acoustic designer, whom he - or influential people around him - had made sure to be appointed for the job). In such cases, the main function of the acoustic advisor may in some cases be to help facilitate a smooth process in which the client feels safe about the project progressing in a positive atmosphere (psychology rather than acoustics?) and leave the fulfillment of the brief to his own ambition.

The halls in question are listed in Table 1 below.

Table 1 - overview of halls discussed in this paper

Name	Location	Shape	Acoustic design	Opening year
Symfonisk sal	Aarhus, Denmark	Shoebox	Artec (Arup)	2007
DR Koncerthuset	Copenhagen, Denmark	Vineyard	Nagata	2009
Musikkens Hus	Aalborg, Denmark	Shoebox	Artec (Arup)	2014
Malmö Live	Malmö, Sweden	Shoebox	Akustikon	2015

The paths from brief to acoustic reality turned out to be quite different mainly due to differences in attitudes of people involved and to differences in organization and economy. This paper attempts

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to review these four projects – as seen from the perspective of the acoustic advisor - and it is discussed how management of the process rather than improvements in our acoustic knowledge could benefit future projects. Along the way, the measured acoustic parameters from each hall will be presented and compared to the targets in the briefs and to the general opinions about whether or not each of these halls has been acoustically successful.

2. THE ACOUSTIC SPECIFICATIONS

In all four cases described in this paper, the acoustic brief specified a target range for the reverberation time, maximum noise levels (minimum sound insultation) and limits on overall dimensions/minimum volume. In all four briefs, we also mentioned the importance of other acoustic qualities (fullness, clarity, spaciousness, sound strength, timbre, and musicians need of support and ability to hear each other) and that most of these can be simulated/measured through other ISO 3382 parameters than Reverberation Time (Early Decay Time, Clarity, Lateral Energy Fraction, Strength and Support on stage). It was mentioned that targets for these would be discussed/fixed during the design phase, and that these measures should be documented through computer or scale model studies during the design phase and be measured in the finished hall. However, no specific values for these other parameters were listed at the time of writing the competition brief, because it was realized that the exact combination of values achieved could depend on the chosen design and on how the design process would develop.

All four briefs also included some verbal descriptions of how the desired acoustic qualities should be promoted in the design. Besides avoiding acoustic faults, these more qualitative guide lines had the purpose of promoting what seems to be the acoustic "taste" for symphonic concert halls of today: to achieve high clarity as well as high reverberance (plus strong envelopment, of course). As discussed in [1], three basic shapes can be considered to achieve this combination, the shoe box (with or without reverberation chambers), the vineyard and Marshall's Directed Reflection Sequence concept. In all four cases, the desired basic concept was specified in the brief (see Table 1).

Besides specifying the desired basic shape and acoustic qualities, the brief texts also mentioned certain design aspects which would be important to meet the goals, like the requirement for properly sized and oriented reflecting surfaces sending early sound to both audience and musicians, size and terracing of the orchestra stage, stage floor construction (massive wood on joists), placing and number of choir seats, placing of audience with max. allowable number in stalls area (to ensure proximity to reflecting surfaces and braking up of the audience areas in terraces and balconies to assist macro diffusion), sight line requirements, limits on balcony depth and height (and on free sight to a certain percentage of the ceiling), and chair dimensions and degree of upholstery and a request for documentation of chair absorption values.

I the three projects in Denmark, it was possible arrange study trips to relevant concert halls during which the client representatives were "educated" by going to concerts and filling out forms about their acoustic experiences. For many of these people, this improved their understanding of and interest in the acoustic issues in the planning phase and helped to de-mystify this important functional aspect of the concert halls, for which they were responsible.

