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SOUND PROPAGATION MODELLING IN A LECTURE HALL

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Abstract. For lecture halls, intelligibility of speech is the most important aspect. To achieve a relative uniform distribution of sound among the listeners, a number of parameters must be taken into account. One method to speed up the design process of a lecture hall is to model the sound propagation in that room using computer acoustic software. In this paper, the authors have chosen a lecture hall from Naval Academy and made numerous simulations to discover what are the week points regarding the acoustics of this room. The acoustical parameters obtained from simulations are compared with the desired ones and a few remarks for the improvement of the room are made.

1. Introduction

Sound propagation modelling has improved over the years along with the improvement of simulation software. The ease of how room geometry and acoustical parameters of room surfaces can be modified represents one of the main advantages of using room acoustic software. Another great advantage is the speed of computer process which can lead to rapid results. All these things allow engineers and architects to execute many simulations in various conditions in short time. Thus, finding the suitable solution for an acoustical problem is achieved faster.

Over the years, many simulation software of interior sound propagation appeared. These software can be used for apartments, offices, teaching rooms, but also for repair shops, industrial halls etc. Some of these software remained at educational level, for teaching purpose. Others have developed and are used successfully in domains such constructions, automobiles, airplanes, ship construction etc. The list of room acoustic software is long, but here are some examples: ODEON, Soundplan, CadnaR, EASE, I-Simpa, CARA, CATT-Acoustic, Comsol Multiphysics.

When it comes to teaching environment, it is very important to design properly a lecture hall or a seminar room. By using room acoustic modelling software, new lecture hall can be designed, but also old teaching rooms can be acoustically improved.

DiMarino et al used ODEON to predict how the sound will propagate in a future to be constructed lecture hall [1]. After the simulations, they made several recommendations to select different construction materials. For a new lecture hall in Ain Shams University, Elkhateeb A. also used ODEON for simulating sound propagation [2]. The simulation results were compared with the measurement result made after the lecture hall was constructed. Elkhateeb concluded the measurement results are in acceptable range. This indicates that the room needs small adjustments compared to the initial project. The use of ODEON in sound propagation modelling in a lecture hall from University of Windsor, Canada [3] revealed the source errors when using this software. The errors are not that big but there are some of the simulated results that are not that close to the measured ones.

CATT-Acoustic was used by Elkhateeb and Eldakdoky [4,5] for acoustical assessment of two lecture halls in Cairo University. In schools and high-schools, classrooms have almost the same geometrical shape. Pavcekova et al [6] have compared the results of the simulations made with CATT-Acoustic for two classrooms with the results of the measurements of the reverberation time in those classrooms. A comparison of the results from simulations made with CATT-Acoustic and EASE was made by Moreno [7]. He concluded that the geometric model should be very accurate so that at low frequencies the results to be better. Also, another source of errors was the lack of accurate knowledge about surfaces materials.

After using modelling software, very good acoustic results can be obtained for new constructed facilities. In the case of existing rooms, the improvements can be more or less significant when the propagation of sound in such rooms is modelled. For the existing rooms, the common improvement method is the installation of an audio system (microphone, amplifier, speakers). Nevertheless, acoustic treatment of room surfaces must be used also. In many cases the combined solution of an audio system and the acoustic treatment of surfaces is the adopted solution. Regarding the financial aspect, the adoption of a solution for the acoustical problems in an existing room depends on the results of the acoustical measurements, results that can show if the problems are simpler or complex.

2. Lecture hall acoustic modelling

The simulation of sound propagation in a lecture hall relies on the same steps as for any other room. First, the dimensions of lecture hall surfaces and furniture must be measured. Then, the computer model is made using either a dedicated module from the simulation software like Odeon Extrusion Modeler in ODEON or a CAD software like AutoCAD [8]. One important step is the definition of the surfaces regarding their acoustical properties: sound absorption coefficient, transmission loss [9,10].

