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ROOM ACOUSTICAL PARAMETERS IN PREDICTIONS OF CONCERT HALL PREFERENCE - ABOUT UNCERTAINTIES, EXPLANATION AND UNDERSTANDING

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INTRODUCTION

Concert hall acoustics are very difficult and expensive to improve once the hall has been built. Thus there is high demand for safe methods to predict the public preference for the concert hall. This paper presents a method for predicting such preference based subjective and objective data for 53 concert halls in Beranek's data collection. Its implications are discussed. Our current explanation of concert hall preference seems to be a black box. A way to deal with uncertainties and lack of insight into the Black Box is suggested and discussed. The importance of the numbers of parameters and halls in the data basis is demonstrated. A summary of important findings after many years of concert hall acoustics research by this author is included in the conclusions section.

Room Acoustical Parameters in predictions of concert hall preference - about uncertainties, explanation and understanding

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Introduction

Concert hall preference is about the question - which halls are more preferred, or less preferred, by the average concert-goer? Motivations for wanting to predict preference could be

- Scientifical or academical reasons
- Pure curiosity
- Basis for decision in concert hall planning

Predictions intended for decision-making is a risky business. Concert hall acoustics are very difficult and expensive to improve once the hall has been built. Thus there is high demand for safe methods to predict the public preference for the concert hall. After a hundred years of experience with room acoustical parameters, we still investigate by the main stream approach: Which set of physical quantities, i.e. parameters, are critical and relevant? What are the preferred values of these parameters? How can we predict the outcome in the planned hall?

Each of these questions can only be answered with some degree of uncertainty, and the uncertainties add up. Not only do we deal with uncertainties in the physical measurements. There are of course the uncertainties in subjective data, in the ranking of halls. Improved predictions and reduced uncertainty in outcome may have the cost of reduced understanding of the details in the causal chain. And not to be forgotten: There is always a zero hypothesis: "Preference is purely random". This paper is a status report on this author's on-going investigations and some findings so far.

A critical limitation in the research has turned out to be the difficulty in finding a large enough selection of halls with sufficient amount of subjective AND objective data. An online concert hall acoustics rating survey is launched in order to collect more data, and anyone interested are invited to participate in the survey on https://www.surveymonkey.com/s/MMFMZ5W

Previous work

A comprehensive review of the work by this author on the subject since 2008 has been presented in the 2012 Status Report [1]. A brief summary of reports follows.

IOA Oslo 2008 [2],[3]

Few listeners experience a set of five ISO-3382 parameter values equal to the set of five hall-averages, raising the question whether hall averages really describes the listening conditions that affects the audience' judgment of the hall

BNAM Bergen 2010 [4]

Objective quantities corresponding to the five ISO-3382 listener aspects are quite precisely predicted with the so-called TVr-predictors, i.e. functions of T30, Volume and source-receiver distance, based on Barron revised Theory [5]; TVr-predictions of 126 points in 11 European halls were compared with measurements by Gade [6]. LF is difficult to predict, and substitute predictors for apparent source width are investigated.

ICA, Sydney 2010[6], objective-subjective correlation

Parameters at listeners ears

A test of correlation between objective data and subjective for 10 halls included in Beranek's Rank-ordering [7] of 58 halls was reported. 5 parameters corresponding to the 5 listener aspects in ISO-3382 were used. During the trials, six objective data sets (different combinations of computer-simulations, TVr-prediction and measurements) representing occupied conditions in the 10 halls are tested.

TVr-predictions came out with the highest correlation ($r^2 \approx 0.9$) with Beranek's ranking.

Computer simulations failed to predict subjective preference for the ten halls ($r^2 \approx 0.6$).

Predicted and measured LF failed to distinguish between good and bad halls, pointing at the inherent uncertainties from a limited selection of halls.

Uncertainties in the subjective assessment of one of the ten halls would result in significant change in data-correlation.

Unwanted consequences from using multiple linear regression or invalid assumptions of linear relationship between objective and subjective data were demonstrated.

