Proposing Acoustic Parameters based on Information Technology

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ABSTRACT: *In this work, the possible prediction of acoustic parameters using information technology is presented which takes the variables such as reverberation time, speech intelligibility and music clarity parameters for the fully occupied concert hall. We have deployed estimation algorithms and the estimated the scores of processed acoustic parameters according to the acoustic analysis of the impulse response. This part has been subjected to analysis and the results are posted. Next we based on the obtained results, measured the acoustic purpose of the concert hall.*

Keywords: Room Impulse Response, Acoustic Parameters, Prediction

Received: 17 April 2021, Revised 12 July 2021, Accepted 27 July 2021

DOI: 10.6025/jitr/2021/12/4/103-110

1. Introduction

In concert halls music and acoustics are inseparable. There are held concerts and events that require, by their features, very different acoustic properties of the space.

A concert hall can be seen as a big resonance box of an instrument, where sound waves reflected off the walls and thereby initiate the phenomenon of reverberation. This phenomenon can be experienced subjectively as pleasant or irritating [1]. An objective classification is achieved with acoustical parameters extracted from the impulse response of the room. Thus, accurate impulse response measurements, already regulated by ISO 3382 standard [2] are desired for the assessment of acoustical properties.

This work contains the analysis of the predicted values of acoustic parameters which characterize the speech intelligibility and clarity of music for the occupied concert hall "Promenadikeskus" in the Pori (Finland).The analysis is based on the data of impulse response of the concert hall, available on http://legacy.spa.aalto.fi/projects/poririrs/. The impulse responses were recorded at three locations of the sound source at multiple measurement points. Using software packages EASERA and Matlab, as well as and theoretical models, the following results were achieved: a) for an empty concert hall for each location of the sound source and all measuring points we determined: reverberation time by octaves $RT_{30unocc}$, mean value of the reverberation time by octaves $\overline{RT}_{30unocc}$, speech transmission indexSTI_{unocc}, mean value of the speech transmission index$\overline{STI}_{unocc}$, clarity of music $C80_{unocc}$ and mean value of the clarity of music $\overline{C80}_{unocc}$ and b) provided for the fully occupied concert hall for each sound source and measurement point: the mean value of the reverberation time by octaves $\overline{RT_{30occ}}$, speech transmission index*STIocc*, the mean value of the speech transmission index $\overline{STI_{occ}}$, clarity of music C_{80occ} and mean value of the clarity of music $\overline{C_{80occ}}$. The obtained values of these parameters were analyzed in relation to standard values and certain conclusions were presented.

The work is organized as follows: Section 2 presents the estimation algorithms of the analyzed acoustic parameters, Section 3 describes the experiment and the results are presented in tables and graphs, Section 4 presents the result analysis, whereas Section 5 is the conclusion.

2. The Evaluation of the Parameters for the Full Room

2.1. Reverberation Time

The evaluation of the reverberation time for the full room RT_{occ} can be carried out using the following formula [3]:

$$RT_{occ} = RT_{unocc} - DT \tag{1}$$

where RT_{unocc} is estimated reverberation time for the empty room, and DT is Shulc's diffusiion time which is calculated using the equations from the Table 1 [3].

f **(Hz)**	***DT*** **(s)**
125	0.510*RT*-0.708
250	0.605*RT*-0.867
500	0.668*RT*-0.929
1000	0.696*RT*-0.935
2000	0.694*RT*-0.889
4000	0.652*RT*-0.752

Table 1. Shulc's Estimated Values for *RT*

2.2. Speech Intelligibility

The evaluation of the speech intelligibility parameters for the full room STI_{occ} can be carried out using [4]:

$$STI_{occ} = STI_{unocc} + \Delta STI\ . \tag{2}$$

STI_{unocc} is the index of the speech transmission for the empty room and ΔSTI je the value which is calculated using the following formula:

$$\Delta STI = 0.45\, ln \frac{RT_{unocc}(2kHz)}{RT_{occ}(2kHz)} + 0.012\ , \tag{3}$$

where RT_{unocc} is the reverberation time of the empty room and RT_{occ} is the reverberation time of the full room. These values are taken at $f = 2$kHz [4].

