ACOUSTIC PROJECT OF A CONFERENCE ROOM OF THE SECONDARY SCHOOL "AVENIR 33" (DELÉMONT, SWITZERLAND)

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Résumé

Cet article rapporte l'étude acoustique d'une salle de conférence dans une école secondaire en Suisse. L'approche architecturale s'est concentrée sur le choix de la forme et des matériaux de l'auditorium, tandis que les traitements acoustiques proposés devaient assurer une bonne isolation et de l'intérieur ainsi qu'une bonne intelligibilité de la parole. Les simulations acoustiques ont été effectuées avec le logiciel Odeon. Elles ont permis de prévoir les principaux indicateurs acoustiques (T_{30}, EDT, C_{80}, D_{50} et STI) et donc d'optimiser les surfaces et les positions des traitements acoustiques pour différentes utilisation de la salle (taux d'occupation). Ainsi, les traitements acoustiques proposés permettent une bonne propagation de la voix de l'orateur sans besoin d'un système de sonorisation. Une campagne de mesure acoustique réalisée à la fin de travaux de construction confirme la bonne qualité acoustique de l'auditorium.

Mots clefs : acoustique de la salle, simulation, maquette virtuelle, auditorium.

Abstract

This paper reports the study of a conference room inside a secondary school in Switzerland. The architectural approach developed focused on the choice of the room's shape and materials, while the acoustic treatments, proposed had to provide a good speech intelligibility. Simulations run with the software Odeon allowed to foresee the main acoustic indicators (T30, EDT, C80, D50 and STI) and therefore optimize the dimensions and positions of the acoustic treatments for different audiences. Moreover, the acoustic treatment aims to enhance the vocal emission of the speaker without amplification systems. Acoustic measurements carried out at the end of the building construction confirmed the good acoustic quality of the conference room.

Keywords: room acoustics, simulation, virtual model, conference room.

1 Introduction

Large enclosed spaces have mainly evolved over time due to the need to accommodate people with common interests for activities and events [1, 2, 3]. The functions for which an environment is intended imply forms of visual and sound communication, it is therefore essential, for the acoustic design, to define the intended use as well as the appropriate choice of the acoustic parameters to be analysed such as reverberation time, definition, clarity and STI (Speech Transmission Index). The optimal acoustic conditions required are achieved by either means of appropriate acoustic correction interventions or inserting appropriate amounts of sound-absorbing material into the room [4]. The environment in question is the conference room of the secondary school "Avenir 33" in Delémont (Switzerland) in 2016. The project as a whole included a school canteen with 212 places, a 154-seat conference room, a library, a wing for the secretariat and teaching rooms, a chemistry lab, 4 computer rooms, 4 theoretical classrooms and 6 classrooms for the carrying out of practical lessons. Prefabricated wood caissons were used for the structures of the load-bearing facades and structural floors. The interior surfaces of the rooms (walls and ceiling) were covered in wood, with the choice of the material being connected to the need to obtain warmer and more domestic tones, which promote a feeling of calm, concentration and warmth. Particular attention was given to sound insulation (impact sound and plane noise) inserting a layer of sand (thickness 6.0 cm) inside the floors. Finally, given the size of the classrooms, the wooden panels were appropriately perforated to obtain a suitable sound-absorbing system to reduce the unwanted reverberation. Figure 1 shows the external view of the school. Furthermore, attention was given to the acoustics of the large spaces on the ground floor such as the conference room and school canteen. The requests of the client were that the walls and ceiling had to be covered in wood and, in this case, perforated wooden panels were chosen. The conference room is a regular volume of parallelepiped shape. Figure 2 shows the internal view of the conference room. While Figures 3, 4 and 5 show the section of the room with the main dimensions. The geometrical

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characteristics are summarized in Table 1. The shape of the room is bound to the entire structure, with a regular geometry and large windows on one side for lighting needs with natural light. The perimeter wall towards the outside is made of large transparent glass surfaces, covering about 33 m^2. The interior side walls and ceiling are covered with wooden panels and the floor is covered with a carpet. The choice to use wooden panels is due to aesthetic and functional requirements. The wooden panels can be either perforated, so as to give the walls suitable sound absorption characteristics or be unperforated and therefore reflect the incident sound waves to obtain suitable sound reflection characteristics.

Figure 1: Photo of the external view of the school (photo by Thomas Jantscher).