Prediction of concert hall preference based on parameter values at listeners' ears turned out to require a wide range of acceptable parameter values. EDT values would need an acceptance range of ±4 JND in trials that showed high correlation between objective and subjective data. The four other parameters needed less tolerance, with G_{late} turning out to be the least fluctuating parameter, needing an acceptance range of ±2 JND.

A reminder of the seriousness in the concert hall prediction business came from one of the results: If the prediction was right, one of the top ten halls among Beranek's 58 ranked halls should not have been built. It came out with the same predicted preference as the hall number three from the bottom.

ICA, Sydney 2010, testing the relevance of a parameter

A method for testing the relevance and justification of introducing extra parameters without requiring linear independency, i.e. orthogonal parameters, was presented [8].

IOA Dublin 2011 [9]

Objective hall-average values correlates better with subjective data than do objective data at listeners' ears. Hall-averages provide explanation in terms of prediction, but leave us without insight in the underlying mechanisms.

BNAM Odense 2012[1]

A status report was given, reviewing the work on the subject by this author since 2008. Apparently, hall-averages provide scientific explanation in terms of prediction, but leave us in lack of insight into the underlying mechanisms.

Extended investigation

Beranek data for 53 halls

More data is introduced in the investigation, as the number of halls is increased to 53, and the number of parameters is increased to 8. At the same time, correlation between subjective and objective data decreases from $r^2 \approx 0.9$ with the 10 halls to $r^2 \approx 0.6$-0.7 with the 53 halls. Objective and subjective input were again taken from Beranek's data. However, in order to provide EDT, C, G, G_{late} and G_{125Hz} for all the halls, TVr-predictors were used. Since objective data corresponding to Apparent Source Width (LF and 1-IACCe3) were available for just a smaller subset of halls, it was instead decided to use measures of conventional source-broadening properties like Width (W) and Height-to-Width ratio (H/W).

Output of the processing of data from the 53 halls is in the form of parameter target values and tolerances, corresponding to the optimum correlation achieved in an iteration process, see Table 1.

Table 1 Parameters, target values and tolerance, see text

Parameter	T (s)	EDT (dB)	G (dB)	C (dB)	GL (dB)	G_{125} (dB)	H/W (1)	W (m)
Hall average, target value	2.0	2.0	4	0	3	4	1.0	23
Tolerance ±	0.1	0.2	1	1	1	1	0.2	5

In Figure 1, the 53 halls are plotted with subjective ranking on the horizontal axis and objective score on the vertical axis.

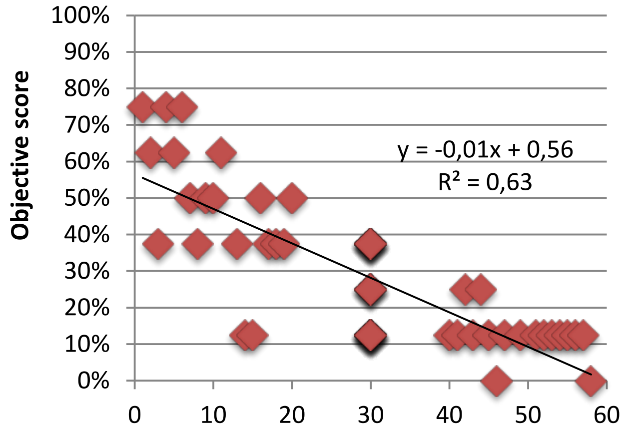


Figure 1 The 53 halls plotted with subjective ranking on the horizontal axis and objective score on the vertical axis

Testing a potential Preference Predictor

So far, we have just determined the parameter criteria that provide the optimal correlation between objective data and subjective preference. We developed a method which assigns to any hall an objective Score, i.e. a preference value between 0% and 100%. In order for the method to work as a Preference Predictor, we need to calibrate it by studying the subjective quality range associated with a given interval on the Score-scale. In particular, we do not want "bad halls" to be built, or "good halls" to be rejected in the planning phase. We want the percentage of overestimation and underestimation to be as small as possible in the prediction method.

