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ANALYSIS OF PHYSICAL AND PERCEPTUAL PROPERTIES OF ROOM IMPULSE RESPONSES: DEVELOPMENT OF AN ONLINE TOOL

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ABSTRACT

Over the past decades, research in room acoustics has established several derivative measures of an impulse response, some of which are incorporated in the ISO 3382 standards. These parameters intend to represent perceptual qualities, but were developed without a consistent modeling of room acoustical perception. More recent research proposed comprehensive inventories of room acoustic perception that are purely based on evaluations by human subjects, such as the Room Acoustical Quality Index (RAQI). In this work RAQI scores acquired for 70 room impulse responses were predicted from room acoustical parameters. Except for *Reverberance*, the prediction of RAQI factors performed rather poor. In most cases, the sound source had a greater impact on RAQI scores. All analyses are published in an online tool, where users can upload omnidirectional and binaural impulse responses, and instantly obtain and visualize several physical descriptors, as well as predicted RAQI scores for three different sound sources. So far, acceptable prediction accuracy is achieved for *Reverberance*, *Strength*, *Irregular Decay*, *Clarity* and *Intimacy*. Larger data sets of evaluated impulse responses are required to improve the model performance and enable reliable predictions of room acoustical quality. Therefore, the administration of RAQI evaluations within the website is currently being developed.

Keywords: *room acoustics, online tool, concert halls*

1. INTRODUCTION

Since W. C. Sabine introduced his famous reverberation time formula [1], there has been plenty of research on how to obtain improved measurements and estimates of the perceptual impression of room acoustics. This research is essentially driven by two sometimes conflicting goals.

The first is the development of simple and yet meaningful, physically measurable parameters to estimate single perceptual qualities from a given physical measurement (usually an impulse response). A ground truth of such parameters can be found in the ISO 3382-1 [2]. The standard defines parameters such as early decay time (EDT), sound strength (G), clarity (C80), early lateral energy fraction (J_{LF}) and interaural cross correlation (IACC), which can be obtained from omnidirectional, binaural, and mid-side impulse responses. Many studies have investigated how well these parameters describe perceptual attributes of room acoustics such as reverberance and listener envelopment, and several augmentations of the ISO parameters have been proposed (see Bradley [3] for a comprehensive literature review). These augmentations range from proposing optimum time intervals and frequency ranges to using linear regression to combine multiple parameters to aggregate predictors of perceptual ratings [4].

More recent research has shifted the focus from accurate modeling of perceptual attributes by physical parameters to the creation of inventories that enable a comprehensive, ecologically valid assessment of room acoustics perception [5-7]. The most recent outcome of these efforts is the Room Acoustical Quality Inventory (RAQI) [5], which allows the quantitative assessment of perceptual qualities. Here, subjects have to rate sets of perceptual attributes that have been determined by an expert focus group and subsequently validated through listening tests. These attribute ratings are

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then aggregated to the nine room acoustical quality factors *Quality, Strength, Reverberance, Brilliance, Irregular Decay, Coloration, Clarity, Liveliness* by means of a factor analysis. The RAQI thus provides both a validated set of perceptual attributes and higher order qualities, and a protocol for their quantitative assessment.

However, to the authors' knowledge, there has been no empirical investigation of the relationship between RAQI factors and physical measures of room acoustics. RAQI ratings can only be acquired through listening experiments, which can be time-consuming and expensive, especially since the inventory comprises 14 to 33 attributes, some of which are best administered to test persons with some kind of professional expertise [5].
Thus, it would come in handy to be able to predict the results of a RAQI assessment by examining impulse response measurements, prior to spending time and money on listening experiments. Even though such a prediction cannot fully replace listening experiments, it would provide a first impression of the perceptual qualities of a room, which could be helpful for example to compare different architectural designs for performance spaces.

This paper presents an attempt to provide such a prediction of RAQI factor scores from simulated or measured room impulse responses, and is organized as follows: first, prediction models for RAQI factor scores are tested using established room acoustical parameters as predictors. Second, an online tool is developed which provides both the calculation of these parameters based on impulse responses and the prediction of RAQI scores within a standard web browser.

2. STUDY 1: RAQI PREDCITION MODEL

2.1 Methods

Predicting RAQI scores from physical parameters poses two central issues: selecting appropriate predictor variables and acquiring a sufficient number of RAQI-evaluated room responses for the reliable estimation of prediction effects.

