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Systematic study of room acoustic texture for different degrees of sound field diffuseness inside a reverberant room.

Bidondo A., Pepino L., Serattin M., Uboldi L.

RESUMEN

La textura acústica se define como la impresión subjetiva que los oyentes perciben de patrones secuenciales de aquellas reflexiones tempranas que alcanzan sus oídos. Ultimamente se propuso un conjunto de descriptores, aún en desarrollo, para describirla a partir de respuestas al impulso (RIR). Éstos incluyen los parámetros *textura esperada* (ETx), *tiempo de mezcla* (Mt) y la *distancia entre modelos* (DBM), entre otros. Éstos expresan diferentes propiedades de la *funcion de densidad de ecos* (edf), definida como la energía acumulada en función del tiempo, de aquellas amplitudes atípicas (outliers estadísticos) de una RIR, luego de habérsele sustraído el decaimiento. Por otro lado, se sostuvo que la difusividad temporal del campo sonoro en recintos podría ser cuantificada experimentalmente a partir de una RIR. En un intento de hallar la capacidad de cuantificación de los parámetros propuestos y su relación con la difusión del campo sonoro y otros parámetros clásicos, se llevó a cabo una investigación sistemática donde se midieron diferentes configuraciones de un recinto de prueba, con diferentes superficies revestidas con difusión en sus paredes, considerando la hipótesis que diferentes extensiones revestidas conducirían a diferentes grados de difusión del campo sonoro. De esta forma el campo sonoro del recinto de prueba fue medido mediante RIRs para superficies planas revestidas por difusores acústicos desde 0 m^2 hasta 18.6 m^2. También se realizaron mediciones del campo sonoro resultante de colocar una distribución concentrada de los difusores en torno a la fuente sonora. Esta investigación muestra el diseño experimental y evalúa los resultados obtenidos relacionándolos mediante modelos de redes neuronales.

ABSTRACT

Acoustic texture is defined as the subjective impression that listeners derive from patterns in the sequence of early sound reflections that arrive at their ears. Lately a set of features were proposed to quantify the room acoustic texture from room impulse responses. These parameters include *Expected Texture* (ETx), *Mixing Time* (Mt) and *Distance Between Models* (DBM). They describe different properties of the particular echo density function (*edf*) defined as the decay-cancelled outliers cumulative energy, over time. On the other hand, temporal sound field diffuseness in enclosures could be experimentally quantified based on measured room impulse responses. In an attempt to find the quantification capability of texture parameters, and their relation with sound field diffuseness, acoustic diffusers extension, early decay time and reverberation time, a systematic investigation was conducted sampling the sound field through RIRs, whereby different room configurations using a variable scattering interior surface extension were tested, considering the hypothesis that varied degrees of surface scattering will ultimately lead to varied degrees of sound field diffuseness in the enclosure. To this end, a test room was established with interior surface configurations ranging from totally plane surfaces to 18.6 m^2 of diffusely reflecting surfaces uniformly distributed all over the enclosure's interior area. Also, a concentrated distribution of scattering surfaces near the sound source was tested. This paper discusses the experimental design and evaluates the results of data collected relating them using neural net models.

PALABRAS CLAVE

Difusión del campo sonoro, textura acústica, difusores, red neuronal perceptrón multicapa.

KEY WORDS

Sound field diffuseness, room acoustic texture, diffusers, multi layer perceptron neural net model.

INTRODUCTION

Acoustic literature usually treats diffusion as a spatial phenomena where - theoretically - an ideal diffuse sound field has equal probability of propagation at any direction [1].

Usually this definition speaks about maximum diffusion when isotropy is verified in all points of an acoustic field, given a stationary sound source. This condition exists just in reverberant chambers while measuring transmission loss, absorption coefficient and sound power. For the rest of the infinity of situations, this condition does not exist. Real situations do not have a stationary sound stimulus, an isotropic sound radiation, nor a constant bandwidth. They have limited and variable sound radiation beamwidth, variable sound emitting focusing, dynamic range and variable frequency bandwidth. For this reason, we propose to talk about temporal diffusion, that would be the thermodynamic process that takes the system from its initial state to enter its final state of equilibrium, that is, maximum entropy [2]. That is to say, the phenomenon takes place in the time domain; to be precise, in the early part of a room impulse response (RIR). This new proposal implies diffusion would be related with the reverberation “texture”.

