COMPARISON OF MEASURED AND SIMULATED ROOM ACOUSTIC PARAMETER VALUES USING HIGH RESOLUTION GRIDS

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When the acoustic properties of enclosures are evaluated, it is normal to use measured and simulated data. So when an auditorium is already built, the usual strategy to analyse the parameter values spatially consists of obtaining experimental results from a few receivers and using this data to validate a simulated model. Working on the basis of acoustic parameter measurements made seat by seat in a medium-sized auditorium, this document analyses a simulation program's capacity and limitations in terms of predicting values for these parameters.

INTRODUCTION

The acoustic parameters described in the ISO 3382 standard [1] are used as a reference for acoustic characterisation of enclosed areas intended both for speech and musical transmission. They can be derived from measured or simulated impulse responses and each strategy has its advantages and disadvantages. When a room has already been built, it seems to be essential to know the measured acoustic parameter values with a view to making an objective assessment of the enclosure under existing conditions. On the other hand, it is clear that for highly detailed spatial analysis - such as in each seat of the audience zones - simulation is an invaluable, if not essential, tool allowing us to assess results in a reasonable time. Apart from making the job easier or faster, it is undeniable that choosing one procedure over the other to assess premises should really come down to the reliability of the data obtained. And it seems that in this aspect, the results of direct measurement have an advantage over results from a simulation. However, it should not be forgotten that each strategy has its limitations and that operator knowledge and experience play a fundamental role in both cases.

Measurements tend to be considered as more accurate given that the geometric model, the absorption of air or the absorption and diffusion coefficients for the materials, main sources of uncertainty in simulation, are inherent to the actual room and are, by definition, entirely included. In addition, wave phenomena such as diffraction or diffusion are also inseparable from the real sound field measured. On the other hand, simulation programs, at least any based on geometric acoustics, generally exclude information relating to the wave phase from their calculations. Consequently, their results should only be considered valid for frequencies over the Schroeder frequency, where room modes are superimposed and wave effects due to the phase can be discarded without significant loss of information over the acoustic field.

In comparison, simulations present a series of advantages relating to the accuracy of the data obtained that should not be ignored. On the one hand, the sound signal issued by a source is directly the Dirac function and not an approximation. There is no background noise so the dynamic range is unlimited at all frequencies. This eliminates possible uncertainties related to truncation processes and background noise compensation. These procedures cannot be avoided when dealing with measured impulse responses. Also errors relating to calculating the start of the impulse responses, perfectly defined geometrically in a simulated model, or possible delays in the filters required for band analysis can be discarded in a simulation. Finally, the sound source, in addition to not needing to be calibrated to measure the Sound Strength parameter (G), does not generate distortion at high levels and, more relevantly, it is also perfectly omnidirectional at high frequencies.

Despite all this, the main factor to take into account when assessing the reliability of a simulated model is the concordance of the results obtained with 'in situ' measurements. It is usual to find technical papers in the literature comparing acoustic parameter values, both measured and simulated, in a few receivers. This strategy has been used in newly built auditoriums, predicting the values of the main acoustic parameters at the planning stage when only the plans are available and putting them up against parameters obtained once the enclosure has been built [2]; when auditoriums are remodelled as part of heritage protection programmes where any action undertaken can cause irreversible damage to the cultural value of the preserved buildings [3]; or to analyse the renowned acoustic capacity of famous old theatres using new techniques such as 3D FDTD methods to simulate wave phenomena such as diffraction or interference [4].

This work aims to go into greater depth on the usual comparison between measured and simulated values for acoustic parameters by means of high resolution spatial analysis, comparing the measured and simulated values of the acoustic parameters seat by seat in a medium sized auditorium. In this scenario, some questions arise about uncertainties involved in both, measurement and simulation results. In particular, a lower spatial homogeneity in measured values is highlighted. Also the lack of omnidirectionality of the real sound source appears to have a noticeable influence on some acoustic parameters derived from the impulse response, especially at high frequencies.