So far, there are not many RAQI ratings available, except for those of the initial study of its development, which are publicly available as the Ground Truth on Room Acoustical Analysis and Perception database (GRAP) [8]. The database comprises 35 simulations of various room sizes (166m³-43790m³) and geometries created with the RAVEN framework [9]. Omnidirectional and binaural impulse responses are provided for two receiver position in each room, as well as RAQI ratings for the three source signals speech, solo trumpet and orchestra, with the latter missing in ten rooms that were too small to be considered as orchestra performance venues [5]. This leads to a total of 190 RAQI ratings and 70 pairs of omnidirectional and binaural impulse responses, which were used as input data for the prediction model.
To achieve a comprehensive prediction of room acoustical quality from physical properties, all nine RAQI factors, comprising 29 items in total, were included in the analysis. Individual factor scores were calculated from the weighted sums of the three to four attributes of each factor, using the weights given in [5].

Table 1. Physical parameters that were used as predictors for RAQI factors. See the parameters' reference for the calculation formula.

Parameter	Reference
Reverberation time (RT)	ISO 3382-1 [2]
Early decay time (EDT)	ISO 3382-1
Centre time (T_S)	ISO 3382-1
Sound strength (G)	ISO 3382-1
A-weighted Sound strength	Soulodre and Bradley [4]
Early sound strength (G_{early})	Bradley [10]
Late sound strength (G_{late})	Bradley [10]
Clarity (C80)	ISO 3382-1
Clarity (C50)	ISO 3382-1
Level-adjusted C80	Soulodre and Bradley [4]
Early lateral energy fraction (J_{LF})	ISO 3382-1
Late lateral level (L_J)	ISO 3382-1
Interaural cross correlation (IACC)	ISO 3382-1
Early IACC ($IACC_{early}$)	ISO 3382-1
Bass ratio (BR)	Beranek [11]
Early bass level (EBL)	Soulodre and Bradley [4]
Treble ratio (TR)	Soulodre and Bradley [4]

As mentioned above, the RAQI assesses room acoustical quality from a purely perceptual perspective, and is conceptually somewhat detached from physical descriptors of reverberation. Yet, some RAQI factors, such as *Strength*, *Reverberance*, and *Clarity* are also addressed in the ISO 3382-1 standard, and there are several room acoustical

parameters that can be tested as predictors for the nine RAQI factors.
Table 1 shows a selection of physical parameters that were considered suitable predictors. Most of these are mentioned in the ISO 3382-1 Appendix, others are extensions of the ISO parameters that have been empirically validated as more meaningful [4,10].

All parameters were calculated according to the formulas given in the ISO 3382-1 standard or the literature proposing the respective parameters (see Table 1). All parameters were reduced to single values because testing each parameter over several octave bands would have resulted in more predictor parameters than impulse responses, and the predictor reduction explained in the next section would have not been feasible.
The parameters defined in ISO 3382-1 were calculated in octave band resolution and then averaged according to the frequency ranges given in Table A.2 of the standard [2], as were these parameters' derivative measures, such as G_{early}, for which the same frequency range as for G was used. The parameters A-weighted sound strength, level-adjusted C80, BR, EBL and TR are based on ratios of decay times or sound strength between specific octave bands are therefore inherently single value parameters.

As the GRAP database does not provide mid-side impulse responses required for the parameters J_{LF} and L_J, these were approached by applying a channel transformation to the binaural impulse response that is also applied to stereo signals in audio codecs. The spectral differences introduced by the HRTF within the binaural impulse responses were not considered an issue here because J_{LF} and L_J are based on energy ratios between channels that are not affected by these differences.

Due to similarities and overlaps in the calculation, considerable correlations between the selected parameters were expected which could raise issues of multicollinearity and the compromise prediction robustness [12]. Therefore, an exploratory factor analysis (EFA) was applied beforehand to reduce the high number of parameters to a few latent factors which were then used as independent variables to predict the RAQI factor scores. Despite the obvious similarities between groups of parameters, an exploratory approach was chosen, because it allows for the aggregation of parameters where strong correlations might emerge from the impulse response data, but are not evident from the parameters' calculation formulas.
To test for the appropriateness of the data and particular parameters for a factor analysis, the Kaiser-Meyer-Olkin criterion (KMO) and the individual mean sampling accuracies (MSA) were examined. In case of MSAs below the common threshold of 0.6, the parameter with the lowest MSA was iteratively removed, and the MSAs were re-evaluated until all MSA values were above the desired threshold. Any parameter that was excluded in this procedure was included to the following prediction models as an individual predictor.