The greatest challenge in computer simulations represents the definition of acoustical properties of the surfaces of that room. For example, the values of the absorption coefficient must be determined through laboratory measurements to establish precisely how the material behaves. Of course, values from previous studies, from books and standards can be used. But in order to validate the computer model, these laboratory measurements must be made so that the results could be very accurate. Also, the simulations results must be compared with the results of the in situ measurements of the acoustical parameters of the room. If the differences between these sets of results are small, then the computer model is close to the real room.

To quantify sound propagation in a lecture hall many acoustical parameters can be used: Noise Level or Sound Level, Reverberation Time, Speech Transmission Index, Speech Clarity, Definition, Early Decay Time etc. Each of these parameters is used to describe one aspect of sound propagation and how the sound is perceived by the listeners in that room [9,10].

The results from the simulations are in fact the results of a calculus based on assumption of acoustical properties of the surfaces. They depend also on the precise dimensions of the room surfaces. A very complex model of a lecture hall doesn't increase the precision of the results. It was proven that the results of simulations of a complex model are very small compared with a simpler model. This means that small geometrical details do not change significantly the results of the simulations. The differences are caused mainly by the imprecise knowledge of the acoustical properties of the materials [11,12].

One first conclusion is that an important step in computer modelling of a lecture hall is the correct measurement of room surfaces and furniture surfaces.

The second important step is the definition of the acoustical properties of the surfaces. The simulation software use formulas which depend on those properties. Also, physical phenomena such as reflection, absorption depend on acoustical properties of the materials. The use of unverified values of the acoustical parameters is a source of errors. These errors can be eliminated by using real values obtained through laboratory measurements. In practice, the acoustical properties of the materials can be obtained by comparing the values of acoustical parameters resulted after simulations with the values resulted after in situ measurements. The smaller the differences, the closer to the real values are the initial assumptions. This method is preferred to the laboratory method. For an existing lecture hall or a room, the determination of acoustical properties of the materials of the room means taking sample from the surfaces which will deteriorate eventually the surfaces.

In conclusion, the error source is the lack of knowledge of the nature of the materials. If nature of the material is known, even if the precise acoustical properties are not known, then the values known from the literature can be used in simulations. Unfortunately, there is no vast database for the materials used in construction.

3. Simulations and results

The lecture hall from Naval Academy „Mircea cel Batran" has 120 seats. Using ODEON, the estimated volume of the room based on the measurements that we have made is approx. 383m^3. The room was modeled in ODEON Extrusion Modeler, a module in ODEON (figure 1).

