Acoustics and new learning environment—a case study

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Abstract

This study presents the results of an acoustic performance evaluation of classrooms and their corridors on a test area of the Finnish Oulu Normal School. The project, “Spaces for learning and creation of new knowledge”, was organised by Rym Ltd and was a re-design pilot study where spatial analysis of some new schools and new forms of future school design have been made.

Two different acoustical setups were evaluated by measurements of the reverberation time, sound pressure level (A-weighted equivalent level, L_{Aeq}), and sound insulation. Other acoustical parameters were also measured via sources of reverberation time to verify the difference of the test rooms. Speech Transmission Index (STI), disturbance radius (r_D), spreading attenuation ($D_{2,S}$), Clarity (C_{50}), and Rapid Speech Transmission Index (RASTI) were calculated. Measurements of noise followed the Finnish guidelines. Measurements of reverberation time and sound insulation followed the International Standards ISO 140-4, ISO 140-5, ISO 717-1, and ISO 3382.

The acoustic quality of the classrooms was analysed based on the measurements’ results (sound insulation and reverberation time), which were compared with the reference values found in the Finnish Standard SFS 5907. Results revealed good acoustical quality of the surveyed classrooms, for both test setups studied. The soft carpet on the floor made the acoustical performance of corridor areas usable for educational purposes. However, the sound insulation and background noise level of all the classrooms did not meet the guidelines of Finnish Standards. Discussion on new learning concepts and acoustical design reveals that new tools for the evaluation of learning spaces should be developed.

Keywords: learning spaces, acoustics, classrooms

1. Introduction

The acoustics of educational spaces should support learning by promoting the needed sound spreading and hindering unwanted noise. New learning spaces are interactive, participatory, and mobile [1–10]. The "New Learning Environment" is one of the Indoor Environment research programmes included in Living Labs, where participatory and inspiring learning environments are being developed [10]. New studies have indicated the emotional regulation system being part of the learning process: people more easily remember things that have aroused interest or positive feelings in them and learning environment plays its own part in this process. However, new technology affects the need to alter future classroom design. As tablets and other mobile devices have conquered the market in the last few years, technology supports education, and this presents a new challenge for space that is both physical and mental at the same time: a social event complemented by a virtual space created by devices.

The Rym Ltd Learning Environments work package has modelled the effectiveness of learning methods and the impact of spaces on learning with the help of multidisciplinary research. According to a study led by the University of Helsinki, the way people experience an indoor environment significantly affects their learning [10].

The changes in learning spaces are also demanding changes in their acoustical performance. Traditional learning spaces are planned for the lecture style or teacher-centred instruction, where teaching is done in front of the class. This is no longer the main teaching method, at least in Finland. More and more alternate forms of teaching such as participatory learning, group work, solitary work, or open learning are being implemented. New forms of pedagogy and learning spaces need more practical ways to design the learning environment.

The acoustics of learning spaces affect learning processes through the students' capacity to hear sound properly and communicate with nearby persons. Because of the useful sound reflections from the classroom surfaces, the wanted sound—the teacher's voice—can be heard even from the back of the classroom. However, at the same time there might be unwanted harmless reflections of space surfaces such as the ceiling and floor that disturb the discussion because of the high reverberation time in the room. Mutual discussion among the pupils is more important in learning than the teacher's speech [7].

In a new learning space there are several small groups that can disturb each other. The previous references [2–11] conclude that the acoustics should be flexible and controllable, and background noise must be suitable for its purposes. Controllability means that the communication environment must be inspiring, and quietness is sometimes needed for concentration purposes.