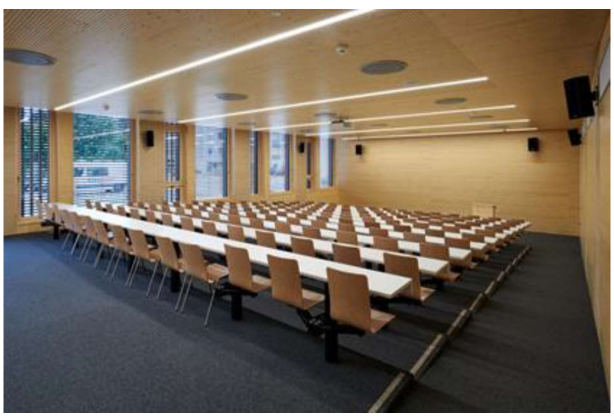

Figure 2: Photo of the conference room (photo by Corinne Cuendet).

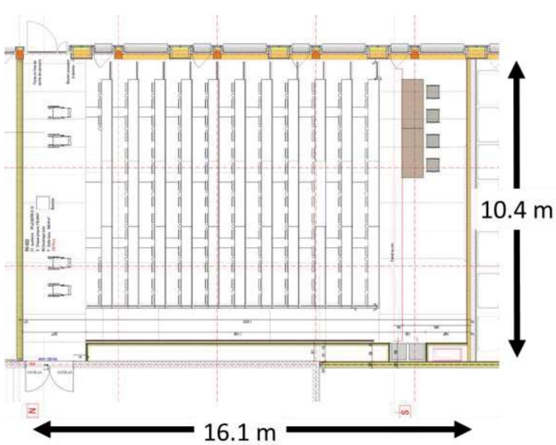

Figure 3: Plan of the conference room.

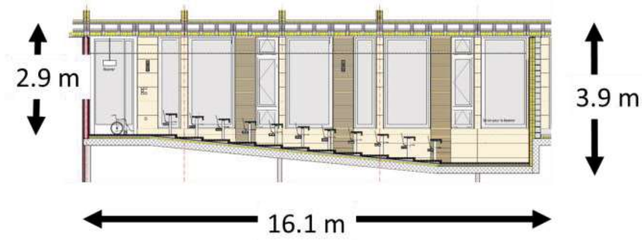

Figure 4: Lateral section of the conference room.

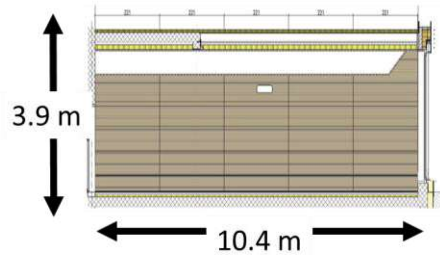

Figure 5: Frontal section of the conference room.

Table 1. Conference room dimensions.

Length, m	16.1
Large, m	10.4
Maximum height, m	3.9
Minimum height, m	2.9
Volume, m^3	570
Maximum capacity	154 seated
Glass surface, m^2	33