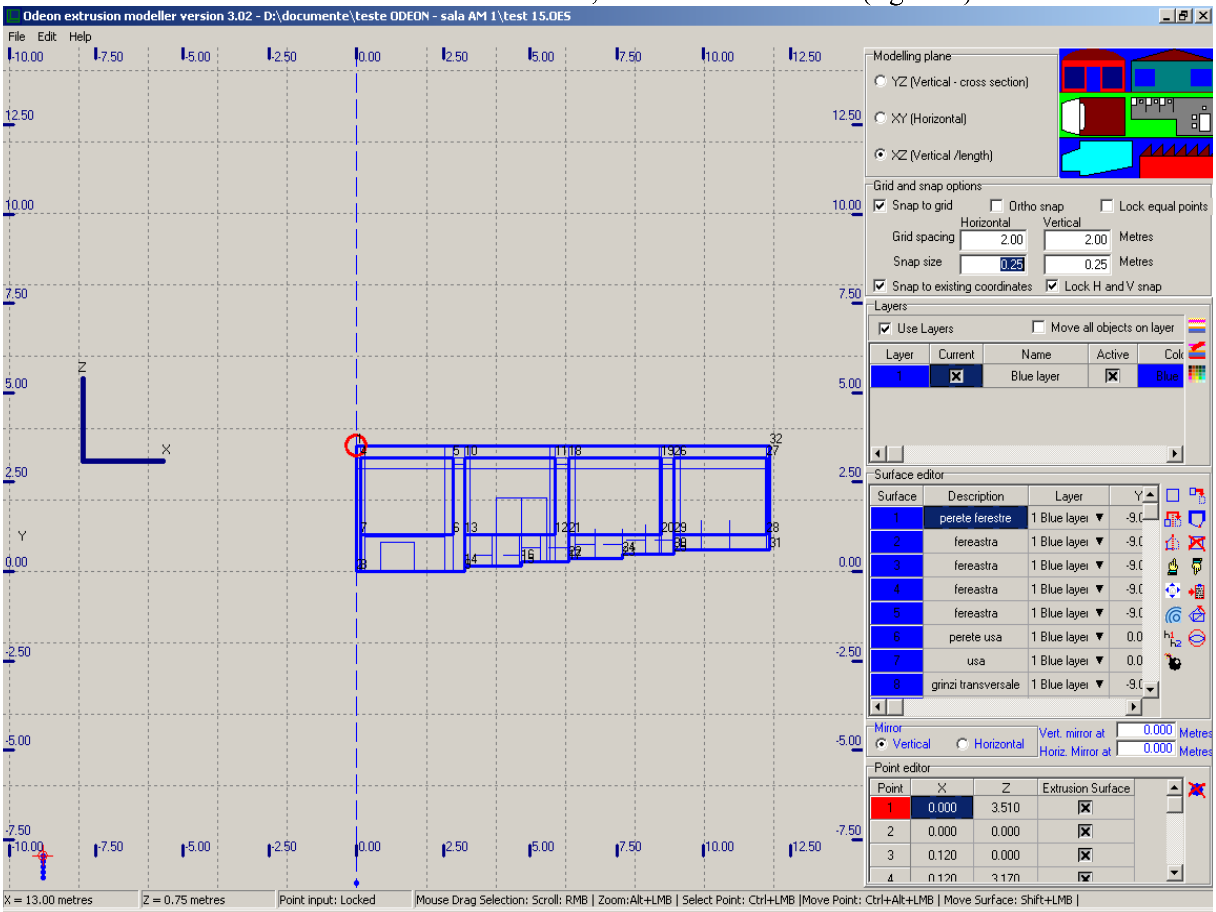

Figure 1 – side view of the lecture hall created with ODEON Extrusion Modeler

After the lecture hall is modelled 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 materials. 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.

In table 1 and in figure 2 are presented the absorption coefficient values of the materials used in simulations.

Table 1. Absorption coefficients

Surface	Material	Absorption coefficient							
		63Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz	4000Hz	8000Hz
Side wall with windows	Concrete block painted (mat.104 Odeon)	0.11	0.11	0.08	0.07	0.06	0.05	0.05	0.05
Side wall with door	Thin plywood panelling (mat.3063 Odeon)	0.42	0.42	0.21	0.1	0.08	0.06	0.06	0.06
Front wall	Gypsum board (mat.4045 Odeon)	0.28	0.28	0.12	0.1	0.17	0.13	0.09	0.09
Back wall	Thin plywood panelling (mat.3063 Odeon)	0.42	0.42	0.21	0.1	0.08	0.06	0.06	0.06
Ceiling	Concrete block painted (mat.104 Odeon)	0.11	0.11	0.08	0.07	0.06	0.05	0.05	0.05
Floor	Parquet on counterfloor (mat.3005 Odeon)	0.2	0.2	0.15	0.1	0.1	0.5	0.1	0.1
Longitudinal girders	Concrete block painted (mat.104 Odeon)	0.11	0.11	0.08	0.07	0.06	0.05	0.05	0.05
Vertical girders	Thin plywood panelling (mat.3063 Odeon)	0.42	0.42	0.21	0.1	0.08	0.06	0.06	0.06
Radiator front panel	Thin plywood panelling (mat.3063 Odeon)	0.42	0.42	0.21	0.1	0.08	0.06	0.06	0.06
Windows	Double glazing 2-3mm glass (mat.10004 Odeon)	0.15	0.15	0.05	0.03	0.03	0.02	0.02	0.02
Teacher desk	Plywood panelling (mat.3068 Odeon)	0.28	0.28	0.22	0.17	0.09	0.1	0.11	0.11
Seats	Audience, medium upholstered seats (mat.11008 Odeon)	0.62	0.62	0.72	0.80	0.83	0.84	0.85	0.85