Because of the different source signals, multiple RAQI ratings were present for the same impulse response, violating the independence assumption of observations for general linear models. Thus, linear mixed-effects models for each RAQI factor were calculated using the EFA factor scores and excluded parameters as fixed effects and the source signal as well as the individual ID for each room and listener position as random effects.

2.2 Results and Discussion

The examination of the parameters' MSA led to the exclusion of BR and TR from the factor analysis. The Kaiser criterion, scree test and parallel analysis supported a solution with three factors that were extracted using maximum likelihood estimation and oblique factor rotation.

Table 2. The physical parameters' factor loadings on the three factors extracted by the EFA. For better interpretability, the factors scores for *Decay* and *Diffusion* were used with inverse polarities. Note: Only loadings greater than 0.4 are shown.

Parameter	Amplification	Decay (inverse)	Diffusion (inverse)
RT		–.769	
EDT		–.821	
T_S		–.806	
G	1.004		
A-weight. G	1.002		
G_{early}	.969		
G_{late}	.954		
C50		.926	
C80		1.001	
Level-adj. C80	.763	.521	
J_{LF}			–.972
L_J	.815	–.454	
IACC		.442	.686
$IACC_{early}$			.974
EBL	.902		

Table 2 displays the factor loadings (for better visibility, only loadings greater than .40 are shown). All parameters with considerable loadings on the first factor are related to sound strength, and all loadings of .80 and more clearly indicate that this factor expresses the amplification of sound through the surrounding environment. To discriminate it from the ISO parameter sound strength, it will be called *Amplification* throughout this paper.

The second factor comprises parameters related to shorter decay times and a higher relative amount of energy within the early reflection time window. Additionally, the parameters IACC and L_J exhibit moderate factor loadings with opposite polarities, indicating incongruency between the left and right hemisphere of the listener position. This factor will thus be referred to as *Decay*, and for a more intuitive use in the subsequent analysis, the factor scores were inverted.

The third factor affects parameters that are based on the spatial distribution of reflections, expressing high congruency between left and right and low relative amounts of laterally arriving energy. Again, the factor scores were inverted for better interpretability and the factor was named *Diffusion*.

There were three cases of double loadings above .40. The level-adjusted clarity is based on both C80 and G and primarily associated with amplification. L_J shows similar loadings on these two factors, but with a positive, moderate loading on decay. Finally, the IACC has an equally moderate loading on decay and exhibits a higher loading on diffusion. Among the factors, there were only moderate correlations between *Amplification* and *Diffusion* (r = –.26) and *Decay* and *Diffusion* (r = .23).

The three factors agree well with a grouping of common room acoustical parameters by Bradley [3] into 'decay times', 'sound strength', 'clarity measures' and 'measures of spatial effects'. 'Sound strength' and 'measures of spatial effects' are overall equivalent to the extracted factors *Amplification* and *Diffusion*, respectively. However, Bradley's two parameters 'decay times' and 'clarity measures' were aggregated to one factor in our study. This factor appears to have a stronger effect on *Reverberance* than it does on *Clarity* and was thus named *Decay*. Starting with Sabine's reverberation time, the research on decay time as reverberance measures has the longest history in research on room acoustics. Interestingly, in this analysis, the 'clarity measures' exhibit higher loadings onto this factor than those classified as 'decay times' (see Table 2).

Following the results of the factor analysis, the linear mixed-effects models included five fixed effects (amplification, decay, diffusion, treble ratio and bass ratio) and two random intercepts (source signal and ID identifying each room and listener position).

Table 3 shows the estimated, standardized regression coefficients of the fixed effects as well as Nakagawa's conditional and marginal R^2 of the models [13], which describe the variance in the RAQI scores explained by the fixed effects and the sum of fixed and random effects, respectively. Additionally, Intraclass correlation coefficients (ICC) for a null model containing only the random effect of the source signal are provided, representing the estimated variance in the RAQI scores explained due to the different sound sources.

Table 3. Fixed effects estimates ('*' indicates $p < .05$), marginal and conditional R^2 (R^2_m and R^2_c, respectively), as well as intraclass correlation coefficients of the source effect (ICC_{src}) for the prediction models of the RAQI factors Quality (Qlt.), Strength (Str.), Reverberance (Rev.), Brilliance (Brl.), Irregular Decay (Ir. D.), Coloration (Col.), Clarity (Cla.), Liveliness (Liv.) and Intimacy (Int.).

