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ASPECTS REGARDING THE ACOUSTICS OF A LECTURE HALL

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Abstract. In a lecture hall it is vital to assure proper teaching conditions meaning that the information from the speaker/teacher must be received correctly by the listeners. Speech intelligibility is the main objective when a lecture hall is evaluated. In this paper, the authors discuss the importance of the acoustics of a lecture hall and the influence of various parameters over speech transmission from the speaker – the professors to the listeners – the students. The number of acoustical parameters is very large, but Speech Transmission Index (STI) and Reverberation Time (RT) are commonly used to evaluate the acoustics of a teaching room. Other parameters like room geometry and seat placement have great influence in speech intelligibility. As an example, a lecture hall of 120 seats from Naval Academy „Mircea cel Batran“ is investigated using virtual simulations with ODEON software. The results of the simulations are discussed and some remarks are made regarding the current condition of the lecture hall.

1. Introduction

The problems regarding the acoustics of lecture halls, seminar halls, classrooms are well known among the constructors, interior designers, acoustics specialists, teaching specialists. Such problems are related to room dimensions and geometry, seat distribution, materials of the surfaces. All of these aspects can be studied in the design stage of the room. It is important to make a solid concept because ulterior modifications cannot solve the errors occurred during the design and construction stages.

The development of simulation software allowed specialists to find the optimal solutions in shorter time rather than by using small scale models. This technique is applied in room acoustics design too. The large number of simulations made with a computer covers many design possibilities of a room. Also, depending the situation, these simulation software can help find a solution to improve the acoustics for a finished room.

If a room is poorly designed or constructed, the propagation of sound if affected, and the information cannot be well perceived by the listeners. When a professor teaches in such room, one must raise the voice and this has a great impact over speech capacity in time.

For each type of teaching room, there are standards regarding the construction of the room, background noise level, noise level at audience and other acoustical parameters

[1,2,3,4,5,6,7,8,9,10,11,12]. The values of these parameters don't vary much from one standard to another and they are generally accepted in most of the countries. Besides these standards, there are guidelines provided by universities and acoustical organizations [13,14,15,16,17,18,19,20].

Over the years, many studies have been conducted regarding the acoustics of teaching room in schools, high-school and universities. Also, these studies have evaluated the effects of teaching over vocal chords of the speakers and the effects of poor acoustics over speech intelligibility among the students. The design of classrooms in schools and high-schools is almost the same. The situation is different for universities because the number of students is larger in a teaching class. It is the case of lecture halls of which destination is not only for teaching, but also for conferences, symposiums. So, the geometry and configuration of lecture halls must be different than of the classrooms in elementary schools and high-schools. The teacher voice effort is higher in universities classrooms than in schools. In the paper *Acoustical Quality Assessment of the Classroom Environment* [21], the authors correlate the noise level produced by the teachers and noise level of the classroom. Their conclusion is that the lecture noise level is poorly correlated to teacher's gender. Rantala and Sala [22] studied the relation between classroom conditions and teacher's voice use. When the reverberation values or EDT were lower, the use of teacher's voice was higher, which affects the health and integrity of voice organs.

The conclusion that can be drown is that it is necessary to have very good acoustical conditions in teaching rooms to reduce the stress on voice organs and to increase the intelligibility of information among the students.

2. Parameters used in acoustic analysis of a lecture hall

In general, all acoustical parameters can be used to analyze sound propagation in a lecture hall. More or less information regarding the acoustics of a room can be obtained from each parameter.

