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Reverberation Time – the mother of all room acoustical parameters

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Wallace Sabine introduced the reverberation time (RT) as a measure of acoustic conditions in rooms a century ago. After some decades of experience with RT it became evident that two rooms with similar RT could be sounding quite differently. Until today, a large number of different parameters have been suggested to describe these differences. In an attempt to settle for a limited number of listener aspects, and a limited number of physical measures, a set of five aspects with corresponding physical measures have been suggested. In the ISO standard 3382-1, the RT is not included in the group of physical measures associated with listener‘s aspects. It is tempting to jump to the conclusion that the reverberation time era has come to an end. However, from statistical analysis of measurements and computer simulations, and from Barron‘s Revised Theory it can be shown that RT is the underlying acoustical parameter governing 4 out of the 5 important listener aspects. In this paper it is shown that all 5 aspects can be predicted from reverberation time, volume and source-receiver-distance.

1 Introduction

Since Wallace Sabine introduced the reverberation time (RT) as a measure of acoustic conditions in rooms a century ago, a large number of different parameters have been suggested. After some decades of experience with RT it became evident that two rooms could be sounding quite differently even if they had similar RT. The post-war design tendency towards wider concert halls led to acoustics with a lack of early reflections and a long initial time delay gap at many seats, an effect that could be measured by the initial time delay gap (IDTG) and the clarity parameters C, D, Ts. By introducing canopies under the ceiling, more early reflections were provided, inherently leading to a more vertical sound field, suppressing the already weak lateral reflections even more. This problem was associated with a lack of apparent source width ASW, which could be measured by the (Early) Lateral Fraction LF and 1-IACC. Since the 1980‘s the early decay time EDT has been used to measure the amount of reverberance, i.e. the perceived reverberation, in contrast to the full decay that usually is perceived only when the music stops. It has also been proved that listeners preference of halls relate to a proper sound level, motivating use of the G (Strength) parameter. By today, acousticians have arrived at some consensus that even the listener‘s sense of envelopment LEV by sound is important to acoustics in a concert hall, and that this can be measured by the amount of late arriving energy. There are still discussions regarding the significance of lateral, vertical and rear directional content of this late energy. For the purpose of this paper we shall ignore these details and assume that LEV is associated with the total late (after 80ms) energy level.

In an attempt to settle for a limited number of listener aspects and a limited number of physical measures, a set of five aspects with their corresponding acoustic quantities have been suggested. Relevant to concert halls are:

Table 1: The 5 listener aspects and their corresponding acoustic quantities

Subjective listener aspect	Acoustic quantity	Just Noticeable Difference (JND)
Subjective level of sound (SOUND LEVEL)	Sound Strength G, in dB	1dB
Perceived reverberance (REVERBERANCE)	Early Decay Time, EDT, in s	5%
Perceived clarity of sound (CLARITY)	Clarity, C80, in dB	1 dB
Apparent source width, ASW	Early Lateral Energy Fraction, LF	0.05
Listener envelopment LEV	Late Sound Level, GL (G late), in dB	1 dB

The five listener aspects listed above are to be considered local, i.e. receiver position dependent, in contrast to RT, which is considered a global parameter describing the overall acoustic properties of the room. In the ISO standard 3382-1, RT is not included in the group of physical measures associated with listener aspects. It may be tempting to jump to the conclusion that the reverberation time era has come to an end. However, from statistical analysis of measurements and computer simulations, and from Barron's Revised Theory it can be shown that RT is the underlying acoustical parameter governing 4 out of the 5 important listener aspects. Besides, if any acoustician where allowed to ask for only one single number in order to obtain information about the acoustics of a concert hall, that would most likely be the mid-frequency RT. Rather than having become an obsolete physical quantity, the reverberation time may turn out to be more significant than ever, defending its position as the mother of all room acoustical parameters.

To study the role of the reverberation time, a statistical analysis of the 126 measurements from 11 European halls by Gade[1] in 1989 has been carried out. This paper reports the result of this study.

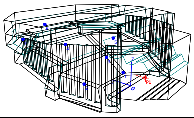
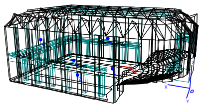
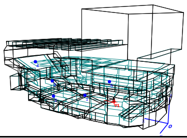
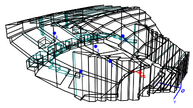
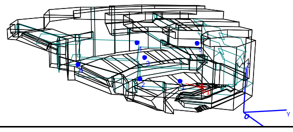
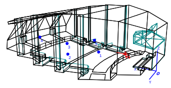
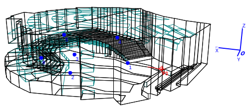
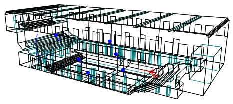
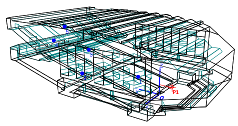
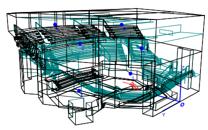
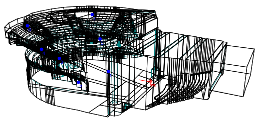
2 Method