3. THE FOUR HALL PROJECTS

3.1 Symfonisk Sal, Aarhus, Denmark

This concert hall is part of a 13,000 m^2 extension to an existing hall complex in Aarhus. Besides the large hall and rehearsal facilities for the Aarhus Symphony Orchestra, the complex also includes a music conservatory and a small children 's theatre. The client followed the authors recommendation to go for a shoe box; but he also suggested that the acoustic requirements should be "guiding values" not mandatory requirements, because he was afraid that the costs would be too high. In the evaluation of the five entries submitted, economy weighted 40 %, "design and functionality" 30 % and acoustics only 8 %. Ironically, acoustic issues occupied most of the time in client meetings during the design phase. The winning team (the only one of five competing teams which promised to build the hall incl. the conservatory within the very tight budget of 40 mio Euro) had Artec as acoustic designer. The tight economy helped to reject a suggestion to add reverberation chambers to the project.

The project was well managed by the Aarhus Municipality and both the architects (C.F.Møller) and the general contractor (A. Enggaard, who must have lost money on this project) were very dedicated to the job.

Fortunately, suggestions, which came up along the way, to reduce the size of the hall and which would seriously have reduced both functionality and acoustic quality, were not implemented; but due to restrictions on building height, we had to accept a reduction of the volume from the desired 17,000 m^3 to 15,000 m^3.

An overview of basic features, acoustic requirements in the brief and measurement results can be found in the table below.

Table 2 – main acoustic data for Symfonisk Sal, Aarhus

Symfonisk Sal; Aarhus	Brief	Realized (2007)
Volume /No. seats	Shoebox; V ≥ 17,000 m^3 / 1200 + 100 for choir	V = 15,000 m^3 / 1200 + 100
Overall dimensions	Guiding: Length = 45m, Width = 22m, Height = 18m	L = 43m, W = 22m, H = 19m
Reverberation time (fully occupied)	≥ 2.2 Sec. (250 – 2000 Hz) ≥ 2,5 Sec. (125 Hz) Reduceable to ≤ 1.6 Sec. (250 – 2000 Hz)	= 2.2 Sec. = 2,6 Sec. < 1.7 Sec.
Background Noise	From ventilation and room light systems: Leq ≤ 20 dB(A) From external traffic: Lpeak ≤ 25 dB(A)	 Ventilation: Leq = 20 dB(A) Traffic: not measurable
Description in brief	Walls and ceiling partly clad with wood. A mix of heavy and light surface constructions to ensure lf control. Stage floor with manually moveable risers. Variable acoustic to be realized through moveable curtains and panels.	

Artec teamed up with acousticians from the Danish engineering company, Cowi, who fortunately were very concerned about meeting the acoustic requirements!

A photo from the finished hall is shown in Figure 1. As can be seen, the detailed shaping of the hall elements was well suited for building the hall from precast concrete elements, which contributed to keeping the building costs low.

Figure 1- Symfonisk Sal, Aarhus. View towards the stage

The room acoustic results have been well documented by Cowi (2) and matched the requirements very well as seen in Table 3.

Table 3 - Acoustic data from Symfonisk Sal, Aarhus; from (2)

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

A niche in the rear wall behind the stage was reserved for installation of a concert organ. This was realized in 2015 and resulted in a modification (for the better) of the reverberation time (unoccupied).

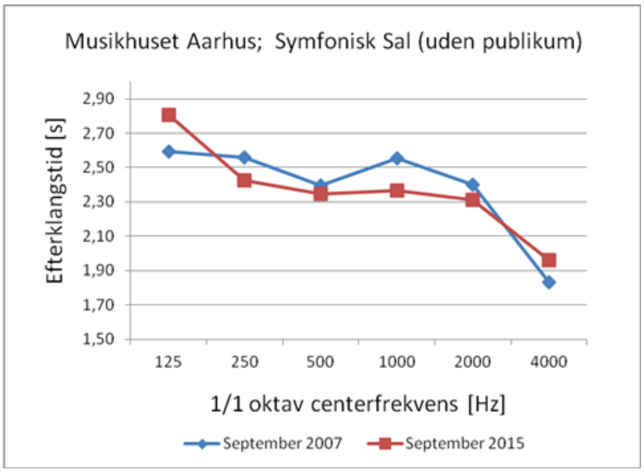

Figure 2 - Reverberation time (unoccupied) before and after installation of the concert organ