EXPERIMENTAL PROCEDURE AND VALIDATION OF THE MODEL USING T_{30}

The results presented in this research come from an exhaustive characterisation carried out in the new Navarre Senior Music Conservatory Auditorium (Pamplona - Spain), where the monaural acoustic parameters were measured and simulated in an empty room for each and every one of the 375 seats intended for the audience. The enclosed area (Figure 1), panelled in two types of wood, has a volume of around 4000 m^3 with the audience area divided into two sections. The experimental device used to take the measurements meets ISO 3382 requirements. As an excitation signal, logarithmic sweeps lasting 20 s were emitted by a dodecahedral loudspeaker. With a diameter of 450 mm and twelve 5 inches drivers, the source was positioned halfway across the front of the stage at a height of 1.50 m. The microphones were placed in the middle of each seat at a height of 1.20 meters.

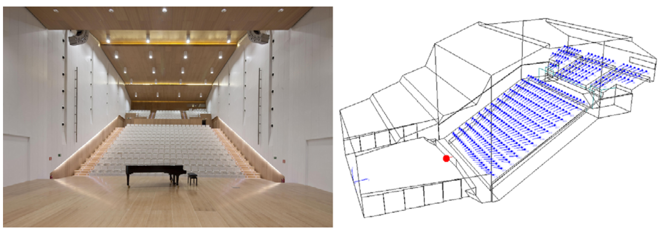

Figure 1. Photo of the auditorium (left) and arrangement of the source and the receiver grid (right)

On the other hand, the simulations were carried out using the ODEON v.12 room acoustic simulation program, using a simplified geometric model of 105 surface areas (Figure 1) recreating the measurement conditions regarding source and receiver positions. The materials' absorption coefficients were initially selected in accordance with the technical sheets provided by the manufacturers of materials used for the panelling and a visual inspection of the room. These coefficients were later refined in order to equal out the average values of T_{30}, both measured and simulated. Through an iterative process of gradual calibration for the absorption and diffusion coefficients, the reverberation time in octave bands is progressively adjusted so that the difference between the simulated and experimentally measured data is maintained within a 5% interval, meaning the just noticeable difference (jnd) in the value of a parameter that can be perceived by the average listener.

This criterion could be met (Figure 2) in all bands except for 8 kHz where the actual air absorption in the simulated model meant that the measured values were unattainable, even when minimising absorption of all materials. It should also be highlighted that there was little spatial variation in the values simulated in all the frequency bands. For the measured values, it increases as the frequency decreases, reaching 0.23 s (3 jnd of a 1.55 s reverberation time) at lowest frequency. The cause of this phenomenon can be attributed to not including the phase in the simulated model, taking into account that repeatability of the measurement usually rounds one tenth of the jnd value for acoustic parameters [5]. However, we should not forget the impact of uncertainty on the measurements as well, usually greater at low frequencies. The measured fluctuation can reach up to one second between adjacent seats and can also be caused by a poor signal to noise ratio during the measurement or due to over-sensitive truncation procedures. Nevertheless, this variability is not justified, at least from the point of view of the average listener's sensitivity.

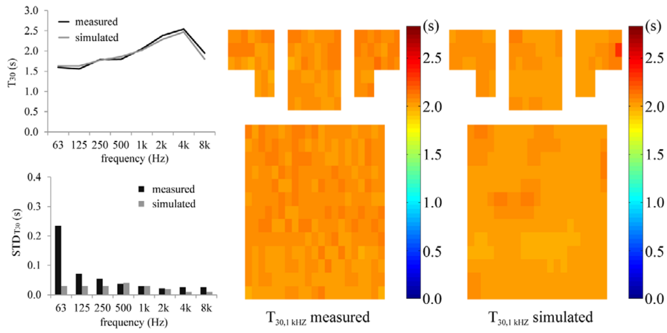

Figure 2. T_{30}. Average values and standard deviations (STD) for the 375 receivers (left). Measured (centre) and simulated (right) values in the 1 kHz band.

The validation process followed or other similar processes are frequently applied when the rooms to be modelled are physically available and it is normally done on the basis of a few receivers. If we analyse the process using the available high resolution grid, the adjustment between the measured and simulated values for the T_{30} is also practically perfect in the 1 kHz band (Figure 2), where barely 2% of receivers differs more than 1 jnd. It is clear that the variability of the analysed parameter, usually used for calibration, is low except in the case of enclosures with strong coupling. This would be a good time to wonder if the same values can be achieved with different refinements in each material, causing inequalities in the different simulated sound fields that might be reflected in the rest of the parameters. For this reason, some authors do not consider this process to be appropriate [6] and they choose to base their simulation just on physical data and databases containing the typical entry data. In this case, it should include an analysis of the uncertainty sources that would established its impact on the accuracy of the results obtained both experimentally and when simulated [7].