The hypothesis is: The 4 listener aspects Level, Reverberance, Clarity and Listener Envelopment can be predicted from RT. In order to test the hypothesis, a set of 5 simplified prediction formulas based on *RT*, room volume *V* and Source-Receiver-Distance *r*, are designed, one for each of the 5 aspects above. 4 of the 5 prediction formulas depend on RT, while the 5th does not. RT and V are the global (hall specific) variables, while r is the spatial variable. The hypothesis can be rejected if it is shown that the 4 aspects cannot be predicted by RT. To assess the outcome of the simplified predictions, they are compared with predictions by the computer simulation software ODEON version 10, which has through round robin tests been proven to be a state-of-the art prediction tool.

3 The 126 measurements in the 11 Halls

With its version 10, ODEON has released computer models of the 11 European Halls investigated and reported by Gade in 1989. While the overall results and data per hall has been published and referred to earlier[4], the 126 measurements together with their coordinates provide a unique set of data for the study reported in this paper. The same measurement data have been compared with simulated results in ODEON in order to evaluate the significance of surface resolution in computer models[2]. All measurements are in unoccupied halls, and the source-receiver constellations are made up by two source positions and 5 to 7 receiver positions in each hall.

Table 2: The 11 halls in this study

	Concert hall	Volume	Seats	RT (unocc)	Model
1	Barbican, London	18000	2000	2,0	
2	Concertgebouw, Amsterdam	19000	2000	2,5	
3	Derngate, Northamton	13500	1300	2,1	
6	Festspielhaus, Salzburg	15500	2200	1,9	
4	Gasteig, Munich	30000	2500	2,2	
5	Konserthus, Gøteborg	12000	1300	1,7	
7	Liederhalle, Stuttgart	16000	2000	2,1	
8	Musikverein, Vienna	15000	1700	3,2	
9	Royal Festival Hall, London	22000	2900	1,6	
10	St David, Cardiff	22000	2000	2,2	
11	Usher Hall, Edinburg	16000	2500	2,0	

4 The 5 prediction formulas

All levels are related to 0 dB being the direct free field sound pressure level at 10m distance from the source.

Formulas for the basic energy components direct energy, reflected energy, early energy and late energy are given from Barron Revised Theory in[5].

The corresponding energy levels are (Reverberation time *T*, Volume *V*, speed of sound *c*, and source-receiver-distance *r*) given in Table 3.

Table 3: Basic energy level components

Level component	Symbol	Formula
Direct energy level	Ld	$10 \cdot \log(100/r^2)$
Reflected energy level	G,refl	$10 \cdot \log(31200 \cdot T/V) - r/c \cdot 60\text{dB}/T$
Total energy level	G	$10 \cdot \log(10^{G,refl/10} + 100/r^2)$
Late reflected energy	GL	$G,refl - 60\text{dB} \cdot 80\text{ms}/T$
Early energy level	Ge	$10 \cdot \log(10^{G/10} - 10^{GL/10})$

Combination of the energy level components in Table 3, together with an empiric estimate for LF, provides the 5 T,V,r–predictors given in Table 4.

Table 4: The 5 aspects and their predictors

Listener aspect	Quantity	T,V,r – Predictor Formula	Intrinsic variables
SOUND LEVEL	G (dB)	G	*T, V, r*
REVERBERANCE	EDT (s)	$T \cdot$ (10dB-(G-G,refl))/10	*T, V, r*
CLARITY	C80 (dB)	Ge – GL	*T, V, r*
APPARENT SOURCE WIDTH	LF (1)	$r \cdot 0.18/18\text{m}$ if $r \leq 18\text{m}$ 0.18 if $r > 18\text{m}$	*r*
ENVELOPMENT	G,late (dB)	GL	*T, V, r*

If G and C80 are given from measurements or simulations, GL can be calculated from $G - 10 \cdot \log(1+10^{C80/10})$

5 Results - testing the predictors

The 5 predictors to the 5 listener aspects in Table 4 are tested by computing the difference between predicted values and the 126 measured values after Gade's work, for each listener aspect. To provide a basis for assessing the quality of the predictors, the results are compared with differences between ODEON 10 simulation values and measured values. The units of difference are the corresponding JND (Just noticeable difference) in Table 1. Results are presented in Table 5. The global reverberation time used in this test is the average of measured RT's in each hall. All quantities are 500 and 1000Hz octave band averages, except LF which is 125-1000Hz average. Volume and RT is given in Table 2.

Table 5: Differences in JND between predicted values and measured values for the 126 source-receiver combinations in the 11 halls. T,V,r – predictor and ODEON-prediction. Comparison in (% of JND) in rightmost column.