- A-weighted sound level (L_A) represents the loudness of sounds and is expressed in dB(A)
- Reverberation Time (RT) is the time that takes for sound to die after the source ends its emission; it can be defined with reference to 30s or 60s, also known as T_{30} and T_{60}
- Speech transmission index (STI) – a measure of the combined effect of ambient noise and room acoustics on speech intelligibility
- Rapid speech transmission index (RASTI) – an abbreviated version of the complete STI
- Definition *D*50 is defined as the ratio of the integral of the square of the overpressure within the first 50 *msec* of the initiation of sound associated with *e.g*. a very short sound impulse (< 50 *msec* duration) to that integrated over all time for that same sound, expressed as a percentage. A "good" listening room regarding speech-intelligibility has *D*50 > 50%. Definition *D*50 can be determined only with ray-tracing simulation software.
- Speech Clarity, C50; for > 80% syllable intelligibility, a clarity of $C50 > -2dB$ is required, and is considered the minimum admissible limit for good speech intelligibility.
- Inter-Aural Cross Correlation (IACC)
- Strength Measure (G)
- Early Decay Time (EDT)
- %ALCONs – per cent Articulation Loss of Consonants

3. General construction guidelines

To construct a good lecture hall, engineers must study all surfaces in the room; the surfaces must be designed so that the speech/sounds will create an intelligible sensation of sound received by the listeners in the positions where they are located. Also, amplified voice systems used in a lecture hall must augment the natural voice of the teacher/speaker. The characteristics of the walls and surfaces separating the lecture hall from exterior must reduce the transmission of the noise from the outside. The background noise level in the room must be relatively uniform all around (if it's possible). The Noise Criterion should not exceed 35 when ambient noise level is measured (measuring points taken throughout the room at 1,2 meters above the floor.

Nowadays, many of the lecture halls have installed an audio system: microphones, amplifier, speakers. It is important to place the speakers at specific points so that the sound received in all areas is clear. Nevertheless, noisy lecture halls still exist. A lecture hall where acoustic design was poorly implemented presents excessive reverberation and echoes.

Regarding the use of sound-reflecting and sound-absorbing materials, the engineers must respect the guidelines mentioned in standards. By using these types of materials, the reverberation time can be modified. The difference between direct sound and reflected sound should not exceed 30 milliseconds. Above 30ms (around 70 ms), the echo sensation appears. The rear wall should have a textured (or a rough) of a faceted surface. The side walls should have a rough surface up to the ceiling. The front wall should have a hard surface or should be covered with hard surface materials. For all walls, the Sound Transmission Coefficient must be 50 or greater (STC > 50). The walls lining with sound-absorbing materials can reach up to 50-100% of the surfaces. The ceiling should have primarily a hard surface. If it must be covered with sound-absorbing materials, this action should not exceed 40-50% of ceiling surface. In case of a large lecture hall, where rear seats do not receive the sound very well, proper ceiling geometry must be designed and/or sound system must be installed. The floor is covered, in general, with carpet. The acoustic properties of the carpet must be taken into account in the design stage of the lecture hall. For the seats, their covering materials must be analyzed also in the design stage and the pre-calculus must be made with the seats occupied and vacant.

The guidelines regarding room geometry involve non-parallel walls. The side walls should have an angle in such way they will form a con or fan shape structure. This way, the sound will be „pushed" towards the back of the lecture hall. The rear wall should not be parallel with the front wall. The rear wall must be tilted to prevent the return of sound directly to the speaker/teacher. The ceiling surface must be stepped or sloped to reflect the sound downwards.

4. Standards and recommended values for acoustical parameters

The influence of room acoustics on the students and teachers is an important factor to assure proper transmission of the information. In various countries the latest knowledge is being incorporated into the respective standards [1…12] and recommendations [13…20]. In table 1 and figures 1 and 2 are presented a few acoustic criteria to design a room for speech transmission.