AVERAGE VALUES AND SPATIAL VARIABILITY FOR THE REMAINING PARAMETERS

While the reverberation time, at least T_{30} is a global parameter that is related to the room and not to a determined position, the remaining parameters show greater deviations. Figure 3 shows the average values, both measured and simulated, for the EDT parameter in the 375 receivers. In addition, its spatial variability in the enclosure is analysed again using the standard deviation (STD). Except for the lower frequency bands where the difference reaches 3.3 jnd, a value that warns us of appreciable inequality in the decay curves obtained using both methods, it can be seen that the values do not differ by more than 1 jnd. However, the same does not happen if we analyse the EDT values using a high resolution grid for the same frequency band as used for analysing the T_{30}. Despite the fact that the average values and the deviations would indicate a good match, the values from 52% of the receivers differ by more than 1 jnd, also showing great deviations depending on the area of the audience being analysed.

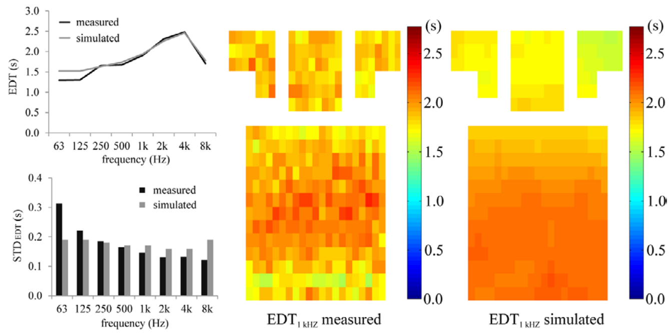

Figure 3. EDT. Average values and standard deviations (STD) for the 375 receivers (left). Measured (centre) and simulated (right) values in the 1 kHz band.

This greater homogeneity in the simulated values is repeated for other parameters and frequencies, generally more noticeable at low frequencies. This is what happens, for example, for musical clarity C_{80} (Figure 4), where the spatial variability of the values measured is clearly greater than what is simulated at low frequencies. However, the average values are within the recommended margin (except at 8 kHz, where the difference is 1.2 jnd), which would indicate good agreement between the values obtained and would validate the simulated model in a usual procedure. However, the availability of the measured values in each of the enclosure's seats allows us to make a more accurate comparison and analyse the causes of both the similarities and the differences encountered. So for example, if we represent the C_{80} values for the 500 Hz band depending on the distance of each receiver (Figure 4), both strategies follow the same trend, above all in the area of the audience closest to the source (up to 18 m approximately), although the dispersion is clearly greater in the measured values. It should be highlighted that if this dispersion were represented using just the standard deviation, these inequalities would not be detected, because they are similar in both cases.

The high spatial resolution of the measurements taken over the audience zone also allow us to analyse the possible lack of omnidirectionality of the real sound source and its influence on the acoustic parameters derived from the impulse response. In addition, the peculiarities of this phenomenon, appearing at high frequencies, leads us to consider that a simulation program - whose main limitation is found at low frequencies - might be an appropriate tool for comparison, considering the constant omnidirectional radiation.

Figure 4 represents the difference between the value of the C_{80} parameter measured and simulated in units of jnd for the 2 kHz band, where the dodecahedral source starts to behave in a noticeably directive way. Despite the fact that the measured values and the STD are practically the same for this parameter and frequency band, it can be seen how a noticeable directivity lobe appears on the middle zone, causing differences that are even greater than 3 jnd in some receivers. In fact, in more than 50% of the receivers, the measured and simulated values are more than 1 jnd apart (20% are more than 2 jnd apart) due to the directivity of the sound source in this frequency band. In a parameter such as D_{50} that is more sensitive to this variable [7], at a higher frequency, 4 kHz, these percentages reach 60 and 30% respectively, confirming previous results based entirely on simulations [8]. Recent research [9] shows that the influence of the dodecahedral sources' directivity is clear even in the later part of the impulse response in highly reverberating environments, and a correct interpretation of the ISO recommendation is required to rotate the source when providing reliable measurements [10].