It could be that studying diffusion in the temporal domain, we may finally infer it´s spatial domain, describing and unifying the diffusion phenomena.

OBJETIVES

The acoustic texture of a room was defined by Beranek: “Texture is the subjective impression that listeners derive from the patterns in which the sequence of early sound reflections arrive at their ears. In an excellent hall those reflections that arrive soon after the direct sound follow in a more-or-less uniform sequence. In other halls there may be a considerable interval between the first and the following reflections. Good texture requires a large number of early reflections, uniformly but not precisely spaced apart, and with no single reflection dominating the others” [3].

The aim of this research was to find a relation between the sound field diffussiveness and some of the texture parameters, varying systematically the diffusers surface extension [m2] inside a test room.

METHODOLOGY

Previous studies

As described by J. D. Polack [4], impulse responses are Gaussian process, provided that global analysis is carried out on hand of a proper model of impulse responses. In this process, is essential to discard the early part with strong reflections, and the very late part which simply is background noise. Finally, every late part of reverberation tale exhibits a gaussian distribution of amplitudes in function of time.

Cheol-Ho – Jeong [5] showed every RIR has high Kurtosis in the early part of it. High Kurtosis values mean the existence of statistical outliers [6].

J. Abel *et al* [7], who proposed a method to detect outliers from a gaussian distribution, considering every outlier as an early reflection, also proposed the echo density profile (EDP), and showed its relation with acoustic diffusion using a synthetic reverberator.

Spatial and temporal diffusion

There are two ways to introduce the notion of diffusion: either a phenomenological approach starting with Fick's laws of diffusion and their mathematical consequences, or a physical and atomistic one, by considering the random walk of the diffusing particles. In the phenomenological approach, diffusion is the movement of a substance from a region of high concentration to a region of low concentration without bulk motion. According to Fick's laws, the diffusion flux is proportional to the negative gradient of concentrations. It goes from regions of higher concentration to regions of lower concentration. From the *atomistic point of view*, diffusion is considered as a result of the random walk of the diffusing particles. In molecular diffusion, the moving molecules are self-propelled by thermal energy. Random walk of small particles in suspension in a fluid was discovered in 1827 by Robert Brown. The theory of the Brownian motion and the atomistic backgrounds of diffusion were developed by Albert Einstein. The concept of diffusion is typically applied to any subject matter involving *random walks* in ensembles of individuals [10].

Every sound field in a room has a particular spatial behaviour - studied through a stationary sound excitation - and infinite local temporal "dynamic" behaviours (source and receiver position dependent) - studied through local room impulse responses. As it is impossible to study the whole space, we focused on studying the local temporal evolution of the system, at a finite number of positions.

The sound reflections of the early part of every RIR exhibits a non gaussian distribution and may be classified as an outlier, decreasing their density with time, finally disappearing; after that, any group of late reflections amplitudes can be described by a Gaussian distribution. We consider the instant of separation between both behaviours, conceptually, as the *mixing time* (Mt).

In this sense we can assume the early reflections (ER) are solely responsible for the non uniform and smooth build-up of early reflections energy over time. The way this build-up is constructed is what we called *texture*, and is correlated with room volume, room shape, reverberation time, early decay time, acoustic diffusers extension, mixing time, and receiver and sound source positions.

Room acoustic texture and sound field difussiveness

For studying the room acoustic texture, a group of parameters under development were defined by Bidondo *et al* [9]. From those, the expected texture (ETx), mixing time (Mt) and distance between models (DBM) seem to be the most descriptive to relate the acoustic texture with reverberation time (RT), early decay time (EDT), room volume (V), acoustic diffusers extension [m^2], sound field diffuseness and sound source location inside a room, among other variables.

Abel *et al* showed that echo density profile (EDP) is sound field diffuseness dependent (through a synthetic reverberator), preliminary studies also showed the proposed room acoustic texture parameters to be sound field diffuseness dependant.

To study the thermodynamic process in the early part of a RIR, it is necessary to first detect all outliers reflections. This was done through a median moving filter (MMF) applied to the RIR under analysis.