	Qlt.	Str.	Rev.	Brl.	Ir. D.	Col.	Cla.	Liv.	Int.
Fixed effects:									
Intercept	.034	.113	–.021	.023	–.043	.014	.009	.105	.063
Amplification	.071	.538*	.131*	.436*	–.015	.141	.147	.597*	.358*
Decay	–.138	.262*	.929*	.181*	.554*	.168	–.574*	.126	–.526*
Diffusion	–.196	.016	–.216*	–.253*	.014	.242*	–.114	–.282*	–.034
Bass ratio	.149*	–.071	–.096	–.111*	–.106*	.018	.134*	.034	.133*
Treble ratio	.218*	.073	.017	.112*	–.072	–.148*	.087	.088	–.076
R^2_m	.137	.280	.696	.112	.334	.189	.469	.176	.350
R^2_c	.668	.884	.903	.759	.759	.652	.760	.802	.833
ICC_{src}	.483	.539	.126	.635	.412	.416	.212	.550	.433

For each RAQI factor, at least two predictors exhibit a significant effect. However, less than 40% of the observed variance in seven out of nine RAQI factors could be explained by the tested physical parameters. The effects are smallest for *Quality* (R^2_m = .131) and *Brilliance* (R^2_m = .108). The source signal, on the other hand, accounts for more than 40 % variance in these factors, and up to 63.5 % in the case of *Brilliance*, as indicated by its ICC. The only exceptions are *Reverberance* and *Clarity*, where the fixed effects explain more variance (69.6 % and 46.9 %, respectively) than the source signal (12.6 % and 21.2 %, respectively).
Out of the three parameters that take into account the spectral distribution of reverberation energy (early bass level, treble ratio and bass ratio), two were deemed unsuitable for the factor analysis and the third was included in the (otherwise frequency-independent) strength measure *Amplification*. This illustrates that, so far, that there are still only a few single descriptors for the spectral envelope of reverberation [3,5], which is also confirmed by the rather poor prediction of the timbre-related RAQI factors *Brilliance* and *Coloration*.
Another perceptual aspect that has received little attention in research on adequate room acoustical parameters is the RAQI factor *Intimacy*. Interestingly, in this analysis, *Intimacy* could be modeled more accurately by established physical parameters alone than by the factor *Strength*, which is a well-researched room acoustical quality that is targeted by several parameters tested here.

Quality might be considered the most interesting RAQI factor, since it does not only describe perception, but preference ratings. While this RAQI factor provides a new standard in comparable measurement of subjective preferences, their prediction from physical parameters remains inaccurate. Yet, the observed small, positive effects of TR and BR as well as statistically insignificant effects of *Amplification*, *Diffusion* and clarity (as part of *Decay*) point in a similar direction as previously reported beneficial effects of perceived proximity and bassiness [6] as well as loudness, treble ratio and clarity [7].

3. STUDY 2: ONLINE TOOL

Major aim of this research was to enable a quick easy-accessible assessment of estimated RAQI scores without having to conduct a listening experiment. To do so, the calculation of all physical parameters used in this analysis and estimated RAQI scores based on the prediction model described above was implemented in an "Online Tool for the Prediction of Room Acoustical Qualities" (OPRA). The tool is publicly available, and all functionalities can be used free of charge at https://www.opra.isave.hs-duesseldorf.de.

3.1 Methods

Users can upload impulse responses as audio files. Calculations of all parameters and RAQI predictions are then performed within the web browser. The user interface provides a display of the time signal, a table displays single values for all parameters, averaged according to the rules mentioned in Section 2.3, and plots that display all frequency-dependent parameters for octave bands between 32.5 Hz and 8 kHz. Also, the tool is able to render auralizations of the uploaded impulse responses. More concretely, users can either auralize a saxophone performance (recorded in the anechoic chamber of Hochschule Düsseldorf) or upload custom source signals.

Furthermore, multiple impulse responses can be uploaded and displayed simultaneously. If omnidirectional impulse responses are uploaded, any parameters based on IACC or lateral energy portions are omitted from the calculation. In contrast, if binaural impulse responses are uploaded, an omnidirectional response is created for the calculation of single-channel-based parameters by applying an inverse of the diffuse field equalization according to ISO 11904-1 [15], as approximate HRTF compensation for arbitrary incident directions.
By default, uploads with two channels are treated as binaural impulse responses, and parameters that rely on mid-side impulse responses are calculated based on a channel transformation described in Section 2.3. However, it is possible to declare an impulse response as a "native" mid-side impulse-response, in which case all based parameters on an omnidirectional impulse response are calculated from the first channel that is considered to be an omnidirectional measurement, and parameters based on binaural impulses (IACC, $\text{IACC}_{\text{early}}$) response are omitted.

