Trends in preference, programming and design of concert halls for symphonic music

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This paper discusses the evolution in taste regarding concert hall acoustics and how this can be reflected in the new halls being built today. The clients' and listener's preferences are not only based on listening in existing halls; but also on listening to reproduced music recorded with microphones close to the orchestra and with artificial reverberation added. The result may be a desire for higher clarity as well as a more full reverberation than what is found in most existing halls. Without being very specific in the brief regarding geometrical detailing – which is not desirable as it will limit architectural freedom and evolution – we can only specify a desire for acoustic conditions in this direction by setting targets for standardized objective room acoustic parameters. In this paper measured ISO 3382 data are used to illustrate typical differences between "live" and recorded concert experiences, and it is seen how visionary hall designs over the last four decades tend to move the acoustics of halls in the same direction. Finally, it is suggested how target values for ISO 3382 parameters – in spite of their limitations – can be set up to drive the design in the desired direction.

1 Introduction

During half of the 20th century, between the opening of Salle Pleyel in Paris 1928 and of Philharmonie Gasteig in Munich 1985, the majority of new concert halls were strongly influenced by Modern Movement architecture. The dominating shape was the fan, and the acoustics in these were characterized by being clear and not very reverberant.

In the last couple of decades however, the shoe box shape as found in the classical halls from before 1900 (e.g. Musikverein in Vienna and Concertgebouw in Amsterdam) has regained popularity, both because of its potential for higher spaciousness - which in the mean time had been revealed as a very important acoustic quality - and because of its more full and reverberant sound. Examples are the Cultural Centre Concert Hall in Tai Pei (1987) and the Kyoto Concert Hall in Japan (1995) as well as most of the halls realized by Artec, see [1].

Probably influenced by the large consumption of recorded music, clients of today are not just interested in reverberance when listening in the concert hall. They also want a very clear and present sound – like when they listen to recordings through their hi-fi set at home.

Most recordings are characterized by the sound being captured by microphones placed much closer to the instruments than the listener in the hall, whereby presence and clarity will be much higher in the recording than in the hall. On the other hand, the recording engineer will often add artificial reverberation to the recording to achieve a full sound as well. Consequently, the hypothesis is that listening to reproduced sound is influencing the standards for acoustics in concert halls towards achieving both high clarity and high reverberance.

In the following, data from the newly opened concert hall in the extension to Aarhus Musikhus are used to illustrate this trend, and it will be discussed, how programming and design of future concert halls can take this into account.

2 Comparison of acoustic data obtained from seats and from broadcast recordings in a concert hall

In September 2007, a new concert hall with 1200 seats for audience plus 120 for choir was opened in Aarhus, Denmark. The acoustic design was carried out by COWI A/S, Denmark and Artec, USA, while the author acted as advisor for the client, which included writing the acoustic brief. The hall is of shoe box shape with length 44m, width 21,9m and height 18.7m. The audience is distributed in stalls, parterre plus two levels of rear and side balconies, while permanent choir seats which can also be sold to the audience are elevated behind the orchestra. A view of the hall is shown in Figure 1.

As part of the acoustic documentation, occupied hall measurements were carried out during a break in a concert on 22nd November 2007. This concert was recorded by the Danish Radio and fortunately, their equipment was also running during the measurement session, in which inflated paper bags were bursted in two positions on stage and recorded in 8 positions in the hall as well as through the recording microphones.

Fig. 1: The new concert hall in Aarhus, Denmark. View towards the stage.

Both sets of impulse responses were analyzed by means of the Dirac software, version 3.1, and values of reverberation time, T, Early Decay Time, EDT and Clarity, C from the two sets of impulse responses are compared in the following.

2.1 Early Decay Time

The graphs in figure 2 show the position averaged EDT values per octave band obtained from the measurements in the hall seats and from the recording respectively. If one believes in EDT representing the fullness or reverberance of the sound during running music, it is seen that the difference between the curves are below the just noticeable difference (JND) of about 5% ≈ 0.1s over most of the frequency range. Thus, this quality should be experienced almost identical regardless of whether one attends the concert or listens to the radio transmission at home.