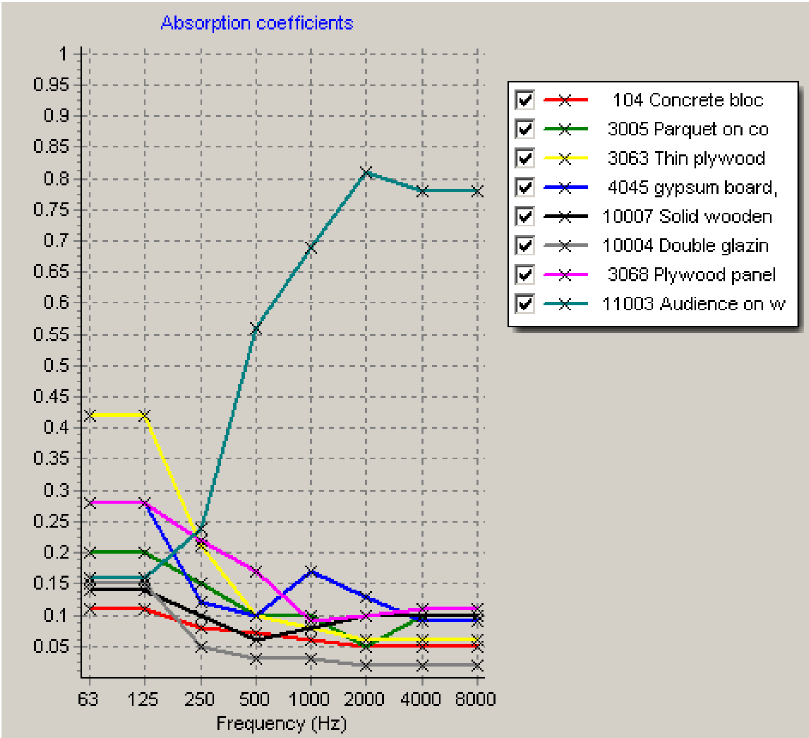

Figure 2 – Absorption coefficients (source: ODEON database)

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. As recommended in standards, 6 receiver positions were chosen. The source used in the simulations is a person talking with raised voice. The file was taken from Odeon database. 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 (figure 3).

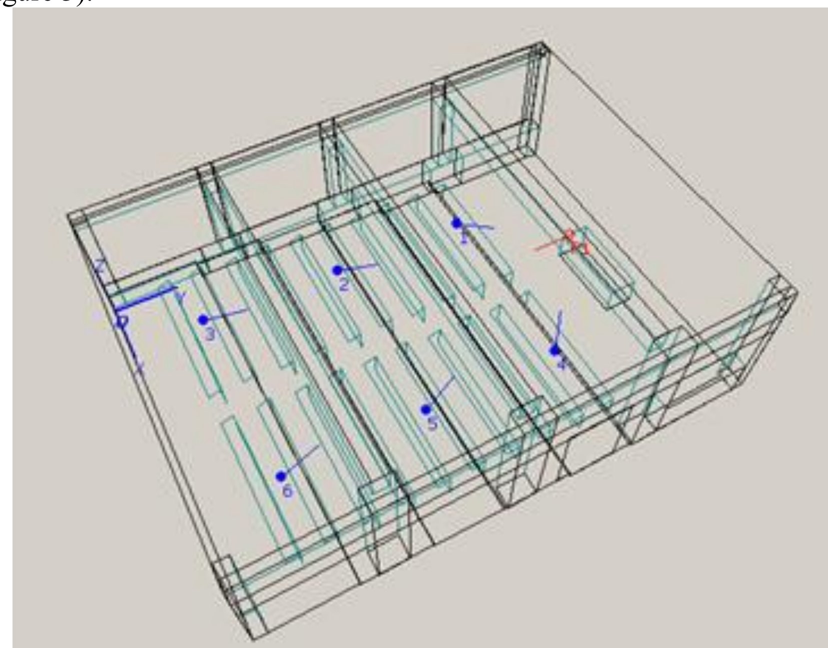

Figure 3 – Positions of the source and the receivers

In the next figure are presented the characteristics of the source: a teacher taking with normal voice.