During the tuning sessions before the opening, the orchestra experienced problems regarding too much reverberation during rehearsals related to Artec's preference for using moderately upholstered seats – like in classical shoe box halls. This caused a quite large RT difference between empty and occupied. The orchestra had problems finding out how to compensate this difference by means of the variable absorption in the hall, because even with identical RT, it sounded differently when the absorption was placed in the upper part of the hall instead of in the seats. Artec suggested a number of "settings" of the variable absorber elements for different situations (degrees of occupancy and repertoire). There were also problems with meeting the – rather modest - noise criterion from ventilation and room lights! It took a couple of years before this was fixed.

Due to the choice of a budget solution for the beams supporting the rear balconies, the balcony fronts became very high, which caused poor view towards the ceiling from under these balconies.

The hall opened in September 2007, just 2 ½ years after the competition, and it has a general reputation for highly successful acoustics.

3.2 House of Music, Large hall, Aalborg

Also this building was to become the home of the local symphony orchestra and a local music conservatory. The project took very long to be launched. I started meetings with the client already back in the 1990'es during which the preference for a shoe box hall was agreed. Strong local enthusiasm ("The friends of the House of Music") managed to get some local funding but it did not match the high ambitions. By 2003 it became clear to me that the client already had a strong preference for a specific acoustic consultant to be appointed for the design – a decision which I felt would hinder an attempt to select the acoustic designer on the basis of more objective criteria and for acoustic specifications in a competition/building program to be respected. I therefore resigned as acoustic advisor and chose to participate in the upcoming "competition" as acoustic designer for the project. In the meantime, Coop-Himmelb(l)au had been chosen as architect. To my surprise, the acoustic brief I now received contained a feature named "Papageno feathers", presumably small panels which were supposed to cover most of the wall surfaces. These "feathers" should be moveable in size and orientation in order to reflect/enhance specific frequencies depending on the type or frequency register of the soloist. Artec was chosen for the acoustic design. (Our acoustic team was rejected – largely due to "lack of experience with reverberation chambers and Papageno feathers".)

In the following years the design changed several times due to a mismatch between architectural ambitions and the budget realities, and the project stopped completely in 2006 because the contractor offers substantially exceeded the budget. In 2007, the project was reorganized with the same design team but with additional, substantial financial support from Realdania (a large non profit foundation getting its income from real estate investments) - on the condition that they took over the project management (by occupying three out of seven seats in the board including that of the chairman). This resulting in firm leadership including a demand to hold the architect and acoustic designer fully responsible for any overrun of the new, higher budget. I was asked to reenter as acoustic advisor and a new PoR and ToR were written. Neither reverberation chambers nor Papageno feathers were included in the revised brief which actually became much like in Aarhus.

During the long design process, a "Letter of Understanding" had to be negotiated in order to allow for some deviations from the acoustic requirements in case it proved necessary to modify these in order to achieve the highest possible overall quality within the fixed budget. Finally, in 2014, the building was finished without any sacrifices regarding the acoustic demands to the large hall. The price was almost 100 mio Euro (more than twice the price of the Aarhus project for almost the same no. of square metres).

The main data for this hall are listed in Table 4 below.

Table 4 – main acoustic data for the Large Hall, House of Music, Aalborg

House of Music; Large hall, Aalborg	Brief	Realized (2014)
Volume /No. seats	Shoebox; $V \geq 17{,}000$ m^3 / 1200 + 120 choir	$V = 18{,}000$ m^3 / 1200 + 120
Overall dimensions	Guiding: Length = 45m, Width = 22m, Height = 18m	L = 43m, W = 21-26m, H =19m
Reverberation time (fully occupied)	≥ 2.1 Sec. (250 – 2000 Hz) ≥ 2,4 Sec. (125 Hz) Reduceable to ≤ 1.5 Sec. (250 – 2000 Hz)	≥ 2.3 Sec. = 2,6 Sec. < 1.4 Sec.
Background Noise	From ventilation and room light systems: NR10 From external traffic: Lpeak ≤ 20 dB(A)	Not measured Not measured
Description in brief	Stage floor with mechanically moveable riser lifts. Variable acoustic to be realized through moveable curtains. Variable stage front: stage, audience floor or orchestra pit. Choir balcony and organ behind the stage. Balconies in two levels.	