2 Acoustic project

For the purpose of a suitable acoustic design, along with a correct assessment of the characteristics of the materials to be used in the room, it was necessary to know in advance the intended use of the environment, from which the optimum reverberation time can be determined. For each use of the room, a suitable value of the optimal reverberation time as well as the other acoustic parameters was provided. The intended use of the school conference room was for conferences and screening films. The design of the room had to therefore be dedicated to the comprehension of speech, with the possible use of electroacoustic sound amplification systems. Therefore, it was necessary to estimate the value of the optimal acoustic parameters according to the intended use. For rooms intended to listening to speech, the reverberation time values required are shorter than those required for concert halls. The effect of the sound tail produced by excessive reverberation can lead to the superimposition of the sound impulses causing the consequent distortion of the perception of the speech. For example, a short reverberation time involves an acoustically too "dry" environment, where the comprehension of speech is insufficient due to the presence of direct sound and the absence of contributions to the sound field coming from the reflections of sound from the surfaces of the room. In this configuration, the voice emitted by a speaker arrives weak and feeble to the listener present, reducing the ability to understand speech. An excessive length of reverberation time or the presence of a long sound tail involves a reverberation environment where the understanding of speech is insufficient due to the overlap of the phonemes, with this effect being generated by multiple number of reflections of the waves. Several solutions were adopted during the design phases to reach the best listening conditions in the conference room. The wooden chairs and tables are periodic surfaces, that give a sound diffusion The floor was covered with a thin layer of carpet, with a low sound absorption. The wall claddings of the hall were made of wooden panels. This panel has good sound absorption characteristics if suitably perforated and installed at a suitable distance from the rigid rear wall, with a layer of sound-absorbing material being inserted into the gap to improve sound absorption. However, it can also be an acoustically reflecting panel if the holes are closed, thus creating a smooth acoustically reflecting panel. The ceiling was partly realized with acoustically reflecting wooden panels positioned in the area where the speaker sits. This solution was chosen so as to reinforce the direct sound component of the voice, while in the area away from the speaker, in the area where the listeners are, sound-absorbing wooden panels were installed. In addition, the wall to the right of the speaker's position is made of a large glazed surface, while the one on the left is completely made of wood. One of the acoustic problems is due to the rectangular hall plan with parallel flat walls. In environments with parallel flat surfaces, many reflections are generated, due to the reflections of the sound on the walls, with undesired acoustic effects such as "flutter echo". To reduce the effects of the multi reflections coming from the side walls, which generate acoustic defects, the wall on the left side of the speaker was made with wooden panels so as to create a smooth reflecting surface, interspersed with 1.0 metre wide stripes and equal height to that of the hall, of sound-absorbing wooden panels. This arrangement allows to reduce the effects of the sound multi reflections. The wall to the right of the speaker, the areas in which the windows are not present, were lined with sound-absorbing wooden panels. Similarly, for the ceiling, this was partly achieved with sound-absorbing wooden panels and partly with reflective wooden panels, with them reflecting the sound and reinforcing the speaker's voice which reflected properly from the ceiling propagates uniformly throughout the conference room. During the design phase, the acoustic study was drawn up using a 3D CAD model of the room, in order to evaluate the appropriate amount of sound-absorbing material to be inserted to obtain the desired reverberation times. Figure 6 shows the location of the wooden panels installed in the conference room on the vertical walls (60 m^2). While Figure 7 shows the location of the sound-absorbing wooden panels under ceiling in the conference room (35 m^2). The total area covered is 95 m^2.

3 Acoustic parameters

One of the most used acoustical parameters for evaluating the quality of a room is the reverberation time (measured in seconds). This parameter was introduced at the end of the 1800s by Clement W. Sabine and is defined as the time interval in which the sound energy decreases by 60 dB after switching off the source [5].

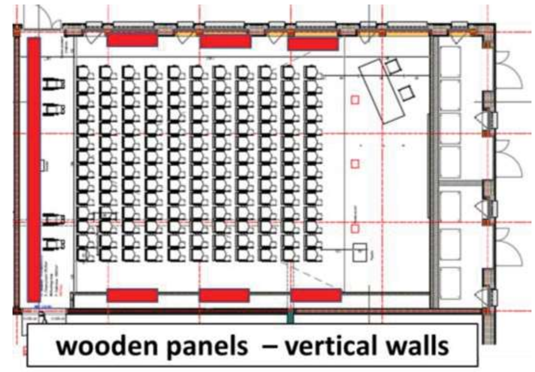

Figure 6: Location of the sound-absorbing wooden panels on the vertical walls in the conference room.

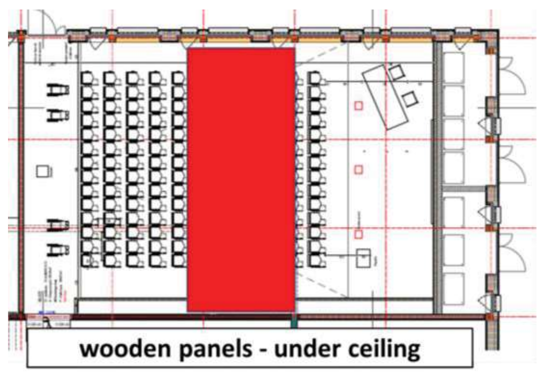

Figure 7: Position of the sound-absorbing wooden panels under ceiling in the conference room.