How can we measure and evaluate these new learning spaces? Traditionally, Finnish Standard SFS 5907 [11] is being used, which offers guidelines for different space types, including schools. There are classrooms, corridors, halls, and special classrooms like music, gymnastics, and technical work spaces. The Standard divides spaces into four classes, A to D, where class C represents minimum demand and the level of basic construction orders [12]. Classes A and B represent the better acoustical demands planning compared to classes C and D. Class D is reserved for evaluation purposes only and for old buildings. For example, the airborne sound insulation index shows that the R'_w between a classroom and corridor varies in classes A and B between 39 and 48 dB, while the minimum value of the normalised impact sound insulation level, $L'_{n,w}$, is 63 dB. The highest accepted background noise level for the A-weighted equivalent level (L_{Aeq}) for HWVE (heating, water, ventilation, electricity) equipment is between 28 and 38 dB, and for outdoor noise between 30 and 35 dB. The reverberation time is recommended to fall between 0.5 and 0.9 s for classrooms and corridors, and the minimum value of the Sound Transmission Index (STI) or RASTI shall be at least 0.7. These recommendations have probably come from the traditional frontal teaching [12–13]. In addition to measurable indoor acoustics, there should be ideas on non-measurable, qualitatively evaluated sound experience [11].

The purpose of this work is to describe the influence of changes in learning space upon the acoustical environment. Simultaneously, our purpose has been to evaluate how the present acoustical guidelines work in this new learning space situation.

2. Materials and methods

We measured traditional and new learning spaces at Oulu Normal School during 2013 and 2014. In this study a new learning environment setup was made. The idea of spaces were zoning from private to public zone for fully functional learning communities in Cells (Fig. 1). All spaces had their own character and the focus was on traffic and movement in space. In the zone cells the pupils can freely move between rooms and, for example, sit on the floor with their iPads. Special attention was paid to self-regulated learning events, learning spaces, and evaluations at all teaching periods. Pupils can divide their learned material by mobile devices through social media [2].

Fig. 1. *New learning space plan (architect 3D plan). The doors and sliding walls are not drawn*

Different acoustical conditions were set in identical classrooms with their area and volume. The test area volume for classrooms were 240 m^3 and for the corridors 750 m^3 (Fig. 1–2). The test area including corridors and classrooms had a soft carpet on the floor (Fig. 1). Both the test and reference areas had acoustical panels on the ceilings (Table 1). Test area classrooms also had special soft furniture (chairs) besides normal desks and chairs.

The height of the classrooms was 3.3 m and the height of the corridors 3.3-5.6 m. The structure of the walls between classrooms and between classrooms and the corridor was 10-15 mm of wood plate + 70-100 mm of absorbing material and again 10-15 mm of wood plate. The structure was same both on test and reference spaces. The structure was also same both in stationary walls and moving wall structures. The moving wall structures were tightened towards stationary walls by rubber seals.

Reference areas were left with their original hard surfaces and traditional classroom furniture (wooden desks and chairs). The school building was on one floor.

Fig. 2. *Measured rooms. The blue dots indicate acoustical measurement sites of the spaces.*

Table 1

Measured spaces and their surface materials.

Tested classroom	**Floor material/Ceiling acoustics % of total surface area**
Test area	
R133 (7.3x11.1 m = 81 m^2)	Soft carpet/50%
R134 (7.3x10.6 m = 77.4 m^2)	Soft carpet/100%
R125 (7.3x10.6 m = 77.4 m^2)	Plastic carpet/50%
C122, corridor (6.8x24.4 m = 165.9 m^2)	Soft carpet/90%
Reference area	
R158 (7.3x10.6 m = 77.4 m^2)	Original hard floor*/50%
C163, corridor (6.8x24.4 m = 165.9 m^2)	Original hard floor*/30%

**Hard floor with epoxy resin on concrete plate*

With the used setup it was possible to create two comparable acoustical test environments, hard and soft, to carry out acoustical measurements (Fig. 1 and Table 2). We carried out airborne sound insulation and impact sound insulation measurements, A-weighted sound pressure measurements, and other acoustical measurements such as reverberation time. We measured the airborne sound insulation measurement with standardised airborne sound insulation (EN 140-4:1998 and ISO 717-1:1996), impact sound insulation (EN 140-7:1998 and ISO 717-2:1996), and reverberation time (ISO 3382-2:2008). A background noise level with the A-weighted equivalent level (L_{Aeq}) was measured according to the Finnish national guidelines [13].

Reverberation time T20, T30, and EDT (Early Decay Time) were all measured. Other acoustical parameters were calculated from the reverberation time values: Sound Transmission Index (STI), disturbance radius (r_D), spreading attenuation (D_2), Clarity (C_{50}), and Rapid Speech Transmission Index (RASTI) [1].