Contrary to Aarhus, the detailed shaping of the hall is more organic with many curved walls and balcony fronts as shown in Figure 3.

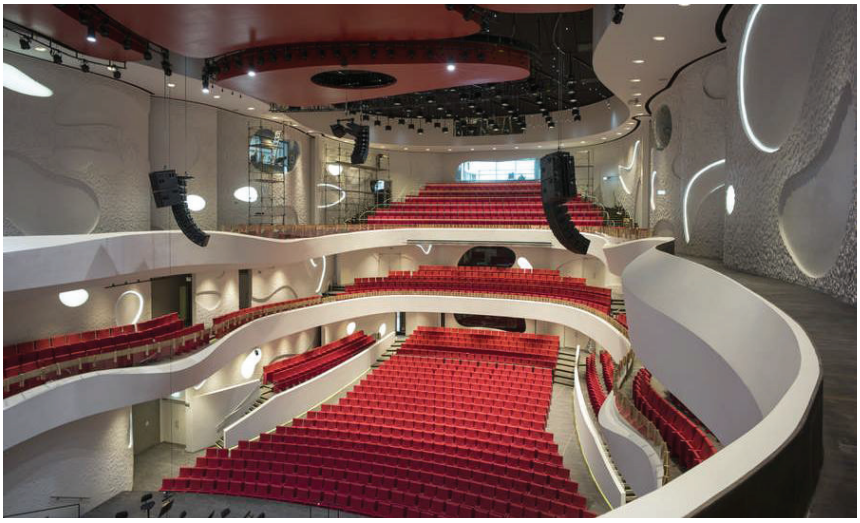

Figure 3 – The Large Hall, House of Music, Aalborg

Very large areas of variable banners can be deployed meaning that the RT range of variation is very large as can be guessed from the measured curves in the unoccupied hall shown below.

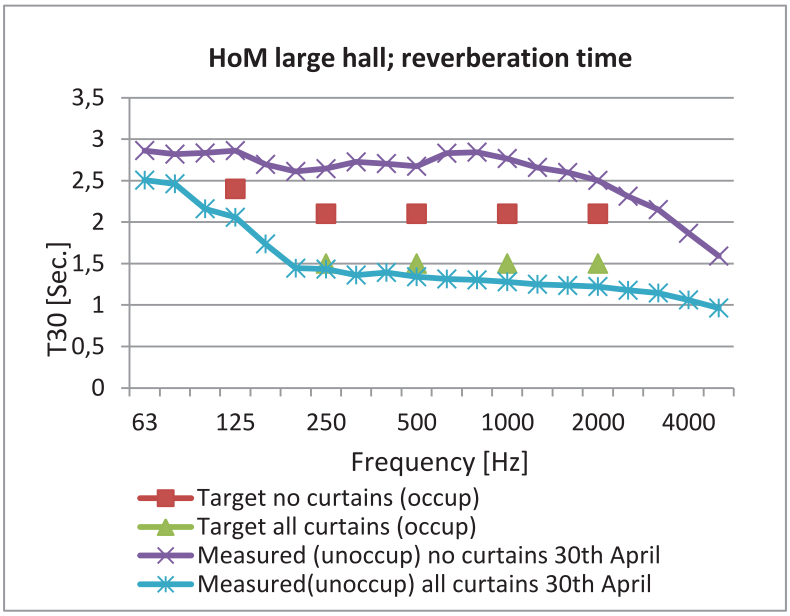

Figure 4 – Target and measured values for Reverberation Time in the Aalborg Hall

The hall is well liked for symphonic music. The long RT at low frequencies is a problem for amplified events (which occupy a large percentage of the program schedule).