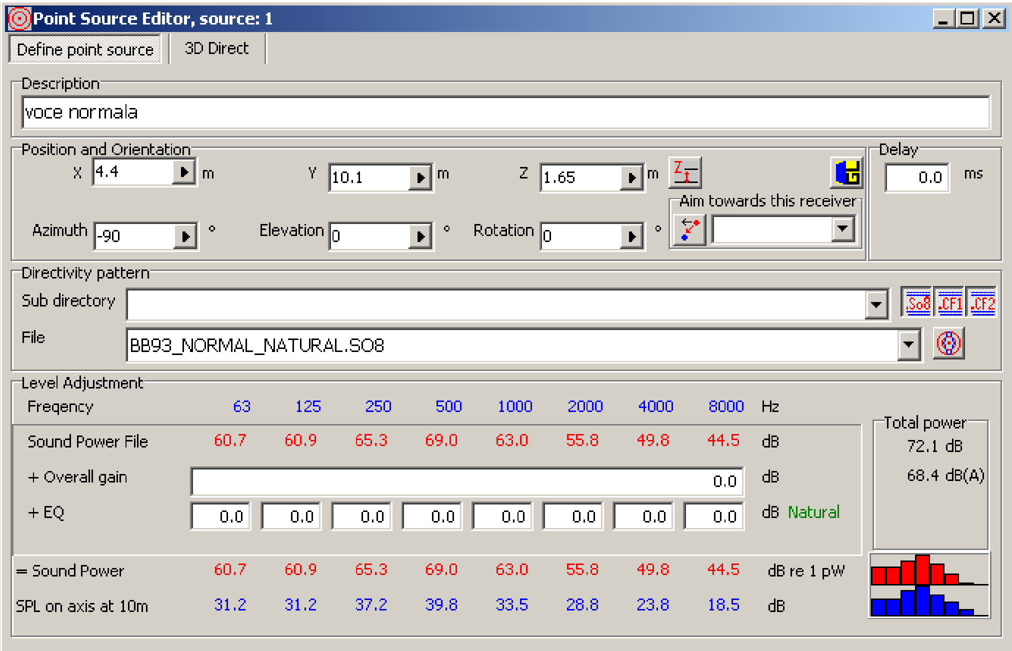

Figure 4

In the next figures are presented the results of the simulations for reverberation time (T_{30}), sound pressure level (L_A) and speech transmission index (STI).