In a room, the longer the reverberation time, the greater the contribution of the components of the reflected sound compared to the direct one. The reverberation time value is a function of the room volume and the total sound absorption of its internal surfaces. The absorption of the materials changes with the variation of the frequency, the reverberation time also varies at the different frequencies considered. In architectural acoustics, for the acoustic correction of closed environments, the frequencies in octave bands from 125 Hz to 4.0 kHz are considered. Frequencies above 4.0 kHz are not considered because sound absorption by air prevails. Frequencies below 125 Hz are not considered because the human voice produces very little sound energy below 125 Hz that would be useful or important for speech intelligibility.

The acoustic parameters, for the purposes of the study and understanding of architectural acoustics, are reported in the ISO 3382-1 (2012) standards "*Acoustics - Measurement of room acoustic parameters*" [6]. EDT, (Early Decay Time) defined as the time taken for the sound level to decrease by 10dB. It is a time that takes into account the direct sound and approaches that which is the subjective perception of the time of decay. C_{80}, index of clarity, measures the goodness of listening to music in a hall. It is also a function of the reverberation time and the distance of the listener from the orchestra and therefore is linked to the subjective intensity of the direct sound. D_{50}, index of definition, is related to the understanding of speech. It represents the ability to distinguish sounds that follow one another over time. Speech Transmission Index (STI) represents the degree of amplitude modulation in a speech signal and refers to the distortion in speech signals caused by reverberation, echoes, and background noise.

In particular, typical suggested values of the different monaural acoustic parameters for both the speech comprehension and music listening are: the reverberation time T_{30} should assume values below 1 s for a clearer perception of **speech**, while it may assume greater values, around 2 s for music listening preference; the definition D_{50} may assume values from 0 to 1.0, but for a good speech comprehension should have values above 0.50; the indices STI can take values between 0 and 1.0, being greater than **0.6** for favorable speech conditions. Table 2 shows the optimal values of the acoustic parameters for the different listening conditions, from which it is noted that for an environment intended for speech an optimal reverberation time of less than 1.0 seconds is required [7, 8].

Table 2: Optimal acoustic parameter values for the different listening conditions.

Parameters	EDT, s	T_{30}, s	C_{80}, dB	D_{50}
Values for musical performances	1.8 < EDT < 2.6	$1.6 < T_{30} < 2.2$	$-2 < C_{80} < 2$	< 0.5
Values for speech performances	1.0	$0.8 < T_{30} < 1.2$	> 2	> 0.5

4 Acoustic virtual model simulations

During the design phase, the architectural acoustics software "Odeon" was used to study the conference room acoustics as well as choose the type of sound-absorbing materials and relative surfaces to be covered [9, 10, 11]. The software Odeon uses the principles of geometrical acoustics and adopts a hybrid calculation method that combines two classical methods, the image source method and the ray-tracing method. The software imports 3D CAD models, modelled as flat surfaces so that the ray-tracing technique or images can be used. The transition order (TO) at which the software changes from the early image source method to the late ray-radiosity method was set equal to 2 in order to consider some efficient early reflections coming from the theatre surfaces. The impulse response length equal to 3,000ms, with a resolution of 3.0ms, and number of rays equal to 100,000. The presence of the chairs is simulated with a box the size of the seating area (lx=9.0, ly=10.0, lz=0.50). It is then necessary to evaluate the presence of diffusing surfaces to which the scattering value must be assigned (for chairs s = 0.7) [12, 13, 14]. The area corresponding to the seating area is equal to 90 m^2. Every material present in the numerical model is assigned a value of the acoustic absorption coefficient in octave bands from 125 Hz to 4.0 kHz [15, 16, 17]. The absorption coefficient values were obtained from current technical literature, with the materials in use being absorbent wooden panels and reflective wooden panels, glazed surfaces, carpet for the floor, wood for the chairs and tables. The area corresponding to the wooden panels absorbent is equal to 95 m^2. Table 3 shows the absorption coefficient values assigned to the different materials using computer-aided simulation. These values are taken from the specifications.