Concerning environmental variables, air temperature and humidity can be defined, with default values of 20 °C and 50 %, respectively. For the calculation of sound-strength-related parameters, the sound power as well as the digital amplitude corresponding to 1 Pa can be specified. Otherwise, the reference measurement is approximated by creating a Dirac impulse with an amplitude matching the direct signal component of the omnidirectional impulse response. The direct signal component is obtained from the maximum amplitude of each response. Finally, frequency-dependent air absorption according to ISO 9613-1 [16], is applied to the Dirac's amplitude. Since this air absorption is already present in the direct signal component of the impulse response, the Dirac's amplitude is increased by cumulative energy loss due to air absorption over frequencies, before frequency-dependent air-absorption is added within each octave band.

Due to the large effect of the source signal, the prediction models for new input data are designed to estimate source-dependent RAQI scores. To do so, the prediction model does not only take into account the estimated fixed effects' regression coefficients and intercepts, but also the random intercept estimated for the source signal. Only statistically significant fixed effects are included in the prediction. RAQI scores are thus estimated for nine factors and the three stimuli speech, solo instrument (trumpet) and orchestra. The calculated parameters as well as the predicted RAQI can be downloaded as JSON file.

The online tool performs all calculation within the user's browser and does not require additional processing on a server. The Web Audio API is used for octave band filtering and real-time auralization. Computationally expensive fourier transforms for the IACC are written in Rust and compiled to WebAssembly for near-native performance. The UI is composed of web components.

To test the online tool's performance, calculated physical parameters and predicted RAQI scores of the GRAP database were compared to ISO parameter data given in the database, and the observed RAQI scores, respectively. Since the database does not provide values for all parameters included in the online tool [8], comparisons could only be made for RT, EDT, G, C80, D50, J_{LF} and IACC. The online tool calculates C50 instead of D50, and the values were transformed according to the formula given in ISO 3382-1 [2].

3.2 Results and Discussion

Table 4 displays the mean and standard deviation values for the differences between the ISO parameters calculated by the online tool and those given in the GRAP database. To estimate whether these differences can be considered perceptually relevant, just noticeable difference values (JND) are given for those parameters this information is provided in ISO 3382-1.

For both RT and EDT, the differences between the online tool and the GRAP database are fairly large. A possible explanation might be, that the GRAP database provides T30 values, while the online tool calculates T20. T20 was chosen for the online tool to obtain more reliable results for real impulse response measurements with background noise. The calculation of G requires a reference measurement that could only be approximated in the online tool's calculations. Thus, it is not surprising that there are deviations of more than 1 dB from the values in the GRAP database that are supposedly calculated within the RAVEN simulation environment, where probably more information on the sound source's behavior in free-field conditions is available.

Table 4. Mean and SD values for the differences between the ISO-parameters calculated in the online tool and those given in the GRAP database, and JND values given in ISO 3382-1 [2]. Note, that for the GRAP database, a mean RT of 1.97 s (SD = 1.21 s) and a mean EDT of 1.97 s (SD = 1.16 s) were calculated.

parameter	mean	SD	JND
RT	0.21 s	0.38 s	-
EDT	0.26 s	0.21 s	5 %
T_S	0.01 s	0.01 s	0.01 s
G	1.67 dB	1.49 dB	1 dB
C80	1.16 dB	0.83 dB	1 dB
D50	0.05	0.03	0.05
J_{LF}	0.06	0.06	0.05
IACC	0.07	0.05	-

For C80, D50, T_S, and J_{LF}, the mean differences are within range of the JND. Note, that for J_{LF}, a mid-side impulse response had to be approximated from the binaural one. The standard provides no JND information for the IACC, but Klockgether and van der Par [17] found that changes in the IACC appear to be generally hardly perceptible. Therefore, the differences in IACC observed here are considered negligible.

Except for RT and EDT, there were overall no unexpected deviations of the online tool's calculations from the GRAP data and the tool is considered to provide acceptable parameter calculations.