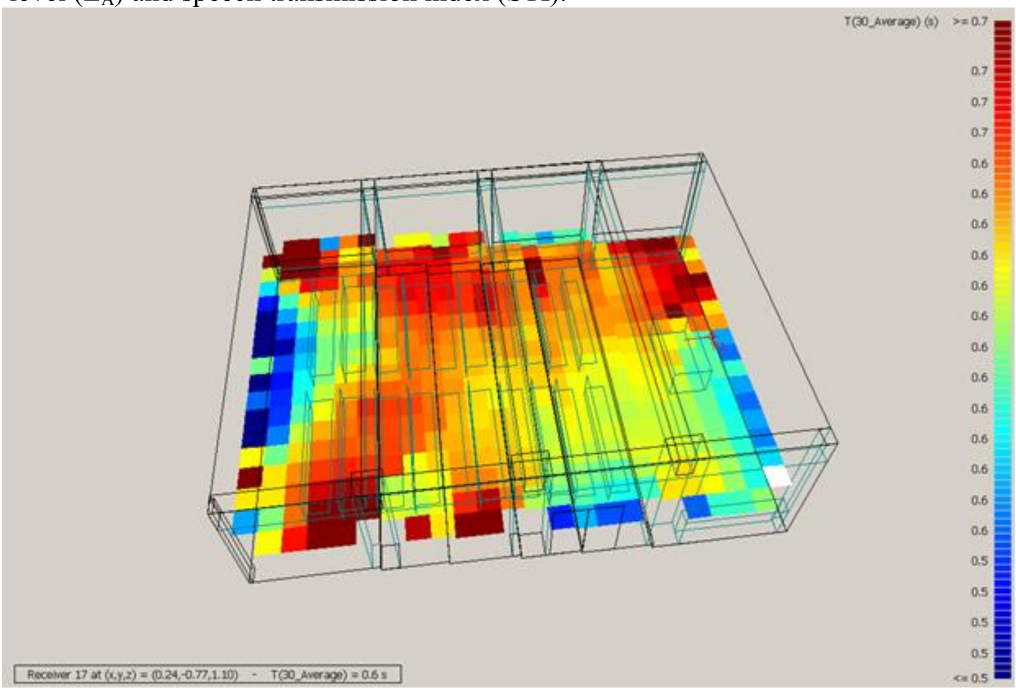

Figure 5 – T_{20} (Reverberation Time 30dB)

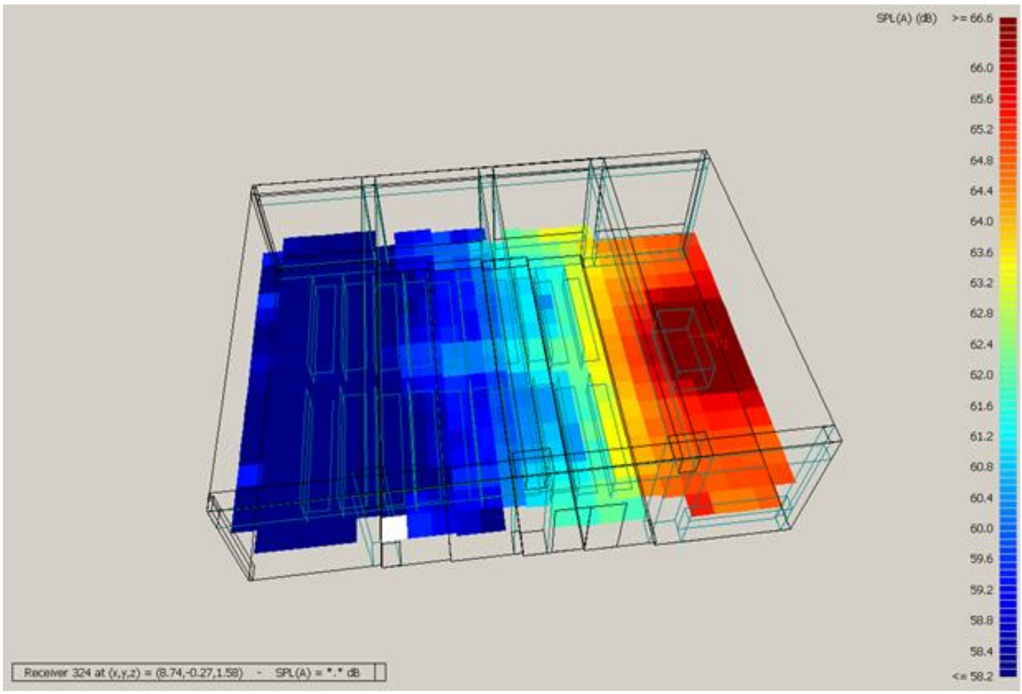

Figure 6 – L_A (A-weighted Sound Pressure Level)

