

Classroom acoustics – analysis, simulation and optimization

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Abstract: Noise is an everyday stress factor in classrooms, a fact that is confirmed by teachers in numerous studies [1]. In this contribution, three tools are presented, which are useful for analyzing, simulating and optimizing room acoustics in classrooms. IntKlaSim analyzes a classroom's acoustics after a reverberation time measurement was performed and simulates an acoustical reconstruction of this room by selecting different absorbers from a data base, which are put in the room additionally. The attention of the analysis and the simulation is directed to reverberation time, STI and AI_{cons} . File Cutter and Noise Level Analyzer can be used to evaluate the noise environment in classrooms depending on the selected teaching method. It is possible to analyze a multichannel recording of a lesson and to evaluate parameters like the background noise at different positions in the classroom simultaneously. Thereby, the possibility to investigate the spatial distribution and spreading of the parameters in the classroom is enabled.

Key words: analysis, simulation and optimization of classroom acoustics, reverberation time, noise evaluation

1. INTRODUCTION

Noise in schools is a problem that occurs daily. But only since a couple of years it is dealt with seriously in Austria. In the search for reasons for the moderate Austrian result at the PISA test, the topic "Noise in schools" was brought into focus. A study with 1459 participating Austrian teachers was performed in 2007 and 2008 [1]. One question of this study was: "How often is the noise in classrooms too loud?" 39% of the participants answered "Rather often" and 20% answered "Very often". 34% of the test persons said "Sometimes" and only 7.4% answered "Rather seldom" or "Seldom" (1.8%). Most of the participating teachers also said that their education is affected by noise. Furthermore, over 50% of the test persons said that the noise has negative influence on their well-being. This study shows that there is clear need for further action concerning the topic "Noise in schools".

As a consequence, the diploma thesis of Maurice Müller [2] investigated the effects of noise and reverberation time on pupils and teachers in a classroom. This thesis proves that a connection between room acoustics and noise level exists and it indicates that it is possible to classify the acoustics of a classroom according to the year of construction. Most of the measurements were performed at Styrian schools. Moreover, the thesis shows that the

acoustical requirements for classrooms specified in the standard DIN 18041 [3] are not complied in most of the cases. This standard defines the set-value for the reverberation time in a classroom with the following formula:

$$T_{set} = \left(0.32 \log\left(\frac{V}{m^3}\right) - 0.17 \right) [s] \quad (1)$$

Referring to this formula, a typical classroom with a volume of $200 m^3$ should have a reverberation time of 0.57 s. This set-value has a specified tolerance band of +/-20% in the octave bands from 250 Hz to 2000 Hz and a tolerance band of +20% and -34% in the octave bands 125 Hz and 4000 Hz (see Fig. 1).

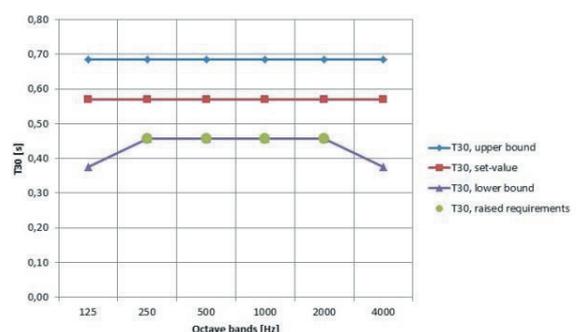


Fig. 1. Tolerance band for T30, $T30_{set} = 0.57 s$

Moreover, the standard defines a reverberation time for raised requirements. This reverberation time improves the speech communication for people with hearing loss and for foreign-language teaching. The values of the reverberation time for raised requirements are defined for the octave bands from 250 Hz to 2000 Hz and are located 20% below the set-value (i.e. the green markers in Fig. 1). Especially old classrooms that were built from 1900 to 1960 do not comply with this standard and do not have reverberation times within this range. This is because the DIN 18041 exists since 1968 and other guidelines have been applied before. For example, classrooms that were built between 1900 and 1950 have reverberation times that are 1 s to 1.5 s above the values defined in DIN 18041 [2].

To easily simulate how to improve the room acoustics in simple shaped classrooms, a first version of *IntKlaSim* was developed in the context of Claudia Reithner's diploma thesis [4]. A broad data base of absorbers was added to the application within the scope of the bachelor thesis of Michael Flohrschtütz [5].