The C_{50} parameter (Clarity or Klarheitsmass) is the early to late arriving sound energy ratio, expressed in dB. It is defined as:

$$C_{50} = 10\log\left(\frac{D_{50}}{1-D_{50}}\right) \quad (1)$$

D_{50} is the early to total sound energy ratio expressed in percentage. It is defined as:

$$D_{50} = \frac{\int_0^{0.050s} p^2(t)dt}{\int_0^{\infty} p^2(t)dt} \quad (2)$$

The used measurement equipment was the sound source dBTechDVXD10, signal generator NTI Minirator AG MR1, impact sound generator B&K 3207, microphone B&K 4189, sound analyser B&K 2250, and sound level calibrator B&K 4231. Guidelines for the used parameters are given in Table 2.

Table 2

Guidelines and recommendations for the acoustical parameters according to SFS 5907.

Room	**Reverberation time**		**Background noise level**		***RASTI****
	Class A/B, s	**Class C, s**	**L_{Aeq}/L_{Amax}, class A/B, dB**	**L_{Aeq}/L_{Amax}, class C, dB**	
Classroom	0.5–0.6	0.6–0.8	28/33	33/38	>0.7–0.75
Corridors	0.7–0.9	0.9–1.1	28/33	33/38	
Staircases	<0.9	<1.3	33/38	38/43	

**Not in SFS 5907, classroom for young pupils, bigger value*

3. Results

The results of the airborne sound insulation R'_w from two measured classrooms (test area and reference area) were 39 and 42 dB. Neither of the results filled the demand of 44 dB by the standard of SFS 5907. The airborne sound insulation between classrooms and corridors were 24 and 32 dB, neither of which reached the demand of 34 dB (Table 3).

The impact sound insulation $L'_{n,w}$ measured 45 and 55 dB in the test areas (both classrooms with carpet on the floor) and 69 and 72 dB in the reference area (no carpet on the floor) (Table 3). The demand of the SFS 5907 was not reached at the reference area, but in the test area the Finnish Standard demand was reached.

Table 3

The results of the sound insulation and impact noise ratio measurement (dB).

Source room, L1	Receiver room, L2	Carpet	R'_w, dB	$L'_{n,w}$, dB
R133, classroom (test)	R134	yes	39	45
C122, corridor (test)	R134	yes	24	55
R159, library room (ref.)	R158	no	42	72
C163, corridor (ref.)	R158	no	32	69
Reference values			**44**	**63**

Table 4

The results of the acoustical measurements within the different parameters.

Source Room	Reverberation time, T20/T30/EDT, s	Background noise, L_{Aeq}/L_{Amax}, dB	RASTI	C50, dB
Classrooms				
R133 (test)	0.47/0.48/0.48	46/54	0.77	5.9
R134 (test)	0.37/0.38/0.36	40/54	0.81	8.5
R125 (test)	0.47/0.47/0.48	45/54	0.76	6.5
R158 (ref.)	0.50/0.50/0.48	50/59	0.75	6.1
Corridors				
C122 (test)	0.70/0.70/0.60	43/51	0.70	3.5
C163 (ref.)	1.00/1.00/1.00	44/51	0.61	0.65

The reverberation times as T30 varied between 0.38 and 1.00 s. There was no specific difference between T20, T30, or EDT in the same test room. All the decays of the classrooms reached the target level of class A/B according to a standard of SFS 5907. However, the result of classroom R134 was less than the recommendation value. Both corridors reached the class C level, but corridor C163 (reference area corridor) did not reach the highest class A/B level. Corridor C122 (test corridor with carpet) even reached the classroom recommendations in a class C. The frequency response of reverberation time in measured classrooms can be seen in **Fig. 3**. We can see that especially in classroom R134, which had an acoustically soft floor and ceiling and the lowest reverberation times at all frequencies.

The background noise level with the A-weighted sound equivalent level varied between 40 and 50 dB in classrooms. All the background noise levels exceeded the recommendation values of SFS 5907. The noise levels were 12–22 dB over the recommendation values of classrooms.