To our knowledge, only RT – in the unoccupied hall - has been checked after completion. The author's role as acoustic advisor became more distant in the late building phase. Often, the client is pretty exhausted and short of money near the end of the process, which means that the calls for assistance become less frequent . . .

3.3 The Danish Radio Concert Hall, Koncerthuset, Copenhagen

For the new Danish Radio concert hall in Copenhagen, which opened in 2009, the brief specified that the shape should follow the vineyard principle. The main reason was that the (partly politically elected) building committee found that this shape distributes the audience in a more "democratic" way than the classical shoe box (which can be accused of ranking the audience after row number). With all seats being placed on open terraces, the seat absorption area is fully exposed to the reverberant sound field in contrast to halls where some seats are hidden under balconies. Consequently, the volume per seat needs to be larger than in a shoe box hall with over hanging balconies. With larger volume, the Sound Strength will be lower, unless also RT is increased. Therefore, we specified a higher minimum RT for this hall than for the shoe box halls.

The main data for this hall are listed in Table 5.

Table 5 – main acoustic data for the Large Hall in the Danish Radio Koncerthuset, Copenhagen

Danish Radio Concert Hall KoncerthusetCopenhagen	Brief	Realized
Volume No. seats	Vieneyard; $V \geq 22{,}000\ m^3$ 1600 + 200 choir	$V = 26{,}000\ m^3$ 1600 +200
Overall dimensions	No guiding values given	L = 55m, W = 40m, H = 25m
Reverberation time (fully occupied)	≥ 2.3 Sec. (250 – 2000 Hz); ≥ 2,6 Sec. (125 Hz) Reduceable to ≤ 1.6 Sec. (250 – 2000 Hz)	= 2.0 Sec. = 2,1 Sec. = 1.5 Sec. (calc.)
Background Noise	From ventilation and room light systems: NR15 From external traffic: NR15	NR17 < NR15
Description in brief	Stage floor with semicircular mechanically moveable riser lifts. Variable acoustic to be realized with curtains. Stage size variable between 100 and 300 m2. Choir balcony and organ behind the stage.	

The volume turned out to be much higher than specified, about 26.000m3, which may contribute to a not very loud and enveloping sound. Both our computer modelling and scale model studies carried out in Nagata's 1:10 scale model (Nagata mainly used the model for checking echoes and studying sound build up) indicated that the RT requirements in the brief would be fulfilled; but unfortunately the result was a substantially lower value – well in accordance with the fact that lack of reverberance/fullness has been the main point of criticism since the hall opened in 2009. One reason for the low RT could be that large perforated panel areas on the upper walls were installed in the hall in order to avoid echoes from these distant surfaces. Another reason could be excessive absorption from the unusually high, upholstered back rests in the audience seats. In 2010, a certain part of perforated upper walls was modified to reduce the absorption; but the effect was limited. After the 2010 modification, RT in the occupied hall was measured during a concert (decay from the Beethoven Coriolan Overture) indicating the values shown below. As can be seen, the requirement for the values at low frequencies to increase to no less than 2.5 Sec. wasn't fulfilled either. Consequently, many critics have found the hall to be too dry and lacking fullness, while others appreciate the high clarity.

