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ROOM ACOUSTICS OF CLASSROOMS WITH DIFFERENT SHAPES

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ABSTRACT

The room acoustics of twelve classrooms in a school building have been investigated. The building was designed in an organic style of architecture encompassing a different floor plan for each classroom in order to fulfil the diverse needs of children of different ages. Room acoustical conditions were of great importance for the architect. However, as a consequence of limited funds, simple solutions were required.

A set of room acoustical parameters has been measured in three classrooms. Reverberation time and speech transmission index STI were in good accordance with today's requirements. In some rooms the reverberation times are somewhat lower than the recommended lower limit for children of normal hearing.

As a supplement to the measurements, a questionnaire survey of the teachers was carried out. The goal was to learn how the acoustics in the classrooms were accepted. The teachers stated that they were highly satisfied with the acoustical conditions, not only with regard to speech but also for playing music.

But considering the concept of the interaction of all the senses and the influence of a living architecture conditions for learning in the classroom should not be evaluated only by the acoustical situation but also by the other sensory aspects of the room.

1 INTRODUCTION

The question of the acoustics in classrooms has been researched internationally in recent years. The influence of poor acoustics on the students and teachers, for example, was looked into in an important study by MacKenzie in 1999 [1] and is presently being investigated in a German study [2]. In various countries the latest knowledge is being incorporated into the respective standards and recommendations. The guidelines establish requirements for background noise and reverberation time. The recently revised Swiss Standard SIA 181 [3] is based on German Standard DIN 18041 [4] and presents guidelines for the reverberation time. The optimum reverberation time for classrooms of volume 125 m^3 - 250 m^3 lies between 0.4 - 0.6 s. In addition, a tolerance is defined (±20 % in the mid-frequency range).

According to DIN 18041 the reverberation time for persons with impaired hearing should lie up to 20 % lower in the octave bands 250 Hz to 2000 Hz for room volumes up to 250 m^3. Similar requirements are also given for other applications such as communicating in a language not native to the children.

Mommertz et al [5] have studied the question as to how it is possible to achieve good speech intelligibility in a classroom. It was found that as a first priority the optimum reverberation time must be adhered to, for example by installing an absorbing ceiling. Through an optimum arrangement of the absorption a slight further improvement can be accomplished.

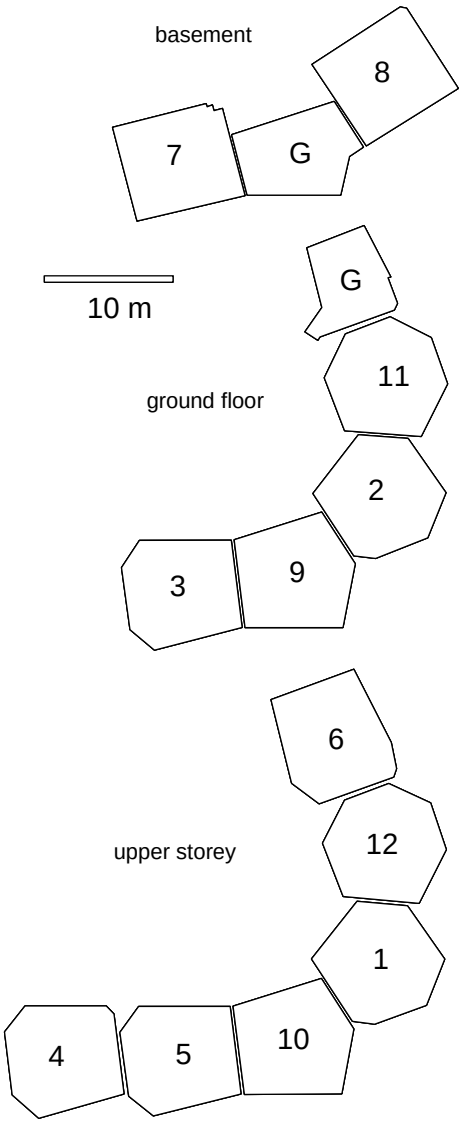

Fig. 1 Plan of the 12 classrooms (1 ... 12) and two group rooms "G" of the Rudolf Steiner School in Wetzikon, Switzerland. The number "1" indicates the 1. class with seven year old children.

2 THE CLASSROOMS INVESTIGATED

The classrooms investigated are located in a Rudolf Steiner School (Waldorf School) in Wetzikon, Switzerland. They include a kindergarten, classrooms for children and adolescents from the 1. to the 12. class as well as a large auditorium, a small multi-purpose auditorium, eurhythmy auditoriums, a gymnasium, the cafeteria and various other rooms. (Architect: Walter Känel with a contribution from Hans van der Heide). The goal of the school is to promote every child according to his age and individual stage of development, thus striving towards a free, independent personality. This concept leads directly to the architectural planning of the classrooms. As seen from the floor plan of Fig. 1, the children move every year to another room suited to their age. In connection with this study it is mentioned that foreign language

instruction already begins in the first class and the arts are emphasized more than in other schools.