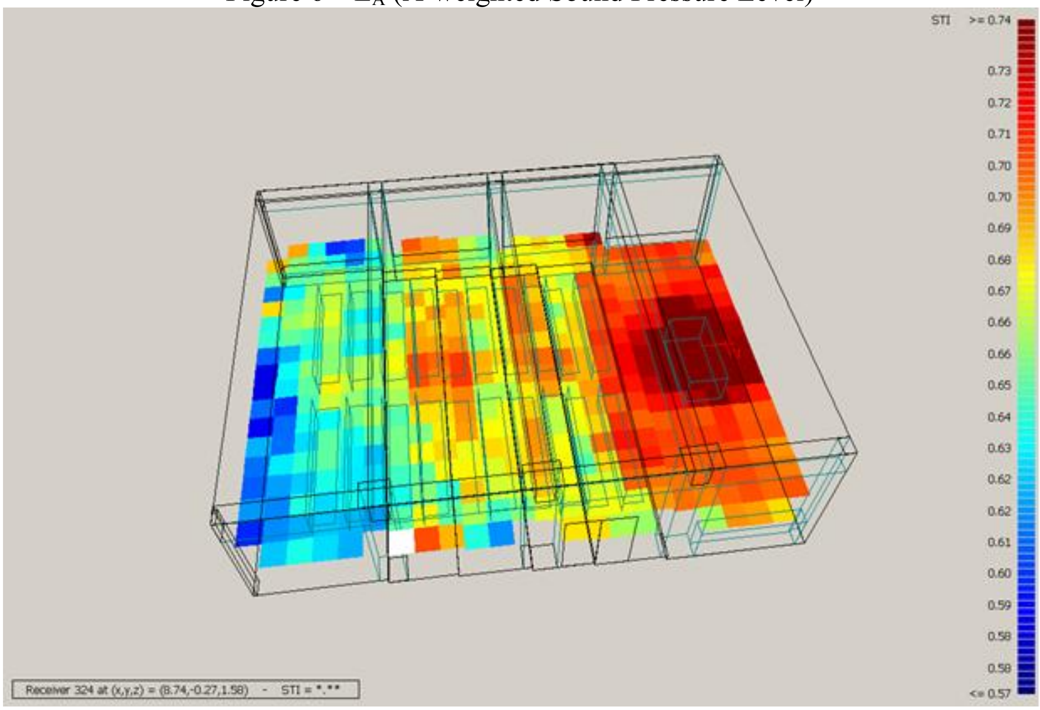

Figure 7 – STI

4. Conclusions

The improvement of the acoustics of a lecture hall represents an improvement of teaching conditions, of information transmission. Such a room with good acoustics allows listeners to follow easily the lectures which mean a small concentration effort for them and a great intelligibility of the information. For teachers, this means a lesser speech effort and a very small impact over vocal chords.

The results of the simulations show there are areas in this lecture hall where the sound do not propagate the way it is desired. Room geometry does not respect entirely the recommendations in the standards. In figure 5 the values of the Reverberation Time are not uniform.

There are noticeable differences of the sound pressure level between the rows. In a lecture hall with good acoustics, the values are expected to decrease relatively uniform from the front rows to the back of the room. From the figure 6 it can be observed that sound pressure level is greater near the speaker, in front of the rows. Then, sound level decreases to the back of the room as expected. The difference between the rows is not that big (8dB). The sound distribution is uniform along each row which means that sound is perceived the same way in that row. Nevertheless, the conclusion that can be drawn from figure 6 is that for the back rows the drop of sound level must be smaller.

Regarding the reverberation time, the values of this parameter should not vary much in a lecture hall; the differences between the first row and the last one should be small. From the simulations, it can be noticed that this is not happening (figure 5). The same conclusion can be drawn regarding the speech transmission index (figure 7).

The simulations results are not a motive to worry very much about the acoustics of this lecture hall. The lack of knowledge of the acoustical properties of the materials is the main source of these contradictory results. To validate the computer model made in ODEON, in situ measurements of the acoustical parameters must be made. The authors have planned such measurements and the results will be published in a future paper. This way, recommendations will be made regarding the modifications that can be done so that the acoustics of the lecture hall will be improved.

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