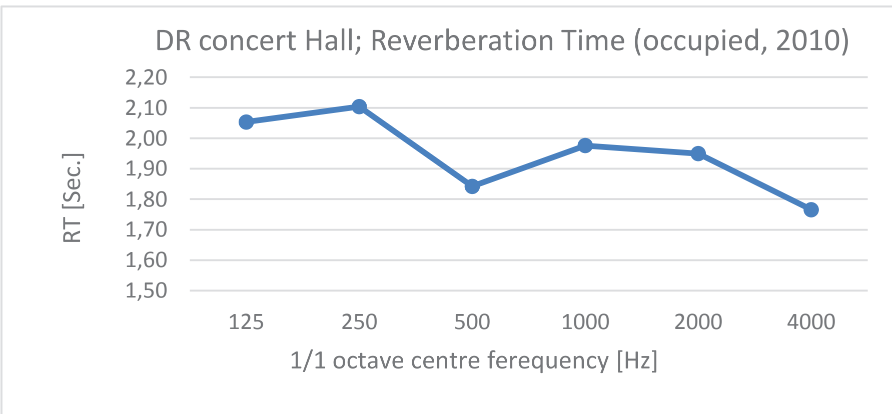

Figure 5: DR concert hall reverberation time measured during concert (Coriolan ouverture)

Besides the short reverberation time, also the sound from the organ has been criticized as being too “weak”. This may of course be related to the moderate reverberation time for organ music (at low frequencies in particular); but it is also likely that it is caused by the position chosen for the organ: in an unusually open casing on the wide “rear wall” framed by flared walls (like in a wide fan shape hall) and surrounded by absorbing audience seating. This may well cause the sound to lack the envelopment which we experience from organs in narrow rectangular halls – and in narrow churches of course. It should be mentioned that in objective terms, the instrument itself is very loud!

Figure 6 - DR concert hall 1:10 scale model with “orchestra” for stage acoustic measurements

For amplified events, large draped curtains can be brought to cover the upper side walls resulting in the reverberation time to drop to 1.6 Sec. in the empty hall.

Nagata has published a description of the hall acoustics (3).

The original budget of about 100 mio Euro for the building including the large hall, three smaller halls/recording studios and editing and office facilities for the Danish Radio had been exceeded by a factor of two when the hall opened in 2009. Although some budget overrun was predicted already in the competition phase, it caused many bumps on the way including sacking the Danish Radio CEO, the project manager and other members of the staff, and worse, also regular staff and the public service broadcast function in the Danish Radio were reduced as a consequence of the high extra costs. One may wonder if the design team or the contractors could have been held responsible for some of the problems – such as the lower RT values; but poor partnering contracts and the client´s interest in calming down these issues to avoid (more) bad press are likely reason why this did not happen. Probably for the same reason, our client did not show any interest in extensive room acoustic measurements (ISO 3382 parameters) being made in the finished hall.

Today, the smoke has left the scene and the hall has been generally accepted not only as home for the DRSO; but also as a hall attracting a much wider audience enjoying a large variety of music genres and even meeting events. For those types of events, the moderate RT at low frequencies is an advantage.

Fortunately, the DR Symphony Orchestra members are generally happy about their new home. In our testing of the 1:10 scale model, we were much concerned about the convex canopy being placed quite high above the stage (typically about 15m above the stage floor); but it seems that the rather steep circular risers ensures free propagation of the direct sound between the players which compensates for the rather weak reflection from the canopy. In spite of low ST_{early} values on stage, the musicians find it easy to hear each other. Some musicians, though, lack the fullness which they have experienced e.g. in the new hall in Malmö (4).

3.4 Malmö Live Concert hall

Like in Aarhus, the competition aimed at a design and build process, which meant that the teams were contractor driven, whereby only four teams with sufficient financial capacity were able to participate in the competition. (One of the four teams was later disqualified.)