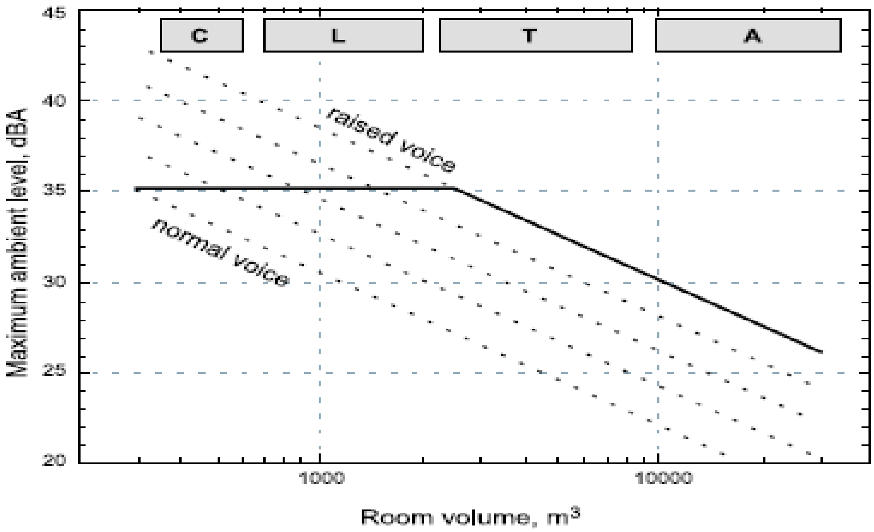


Figure 1. *Maximum ambient noise level goals (solid line) (C=classrooms, L=lecture halls, T=theatres, A=large auditoriums)* [23]

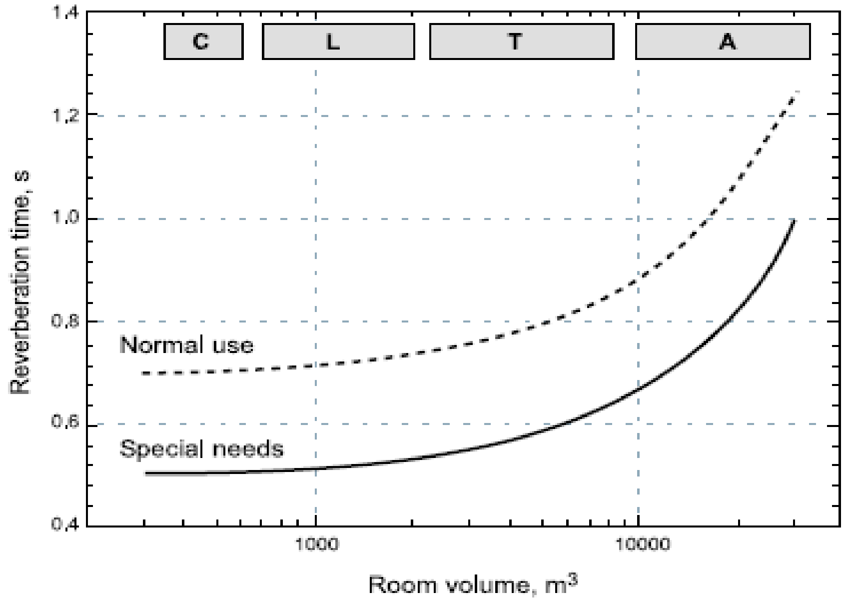


Figure 2. *Mid-frequency (500 to 2k Hz) reverberation time design goals (C=classrooms, L=lecture halls, T=theatres, A=large auditoriums)* [23]