2.3. Music Clarity

The evaluation of the music clarity in the room, C_{80}, can be carried out using Baron's theory of sound decreasing in which the direct sound follows an exponential decrease in sound energy [5, 6]. Propagation time of the direct sound from the source to the receiver at the distance r is $t_D = r/c$, where c is the speed of sound.

For the room of the volume V integrated acoustic energy l for the time $t \geq t_D$, where $t \to \infty$, at certain location in the room is:

$$l(t) = 31200\,\frac{RT}{V}\,e^{-\frac{13.82t}{RT}} \tag{4}$$

where RT is the reverberation time.

The evaluation of music clarity parameters in the room, C_{80}, includes three components of the received sound at the receiver position: the direct sound d (Eq. 5), the early reflected sound e with the delay less than 80 ms (Eq. 6) and the late reflected sound l with the delay of more than 80 ms (Eq. 7):

$$d = \frac{100}{r^2}, \tag{5}$$

$$e = 31200\,\frac{RT}{V}\,e^{-\frac{0.04r}{RT}}\left(1 - e^{-\frac{1.11}{RT}}\right) \tag{6}$$

and

$$l = 31200\,\frac{RT}{V}\,e^{-\frac{0.04r}{RT}}\,e^{-\frac{1.11}{RT}} \tag{7}$$

where r is the distance between the receiver and the source. The estimated parameter of the sound clarity in the room C_{80} is:

$$C_{80} = 10\,log\,\frac{\int_{t_0}^{t_0-0.08} p^2(t)dt}{\int_{t_0+0.08}^{\infty} p^2(t)dt} = 10\,log\,\frac{d+e}{l} \tag{8}$$

3. Experiments

The evaluation of the acoustic parameters has been carried out for the Promenadikeskusconcert hall in Pori, Finland, which is shown in the Figure 1.

According to the impulse responses [7] we determined the alue of the objective acoustic parameters RT_{30}, STI and C_{80} for the unoccupied concert hall. Evaluation of these parameters was performed using theoretical models andMatlab program package.

For the analysis of acoustic parameters, we considered three locations of the sound source S and 4 (of 7) measurement locations, MP, the receiver, with the arrangement shown in Figure 2.

Figure 1. Promenadikeskus concert hall in Pori

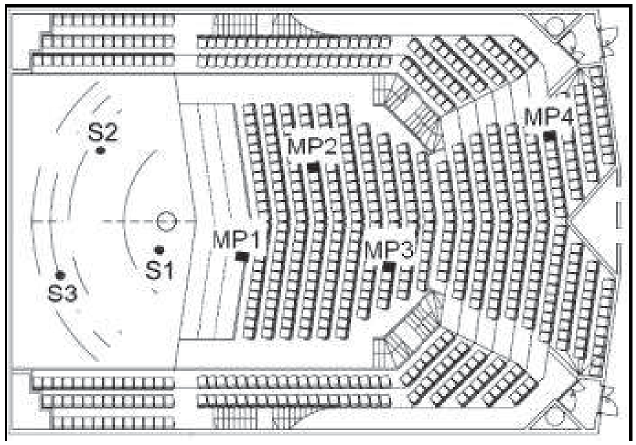


Figure 2. Location of sound sources (S1, S2 i S3) and measuring points (MP1 ¸MP4)

For the purpose of the room acoustic analysis, we calculated mean values of acoustic parameters considered for each position of the sound source at the measuring point and for each position of the sound source at all measuring points in the analyzed hall. The results are presented in tables and graphs.

3.1. The Basis

The impulse responses base contains audio recordings of the Pori Promenadikeskus concert hall impulse responses that have been recorded within the TAKU/V *A* RE technical project [7]. The dimensions of the hall are: 33 × 23× 15m. Total volume is approximately 9500 m^3 and capacity of about 700 people.