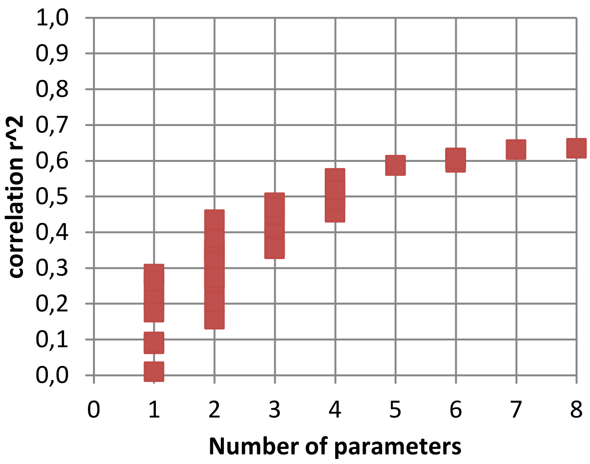
As an example of assessing the output scores: Assuming that only the best halls should be built or replicated, halls with the same objective properties as the Class II and Class III halls in Beranek's ranking of 58 halls should NOT be built. As a consequence, only halls with a score of 50% or better get the "green light" from the Preference Predictor. Further, as a consequence, some of the Class I halls could not be built on basis of their parameter values, see Table 2 in Appendix.

A suggested way to assess the scores is to establish a scale with a Green interval for the "YES" halls (score 50%-100") and appropriate yellow and red ones for scores less than 50%. Yellow would mean "MAYBE", i.e. they would need other justification than their parameter values, and Red would mean "NO". The border between Yellow and Red needs to be settled.

Calculated preference scores for the better part of the 53 concert halls and some more halls are presented in Table 3 in Appendix. More examples of results are presented in a slides version at AIA-DAGA 2013 in Merano [10].

Uncertainties related to data size

Uncertainties related to changes in number of parameters and number of halls was demonstrated, see Figure 1. While reducing the number of parameters always resulted in lower correlation, a smaller selection of halls would result in greater uncertainty in correlation. A smaller subset of halls would randomly exhibit higher correlation, lower correlation, or practically unchanged correlation. With random selected subsets of e.g. 10 halls, correlation would vary between $r^2 \approx 0.15$ and $r^2 \approx 0.95$, clearly warning against drawing any conclusions from an apparently convincing r^2 outcome, either high or low, based on a low number of halls. With an expansion in terms of more parameters, not only correlation improved: Uncertainty is improved too.



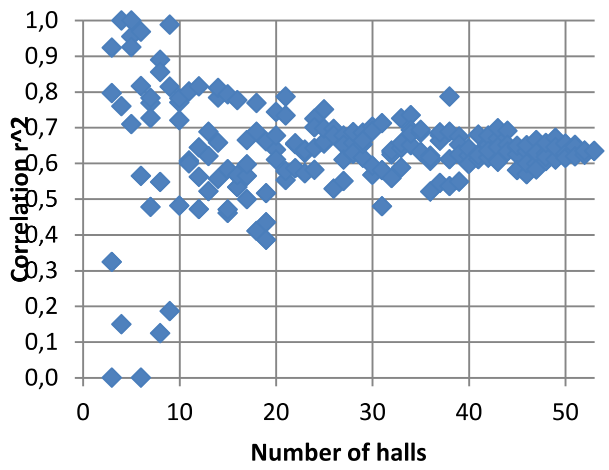


Figure 2: Correlation between objective and subjective data depending on the number of objective parameters (upper diagram) for 53 halls, and on the number of halls (lower diagram) with 8 parameters. See text.

Discussion

Contradiction or inevitable consequence of uncertainty?