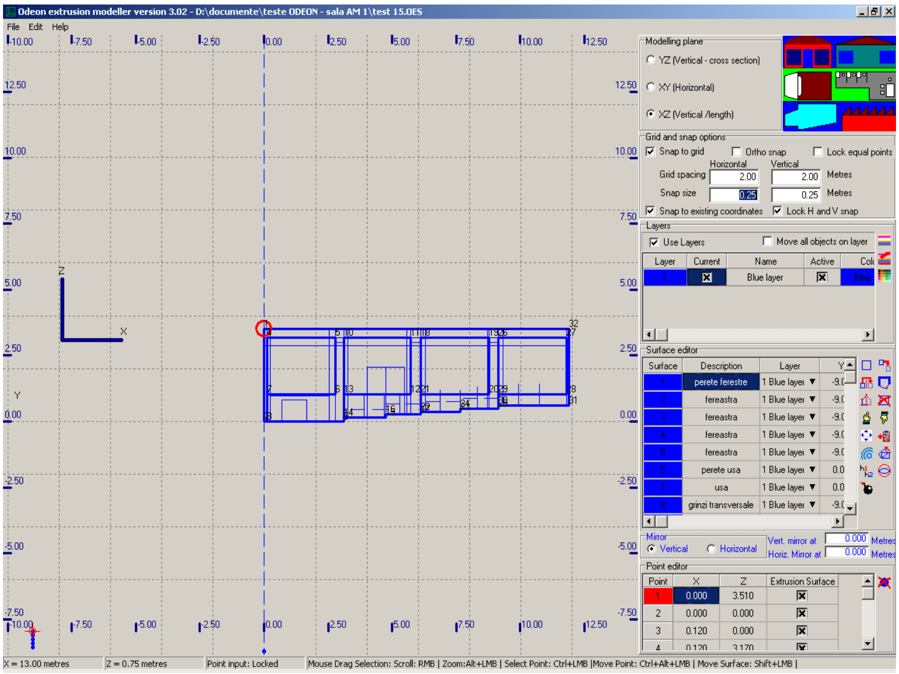
Table 1. Source: J.S.Bradley – Acoustical design of rooms for speech [23]

Example situations	Noise level, L_A [dbA]	Noise Criterion, NC	Reverberation Time, RT
Primary school classroom Broadroom for elderly adults	30	23	0,5
Law court	30	23	0,5
High school classroom General meeting room	35	28	0,7
Large lecture hall	30	23	0,7

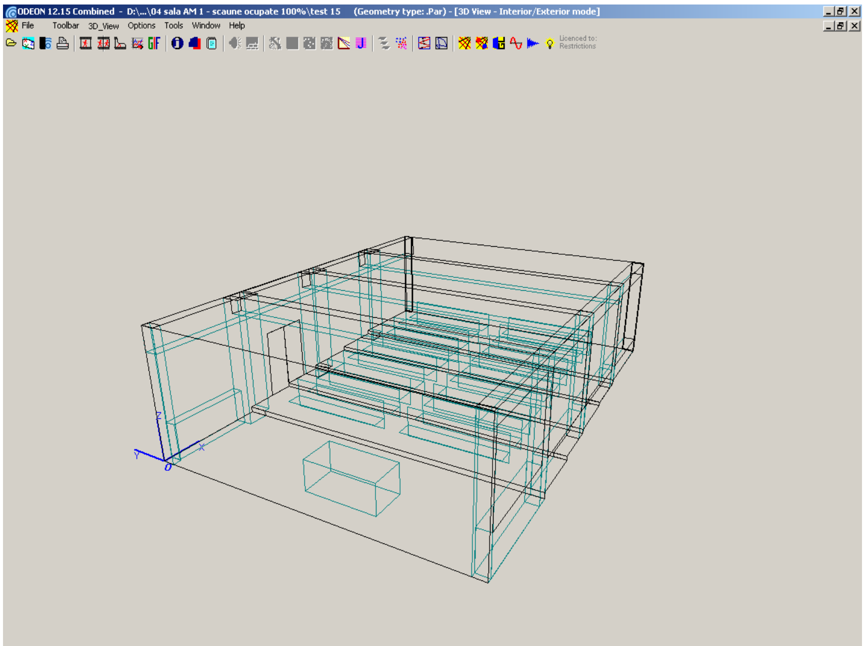
5. An example of sound propagation modelling in a lecture hall

In this paper we discussed the important issues related to acoustics of lecture halls, the basic principles for room geometry and which acoustical parameters are used to evaluate a lecture hall.