RASTI values varied between 0.61 and 0.81. All the classrooms reached the target level recommendations of >0.70–0.75. Clarity values of C_{50} varied between 0.65 and 8.5 dB. The highest Clarity value was reached in classroom R134 (with carpet on the floor and 100% acoustic panels on the roof) and the lowest was reached in corridor C163 (all surfaces hard).

Fig. 3. *Reverberation time of classrooms.*

4. Discussion

Comments on measurement results

No airborne sound insulation results reached the SFS 5907 minimum demands of class C. However, the impact sound insulation levels reached the demands in the test area, but not in the reference area. The poor sound insulation results were mostly explained by flanking transmission through ventilation ducts and valves. Also the mobile wall between the classroom and corridor could not be closed properly during the measurements, which had the most effect on low airborne sound insulation index values. The impact sound insulation values differed remarkably between the test and reference areas. Results confirm the assumption that carpet had an important effect on impact sound insulation values. The difference was at maximum 27 dB between test area classrooms compared to reference area classrooms (similar volume). The carpet effectively absorbs the impact noise (steps) between two rooms.

Reverberation time varied between 0.37 and 0.50 s (T30) and RASTI values between 0.75 and 0.81 s. The difference with these parameters between the tested rooms was small. However, the lowest reverberation time (0.37 s) and the best RASTI value of 0.81 was reached in a classroom with soft carpet and roof absorption of acoustic panels over 100% of its area. Also with the low frequencies (under 500 Hz), the reverberation time was even lower compared to other tested rooms (**Fig. 1**).

There was no overall difference in Clarity values among test area classrooms compared to reference area classrooms. However, the classroom with both carpet and 100% acoustics on the ceiling had the best Clarity at 8.5 dB, more than 2 dB of difference compared to other classrooms (variation of 5.9–8.5). The Clarity value of the corridor was almost 3 dB better in the test area compared with the reference area.

The background noise levels were all too high in every measured space compared with the recommendation values. The A-weighted equivalent sound levels exceeded the recommendations with 12–22 dB (variation of 40–50 dB). The reason for these high values was mostly related to ventilation equipment systems.

General discussion

The results of all acoustical parameters were slightly better in the test area compared to the reference area. The best values were reached in room R134, which had carpet on the floor and acoustic panels on the entire ceiling area. However, the most positive difference with all possible measures and the overall effect of acoustics and impact sound insulations was seen in test area corridor C122. According to the acoustical results of this study, this space can be used for educational purposes. All classrooms reached the minimum needs of acoustical demands. However, the airborne sound insulation and background noise levels did not meet the demands of SFS 5907.

The study also has weaknesses. The current study is only a pilot, and more data should be provided for more reliability and significance. Also, the soft furniture of a test area can affect the acoustical measures of classrooms. This was not separately tested, but could be seen among the results of the similar test area rooms, where one of the floors used plastic on the concrete, but had similar soft furniture like classrooms with carpet.

It is also possible to make classrooms too "dry" for their acoustical performance. Especially in a big classroom, the wanted ceiling reflections are needed for the back seating area. These positive reflections do not exist if the ceiling covers 100% of soft acoustical material. This could lead to discomfort for the teacher when speaking, and also to poor speech recognition in the back seats of the classroom.

At a distance of less than five metres from the sound source, speech recognition should be clear, but outside the reverberation time radius as poor as possible. This type of technical solution could be an electrical sound ceiling like those used at some restaurants. Under this type of ceiling the sound is heard well, but outside of it, the attenuation of sound is effective. This type of solution needs the construction of an electronically amplified sound system.

How can the acoustics of educational spaces be done in practice? According to the previously mentioned results, the attenuation of sound further than five metres is crucial. Essential facts shall be the use of carpet on the floor, and most of all, partial use of acoustical material or zones on the ceiling. Important elements are also the horizontal sound traps like screens, cupboards, lockers, etc. Soft furniture may be used as extra sound absorption surfaces, especially in large classrooms. In addition, the electronically amplified sheds or electroacoustical ceilings could be designed and used like curtains to separate the different needed areas of sound and communication. This type of space design allows different groups to work in a large space with social media, either together or in small groups.