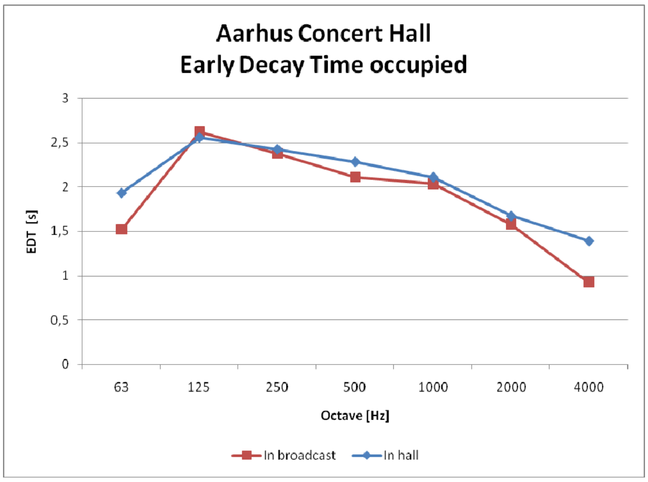

Fig. 2: EDT in the occupied Aarhus concert hall – measured in the seats as well as through the recording chain.

However, the picture is different if we look at the values for Reverberation Time or Clarity.

2.2 Reverberation time

Figure 3 shows the Reverberation Time values from the two sets of measurements. It is clear, that the recording engineers have added a long – obviously artificial – tail of reverberation to the impulse response, because the values obtained from the recording are more than half a second longer than the – already generous – values in the hall.

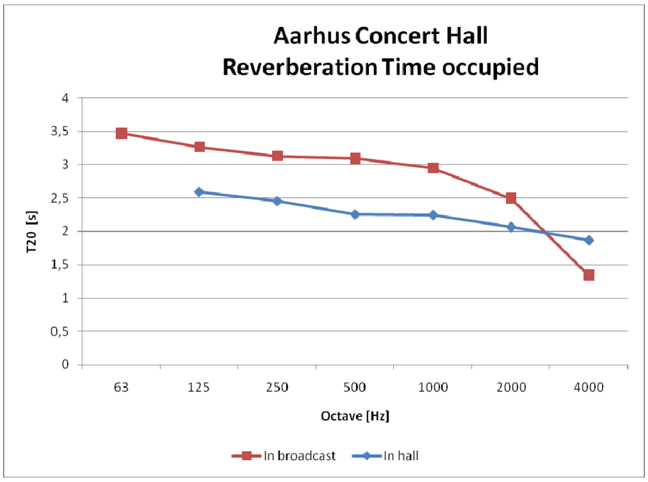

Fig. 3: T in the occupied Aarhus concert hall – measured in the seats as well as through the recording chain.

2.3 Clarity

The graphs for the Clarity values shown in Figure 4 clearly show the effect of the recording microphones being placed close to – and probably within the reverberation distance of - the sound source on the stage. The values obtained from the recordings are about 4dB higher than those obtained in the audience seating.

The engineer will choose the positions (and the directivity patterns) of the microphones depending on the layout of the orchestra and the score in order to achieve a well balanced recording. This is often achieved by a main set of microphones placed a few meters behind the conductor and some distributed microphones placed within about 2m from selected groups in need of enhancement. Subsequently, the engineer will select the duration and level of the artificial reverberation so as to achieve the degree of fullness to suit his taste. There are many philosophies regarding the best configuration of microphones for recording of symphonic music; but in any case the result is, that the values for both Reverberation Time and Clarity are substantially higher in the recording than in the audience seats.

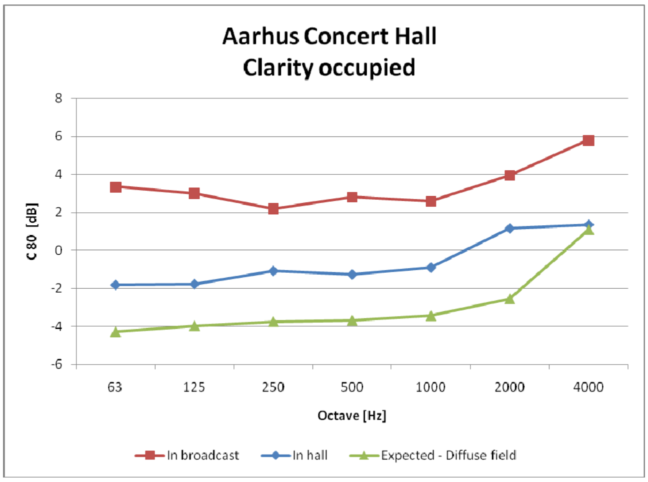

Fig. 4: C in the occupied Aarhus concert hall – measured in the seats as well as through the recording chain.