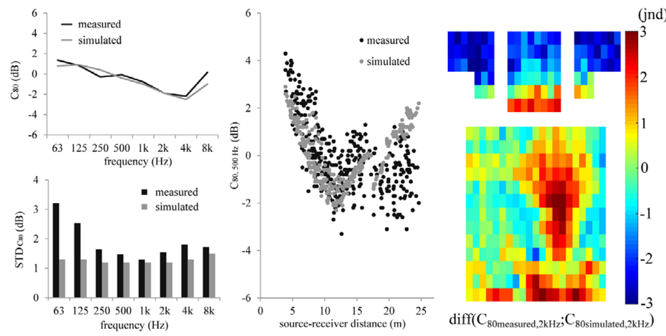

Figure 4. C_{80}. Average values and standard deviations (STD) for the 375 receivers (left). Values depending on the source-receiver distance for the 375 measured and simulated receivers in the 500 Hz band (centre). Difference between the measured and simulated values (ref: 1 jnd) in the 2 kHz band (right).

CONCLUSIONS

Despite the fact that the acoustic parameters from measured impulse responses are generally taken as 'true' and are used as a reference, other factors should be taken into account when validating a simulated model. The directivity of the dodecahedral sources, the algorithms for processing the impulse responses or the poor signal to noise ratio can cause noticeable differences between measured and simulated values that cannot merely be attributed to the limitations of the simulation programs based on geometric acoustics.

A high resolution comparison, as has been carried out here, has revealed differences in the spatial analysis of the parameters that could be masked in a usual validation procedure, based on a few receivers. It is clear that the procedure followed in this work is not feasible to be performed regularly and so more research is required based on analysing the validity of the usually used adjustment processes.

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Inter-Noise 2014

MELBOURNE AUSTRALIA 16-19 NOVEMBER 2014

The Australian Acoustical Society will be hosting Inter-Noise 2014 in Melbourne, from 16-19 November 2014. The congress venue is the Melbourne Convention and Exhibition Centre which is superbly located on the banks of the Yarra River, just a short stroll from the central business district. Papers will cover all aspects of noise control, with additional workshops and an extensive equipment exhibition to support the technical program. The congress theme is *Improving the world through noise control*.

Key Dates

The dates for Inter-Noise 2014 are:
Abstract submission deadline: 10 May 2014
Paper submission deadline: 25 July 2014
Early Bird Registration by: 25 July 2014

Registration Fees

The registration fees have been set as:

Delegate	$840	$720 (early bird)
Student	$320	$255 (early bird)
Accompanying person	$140	
Congress Banquet	$130pp	

The registration fee will cover entrance to the opening and closing ceremonies, distinguished lectures, all technical sessions and the exhibition, a USB containing the full papers and light lunch plus morning and afternoon teas. The Congress Banquet will have a strong Australian theme and feature the opportunity for delegates to take photographs of themselves with native Australian animals, so should prove to be a major attraction.

The social program commences with the welcome reception on the Sunday evening after the opening and first plenary lecture. On each of the following days, the morning and afternoon refreshments and light lunch (all included in the registration fee) will be provided in the exhibition area. The optional banquet (additional charge applies) will be held at the venue and provide, along with great food and wine, an Australiana theme. After the final sessions the closing reception will bring the congress to an end. Additional features are included in the program for accompanying persons.

An exhibition of the latest developments in equipment and acoustic related materials will take place in the foyer of the Conference centre from Monday morning until Wednesday lunch-time. Over 50 out of 60 booths are already booked by international and Australian companies. More details on booking space in the exposition available from www.internoise2014.org.

Technical Program

The opening plenary lecture will be: "Sound Sketch: its Theory and Application using Loudspeaker Arrays" by Prof. Jung-Woo Choi of South Korea.

The closing plenary lecture will be: "Soundscape Planning as a Complement to Environmental Noise Management" by Prof. Lex Brown of Australia.

The four keynote topics, by world authorities on their subject, will complement major areas within the Congress. They cover Aircraft Noise, Active Noise Control, Wind Turbine and LFN as well as the Impact of Building Acoustics on Speech Comprehension and Student Achievement.

ABSTRACT SUBMISSION IS NOW OPEN and submissions are sought in relation to the broad theme of the Congress - "Improving the World through Noise Control" . The online abstract submission allows you to select the most appopriate session from the list of over 100 sessions. The Congress will feature 12 parallel sessions as well as an area for poster presentation.

Abstract deadline is 10 May 2014 and this date is firm and will NOT BE EXTENDED

During the year the details of technical study group meetings plus workshops and courses will be provided on the website.

More details on all aspects of the conference at www.internoise2014.org