Table 3: Sound absorption coefficient values of the materials using computer-aided simulation

Freq. , Hz	125	250	500	1 k	2 k	4 k
wooden panels rigid panels	0.03	0.03	0.03	0.04	0.05	0.07
wooden panels abs. panels	0.30	0.40	0.80	1.00	0.80	0.60
Wooden chairs unoccupied	0.06	0.10	0.10	0.20	0.30	0.20
Wooden chairs occupied	0.30	0.50	0.80	0.80	0.90	0.80

The numerical simulations, based on the absorption coefficient values assigned to each surface of the room, provided values of the acoustic characteristics during the design phase. For example, according to these evaluations, the reverberation time at the frequency of 1.0 kHz is about 1.0 s, this value represents the final goal of acoustic design, i.e. to obtain a room in which the comprehension of speech is the main objective. Numerical simulations were also performed to evaluate the presence of the audience in the hall. This simulation was performed by replacing the absorption coefficient value of the empty chairs, with the absorption coefficient value of the seats occupied by the public [18, 19]. Figures 8, 9, 10 and 11 show, respectively, the trends of the values of the predicted without audience and predicted with audience of the acoustic parameters (EDT, T_{30}, C_{80} and D_{50}). The values of the T_{30} and EDT at medium frequencies are about 1.0 s. In the simulations as shown in the graph, the effect of the presence of the audience manifests itself in a significant way on the parameter D_{50} that from 0.50 of the empty hall increases to 0.6 with an occupied hall. The frequencies of 500 Hz and 1.0 kHz are important for the purpose of understanding speech. The acoustic simulations show that at the frequencies of 500 Hz and 1.0 kHz the room, also with the presence of the audience, has good features for speech understanding.

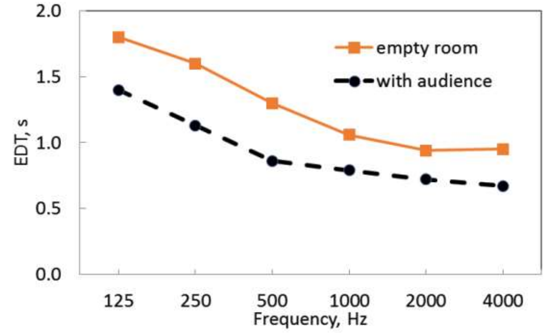

Figure 8: Average calculated values of EDT.

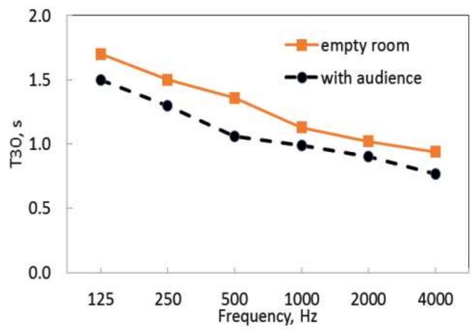

Figure 9: Average calculated values of T_{30}.

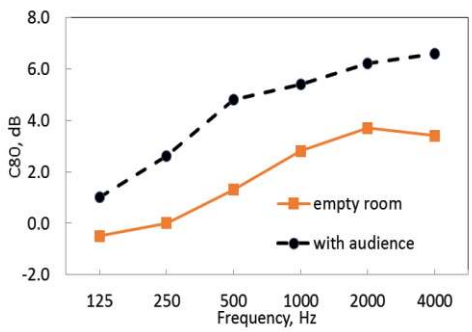

Figure 10: Average calculated values of C_{80}.

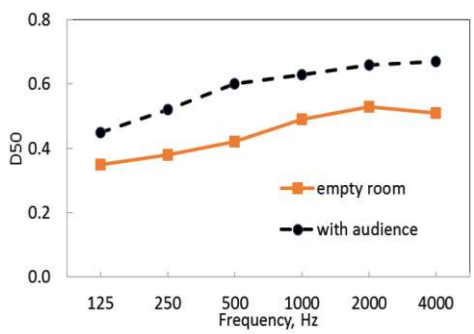

Figure 11: Average calculated values of D_{50}.

5 Acoustic measurements

After the room was designed according to the design guidelines and following the indications of the processing performed with the Odeon software, measurements of the acoustic characteristics were carried out to evaluate the acoustic conditions of the project. The acoustic measurements were carried out in an empty room with an average internal temperature of about 20 °C and a relative humidity of 50%. There were no noisy activities in the school, and the noise of vehicular traffic was negligible considering the distance from the nearest road. During the acoustic measurements the sound level was less than 35dBA. To reduce the background noise, the measurements were taken in empty conditions without students, so the impulse responses were all recorded under empty conditions. An ambisonics microphone was used for recording the impulse responses. Toy balloons, inflated with air, were used as sound sources. A balloon popping produces an impulse that excites the sound field, furthermore the background noise is very low due to it being far from any intrusive noises. A balloon popping gives a sufficient signal to noise ratio (SNR). The sound sources were positioned, at the height of 1.6 m from the floor (the height of the orator) in the position where the orator would be standing, the microphone was located on the seats, at a height of 0.8 m in different positions, to simulate the possible positions of the listeners. Eight measuring microphone points were identified (Figure 12) for the evaluation of the spatial average values of the acoustic parameters. The position of the sound source as well as the measuring points coincides with the points considered in the numerical simulation with the software Odeon.