Table 5 shows the correlations between predicted and observed RAQI scores, as well as mean values and standard deviations, for each source signal. Except for *Quality*, *Brilliance* and *Intimacy*, the prediction seems to be most accurate for speech. The correlations of factor scores for trumpet exhibit the lowest mean and the largest standard deviation, indicating a more heterogeneous prediction accuracy across the nine factors. Note that for 20 out of 70 impulse responses, there were no RAQI ratings with orchestra as the sound source, which might be one reason for the signal type exhibiting the lowest standard deviation among correlations.

Table 5. Correlations between the observed and predicted RAQI factor scores for each source signal.

RAQI factor	speech	trumpet	Orchestra
Quality	.374	.236	.547
Strength	.840	.816	.807
Reverberance	.892	.889	.889
Brilliance	.494	.559	.507
Irregular Decay	.789	.789	.769
Coloration	.459	.371	.426
Clarity	.830	.759	.783
Liveliness	.715	.552	.737
Intimacy	.833	.743	.814
Mean	.691	.634	.698
SD	.195	.220	.162

The RAQI scores' dependence on the source signal is a central issue in their prediction that has also been discussed by the RAQI's authors [2]. It was found that not only the RAQI scores, but also the accuracy of their prediction can be highly source-dependent. Acceptable predictions (correlations between predicted and actual scores above .70) are achieved across all source signal types for the five factors *Strength*, *Reverberance*, *Irregular Decay*, *Clarity* and *Intimacy*.

4. GENERAL DISCUSSION

A set of 70 simulated room impulse responses was used to predict RAQI factor scores from various physical parameters that have been previously established as perceptually relevant. These parameters were aggregated to three latent factors *Amplification*, *Decay* and *Diffusion*. Linear mixed effects models showed that, except for the factors *Reverberance* and *Clarity,* these measures only accounted for rather small amounts of variance in the observed RAQI factor scores, and that the source signal had greater impact on the RAQI scores. These analyses were used to calculate a generic prediction model of regression coefficients for physical parameters and source-type-intercepts to predict source-specific RAQI scores. Both the parameter calculation and the prediction of RAQI scores are made publicly accessible within an online tool.

The grouping of parameters within the factor analysis as well as their comparatively weak prediction power for most RAQI factors illustrate, that despite extensive research on appropriate, objective descriptors of room acoustics, these parameters cannot represent singular facets of room acoustical perception. Especially the qualities related to the timbre and spectral balance of reverberation cannot be accurately modeled by the physical parameters that are currently available.

To thus improve the performance of RAQI predictions, the source was explicitly included in the model, which limits it to the three source signal types speech, solo instrument (trumpet), and orchestra. Here, the application of the RAQI with different sources (sung voice, smaller ensembles) might enhance the capability of room acoustical quality prediction.

More important, however, is the acquisition of RAQI evaluation data of more rooms and concert halls. The GRAP database provides a variety of room sizes, geometries, and acoustical characteristics. Yet, for the exploratory factor analysis applied here, 70 room impulse responses constitute a fairly small sample size [18].

The low sample size does not only weaken prediction models, it also prevents a) taking more spectral bands of each ISO parameter into account that can enable better modeling of timbre-related RAQI factors, and b) a more sophisticated variable selection through machine-learning algorithms such as the percentile-Lasso regression method, that has been successfully used to predict perceptual evaluations of low-level sounds [19]. These techniques would allow for a selection of a set of single, best performing predictors, instead of aggregating variables by means of a factor analysis, as it was done in our study.

Additionally, the sample used in the study exclusively consisted of simulated room impulse responses. While state-of-the-art simulations can be expected to produce plausible auralizations, the simulated sound propagation is subjected to simplifications that create systematic deviations between real rooms and simulations, such as spectral differences in early reflections [20]. These deviations could, for example, affect how parameters such as EBL and TR influence the perception of *Coloration* or *Brilliance*. Thus, the prediction model should be improved by including RAQI ratings of real rooms into the input data.

5. OUTLOOK

The online tool is still being developed further. Current work includes the development of a survey platform to perform RAQI evaluations of uploaded impulse responses. The implementation of listening tests with standard online survey tools can be tiresome, so that the goal is to provide a standardized test interface and lower the barriers for using the RAQI to gather perceptual data. The survey platform will further provide the option to upload the results that will then be used to subsequently refine the implemented prediction model. This way, the RAQI score prediction will hopefully improve and in the best case, a high number of evaluated impulse responses can be collected enabling the use of machine-learning techniques that would allow more sophisticated predictor selection methods.

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