Table 6 – main acoustic data for the Malmö Live, Concert Hall, Malmö Sweden

Malmö Live, Large hall	Brief	Realized
Volume /No. seats	Shoebox; V ≥ 22,000 m^3 1600 + 120 choir	V = 21,500 m^3 1500+100
Overall dimensions	Guiding: Length = 50m, Width = 22m, Height = 20m	L = 52m, W = 23m, H = 22m
Reverberation time (fully occupied)	≥ 2.1 Sec. (250 – 2000 Hz) ≥ 2,4 Sec. (125 Hz) Reduceable to ≤ 1.5 Sec. (250 – 2000 Hz)	≥ 2.1 Sec. = 2,6 Sec. < 1.4 Sec.
Background Noise	From ventilation and room light systems: NR10 From external traffic: Lpeak ≤ 20 dB(A)	NR15 Not measured
Description in brief	Stage for 110 musicians with area 230 extendable to 270 m2 and floor with mechanically moveable, semicircular riser lifts. Variable acoustic to be realized through moveable curtains. Variable stage front: stage or audience floor. Choir balcony and organ behind the stage. Balconies in two levels.	

For the large hall, the future home of the Malmö Symphony Orchestra, a rectangular shoe box shape was specified, and the acoustic brief ended up not deviating much from those for Aarhus and Aalborg. The management of the Malmö Symphony Orchestra had many innovative ideas about alternative orchestra performances and productions being distributed through modern media technology leading to an unusual requirement for an open grid ceiling over the stage area to allow for installation of more advanced rigging facilities than normally seen in concert halls dedicated for symphonic music. The complex also includes a smaller flexible hall, a large conference hall and a hotel. The main data for this hall are listed in Table 6.

The request for a larger seat count was reflected in a larger volume (21,000 m^3); but both the acoustic designer and the author expressed concern about the risk of uncontrollable absorption from the open grid ceiling and the stage mechanics above the stage.

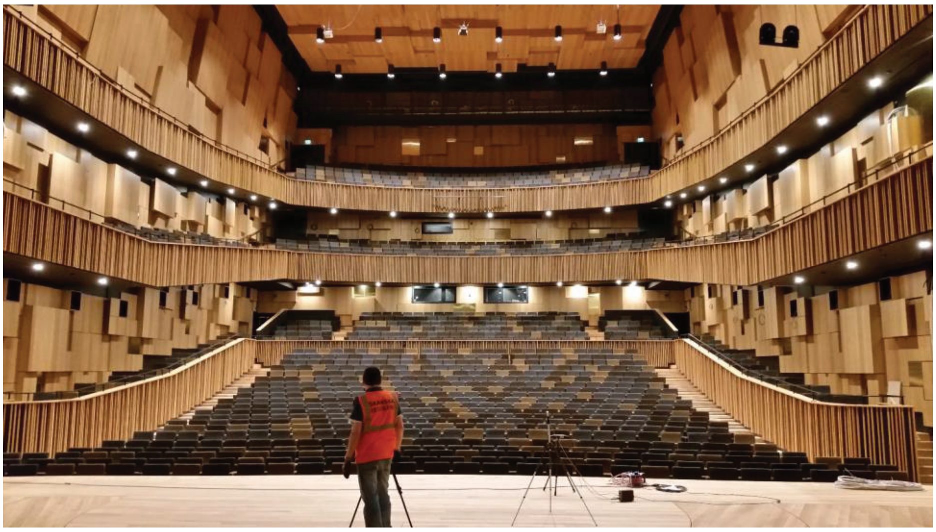

Figure 7 – The large concert hall in Malmö Live, Sweden

The winning contractor who had teamed up with SHL Architects and Akustikon as acoustic consultants, was for some time afraid of signing the contract because he feared to be sued in case the client would find that the verbally phrased acoustic qualities described in the brief were not fulfilled. Fortunately, sufficient confidence between the parties was established for the building to start and be completed on time.

As seen from the measured reverberation curves below, the target was not quite achieved at high frequencies – likely due to an abundance in sound diffusing elements on both walls, ceiling and balcony fronts. The acoustic designer and the author agree, that the hall is slightly lacking brilliance.