The latest version of *IntKlaSim*, which will be presented in this paper, was released in the context of [6]. Among other things, the room acoustical simulation possibilities were enlarged and a simulation that demonstrates the influence of room acoustics on communication acoustics was added. Thereby, the dependency of the reverberation time on the background noise and the background noise's influence on STI, AI_{cons} and the teacher's voice level are investigated. Detailed information about the possibilities of *IntKlaSim* can be found in chapter 2.

Further investigations concerning the noise situation in classrooms can be done with *File Cutter* and *Noise Level Analyzer*. These tools were also developed in the context of [6]. With these applications it is possible to investigate the noise environment at different positions in the classroom simultaneously, while the analysis is performed according to the chosen teaching method (for example: Only teacher is talking or team work is employed). The possibilities of the *File Cutter* and the *Noise Level Analyzer* are explained in chapter 3.

2. ROOM ACOUSTICAL SIMULATIONS USING THE TOOL *IntKlaSim*

The tool *IntKlaSim* (*Interdisciplinary classroom acoustics simulation tool*) is an application for the analysis of the present acoustical situation after a reverberation time measurement was performed and for the simulation of a room acoustical optimization. The focus of the simulation is put on reverberation time, STI and AI_{cons} .

Essential input data are the year of construction, the maximum number of pupils, the room dimensions and the wall area that is not suitable for an acoustical restoration, like blackboard or windows. These data are needed to calculate the room volume, the acoustical suitable ceiling area and the acoustical suitable wall area. The acoustical suitable areas are the surfaces where additional absorbers

can be placed. The room volume is used to compute the optimal reverberation time and the reverberation time for raised requirements according to [3]. With selecting a year of construction, the reverberation time curve that is typical for the year of construction is displayed. These values are the results of the measurements of [2] and are rough approximations.

The next step is to import a reverberation time measurement. It is possible to import measurements that were performed either in the empty state or with pupils present. In the following, *IntKlaSim* always simulates the parameters for both states. The measurement import is optimized for measurements that were performed with *ARTA* (<http://www.artalabs.hr/>). The STI and the AI_{cons} of the measurement must be entered as well. After all data are entered, the acoustical state after the measurement will be visualized.

The next step is to select different absorbers from the data base. This data base contains numerous different absorbers for ceiling and wall from different manufacturers. After the desired absorbers are selected, the absorbers' influence on reverberation time, STI and AI_{cons} are shown. Thereby, the state without the absorbers is compared with the state respecting the absorbers. The result for the empty state of occupation is opposed to the state respecting the entered maximum number of pupils. These comparisons are illustrated graphically (see Fig. 2).

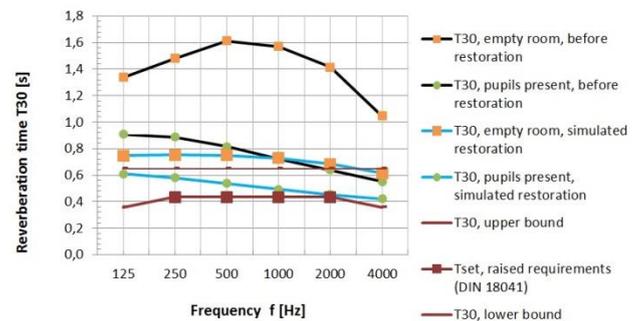


Fig. 2. T30 simulation for the different states

Moreover, the influence of decreasing SNR on the AI_{cons} is visualized as well. In this graph, the values at 10 dB and 15 dB are of particular importance because these are typical values for the ratio between the teacher's voice level and the pupils' background noise (see Fig. 3). In fact, studies showed that the power of the teacher's voice is about 11 dB higher than the background noise produced by the present pupils [7].

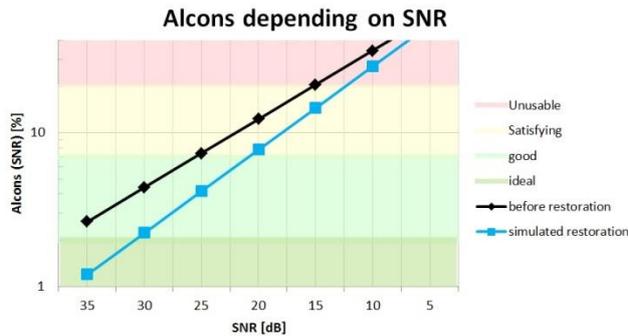


Fig. 3. Al_{cons} in dependency of the SNR

When the room acoustical simulation is finished, the actual working situation in the room can be analyzed. The background noise measured in the empty room and the present number of pupils must therefore be entered. These values are used to calculate the background noise considering the present number of pupils. The influence of this background noise level on the STI, the Al_{cons} and the teacher's voice level is simulated and represented graphically. In a next step, *IntKlaSim* calculates the reduction of the background noise level by respecting the chosen absorbers. The consequence of the reduced background noise on STI, Al_{cons} and voice level is analyzed afterwards. The results are illustrated and compared with the state without the absorbers respected (see Fig. 4).