In Figure 4 a third graph, the green curve, is added. This represents the calculated value of Clarity corresponding to the measured reverberation time in the hall (the blue curve in Figure 2) if the decay curve was a true exponential function as assumed by Sabine diffuse field theory. This value, C_{exp}, is calculated from T as:

$$C_{\exp} = 10 \times Log_{10}\left(\exp\left(\frac{1.104}{T}\right) - 1\right) dB \qquad (1)$$

With this value being yet about 2dB lower than Clarity measured in the hall, it can be concluded that the room design in this new hall in Aarhus promotes the generation of early reflections in the audience seats. (All measurement positions in the seating area were much further away from the source than the reverberation distance, which is no more than 5m in this hall. Therefore it is unlikely that the direct sound has had a strong influence on the values obtained.)

3 Realization of high clarity and high reverberance in concert hall design

Under the assumption that clients and audiences favor acoustic conditions in halls to be close to the listening experience from recordings, the next question is how this can be realized in the physical design of a concert hall.

High Clarity can be obtained by the audience being placed close to the orchestra; but with an audience of more than one thousand, this is not practical. Besides, the orchestra normally covers a floor area of about 200m^2, which means that the orchestral sound will be unbalanced, if you are too close. Therefore, high clarity for all (or most) seats can only be achieved by strong early reflections being sent to the listeners within a short time interval (50-80ms) after the arrival of the direct sound. This means that major reflecting surfaces must be placed fairly close to all audience seats.

On the other hand, a long reverberation time requires a large room volume, which implies the boundary surfaces being placed far from each other – and far from the listeners. The natural consequence is that at least some of the early reflecting surfaces must be separated from the room boundaries if both requirements are to be fulfilled in a large hall.

In the introduction, only two concert hall shapes of the 20th century were mentioned, the “fan” and the “shoe box”. However, as explained in [2], at least three innovative shapes appeared in the late half of the century, which all have a potential for achieving the goal as stated above. Schematic sketches of these three shapes are shown in Figure 5 below.

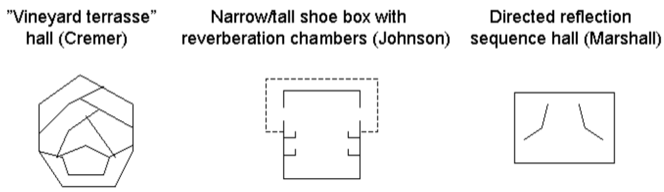

Fig. 5: sketches of three innovative concert hall concepts from the 20th Century: Vineyard (plan), shoebox with reverberation chambers and the DRS principle (both cross sections).

The first of these was the terraced arena or “vineyard” shape realized by Lothar Cremer in the Berlin Philharmonie in Germany inaugurated in 1962. By arranging the terraces in different heights and by choosing the shapes of each terrace with care it is possible to use the walls rising between the terraces as efficient early reflectors for all seating areas – almost independently of the overall size and floor area of the space.

Another promising design is the Directed Reflection Sequence model invented by Harold Marshall, in which the early reflections are generated by means of large, free hanging surfaces and balcony fronts inside the space. This concept was first realized in the Christchurch town Hall in New Zealand in 1972. This concept also tried to promote the early reflections to reach the listeners from lateral directions, in order to enhance spaciousness, which before had mainly been experienced in narrow, rectangular halls.

The third concept is seen in a series of halls designed by Russell Johnson/Artec since the 1980ies. Here, the starting point is a fairly narrow shoe box; but by arranging large, empty cavities outside the hall which can be coupled to the main volume by means of large doors, the acoustic volume can - at least in principle - be increased beyond the visual boundaries of the hall. In practice, however, the audible effect as well as the change in reverberation is often very subtle probably due to the opening areas being too small. Thus, the money might be better spent on increasing the ceiling height or – in case a variation in volume is really needed – a system whereby the ceiling height can be varied.