It should be noted that the controlling of purely acoustical elements of space does not solve all sound-related problems, but makes actions possible within certain limits. One of the most important space designing elements are the behavioural actions of teachers and students and the functional aspects of design. Then, the most important aspect is the co-operation with actual users of a space. The purpose and the use of space with all possible work and action forms shall be determined; the placement and moving of people and the use of voice will be needed for initial data when the acoustical circumstances of space are being defined. The action determines the environment, not vice versa. In practise, this means rules of behaviour and its actions.

Acoustical evaluation, tools

The reverberation time and RASTI seem to be rather rough measures of solving acoustical problems, especially in small classrooms (under 80 m^2). In larger classrooms (over 80 m^2), the difference may be bigger because of the distance effect. The acoustical panels on the ceiling had more effect than the carpet.

The acoustical evaluation methods for small educational rooms should be developed. There are not enough accurate tools and criteria to make analyses properly when considering action and environment. Specific sound transmission analyses may give more appropriate tools for future needs in practice. On the other hand, in a small room, a voice directed straight ahead dominates, and the effects of surface reflections of sound are smaller compared to large classrooms where reflections are more dominant and effective. For small groups and in a small space, the acoustical guidelines of SFS 5907 may be practical. However, the evaluation shall be made also by taking account of disturbing noise, which could be controlled by acoustical design and technical solutions, but also through the leadership and guidance of the pupils (pedagogy) as well as the behavioural rules. Evaluation of distance absorption is difficult in small spaces like small classrooms and meeting rooms. Improvement of distance absorption shall be one target in the future.

The big picture and the future

The biggest difference between Finnish learning spaces in comparison with others is the volume, especially the height of the rooms [5–7]. Many new schools abroad have more volume (in height or open space), and the schools often resemble open offices or even outdoor areas. In Finland, heating expenses are high, so very high ceilings are not preferred, meaning more effort is required of planners to create a similar acoustical atmosphere designed for low-height spaces. This leads us to consider both ceiling and floor sound surface absorption.

Previously presented results and ideas are still only a glimpse of new learning spaces. Future work on this means new thinking and evaluation, and multi-professional co-operation among the space users, designers, researchers, and executors. The key to this is to look at the future learning habits of people and their needs, practices, solutions, and actual working models and technical tools. These new types of action environments challenge space design, for new opportunities shall be recognised and changing needs shall be estimated and predicted.

5. Conclusions

The results of all acoustical parameters were slightly better in the test area compared with the reference area. The greatest effect of acoustics and impact sound insulations was seen between the test area corridor and the reference area corridor.

All classrooms reached the minimum acoustical demands. However, the airborne sound insulation and background noise levels did not meet the demands of SFS 5907. The best result was seen in the test area corridor, which achieved the greatest acoustical improvement. The test area corridor may be used for educational purposes, which adds more space to be used, and more flexibility in educational use and learning.

New ways to think of the space design and information acquisition by users of the spaces and co-operations on all sides of the building process shall be made for better practical work and learning spaces in the future.

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Figures

Fig. 1. *New learning space plan (architect 3D plan). The doors and sliding walls are not drawn*

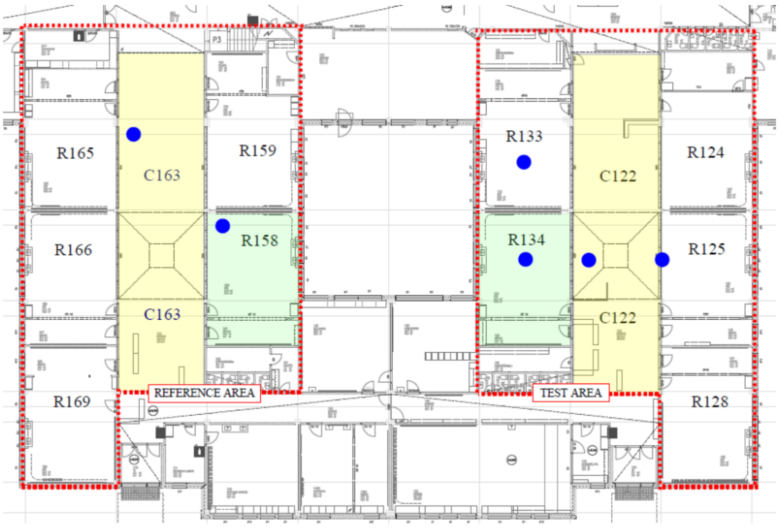

Fig. 2. *Measured rooms. The blue dots indicate acoustical measurement sites of the spaces.*