The responses were acquired using the IRMA measurement system. For all measurements, 48 kHz sampling rate and 16- bit *A/D* and *D/A* conversion were used. Two sound sources were utilized in the measurements. The measurements were performed using an omnidirectional loudspeaker DPA 4006 and a subwoofer. The impulse responses were measured using logarithmic sinusoidal sweep excitation. For measurements, the sweeps were synthesized in the time domain.

3.2. Results

Table 2 shows the values: a) the reverberation time $\overline{RT_{30unocc}}$,and mean value of the reverberation times, $\overline{RT_{30unocc}}$, for the unoccupied hall, b) of the Schultz diffusion, *DT* and c) mean value of the reverberation times $\overline{RT_{30occ}}$ for the occupied hall.

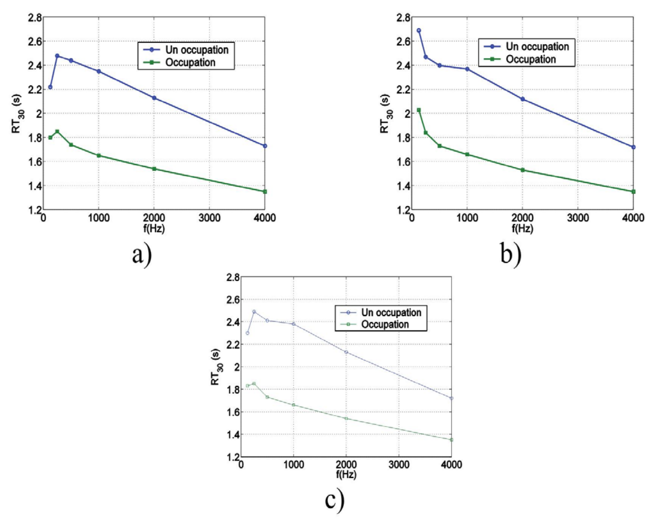
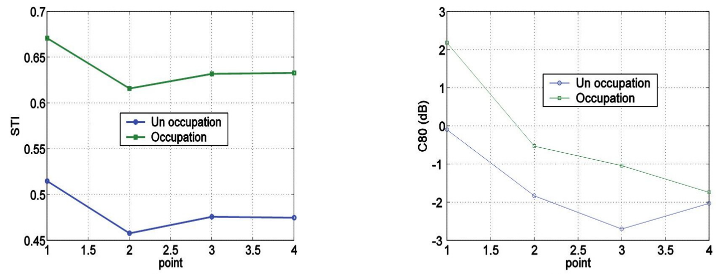


Figure 3. The mean value of the reverberation time at the measured points for both unoccupied and occupied concert hall for sound source locations: a) S1, b) S2 and c) S3

Tables 3 – 5 show the values: a) the reverberation time (1kHz, 2kHz), the speech transmission index and the clarity for the music for the unoccupied and occupied hall and b) the mean values of these parameters for MP points for sound source locations $S1$, $S2$ and $S3$. The change in mean values of reverberation time at measuring points for the unoccupied and occupied concert hall for the sound soucers positions $S1$, $S2$ and $S3$ is shown in Figure 3. The change in the mean values of transmission index and clarity for music at measuring points for the unoccupied and occupied concert hall for the sound soucers positions S1, S2 and S3 is shown in Figure 4. – Figure 6., respectively.



a) b)

Figure 4. The mean value of the transmission index (a) and clarity for music (b) at the measuring points for unoccupied and occupied concert hall for positions of sound soucers S1

4. The Results Analysis

Based on results shown in the Tables 2 – V and in the Figures 3. - 6. we can draw the following conclusions:

1) The predicted mean values $\overline{RT_{30occ}}$, obtained by using the values to predict Schultz values (Table 1), are for all sound sources and measuring points less than the mean values $\overline{RT_{30unocc}}$. The decrease in the values of the reverberation time is especially important at frequencies close to or equal to the frequency $f = 1$ kHz because they are most important to the quality of speech intelligibility. At the positions of the sound source S1, S2 and S3, the decrease of the value of this parameter is $\Delta\overline{RT_{30}}$ (1 kHz) = $\{0.7\ s, 0.715\ s, 0.72\ s\}$.