All the hall mentioned are well described in [1].

4 Aarhus Concert hall measurements

To achieve sufficiently high Clarity as well as a full reverberant sound in a medium sized concert hall (up to say 1500 seats) of shoe box shape, it is probably sufficient to 1) limit the width, 2) ensure generous room height, and 3) apply the terracing principle in a stalls/parterre solution combined with 4) parts of the seating being placed on side wall and rear balconies. At least, this was what we demanded in the brief for the new concert hall in Aarhus, along with a requirement for the reverberation time at mid frequencies to be no less than 2.2s at mid frequencies in the fully occupied hall. As seen from Figure 3, this reverberation time target was achieved. As shown in Figure 4, the design has also promoted early reflections beyond what could be expected in a hall with “neutral” Sabine diffuse field acoustics (is such a thing exists!).

From empirical experience based on measurements and geometrical registrations in a large number of existing halls, it is possible to predict whether the actual design has had an influence on e.g. Clarity beyond what one could have found in other halls with similar reverberation time and overall geometry. Unfortunately, extensive measured data are available only from unoccupied halls (which are easier to access when extensive acoustic measurements are to be carried out). Therefore, the prediction formulas are only strictly valid for unoccupied halls. However, if the seats are well upholstered to minimize the difference between the occupied and empty situation, it should be possible to extrapolate to the occupied condition as well.

Two such prediction formulas quoted in [2] for Clarity are listed below.

$$C_{predicted} = -0.1 + 1.0\, C_{exp} \quad (2)$$

$$C_{predicted} = -1.4 + 0.95\, C_{exp} + 0.47\, W/H + 0.031 \text{ Floor slope} \quad (3)$$

In these regression formulas, C_{exp} can be found according to Equation (1). In equation (3), W equals the average room width, H is the average room height, while in floor slope is the average angle of the main floor/parterre seating in degrees.

When the geometrical data for the Aarhus concert hall, W = 21.9m, H = 18,7m, and the Floor slope = 10□ are used along with the measured unoccupied reverberation time, graphs for the predicted C values appear as shown in Figure 6.

For the measurement of impulse responses in the unoccupied hall, the Dirac system was used in conjunction with a dodecahedron loudspeaker emitting 20s long sweep signals. In comparison with the measured curve shown in red, it is seen that also in the unoccupied hall, the measured values are about 2dB higher than predicted considering the reverberation time and overall geometry. This is in line with the findings for the occupied hall shown in Figure 4.

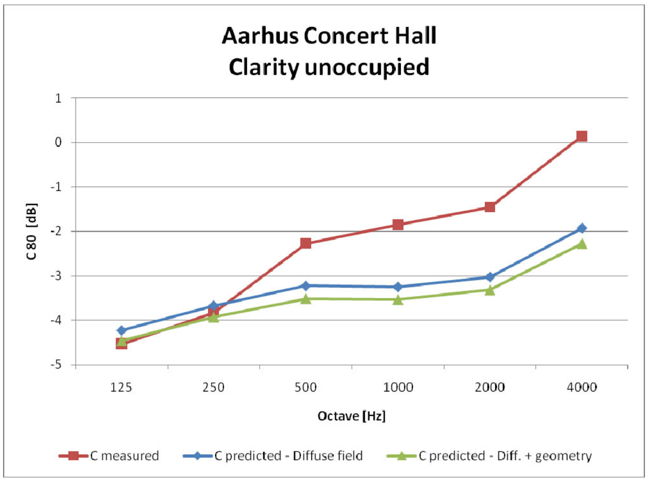

Fig. 6: Measured and predicted values of Clarity versus frequency in the unnocupied Aarhus concert hall. Blue curve: predicted according to Equation (2), green curve: predicted according to Equation (3).

The data confirm that the design of the new concert hall in Aarhus, Denmark has achieved the goal set up in the brief for the competition: to provide high clarity as well as a full reverberant sound for symphonic music.

5 Programming new concert halls

The author is currently involved in five new concert hall projects in Northern Europe as acoustic advisor for the client. Four of these are shoe boxes and one arena with terraces.