Good acoustical conditions were important to the architect. However, the financial situation of the school had to be considered in the planning. From the start, the architect planned to include acoustical ceilings. These consist of wooden slats with an air space above, filled with a minimum thickness of 40 mm mineral wool sheeting. Thanks to this construction it was possible for the parents to assist in the installation. The ceilings in the basement level and ground floor are flat with a height of 3 m. In the upper floor the ceiling follows the form of the roof, achieving a height of up to approximately 5 m.

3 MEASUREMENTS

Within the framework of a study program of an architectural student at the ETH Zurich, room acoustical measurements could be undertaken in three classrooms, namely the rooms of the 8. class in the basement level (ceiling height h = 3 m, volume V = 200 m^3), the 2. class on the ground floor (h = 3 m, V = 210 m^3) and the 5. class on the upper floor (h = 3 - 5 m, V = 265 m^3). The results of the reverberation time measurements are given in Fig. 2. From measurements with an omni directional loudspeaker the Speech Transmission Index STI was also determined. In every case, the STI values were high (0.71 - 0.80).

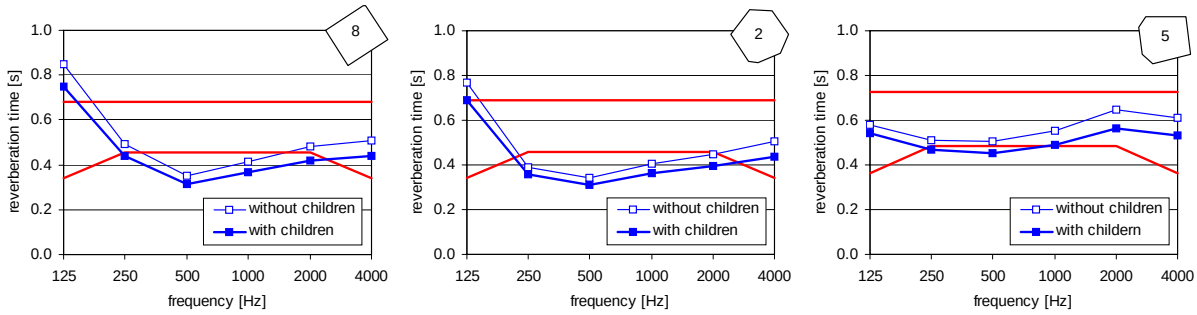

Fig. 2 Reverberation times in three classrooms. Measured without children. The values with children were calculated. 8. class, basement; 2. class, ground floor, 5. class upper floor. Tolarance range according to DIN 18041.

4 RESULTS OF A SURVEY OF THE TEACHERS

As a supplement to the measurements, a questionnaire survey of the teachers was carried out. The goal was to learn how the acoustics in the classrooms were accepted. The framework of this study did not allow a similar questioning of the children.

In the first part of the survey a polarization profile with six adjective pairs was employed. These were adapted from a German study [6] of classroom acoustics. On the basis of various tests of the acoustical atmosphere in classrooms, the following adjective pairs were found to be suitable: *indistinct - distinct, booming - clear, unpleasant - pleasant, reverberant - dry, strenuous - effortless, clashing - insulated.* In our study, the first question pertained explicitly to speech, the second to music.

Furthermore, questions were asked about noise disturbances: traffic noise by closed and open windows, noises from other classrooms, from technical installations (heating, plumbing) and from children in the same classroom.

Finally the teachers were asked for a general evaluation, again using adjective pairs:

A Acoustical conditions for the teacher with regard to speech (strenuous - effortless).
B Presumed suitability regarding speech intelligibility for the children (negative - positive)
C Learning of the German language or foreign languages (negative - positive).
D Relation to the special form of the room (unimportant - important).
E Comparison with other school houses (poorer or better acoustics).

Eventually nearly 20 survey questionnaires were sent back. Some of these did not relate to the classrooms but rather to the kindergarten and the eurhythmy auditoriums. In the left part of Fig. 3 the results of the polarization profile for speech acoustics are presented. Concerning the question of music acoustics, considerably fewer responses were obtained. The results differed little from those concerning the speech acoustics. The classrooms were found to be pleasant for musical activities as part of the instruction, that is, clear and effortless, although somewhat dry. One music teacher who also taught other subjects found the acoustics basically good. The responses to the questions about the background noise revealed little disturbance, even with open windows except in some cases including noises during the recess periods of other classes. The general questions were answered as shown in Fig. 4.