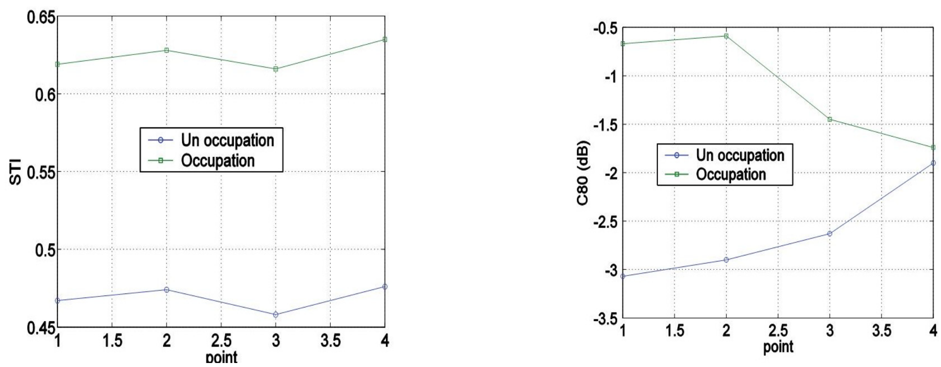
Sound source	f (Hz)	$RT_{30unocc}$ (s)				$\overline{RT_{30unocc}}$ (s)	DT (s)	$\overline{RT_{30occ}}$ (s)
		MP1	MP2	MP3	MP4			
S1	125	2.71	2.59	2.83	0.76	2.22	0.42	1.8
	250	2.44	2.42	2.56	2.51	2.48	0.63	1.85
	500	2.45	2.4	2.43	2.47	2.44	0.7	1.74
	1000	2.33	2.34	2.36	2.36	2.35	0.7	1.65
	2000	2.12	2.13	2.12	2.13	2.13	0.59	1.54
	4000	1.72	1.72	1.72	1.76	1.73	0.38	1.35
S2	125	2.62	2.64	2.7	2.79	2.69	0.66	2.03
	250	2.41	2.36	2.54	2.57	2.47	0.63	1.84
	500	2.45	2.33	2.42	2.4	2.4	0.67	1.73
	1000	2.36	2.37	2.4	2.35	2.37	0.71	1.66
	2000	2.09	2.11	2.13	2.15	2.12	0.59	1.53
	4000	1.7	1.68	1.75	1.75	1.72	0.37	1.35
S3	125	2.71	2.66	1.04	2.8	2.3	0.47	1.83
	250	2.46	2.52	2.48	2.5	2.49	0.64	1.85
	500	2.4	2.39	2.44	2.41	2.41	0.68	1.73
	1000	2.38	2.36	2.37	2.41	2.38	0.72	1.66
	2000	2.13	2.1	2.14	2.14	2.13	0.59	1.54
	4000	1.73	1.7	1.7	1.76	1.72	0.37	1.35

Table 2. The values the reverberation time for unoccupied and occupied concert hall and schultz diffusion time, *dt*

2) At medium frequencies, the predicted mean values $\overline{RT_{30occ}}$ for all positions of the sound source are the same and equal RT_{30srf} = 1.695 s. The calculated optimum reverberation time (depending on the volume) is RT_{opt} = 2.04 s. These values are