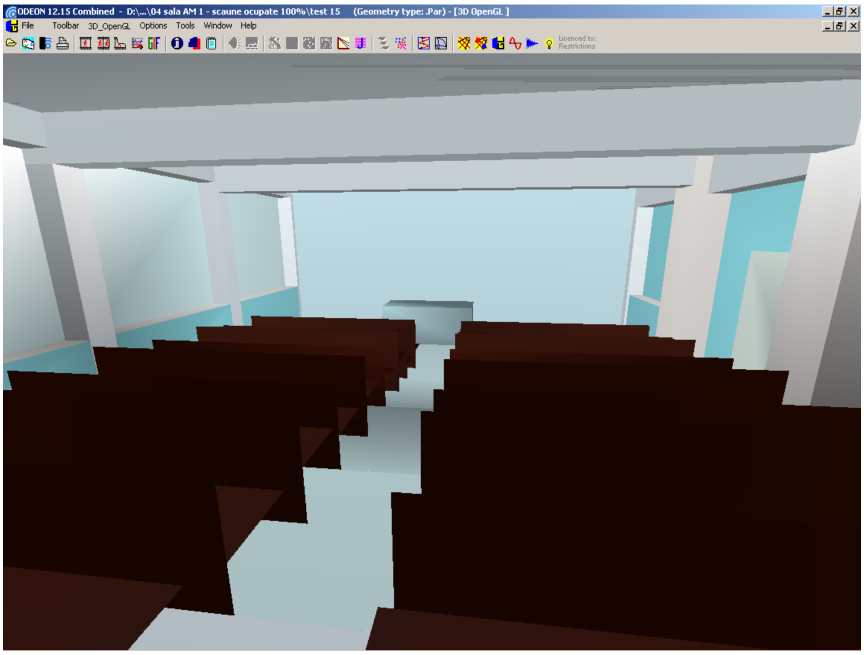
Here we present an example on how the sound propagates in a lecture hall. This modeling can be done by using a room acoustic software called Odeon. For this, we have chosen a lecture hall from the naval academy. This lecture hall has 120 seats, a volume of approx. 450m3. The lecture hall was modeled using Odeon Extrusion Modeler and then imported into Odeon.



Model of lecture hall made with Odeon Extrusion Modeler



Imported lecture hall model in Odeon

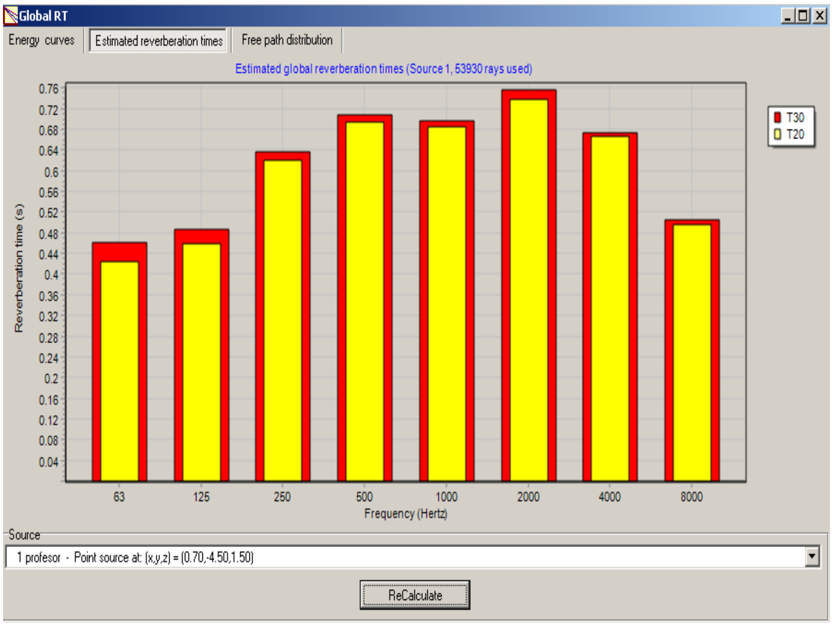


The interior of the lecture hall using a feature from Odeon called **3D open GL**