For a reflection to be an outlier in our case, its amplitude has to stand out with respect to values close in time. The method includes a decay subtraction to the RIR under analysis and further normalization, relative to the total summation of the outliers energies.

The median moving filter was applied to the energy time curve (ETC), as described by eq. 1.

$$RIR_{Median}(t) = MMF\left(10 \cdot \log_{10}\left(RIR(t)^2 + \xi\right)\right) \quad (1)$$

Afterwards, the Decay - cancelled Early Reflections (DcER) information was obtained as described by eq. 2.

$$DcER(t) = 10 \cdot \log_{10}\left(RIR(t)^2\right) - RIR_{Median}(t) \quad (2)$$

And the echo density function, *edf*, from the RIR under analysis, is obtained by eq. 3.

$$Actual\ edf\ (t) = \frac{cumsum\ (DcER\ (t))}{Max\ (cumsum\ (DcER\ (t)))} \quad (3)$$

Where:

- *RIR (t)* is the room impulse response.
- RIR_{Median} is the room impulse response after the MMF processing.
- *DcER*: are the Decay-cancelled Early Reflections or outliers information, over time.
- *Actual edf(t)*: is the calculation applied on the actual RIR under analysis.
- *edf (t)*: generally speaking, is the echo density function.

Synthetic RIRs were generated from exponentially decaying gaussian white noise with different RT60s. These cases implied an absence of outlier reflections, resulting in a smooth growth of the *edf*. We refer to this type of cases, the perfectly distributed ER over time, with outliers amplitudes not disturbing the sound field. It was observed the cumulative energy of the outliers follows eq. 4, and can be thought as a capacitor charging over time. The generalized and *ideal* equation modelling this behaviour is eq. 4.

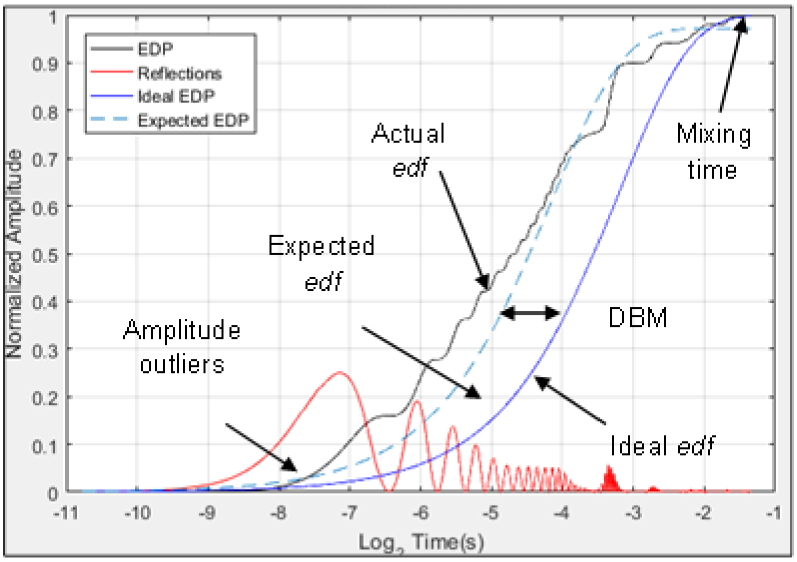
$$edf(t) = \left(1 - a \cdot e^{b \cdot t}\right) \quad (4)$$

Three *edf*s are calculated for every RIR: One *actual edf* and two "reference" *edfs.*

- *Actual edf:* is the direct application of the eq. 3 on the actual RIR under analysis.
- *Ideal edf*: For the first "reference" *edf* of eq. 4, *a* and *b* constants are adjusted using two known values taken from the actual *edf*: the initial value of the function, t_0, which corresponds to the initial time delay gap (ITDG) and *Mt*, where the *actual edf* (t) reaches an amplitude of 0.99 from its final value. Also, third octave frequency filtering can be applied to the actual RIR, to find Mt values over third octave frequency bands. This way, the *ideal edf*, is established through the ITDG and *actual Mt.*
- *Expected edf*: A second "reference" *edf* is calculated by best fitting eq. 4 to the *actual edf.*

Once the models are attained, the curves are displayed in a log(t) scale.In figure 1, resulting curves at 315 Hz frequency band are shown with some of the associated texture descriptors.