MP	$RT_{30unocc}$ (1 kHz) (s)	RT_{30occ} (1 kHz) (s)	$RT_{30unocc}$ (2 kHz) (s)	RT_{30occ} (2 kHz) (s)	STI_{unocc}	STI_{occ}	$C_{80unocc}$ (dB)	C_{80occ} (dB)
1	2.33	1.64	2.12	1.54	0.515	0.671	-0.1	2.18
2	2.34	1.65	2.13	1.54	0.458	0.616	-1.83	-0.53
3	2.36	1.65	2.12	1.54	0.476	0.632	-2.7	-1.04
4	2.36	1.65	2.13	1.54	0.475	0.633	-2.03	-1.74
	$\overline{RT_{30unocc}}$ (1 kHz) (s)	$\overline{RT_{30occ}}$ (1 kHz) (s)	$\overline{RT_{30unocc}}$ (2 kHz) (s)	$\overline{RT_{30occ}}$ (2 kHz) (s)	$\overline{STI_{unocc}}$	$\overline{STI_{occ}}$	$\overline{C_{80unocc}}$ (dB)	$\overline{C_{80occ}}$ (dB)
	2.35	1.65	2.125	1.54	0.48	0.638	-1.67	-0.28

Table 3. The values: The reverberation time (1khz, 2khz), the speech Transmission index and the clarity for the music for the Unoccupied and occupied hall for mp points for sound Source location s1



(a) (b)

Figure 5. The mean value of the transmission index (a) and clarity for music (b) at the measuring points for unoccupied and occupied concert hall for positions of sound soucers S2

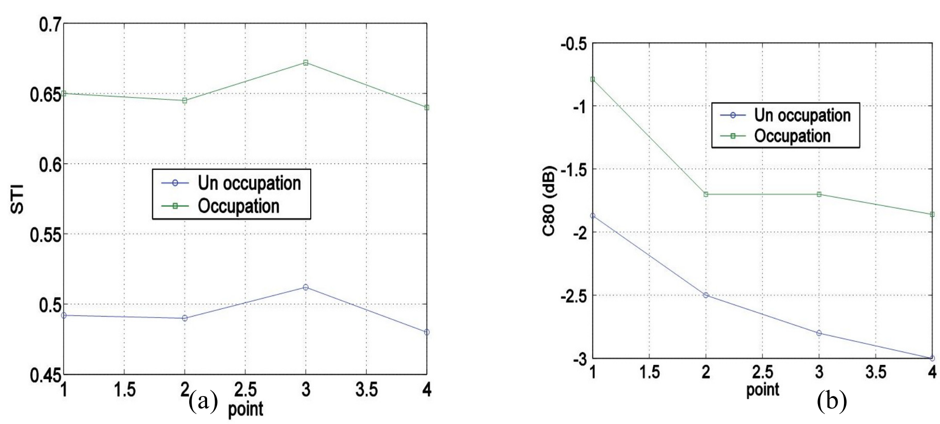


Figure 6.The mean value of the transmission index (a) and clarity for music (b) at the measuring points for unoccupied and occupied concert hall for positions of sound soucers S3

MP	$RT_{30unocc}$ (1 kHz) (s)	RT_{30occ} (1 kHz) (s)	RT_{30unoc} (2 kHz) (s)	RT_{30occ} (2 kHz) (s)	STI_{unocc}	STI_{occ}	$C_{80unocc}$ (dB)	C_{80occ} (dB)
1	2.36	1.65	2.09	1.53	0.467	0.619	-3.07	-0.67
2	2.37	1.66	2.11	1.54	0.474	0.628	-2.9	-0.59
3	2.4	1.66	2.13	1.54	0.458	0.616	-2.63	-1.45
4	2.35	1.65	2.15	1.55	0.476	0.635	-1.9	-1.74
	$\overline{RT_{30unocc}}$ (1 kHz) (s)	$\overline{RT_{30occ}}$ (1 kHz) (s)	$\overline{RT_{30unocc}}$ (2 kHz) (s)	$\overline{RT_{30occ}}$ (2 kHz) (s)	$\overline{STI_{unocc}}$	$\overline{STI_{occ}}$	$\overline{C_{80unocc}}$ (dB)	$\overline{C_{80occ}}$ (dB)
	2.37	1.655	2.12	1.54	0.469	0.625	-2.63	-1.11

