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Association between measurement and modeling results of room acoustics in open-plan learning spaces

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ABSTRACT

The measurement methods presented in standard ISO 3382-3 have been suggested for evaluation of acoustics in open-plan learning spaces. This means that there should also be a suitable design method to ensure the acoustics beforehand. The purpose of this study is to find out whether the results of the measurements carried out in recently built open-plan learning spaces correspond to the results of room acoustic modelling performed in design phase of the spaces. Measurements were done in five new open-plan schools. The results show that room acoustic modeling can be used as a design method for open-plan learning spaces.

Keywords: Room acoustics, modelling, open-plan learning spaces

1. INTRODUCTION

Traditionally the room acoustic criteria for designing classrooms has been reverberation time T, [1] and in some cases also speech transmission index STI [2, 3]. The acoustic design criteria for open plan schools has been proposed to be the spatial decay rate for speech $D_{2,S}$ and STI. [4, 5] To measure these quantities one could use the open plan office measurement standard ISO 3382-3 [6].

In this paper, our aim is to find out whether it is possible to use room acoustic modelling as a tool to meet the acoustical design criteria of $D_{2,S}$ and STI for open-plan learning spaces. This was studied by collecting acoustical modelling data from the design phase of five different open plan schools and this data was compared to the measurement data from the same schools once they were finished. AINS Group has made both, the modelling and the measurements, therefore the measurements could be done exactly at same positions as the modelling was carried out.

The five schools studied were all open plan schools with mineral wool ceiling and some dividing elements such as curtains, large furniture or screens. The school 2 was different from the other four schools because it was made for temporary use for the school. The temporary space was situated in a large hall that was a former department store with a very high ceiling (~5 m) where the classes were separated from each other by a ~3 m high curtains and some cabinets. The other four schools followed the same pattern of modern open plan schools: large space that has a lot of absorbing surfaces and space dividers. The basic data of the schools is presented in table 1. An example of this kind of modern open plan school is presented in figure 1.

Table 1 – The basic information of the studied open plan schools.

	Area [m^2]	Flooring	curtains	soft furniture	Furniture and notes
School 1	260	carpet	yes	yes	screens, furniture, curtains
School 2	1200	carpet	yes	no	cabinets, curtains, high ceiling
School 3	380	soft flooring	yes	yes	"nests", sliding walls, high cabinets
School 4	1000	soft flooring	yes	yes	"nests", sliding walls, high cabinets
School 5	400	carpet	yes	yes	"nests", cabinets, low ceiling height

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Figure 1 – 3D Layout of measured and modelled modern school (School 3).
The layout has a lot of curtains and other space dividing furniture.

2. MATERIALS AND METHODS

2.1 Room acoustic modelling

Room acoustic modelling was made with ODEON 14 software. First the 3D surface model was made with Trimble SketchUp with the desks, curtains and bigger furniture in place. Then the 3D surface model was exported to ODEON (figure 2) and all the surfaces were given absorption coefficients depending on what material they were.