Figure 1: .Resulting edf curves from the texture calculation for 315 Hz frequency band of a very renowned local national opera theater RIR (2nd level balcony). Observing the actual edf curve, deviation from the smooth growth of the expected edf can be seen. Expected texture (ETx) is the Pearson correlation coefficient between the actual edf and the expected edf. As ETx values are mainly spread between 0.8 and 1, it was decided to display r^{20} to get a spread between 0 and 1. DBM is the Bhattacharya distance between expected edf and ideal edf curves. Associated numerical results in this example are: ETx = 0.7, DBM = -4.62, Mt = 189 ms.



For this reason it was decided to study the sound field variations in function of a systematically varied degree of sound field diffuseness, inside a small reverberation chamber. Showing a relationship between the variation of the diffusion surface extension and the texture of an RIR, for constant volume, different RT and EDT conditions, would allow, at least, to quantify the degree of diffuseness of the sound field.

To produce these variations, a total of 50 numerical - curved diffuser tile units (61 x 61 cm each) were used, distributed in 14 different experiments: 1, 2, 3, 4, 5b, 6, 7, 8, 9, 10, 11, 12, 13 and 16.

Also, two combinations of extended bandwidth resistive absorber tiles were included in the test room to vary RT and EDT.

Experiments

The experiments were carried out inside a reverberation room with volume 37 m^3, by varying the diffusers surface extension and their spatial distribution, with different RT and EDT. The test room is shown in Figure 2. The diffusers spatial distributions were a) distributed *uniformly* (within the test room) and b) a few units *concentrated* near the sound source.

20 Earthworks M50 measurement matched microphones were positioned hanging from a horizontal grid at different heights to sample the sound field uniformly.

An Outline Globe Source radiator was positioned in a corner of the test room, on a rotating turntable. Room impulse responses were obtained for 0°, 30° and 60° rotation angles of the sound source, using a 90 s log sine sweep, from 415 Hz to 12500 Hz. Although the acoustic diffusers were designed for a minimum frequency of 500 Hz, the RIRs analysis bandwidth was established between 630 Hz and 10 kHz.

Because the reverberant chamber is of reduced volume (what should produce naturally high texture values), and its reverberation time is also high (what should also produce naturally high texture values), ETx and DBM results include at least 3 decimal numbers, to quantify every change in the sound field.

DBM Values come with a sign, which means the displacement direction of the expected *edf* curve from the ideal *edf*. To obtain a global DBM value excluding the sign, absolute DBM values average (Abs DBM) were calculated and evaluated.

Figure 2: Test room interior. 20 Matched measurement microphones were uniformly distributed in the space, and hung vertically at different heights. On the right wall two samples of the acoustic diffusers are shown.

After the full size scale measurements processing, results from the uniform distribution of diffusers setting were used as input of a Multilayer Perceptron Neural Net Model (MLP NNM) [10] to get the set of independent variables affecting Abs DBM and ETx, and their importances. Afterwards, the Pearson correlation coefficient between all variables was calculated as a correlation matrix, to confirm the MLP NNM results.

RESULTS AND DISCUSSION

Results

To evaluate the behaviour of the sound field for different setups, results from similar conditions were compared.

Diffusers Uniform Distribution condition

In this setting, diffusers were installed over the lateral walls, in rows, all around the test room. Experiments with 0 m^2, 6.7 m^2, 13 m^2 and 18.6 m^2 corresponded to empty, one, two and three rows completely filled with diffusers tiles respectively, as seen in Figure 3.

Global results, obtained as the average of the third octave bands results, for the three rotation angles (0, 30 and 60 degrees), are shown in Table 1.

Figure 3: Pictures of test room with the diffusers uniform distribution configurations for three different coating surface extensions. At the bottom of the room can be seen the full band absorbers to set different reverberation and early decay times. At one dihedral corner, the omnidirectional sound source (mounted on a rotating turntable) and subwoofer (not used) can be seen. Upper paired pictures: one row uniform distribution configuration. Mid paired pictures: two rows uniform distribution configuration. Lower paired pictures: three rows uniform distribution configuration.