STI			Skala		
Empty room	Pupils present				
Before restoration			von	bis	Bewertung
Without L_N	Without L_N	With L_N			
0,53	0,77	0,33			
Simulated restoration					
0,80	0,91	0,47			
			0,75	1	Excellent
			0,6	0,75	Good
			0,45	0,6	Fair
			0,3	0,45	Poor
			0	0,3	Bad

Fig. 4. Simulation of the L_N 's influence on the STI

Hereby, the application investigates the influence of the background noise level on the Lombard-effect. The Lombard-effect describes the connection between background noise and the voice level of an announcer. Furthermore, *IntKlaSim* analyzes the influence of room acoustics on communication acoustics, i.e. the tool simulates how the background noise changes when the reverberation time is changed and how STI, Al_{cons} and voice level are affected by the changing background noise.

After a real renovation of the room has been completed, the results of the real renovation can be compared with

the state before and the simulated results. In order to do so, the data of the reverberation time measurement after the renovation have to be imported to *IntKlaSim* in a similar manner as the data before. After the data have been imported, the application compares the reverberation time, the STI and the Al_{cons} graphically for the three different states (i.e. before restoration, simulated restoration and after restoration) (see Fig. 5).

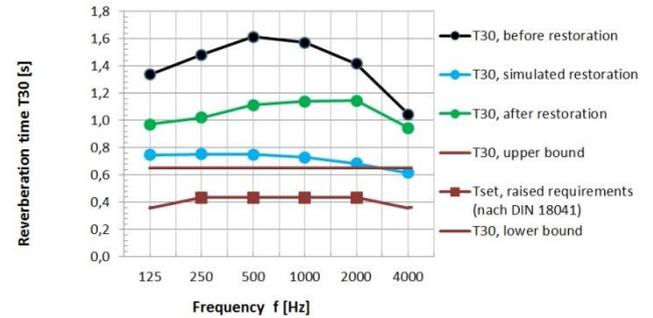


Fig. 5. T30 comparison after the restoration

Whether the data for the empty room or for the state with pupils present are chosen for the comparison is depending on the selected state of occupation that was chosen for the measurement after the restoration.

To sum up, it can be said that *IntKlaSim* offers the possibility to simulate an acoustical restoration by checking the influence of additional absorbers on reverberation time, STI and Al_{cons} . Moreover, the application demonstrates the connection between room acoustics and communication acoustics. The influence of the present number of pupils on the background noise and the background noise's influence on the STI, the Al_{cons} and the teacher's voice level are thereby shown.

In order to investigate the background noise in classrooms in an even more versatile manner, the next chapter introduces the applications *File Cutter* and *Noise Level Analyzer*.

3. NOISE EVALUATION IN CLASSROOMS

3.1 Possibilities of the *File Cutter*

In a classroom, various teaching situations can occur, like lecture or partner work. According to the style of teaching, different noise levels with varying frequency spectra define the noise situation in the classroom. To perform an analysis of the noise situation in dependency of the different selected teaching methods, *File Cutter* categorizes a multichannel recording of class according to the chosen styles of teachings. After a file has been loaded, the user can classify the file into different sections. These sections can be categorized according to a certain style of teaching. Altogether, eight different teaching methods can be selected for the categorization: classroom teaching, lecture, individual work, partner work, group work, presentation, exam and other (if none of the previous ones should match). An audio player that plays the individual se-

quences is available as well. After the whole file is categorized, the tool copies all the parts that belong to the same style of teaching into separate wave files. If several parts are categorized to the same style of teaching, the parts are copied in one file in chronological order. A text file that contains the start and stop positions of the single sections and the allocated teaching method is generated, too.