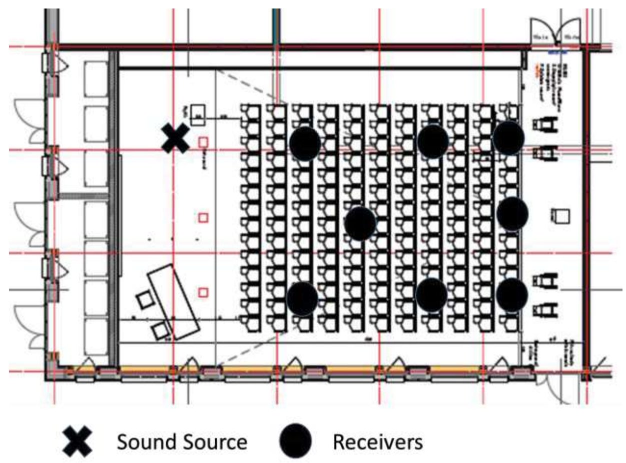

Figure: 12. Position of the sound source and the receivers.

The recorded impulse responses were elaborated with the software Dirac 4.0, analysing the acoustic parameters defined in the ISO 3382-1, such as reverberation time (T_{30}), EDT, clarity (C_{80}), definition (D_{50}), and sound transmission index for speech intelligibility (STI). The acoustic procedure and post processing methodology were similar to those used in other spaces, as in many other theatres and rooms [20, 21].

6 Discussion

Figures 13, 14, 15 and 16 report the average measured values of the acoustic parameters EDT, T_{30}, C_{80}, and D_{50}, together with the intervals of the standard deviation. These values are averaged among the eight receiver locations for each octave band frequencies from 125 Hz to 4.0 kHz, while with an overall average STI=0.62 (+/- 0.03). All the measurements were carried out under unoccupied conditions. Obviously, the audience would have had an absorbing effect with a consequent reduction of the reverberation as well as the EDT and the increase of D_{50} and STI. The parameters C_{80} and D_{50} are sensible to the early part of the impulse response, because there are large spatial variations. While for the parameter EDT at the frequencies of 125 Hz and 250 Hz, there are sensible variations of the standard deviation. For the parameter T_{30}, there are no sensible variations of the standard deviation.

The average values of the measured acoustic parameters coincide with the values obtained from the numerical prediction using the software Odeon. The value of T_{30} is almost uniform in the considered frequency range with it varying from 1.18 s to 125 Hz to 0.9 s at 4.0 kHz. Moreover, T_{30}, at the frequencies of 500 Hz and 1.0 kHz, obtained through the measurements in situ is about 1.0 s. The parameter D_{50}, which expresses in percentage the number of phonemes actually included, assumes values of about 0.5, also confirming the prediction made with the software, the value of D_{50} = 0.5 confirms that the room has good conditions for listening to the spoken. The values of C_{80}, measured experimentally post work, deviates slightly from the values obtained by the prediction made with Odeon 11. The Speech Transmission Index (STI) was considered, with this parameter representing the degree of amplitude modulation in a speech signal and refers to the distortion in speech signals caused by reverberation, echoes, and background noise. This index can assume values between 0 and 1, being greater than 0.6 for favourable speech conditions. The measured average value, with an empty room, of the STI = 0.62, confirms that there are good characteristics for listening to speech. The presence of sound absorbing lateral surfaces prevented the formation of possible acoustic defects due to the multiple reflections such as flutter echo. Therefore, the insertion of the sound-absorbing and partly reflective wooden panels allowed to obtain good acoustic comfort conditions inside the conference room.