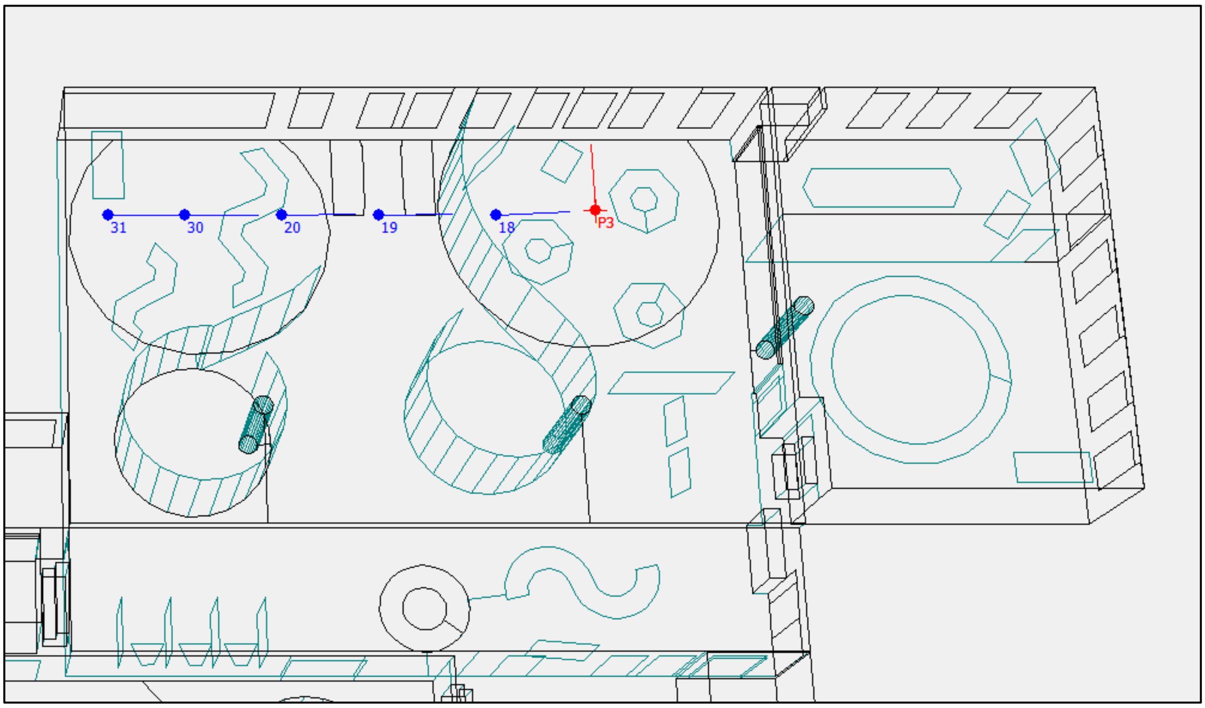

Figure 2 – The speaker position (red) and the microphone positions (blue) in a room acoustic model.

After importing the needed absorption coefficients, the sound source and the microphone positions was put in place. The height of the sound source and microphone positions were put as ISO 3382-3 suggests: sound source 1,5 m above the floor and the microphone positions 1,2 m above from the floor. Also, the sound source was determined to have the sound power of speech as an omnidirectional sound source according to the standard ISO 3382-3 [6].

The sound source was positioned to be on the place of teacher and the microphone positions were positioned in a straight line away from the teacher. The distances of the microphone positions were typically 2 m from each other, but if a curtain or other obstacle was too close then this position was changed to meet the requirements of the ISO 3382-3. An example of the room acoustic model and the microphone and sound source positioning can be seen in figure 2. The curved “walls” in the middle of the room are curtains that can be used to divide the room.

2.2 Room acoustic measurements

The room acoustic measurements were made according to the standard ISO 3383-3. The described measurement method in the standard is based on measuring acoustic parameters at different distances from the speaker (figure 3). The spatial decay rate for speech $D_{2,\mathrm{S}}$ is calculated from the measured sound levels $L_{\mathrm{p,A,S}}$ of different distances from a speaker that has the sound power of a speech according to the standard. The distraction distance r_{D} and the privacy distance r_{P} is determined by measuring STI from different distances from the speaker. The distraction distance is the distance from the speaker where STI is 0,5 and the privacy distance is the distance from the speaker where STI is 0,2. To determine the STI the background noise levels $L_{\mathrm{p,A,B}}$ were also measured.

The speech transmission index STI measurements were made using Odeon software, a laptop, a digital sound card and an omnidirectional microphone. To measure the STI correctly with Odeon, the whole measurement setup (laptop, sound card, cords and microphones) was calibrated in an anechoic chamber according to Odeon manual. The distances between the microphone and the speaker was measured using a laser distance meter. From these measures the distraction and privacy distances were calculated.

Figure 3 – An example of the measurement setup in an open plan school. The microphone positions are to be on a straight line from the speaker to the right behind the cabinets.

The spatial decay rate for speech $D_{2,S}$ was measured using a omnidirectional speaker with a sound power level calibrated in anechoic chamber. The sound levels at different distances were measured using class I sound level meter. The same sound level meter was used to measure the background noise levels.

2.3 Comparison

The comparison of the spatial decay rate of speech is easily comparable for the modelled and simulated results because the $D_{2,S}$ parameter is only dependent on the measured sound level of the speaker and the distance between the microphone and the speaker. The comparison was done by subtracting the measured values from the modelled values individually for each school. Also, the average subtractions of all the results were calculated. The modelled and measured STI as a function of distance is shown in figure 4. The modelled and measured sound levels of speech as a function of distance is shown in figure 5.