A consequence of the example above is that 8 of the top 20 halls should not be replicated, one of these being Carnegie Hall, New York, (Table 3 in Appendix). Immediately this result would seem like a contradiction between input and output: "Carnegie Hall is first class" results in "Carnegie Hall is not first class". However, this is not the case. The input is data for 53 halls, and the output is the parameter values that best explain their preference. Thus Carnegie is one of the 8/53 of the halls that are preferred despite of its parameter values. Instead of a contradiction, this can be interpreted as an uncertainty in terms of 15% risk of underestimating the reception of a hall under consideration. As a consequence of a conservative "safety first" policy, i.e. lack of precision in the prediction method, some of the Class I halls would need to be banned.

Concert hall planning is a risky business

There is an inherent risk in the business of concert hall prediction, planning and decisions. Not even the strategy of making an exact replica of an existing building would be 100% safe, because other uncertainties than the objective ones would immediately become evident: "Which one do we choose – Vienna, Berlin, Tokyo, Boston or Amsterdam?" They all sound very differently. Besides, what if the client loves Concertgebouw but has only been there when the Concertgebouw Orchestra plays? Preference is based on listening experience, affected by the performance of the orchestra. Not with any strategy can uncertainty be eliminated, it can only be statistically limited.

Black Box – explanation by prediction without insight

In science, our demand for understanding and insigth is always a driving force. So we keep on researching tirelessly. But above all, scientific explanation requires predictability of outcome. The method presented offers prediction of subjective response from the average concert-goer, but without insight in underlying mechanisms. We seem to deal with a black box, and the black box seems to be our brain. Parameter values are fed into the black box, and out comes the predicted preference score with some uncertainty.

Even if we lack insight into our brain, and even if we have not yet defined listening quality, we are able to use our data to reduce the risk of complaints over a new concert hall. Controversies over lack of understanding is not uncommon, suffice to mention Einstein and Bohr's discussions over Quantom Physics.

Evolution model, and the freedom in design

The resident-orchestra-problem is mentioned above: How can we measure the effect a concert hall has on subjective preference if preference is established by a majority of audience who allways listens to the resident orchestra? Even more – concert halls, audience, orchestras, conductors, composers, music works have all developed to what they are through an evolution process where these elements interact. One consequence may be that proper acoustics for symphonic music cannot not be expected in halls dissimilar to those where the symphonies evolved. Thus Freedom-in-design can be a self-contradiction. Yes, we have the freedom to design halls for any purpose. But once you have made your choice of purpose, freedom of choice is given away. Optimum acoustical conditions for 2000 people listening to symphonic music is a very special outcome of evolution. Assuming concert hall design is an art, still every art is defined by the constraints within which freedom unfolds. An unlimited number of parameters would be equivalent to replication. By using a limited number of parameters, we have the freedom to build without making copies of Muskverein, Boston or Concertgebouw, but the cost of freedom is risk – the risk of not hitting the target defined by the building committee. On the other hand, Berlin Philharmonie stand out as an example of freedom and risk hand-in-hand, where conductors, musicians and listeners succeeded in adapting to an outcome of evolution that deviates from the classical halls. In terms of survival-of-the-fittest (fittest = best adapted), which is the species and which is the environment?

Conclusions

Conservative use of parameter prediction in concert hall planning can reduce risk of overestimating a hall. Correlation in the order of $r^2 \approx 0.6$-0.7 is found between objective and subjective concert hall data for 53 halls in Beranek's data collection. Uncertainties related to target values and tolerances are reduced by increasing the number of concert halls and the number of parameters in the basis, and the number of parameters is in principle only restricted by availability and predictability. Experiments show that LF and 1-IACCe seems to be surprisingly well substituted by H/W and W. TVr predictors and geometrical data still prove to be very useful. Remaining uncertainty in the prediction method naturally leads to a "safety first" policy with high acceptance limits for the objective data. As a consequence, some appreciated halls may not be recommended for replication, and so the question of freedom in design arises. These consequences need to be discussed in further work. Other conclusions:

- Predictors should be tested for consequences, not only by the subjective-objective correlation
- Relationship between Parameter and Preference is Non-Linear: Too much and too little can be equally unpleasant
- Use of more parameters, if available, can reduce risk
- Beware of small selection of halls, since correlation is very uncertain (r^2 between 0.15 and 0.95)
- Prediction without Insight in underlying mechanisms can be useful, however unsettling
- We need more subjective data, give your on-line rating on www.akutek.info

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APPENDIX – DATA TABLE OF RESULTS

Table 2 Parameters and target values corresponding to optimum data-correlation, see text in this paper

Parameter	T (s)	EDT (dB)	G (dB)	C (dB)	GL (dB)	G_{125} (dB)	H/W (1)	W (m)
Hall average, target value	2.0	2.0	4	0	3	4	1.0	23
Tolerance ±	0.1	0.2	1	1	1	1	0.2	5

Table 3 Examples of concert halls that would be approved on the basis of target values in the table above.

Hall	Rank	V (m^3)	r_{avr} (m)	T (s)	EDT (dB)	G (dB)	C (dB)	GL (dB)	H/W (1)	W (m)	Score (%)
Vienna Grosser Musikverinsaal	1	15000	29	2,0	2,0	4	-1	1	0,9	20	**75 %**
Berlin Konzerthaus (Shauspielhaus)	4	15000	25	2,0	1,9	4	-1	2	0,9	21	**75 %**
Tokyo Opera City, Concert Hall	6	15300	30	2,0	1,9	4	-1	1	1,1	20	**75 %**
Boston Symphony Hall	2	18750	32	1,9	1,9	2	0	-1	0,8	23	**63 %**
Amsterdam Concertgebouw	5	18780	29	2,0	1,9	3	-1	0	0,6	28	**63 %**
Dallas, Meyerson Symphony Center	11	23900	30	2,8	1,9	4	-3	2	1,0	26	**63 %**
Zurich Grosser Tonhalsaal	7	11400	28	2,1	2,0	5	-1	3	0,7	20	**50 %**
Basel Stadt Casino	9	10500	25	1,8	1,7	5	0	2	0,7	21	**50 %**
Cardiff, St Davis Hall	10	22000	29	2,0	1,9	2	0	-1	0,7	27	**50 %**
Berlin Philharmonie	16	21000	34	1,9	1,8	2	0	-1	0,3	43	**50 %**
Baltimore, Meyerhoff Symphony Hall	20	21530	34	2,0	2,0	2	-1	-1	0,6	29	**50 %**
Manchester Bridgewater Hall	-	25000	25	2,0	1,9	2	0	-1	0,9	26	**75 %**
Lucerne, Cultural Ctr. Concert Hall	-	18000	23	2,1	2,0	4	-1	1	1,1	22	**75 %**

Table 4 Examples of high ranked concert halls that would NOT be approved, based on the target values above.

Hall	Rank	V (m^3)	r_{avr} (m)	T (s)	EDT (dB)	G (dB)	C (dB)	GL (dB)	H/W (1)	W (m)	Score (%)
Buenos Airos, Teatro Colon	3	21524	31	1,6	1,6	1	1	-3	1,1	24	**38 %**
New York Carnegie Hall	8	24270	31	1,8	1,7	1	0	-2	0,9	26	**38 %**
Lenox, MA, Seiji Ozawa Hall	13	11610	28	1,7	1,6	4	0	1	0,7	21	**38 %**
Tokyo, Suntory Hall	17	21000	31	2,0	1,9	2	-1	-1	0,5	31	**38 %**
Tokyo, Bunka Kaikan (Ueno)	18	17300	31	1,5	1,5	1	1	-2	0,7	27	**38 %**
Brussels, Palais des Beaux-Arts	19	12520	29	1,6	1,6	3	0	0	1,3	23	**38 %**
Costa Mesa, Segerstrøm Hall	14	27800	37	1,6	1,5	-1	1	-5	0,6	42	**13 %**
Salt Lake City, Symphony Hall	15	19500	34	1,7	1,6	1	0	-2	0,6	30	**13 %**