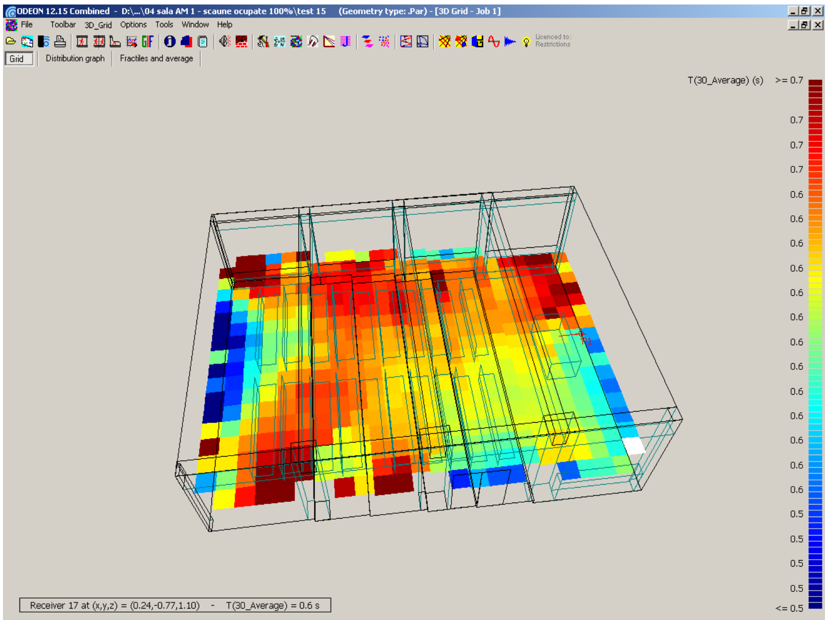
View of actual lecture hall from Naval Academy

After the lecture hall is modeled and imported into Odeon, the next step is to assign material properties to the room surfaces based on the bill of material for the building design. These include absorption at select frequencies and scatter, or diffusion coefficient. The software has an extensive library of values which can be chosen by the user for these. The room materials are common, such as tile and concrete floors, gypsum board, wooden desks and fabric covered seats. The software did provide some guidance by providing a general range for these coefficients taken from similar applications and materials. These recommendations were used to estimate the unknown coefficients. The next step in the process is to identify source and receiver locations representing where talkers and listeners would normally be located. For the sources, both position and directivity of the sources required specification. The goal of a good design for the lecture hall is to have a space with uniform acoustic performance throughout the space.

The source used in the simulations is a person talking with raised voice. The file was taken from Odeon data base. The position of the source, the lecturer is in front of the seats, and the positions of the receivers, the microphones are in raw no.1, raw no.5 and raw no.10, both on right and left column seats.



Estimated reverberation times before simulations



Reverberation Time (T_{30}) values after simulations

6. Conclusions

Lecture halls must complain with rigorous acoustic design to assure speech intelligibility all around the room. The design stage is critical to establish good and very good conditions for the audience as well as for the teacher or the lecturer. In the years when the simulation software developed, designing a lecture hall became quite accessible. Acoustic simulation software allow acoustic engineers and architects to explore various solutions in relative short time. Following the acoustic design principles for a lecture hall, engineers can predict easily how sound will be distributed and how it will be perceived by the listeners.

In this paper, the authors have created a virtual model of an existing lecture hall from the Naval Academy „Micea cel Batran“. From the results of the simulations it can be concluded that there are areas in the lecture hall where the sound is not received very well by the listeners. Because the geometry of the room is very difficult to alter, covering the walls with acoustic materials represents a viable solution. The authors recommend exploring these solutions in order to improve the acoustics of this lecture hall. More experiments and simulations will be carried out to determine the optimum solution for the problems encountered here. The results will be presented in our future papers.

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