Listener aspect	**Quantity**	**T,V,r – predictor re measured (JND)**	**ODEON predictions re measured (JND)**	**JND's T,V,r-predictor re ODEON prediction**
SOUND LEVEL	G (dB)	1,62	2,25	-28 %
REVERBERANCE	EDT (s)	0,78	1,14	-32 %
CLARITY	C80 (dB)	1,40	1,81	-23 %
APPARENT SOURCE WIDTH	LF (1)	1,25	1,33	-6 %
ENVELOPMENT	G,late (dB)	0,81	1,32	-38 %
ALL 5 ASPECTS	**-**	**1,20**	**1,57**	**-25 %**

A graphical presentation of the results in Table 5 is given in Figure 1 below.

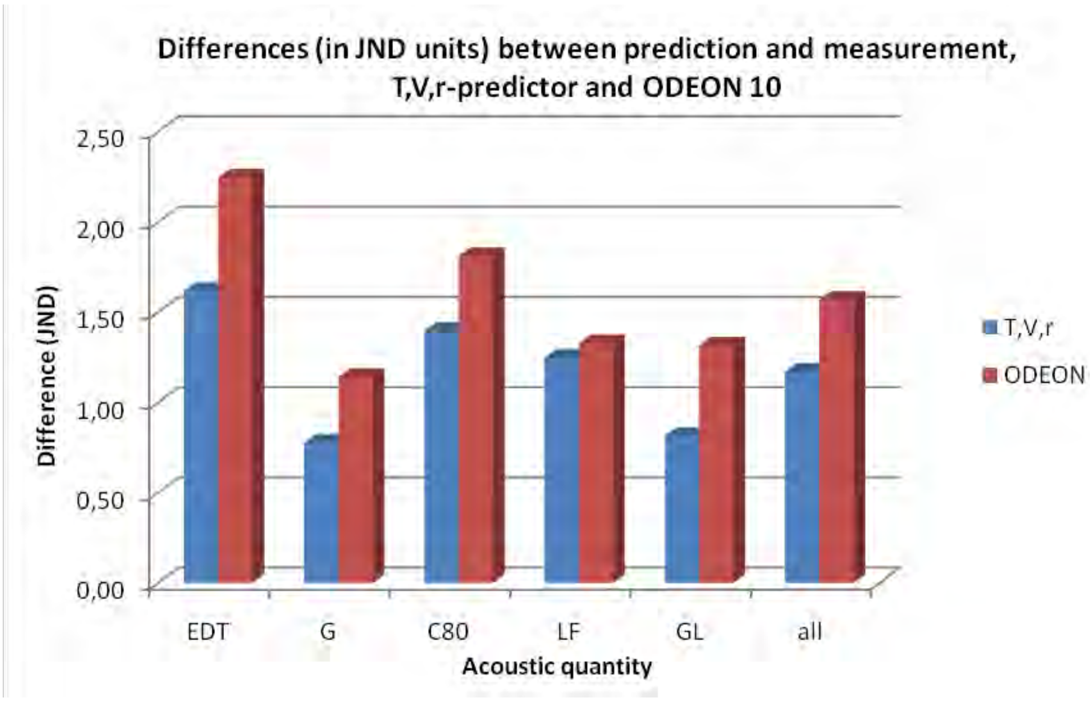


Figure 1

6 Comment and conclusion

As can be seen from Table 5, the T,V,r-predictors predicts the 5 aspects with less (25%) difference (in JND) from measured results than the corresponding ODEON predictions. The 4 predictors including RT show better quality than the one (LF) not including RT. From this it is concluded that the T,V,r-predictors are qualified predictors, and in particular those predictors including RT. This means that the hypothesis was not rejected by the test. The hypothesis still stands:

The 4 listener aspects Level, Reverberance, Clarity and Listener Envelopment can be predicted from RT.

Further investigations with more data should be carried out to increase the statistical confidence of the results.

7 Further work

It cannot be concluded from this test that the T,V,r-predictor is superior to ODEON-predictions. However, there is reason to pursue the quite promising result. It will in further work also be pursued the fact that the 5 listener aspects depend on only 3 variables, two global ones and one spatial. This is interesting in light of the search for so-called orthogonal parameters. The LF-predictor should be studied further to see if it can be improved in accuracy. In the test reported above, the measured RT was used. If the T,V,r-predictor proves to be one that can be applied to halls in general, it will become increasingly important to develop the methods for predicting the RT itself during the planning of halls.

A brief study showed that exchanging the RT-input in the T,V,r-predictor from measured RTs to RTs from ODEONS‘s Global Estimate, made the overall difference (1.20 in Table 5) raise to 1.22. This is interesting because this it is still a considerably smaller difference from measured results than the difference between the direct ODEON-predictions and measured results. If this is a trend that can be confirmed by expanding the study, it opens up for a new way to predict room acoustics.

References

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