A multichannel recording can be categorized with *File Cutter* as well. It is not necessary to categorize each single track, but rather only one track. The sections' start and stop positions and the allocated teaching methods are stored in a background data file after the categorization of the first track is finished. This background data file will be loaded automatically together with the other tracks of the multichannel recording. Thereby, the application transfers the data of the background file to the new file. Thus, only the categorized parts have to be copied into the different wave files and the remaining tracks are categorized as well.

3.2 Possibilities of the *Noise Level Analyzer*

Noise Level Analyzer evaluates the time dependent sound pressure level of a wave file and calculates a statistical analysis of the sound pressure level. Thereby, the application offers the possibility to select different frequency weightings (dB(A), dB(B), dB(C) and dB(Z)) and time average constants (fast, slow and impulse). It is also possible to analyze only a section of the loaded file. The histogram of the time dependent sound pressure level can also be pictured. The statistical analysis contains the L_{eq} , $L_{0.1}$, $L_{1.0}$, $L_{10.0}$, $L_{33.3}$, $L_{50.0}$, $L_{66.6}$, $L_{90.0}$, $L_{95.0}$, $L_{99.0}$ and $L_{99.9}$. This level statistics can be exported as a text file.

Besides the sound pressure level analysis, the tool additionally offers the possibility of a spectral file analysis. Different resolutions (octave band, third octave band or twelfth octave band analysis) are available.

The plots of the time dependent sound pressure level, the histogram and the spectral analysis can be exported as jpeg files individually. An audio player that respects the selected frequency weighting is implemented as well.

3.3 Approach during the analysis

This chapter describes the steps that need to be performed when the noise environment in a classroom is investigated with the *File Cutter* and the *Noise Level Analyzer*.

Before the main analysis can be started, it is necessary to record a day or a lesson at school with several microphones distributed in the classroom. Conventional recording equipment is sufficient. The calibration of the microphones has to be recorded as well, because a reference signal for the calculation of the sound pressure level has to be loaded to the *Noise Level Analyzer*. During class recording, a list needs to be prepared that contains the times with the respective chosen teaching methods. According to this list, the tracks will be categorized with the *File Cutter* later on. After class is finished, the single tracks must be exported as wave files. Thereby, it is re-

quired to create an extra track that contains the calibration signal for each single track. Following this, the tracks are loaded to the *File Cutter*, where the categorization according to the respective style of teaching takes place. After categorization is finished, the *File Cutter* copies all the parts that belong to the same style of teaching in a separate wave file. These categorized files, together with the respective calibration file, are loaded to the *Noise Level Analyzer*, where the noise analysis takes place.

4. CONCLUSION

In this contribution, tools that realize a versatile and accurate investigation of classroom acoustics and the noise environment were presented. The application *IntKlaSim* offers the possibility to analyze the present acoustic situation in a classroom after a reverberation time measurement was performed. After that, it is possible to simulate an acoustical restoration of this classroom. By taking the background noise and the present number of pupils in consideration, it is possible to investigate the real working situation in the classroom and to connect room acoustics with communication acoustics. In the end, a real restoration can be compared critically with the simulated results and the state before the restoration.

With the *File Cutter* and the *Noise Level Analyzer*, two new applications were created that allow the evaluation of the noise environment during class using conventional recording equipment. The *File Cutter* offers the possibility to classify a multichannel recording of class according to the chosen teaching methods. With the *Noise Level Analyzer*, the investigation of the noise environment can thus be performed depending on the individual teaching method. Thereby, the wide level statistics and the histogram of the time dependent sound pressure level offer the possibility to make detailed conclusions about the noise environment. Of course, the application area of these tools is not limited to classrooms.

5. OUTLOOK

These tools will be applied in a master's thesis. This thesis will include experiments that investigate the background noise in classrooms and the dependency of the teacher's voice level on the background noise. These investigations can be performed excellently at the BRG Kepler in Graz, because approximately one half of the classrooms were sanified acoustically during the summer holidays in 2014. The remaining classrooms are in the same acoustical state as in the year of construction at the beginning of the 20th century. Under these conditions, the impact of good and bad acoustical environments on the communication acoustics can be analyzed very well. During these experiments, the parameters can be analyzed under spatial surveillance and can be connected with the acoustic situation in the room. Meanwhile, the spatial spreading of the values can be observed, too.

Investigations that evaluate the teacher's daily noise exposure level $L_{EX,8h}$ shall be performed, too. In these investigations, it shall be found out how the $L_{EX,8h}$ depends on the room acoustics and by how much the $L_{EX,8h}$ is decreased by shorter reverberation times.

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