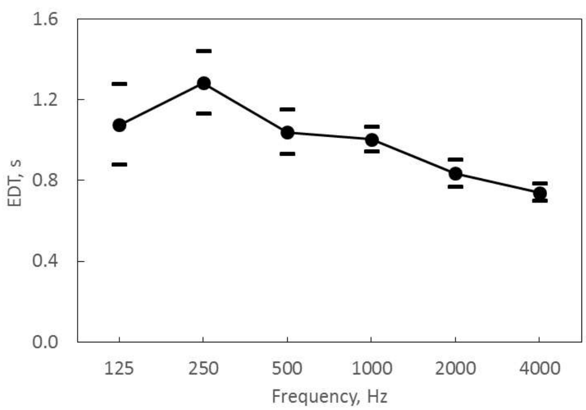

Figure 13: Average measured values of EDT.

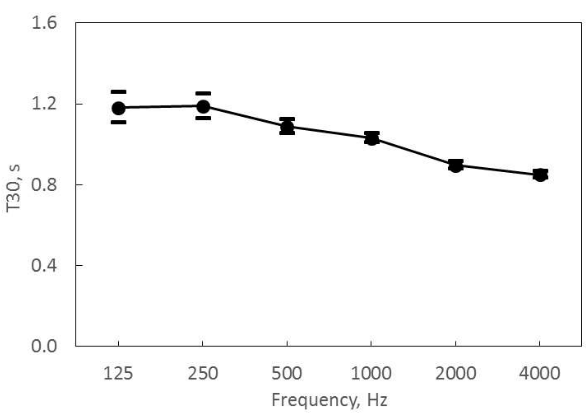

Figure 14: Average measured values of T_{30}.

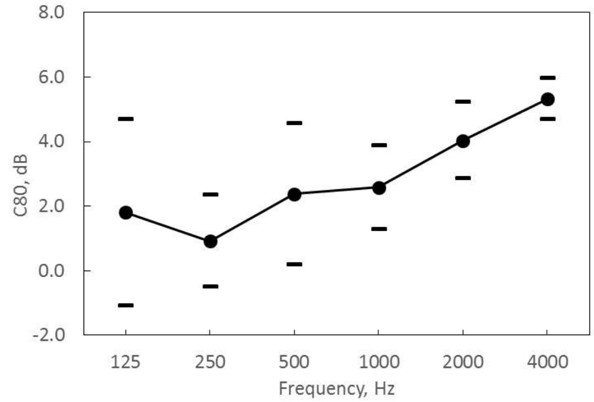

Figure 15: Average measured values of C_{80}.

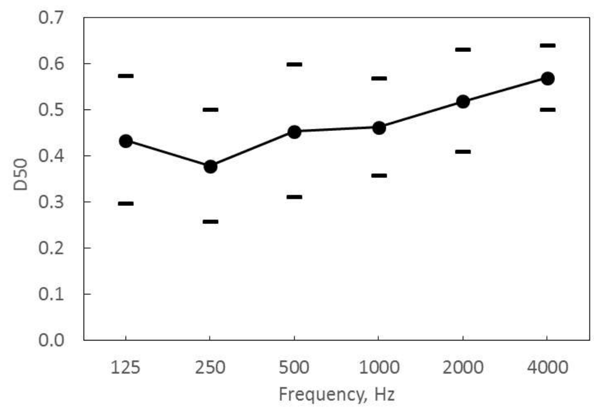

Figure 16: Average measured values of D_{50}.

7 Conclusions

This work reports the acoustic simulation of a conference room. The study was performed in a first phase by choosing the materials to be used to obtain an adequate value of the acoustic characteristics for the speech understanding. The conference room was built, and after acoustic measurements were carried out to check if the acoustic characteristics correspond to those required by the project. Simulation techniques, using the software Odeon, provided useful information for understanding how to improve the acoustics of the conference room. Firstly, simulations were used to obtain realistic data about the current acoustics of the conference room under unoccupied conditions. The acoustic treatments that were proposed guaranteed an optimal value of the reverberation to about 1.0 s at middle frequencies. The insertion of the sound-absorbing and reflective wooden panels allowed to obtain good acoustics of the conference room. The estimated values of the reverberation time (T_{30}) and definition (D_{50}) with the numerical prediction using the Odeon software coincided with the values of the experimental measurements. In conclusion, the results of this study attest to the effectiveness of the planned intervention with the acoustic simulation and therefore the reliability of the prediction carried out using the software.

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