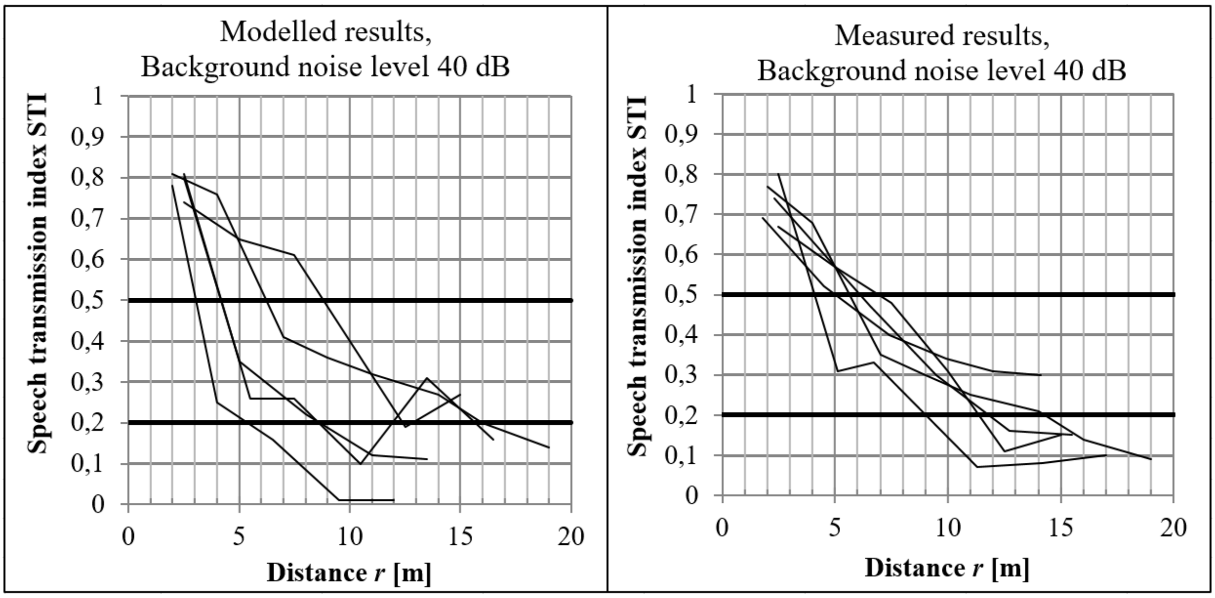

Figure 4 – The modelled and measured STI as of results distance of five schools.

Background noise 40 dB, -5 dB per octave

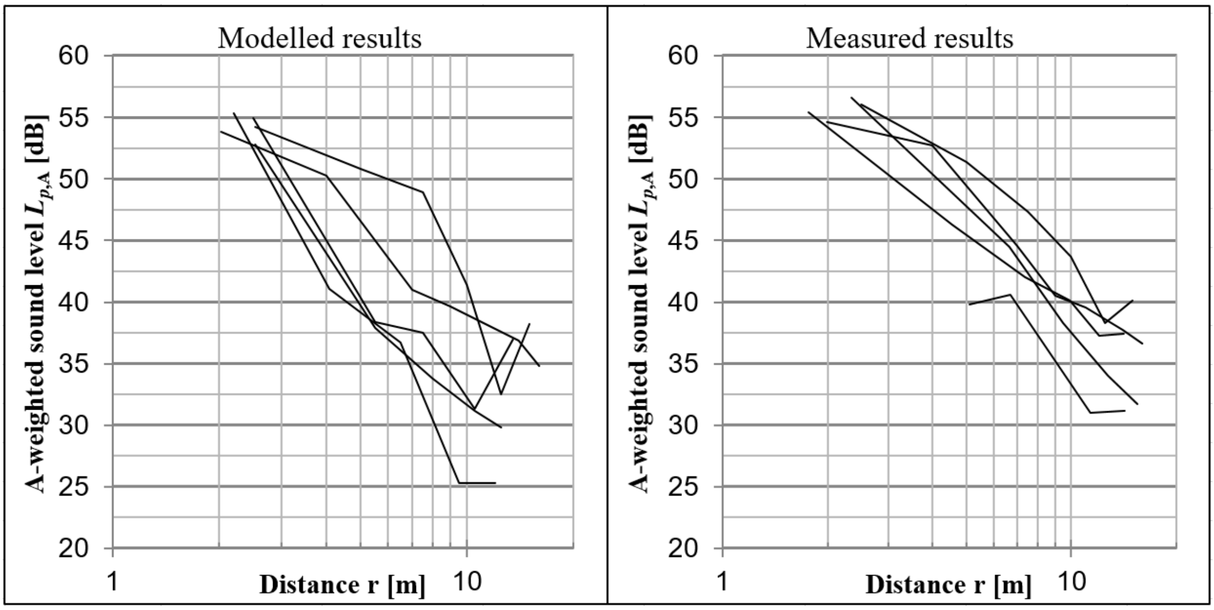

Figure 5 – The modelled and measured spatial decay rates of speech as of results of five schools.

The distraction distance and privacy distance results are not comparable by subtracting the modelled results from the measured results because the measured background noise levels were different on each of the measurement sites. The measured background noises between the schools varied from 25 dB to 34 dB. In the Odeon software, the background noise cannot be measured. Therefore, it is mandatory to measure the background noise with calibrated sound level meter and put the result in the software by hand. This allows the changing the background noise of the measurements and the modelled results with ease afterwards. Both the measured and the modelled results were modified to have the same background noise of 40 dB with -5 dB drop in every octave from 63 Hz to 8000 Hz. Background noise of 40 dB was chosen to show how the space would act with sound masking [4]. The measured and modelled STI results as a function of distance is shown in figure 4 with the modified background noise of 40 dB.