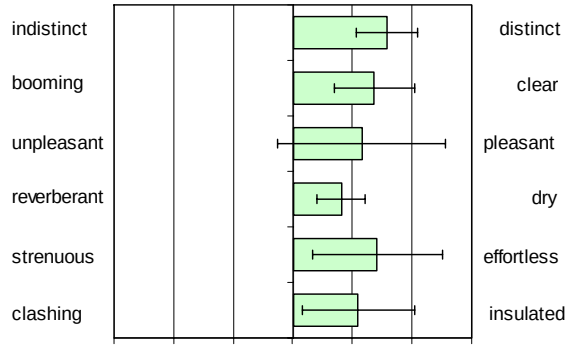

Fig. 3 Results of polarization profile; speech

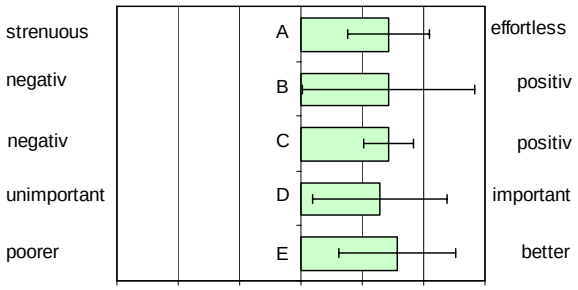

Fig. 4 Responses to questions A- E

5 DISCUSSION

5.1 Acoustical Conditions and Results of the Survey

The acoustical measurements in three classrooms showed a low reverberation time. In the two rooms with a volume of approximately 200 m^3 for the mid-frequency range it even lied below the recommended range given in DIN 18041. On the one hand according to DIN 18041 such conditions are advantageous to children with slight hearing impairments and for teaching foreign languages. On the other hand it is sometimes felt that the acoustics are unpleasant in rooms where the reverberation time is too low. In addition, depending on the room size, too much absorption can lead to a decrease in speech intelligibility.

In the present case, the schoolrooms are not especially large. The speech intelligibility can hardly be improved through support from room reflections as a consequence of an optimum

arrangement of absorbing and reflecting surfaces. Furthermore, due to the furnishings and the irregular room form, no damaging flutter echoes occur.

In any case it was certainly of interest to learn how the users react to the acoustical conditions. Although the results of the survey cannot necessarily be applied to the children, they still give important indications of the acoustical conditions. It was found that the classrooms are somewhat "dry" but are not unpleasant and do not require a strenuous effort. Indeed they are pleasant, resp. not strenuous. Above all, the acoustics are judged as positive for the instruction. Nevertheless, considering the mean values and the rather large spread of the adjective pair "pleasant - unpleasant" (Fig. 3), it can be concluded that the reverberation time lies at the lower limit.

Since the classrooms in the upper floor have somewhat higher reverberation times than the other two floors, the results were analyzed separately for the two groups. It was found, however, that the separate responses of the two groups were practically identical with the total results (all the teachers).

It may be assumed that the conditions of the examples presented here cannot necessarily be transferred to classrooms in other school houses, with other designs. In the next section it will be pointed out that other factors must also be included in the perception of a room.

5.2 Multisensory experience

Particularly in a Rudolph Steiner School it is logical that the discussion of the acoustical conditions should not only focus on the acoustics but also involve the other senses. About 80 years ago Rudolf Steiner (1861-1925) postulated twelve senses and the relation between them [7]: These are the senses of touch, life, self-movement, balance, smell, taste, vision, temperature, hearing, language, the conceptual, and the ego senses. Steiner's sensory theory has been considered in the fields of medicine, education, pedagogy, architecture and design. With regard to architecture and design, Wulf Schneider [8] recently made a contribution to Steiner's sensory theory. He presented examples and showed that by considering sensory perception, improved planning and design can be achieved.

It now appears that intermodal perception is also receiving attention in other areas. In this respect, a book by the interior architect and designer Rudolf Stricker is mentioned [9]. He takes a unique position among the many interior designers and architectural publications. With numerous illustrations and a good layout, the book is dedicated to the acoustical room shape from the viewpoint of the interior architect. Nevertheless, in the area of intermodal perception, there is a great need for further research (see, for ex. [10], [11]).

In the example presented in this paper it should be considered that the perception of a room is based on the sum of all sensory impressions. Therefore, in evaluating the acoustical situation it is necessary to consider the other senses. A reduction to merely the acoustical sense is incomplete. Perhaps the following can be postulated: In a room which is visually unpleasant and which contributes little to the senses, the acoustical situation will be judged more negatively than in a room which is "living" for the senses, although the reverberation times in both rooms are identical. If the goal of an organic architecture has been achieved in the rooms described above, then this must have an influence on the results of the survey.

6 CONCLUSIONS

The results of this paper should not be interpreted as an invitation to strive for very short reverberation times or applying absorption only on the ceiling. Likewise, it is not implied that a good and "living" architectural form automatically produces good acoustics – architects express this opinion from time to time. Rather, the results show the following:

If flutter echoes can be avoided in a classroom through the room shape and furnishings, a very good speech intelligibility can be attained, provided that the optimum reverberation time is adhered to. Then, if the room is not too large, the absorption may be placed exclusively on the ceiling.

Although the reverberation time in the classrooms under investigation lay at the lower limit, this did not lead to negative statements from the teachers. In fact, the acoustics in the classrooms was judged as clear, pleasant and effortless.

Considering the concept of the interaction of all the senses and the influence of a living architecture it is clear that conditions for learning in the classroom should not be evaluated only by the acoustical situation but also by the other sensory aspects of the room.

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