With so many new halls - all following well known (read conservative) concepts - it is relevant to consider, how the acoustic advisor can ensure the success of the new hall without blocking attempts to develop concert hal design further. The advisors job starts by writing the acoustic brief after having discussed acoustic preferences and the virtues of different hall shapes with the client.

As in many competitions one does not know, who will be responsible for the acoustic design, it is important to ensure a solid acoustical quality by setting up suitable acoustic criteria in the competition brief. For the time being, we have not found it feasible or wise to set up numbered acoustic criteria in terms of other objective parameters than reverberation time – although such criteria as defined in the ISO 3382 are today widely acknowledged and used by many acousticians. The reasons are that some acousticians still doubt the value of these measures and, for sure, the parameters do not (yet?) tell the full story about the acoustic quality of a concert hall.

Instead, we have set up criteria about overall dimensions and make qualitative descriptions of elements in the design which are important for driving the acoustic performance in a desired direction; but which also limit freedom in the design. We then combine this description with a requirement for documentation during the design process by means of investigations in computer or scale models, from which values of the acoustic parameters are derived.

However, in order to avoid the geometrical descriptions which inevitably will limit architectural freedom and so be a hindrance to further development of concert hall design, it would be a great advantage to specify the desired performance in terms of acoustic parameters alone, which can be monitored in simulations throughout the design period as well as measured in the finished hall.

In order to start a process in this direction, a set of goals for such parameters in large halls for symphonic music and small halls for chamber music are suggested in Table 1.

The values in the table relate to empty halls with well upholstered seats assuming that when fully occupied, the values will not drop by more than say 0.2s.

The values listed take the outset in suggestions for T, which should ensure a rich reverberant sound in the hall, while the correlative goals for EDT, G and C stem from the diffuse field values but have been slightly changed to promote high clarity, high levels and high reverberance simultaneously.

EDT is suggested 0.1s lower than T in the small hall and 0.2s lower than T in the large hall.

Since high Clarity is particularly needed in large halls, the C value listed is 2 dB higher than C_{exp} in the large hall but only 1dB higher than C_{exp} in the small hall.

G is suggested 2dB less than G_{exp} (= 10 $LOG_{10}(T/V)$ +45dB) in small halls and 1 dB less than or equal to G_{exp} in larger halls. Please notice that this means that G will be higher than normally found in halls without early reflections being cultivated: 1dB higher in small halls and 2dB higher in the large hall.

For halls of size between 2500m^3 and 25000m^3, one may of course interpolate according to taste.

Parameter	Symbol	Chamber music	Symphony
Hall size	V / N	2500 m^3 / 300 seats	25000 m^3 / 2000 seats
Reverberation time	T	1,4 Sec.	2,3 Sec.
Early decay Time	EDT	1,3 Sec.	2,1 Sec.
Strength	G	10 dB	3 dB
Clarity	C	3 dB	-1 dB
Lateral Energy Fraction	LEF	0,20	0,25
Bass Ratio	BR	1.0	1.3
Early support	ST_{early}		-11 - -14 dB

Table 1 Suggested recommended values of objective room acoustic parameters depending on hall size. Intended for unoccupied auditoria for classical music concerts; but assuming that the difference in T between the occupied and unoccupied situation is no more than 0.2s.

5 Conclusion

It is demonstrated that recordings can have higher Clarity as well as higher Reverberation Time values than what is realistic when listening in the concert hall. It is argued that

this fact may have influenced the taste regarding acoustics for concert halls, for which at least three new design concepts promoting this tendency appeared in the second half of the 20th Century.
This trend towards high clarity and reverberation alike also influenced the programming and the design of the new concert hall in Aarhus, Denmark, which is found to have C values about 2dB higher than what is justified by the already high Reverberation Time – both in the occupied and unoccupied condition.
Finally it is suggested, how targets for acoustic conditions in concert halls can be formulated quantitatively in terms of the objective acoustic parameters defined in ISO 3382.

Acknowledgments

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References

[1] L.L. Beranek: Concert Halls and Opera Houses, Music Acoustics and Architecture, Springer, New York, 2nd Edition 2004.

[2] A.C. Gade: “Acoustics in Halls for Speech and Music”, Cpt. 9 in Springer Handbook of Acoustics, edited by T. D. Rossing, Springer, New York 2007.