Table 4. The values: The reverberation time (1khz, 2khz), the speech transmission index and the clarity for the music for the unoccupied and occupied hall for mp points for sound source location s2

MP	$RT_{30unocc}$ (1 kHz) (s)	RT_{30occ} (1 kHz) (s)	RT_{30unoc} (2 kHz) (s)	RT_{30occ} (2 kHz) (s)	STI_{unocc}	STI_{occ}	$C_{80unocc}$ (dB)	C_{80occ} (dB)
1	2.38	1.66	2.13	1.54	0.492	0.65	-1.87	-0.79
2	2.36	1.65	2.1	1.53	0.49	0.645	-2.5	-1.7
3	2.37	1.66	2.14	1.54	0.512	0.672	-2.8	-1.7
4	2.41	1.67	2.14	1.54	0.48	0.64	-3	-1.86
	$\overline{RT_{30unocc}}$ (1 kHz) (s)	$\overline{RT_{30occ}}$ (1 kHz) (s)	$\overline{RT_{30unocc}}$ (2 kHz) (s)	$\overline{RT_{30occ}}$ (2 kHz) (s)	$\overline{STI_{unocc}}$	$\overline{STI_{occ}}$	$\overline{C_{80unocc}}$ (dB)	$\overline{C_{80occ}}$ (dB)
	2.38	1.66	2.13	1.54	0.49	0.65	-2.54	-1.51

Table 5. The values: The reverberation time (1khz, 2khz), the speech Transmission index and the clarity for the music for the Unoccupied and occupied hall for mp points for sound Source location s3

in the range determined by the value of the optimum reverberation time for the concert hall standard: $RT = 1.5 \div 2.2$ s.

3) According to Barron's recommended reverberation time values for the occupied concert hall [5], the analyzed concert hall with the value for $RT_{30srf} = 1.695$ s is suitable for performing the following: early classical music ($RT = 1.6 \div 1.8$ s), opera ($RT = 1.3 \div 1.8$ s) and chamber music ($RT = 1.4 \div 1.7$ s).

4) At the positions of the sound source S1, S2 and S3 the increase in the mean value of index transmission is uniform: $\Delta\overline{STI} = \{0.158 \div 0.156 \div 0.16\}$.

5) The mean values of this parameter for the unoccupied hall at all three positions of the sound source, $\overline{STI}_{unocc} = \{0.48, 0.469, 0.49\}$ are in the range determined by the values that represent the acceptable speech intelligibility: $0.45 \div 0.6$.But the value of this parameter for an occupied hall, $\overline{STI}_{occ} = \{0.63, 0.625, 0.65\}$, are in the range determined by the values that represent good speech intelligibility: $0.6 \div 0.75$.

6) The estimated values of the medium index of music clarity in all positions of the sound source, for both the unoccupied is ($\overline{C}_{80unocc} = \{-1.67dB, -2.63dB, -3dB\}$), and occupied hall is ($\overline{C}_{80occ} = \{-0.28\ dB, -1.11dB, -1.86dB\}$).

7) The increase in the mean value of the index of music clarity for the occupied hall at all sound source positions S1, S2, and S3 is ΔC_{80} = {1.39dB, 1.52dB, 1.14dB}).

The predicted average values of music clarity meet the criteria of optimum values for orchestral music: (0 ÷ -3)dB

5. Conclusion

The work includes the analyzes of the predicted values of acoustic parameters: reverberation time, the index of speech intelligibility and music clarity , for an occupied concert hall. The presence of people in the concert hall led to a decrease in the mean value of the reverberation time for $\overline{\Delta RT_{30}}$ (1kHz) ≈ 0.7 s, increase in the mean value of the speech transmissionindex for $\Delta STI \approx 0.16$ and the maximum increase in the mean value of music clarity of ΔC_{80} = 1.52 dB. The predicted values of acoustic parameters confirmed the fact that this concert hall has been acoustically designed for early classical, opera and chamber music.

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