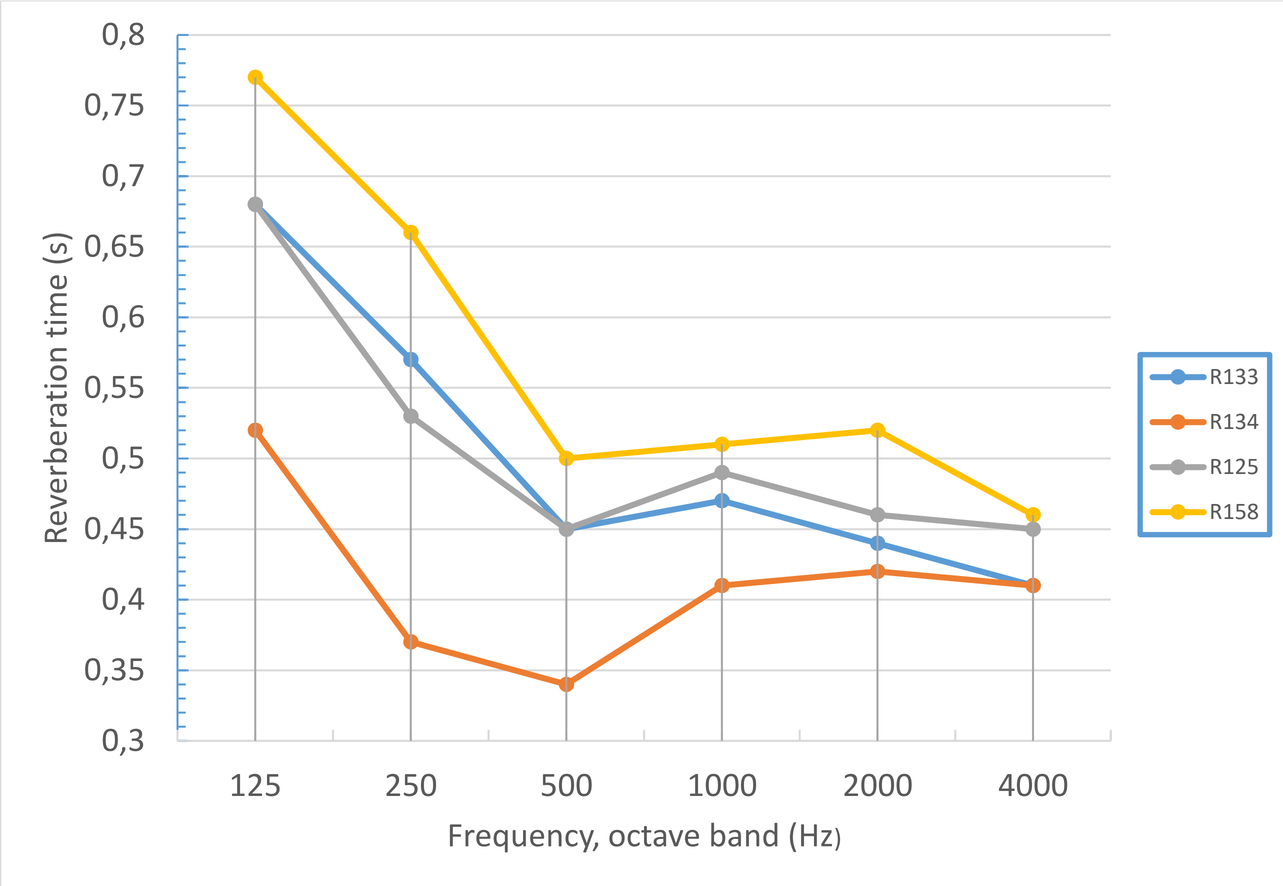

Fig. 3. *Reverberation time of classrooms.*