3. RESULTS

The measured spatial decay rate of speech varied from 6,2 dB to 9,2 dB and the modelled from 6,7 dB to 12 dB. The measured distraction distances varied from 4,7 m to 9,2 m and the modelled from 3,3 m to 7,9 dB. The measured privacy distances varied from 10,1 m to 15,6 dB. The acoustic measurement and modelling results are presented in table 2 in detail for all five schools.

Table 2 – The modelled and measured room acoustic parameters for open plan schools.

	Modelled values			Measured values		
	$D_{2,S}$ [dB]	r_D [m]	r_P [m]	$D_{2,S}$ [dB]	r_D [m]	r_P [m]
School1	9,7	4,9	10,1	6,2	5,9	15,6
School2	7,4	7,8	13,4	6,9	6,2	11,6
School3	6,7	7,9	15,6	6,6	6,4	14,0
School4	8,3	3,8	12,9	7,2	4,7	10,1
School5	12	3,3	6,6	9,2	6,4	12,8
Average	**8,8**	**5,5**	**11,7**	**7,2**	**5,9**	**12,8**
Standard deviation	**1,9**	**2,0**	**3,1**	**1,0**	**0,7**	**1,9**

From the data of table 2, the subtraction of the modelled and the measured values was made. After that the average and the standard deviation of the subtractions was calculated. These results are shown in detail in table 3.

Table 3 – The subtraction of table 1 results: modelled values – measured values.

On the bottom line is the standard deviation of the subtractions.

	$D_{2,S}$ [dB]	r_D [m]	r_P [m]
School1	3,5	-1,1	-5,5
School2	0,5	1,6	1,8
School3	0,1	1,5	1,5
School4	1,1	-0,9	2,8
School5	2,8	-3,1	-6,3
Modelled average - measured average	**1,6**	**-0,4**	**-1,1**
Standard deviation of the subtractions	**1,3**	**1,8**	**3,9**

Table 3 results show that on average the difference between measured and modelled spatial decay rate of speech $D_{2,S}$ is 1,6 dB, for distraction distance r_D 0,4 m and for privacy distance r_P 1,1 m. The standard deviation of the subtractions are 1,3 dB for $D_{2,S}$ and 1,8 m dB for r_D and 3,9 m dB for r_P. The biggest difference in modelling versus measurements of spatial decay rate of speech was 3,5 dB, for r_D 3,1 m and for r_P -6,3 m.

4. DISCUSSION

Table 2 shows that the modelled values for $D_{2,S}$ were bigger than the measured values and the r_D and r_P were not always accurate, especially in the case of schools 1 and 5. The comparison of schools 2,3 and 4 showed, however, quite a good agreement between the modelled and measured values.

The modelled version of the rooms were the design versions. From the time of the design to the ready space, many things can affect the outcome since acoustic engineer is only one designer in the big construction project. Sometimes the construction work might not have gone in budget and many times it is the furniture, acoustic treatments and surfacing where saving money is most likely. In some cases, the furniture design was changed in the design process and the changed furniture was not modelled. But it is also the nature of the open plan schools to have maximum mobility of the space.

In most of the cases, the furniture designed for the space is something that doesn't have measured absorption data to use in the model. When this occurs, the acoustic modeler must make an estimation about the absorption coefficients. Of course, it is not especially exact to estimate the absorption data by looking a brochure of a furniture. However, the architects usually want the furniture to help with the acoustics and therefore the furniture are covered with a 2–4 cm thick soft materials thus making the evaluation of the absorption coefficients somewhat easier. This is a known problem with any type of acoustical modelling, but in open plan schools there are a lot of different furniture to model and therefore the absorption coefficients can make the model inaccurate if the estimations are wrong.

The modelling and measurements were both done with teacher to student situation. In the reference [5] it is proposed to use three different situations: teacher to student, student to teacher and student to student. It is not possible to say how the different situations change the STI from the data of this study, but it would be a natural next step to study in the future.

The receiver height in this study was the same as in ISO 3382-3 [6], but in the reference [5] the heights vary from 0,8 m to 1,65 m (ISO 3382-3 1,5 m and 1,2 m) and therefore it is rather complex to use in consultant work for the everyday measurements in-situ. The more variation the bigger risk there is for mistakes. From this perspective it would be more convenient to use the heights of the standard [6]. The differences of the heights in [5] should be compared to ISO 3383-3 and study the differences they create.

5. CONCLUSIONS

The results indicate that room acoustic modelling can provide useful data to design open plan schools. When comparing the modelled and the measured results one should keep in mind that the originally designed space might be different from the plans due to many decision makers in the project or possible cost reductions.

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