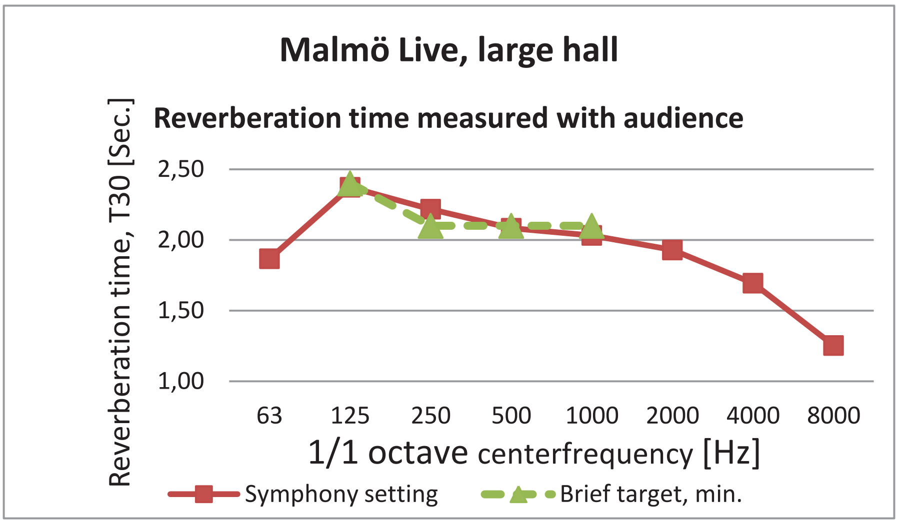

Figure 8 – Target and measured values of Reverberation Time in Malmö

Regarding ventilation noise, a compromise was agreed meaning that the target of NR 10 only applied in the "recording" mode, with only musicians (and choir) present and therefore reduced need for air capacity. With full audience, the realized value of NR15 was considered acceptable.

ISO 3382 parameters were measured in the unoccupied hall. Criteria discussed during the design were reached (averaged over 250 – 2000 Hz and seats): EDT = 2.2 Sec. C80 = -1.5 dB (half a dB higher than the diffuse field prediction), G = 2.7 Sec. and LEF = 0.19.

The value for Support on stage, ST_{Early} = -13 dB (4) is optimal in the authors opinion. This is 3 dB higher than the -16 dB in the Danish Radio hall, which illustrates the difficulties in obtaining high early reflection energy on stage in vineyard halls.

The hall opened in 2015 and has been very well received. The acoustic designer has described the hall in a conference paper (5).

4. CONCLUSIONS

In all the cases described in this paper, the competition briefs requested well known "standard" hall shapes: shoebox and vineyard. In such cases, specifications of RT target values and qualitative descriptions have proved sufficient to direct the architects towards successful solutions. The clients appreciate being educated and being exposed to listening for specific acoustic qualities in concert halls; but the correlative objective parameters values (measured according to ISO 3382) can be left to the discussions between the acoustic designer and the client advisor.

In three out of four cases, no serious mismatch between the acoustic targets and the measured results were found. The projects which the author experienced as well managed: Aarhus and Malmö, were also the most successful in acoustic terms. It is interesting to see that both of these were OPP projects, whereas the Aalborg and the Danish Radio projects, both of which had a design team referring to the client and not to the contractor, turned out much more expensive, experienced many more bumps on the road, took much longer to realize and had clients who were less interested in making the designers and builders fulfill the acoustic targets – likely as a consequence of poor contracts, general exhaustion and fear of (even more) negative comments in the press if further mistakes were exposed to the public.

The biggest challenges in client advisory are related to problems in communication and lack of confidence between the parties involved (sometimes fueled by differences in cultural background). A low budget is not a limitation by itself – as long as the client and his advisor are realistic about what he can get for the allotted amount.

Client advisory is of limited value unless the client has at least as much confidence in the advisor as in the acoustic consultant. But this should not generate a competition between the two. Agreement between them about important acoustic issues has a strong, positive impact on client and design team decisions. Therefore, it is important that the client advisor sees his/her role as one of moderating the process towards a successful hall. The advisor role is not to take the alternative stand (in a misunderstood attempt to show his influence and value). He should work towards consent and facilitate a smooth process – whenever possible.

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