Fuente: Elaboración propia.

- For almost the same EDT and RT values, from Experiments 3 and 12, an increase of the diffusers surface extension reflects an increase in ETx and a decrease of Abs DBM.

- For almost the same EDT and RT values, from Experiments 8 and 10, an increase of the diffusers surface extension reflects an increase in ETx and a decrease of Abs DBM.

- For the same Abs DBM values, from Experiments 1, 11 and 16, with different RT values, 2.15 s, 0.77 s and 0.73 s, the difference was just the diffusers surface extension, with 0 m^2, 13 m^2 and 18.6 m^2.

- For 0 m^2 of diffusers surface extension and different (descending) RT values, from Experiments 1, 2 and 3, Abs DBM increased and ETx decreased. This means that even with no diffusers inside, the sound field has certain degree of diffuseness, which data is included into ETx and Abs DBM parameters.

- For constant diffusers surface extension and room volume, reducing EDT, Abs DBM tends to increase (Experiments 1 - 2 - 3, 8 - 9 and 12 - 13).

- For constant diffusers surface extension and room volume, reducing RT, ETx tends to decrease (Experiments 1 - 2 - 3, 8 - 9 and 12 - 13).

Table 1: Results from Experiments, for different diffusers surface extensions and uniform spatial distribution. All results are the average of the bands results from 630 Hz to 10 kHz, for three rotation angles (0, 30 and 60 degrees).

BW: 630 Hz - 10 kHz							
# Experiment	**Diffusers Surface extension [m^2]**	**Expected Texture (ETx) [-]**	**Abs_DBM [-]**	**EDT [s]**	**RT [s]**	**Mt [ms]**	**Diffusers spatial distribution condition**
1	0.0	0.8134	1.9186	2.1192	2.1595	297.8	**Uniform**
2	0.0	0.7772	2.1187	1.1964	1.2195	175.8	
3	0.0	0.7245	3.3751	0.9251	0.9454	163.3	
8	6.7	0.7351	1.8688	1.0756	1.0714	167.5	
9	6.7	0.7232	1.9213	0.8288	0.8310	135.2	
10	13.0	0.7508	1.8163	0.9797	0.9871	159.1	
11	13.0	0.7105	1.9126	0.7671	0.7750	125.5	
12	18.6	0.7579	1.7983	0.9374	0.9357	152.6	
13	18.6	0.7305	2.1609	0.7463	0.7532	120.8	
16	18.6	0.7244	1.9178	0.7299	0.7331	119.3	

Fuente: Elaboración propia.

Diffusers Concentrated Distribution condition

In this setup, diffusers were installed very close to the sound source, including on the floor, as can be seen in Figure 3.

Global results, obtained as the average of the third octave bands results, for the three rotation angles (0, 30 and 60 degrees), are shown in Table 2.

Figure 3: Test room with the diffusers concentrated distribution configuration around the sound source. At the sides of the room can be seen the full band absorbers to set different reverberation and early decay times. At one dihedral corner, the omnidirectional sound source (mounted on a rotating turntable) and subwoofer (not used) can be seen.

Fuente: Elaboración propia.

Table 2: Results from Experiments, for different diffusers surface extensions and concentrated spatial distribution. All results are the average of the bands results from 630 Hz to 10 kHz.

BW: 630 Hz - 10 kHz							
# Experiment	**Diffusers Surface [m^2]**	**Expected Texture (ETx) [-]**	**Abs_DBM [-]**	**EDT [s]**	**RT [s]**	**Mt [ms]**	**Diffusers spatial distribution condition**
1	0.0	0.813	1.919	2.119	2.160	297.8	Concentrated
2	0.0	0.777	2.119	1.196	1.220	175.8	
3	0.0	0.724	3.375	0.925	0.945	163.3	
4	3	0.713	2.345	1.164	1.170	170.3	
5b	3	0.722	1.861	0.897	0.906	145.4	
6	3	0.742	1.997	1.165	1.178	174	
7	3	0.743	1.787	0.898	0.912	146.9	

Fuente: Elaboración propia.

- For the same diffusers surface, and almost the same RT and EDT, from Experiments 4 and 6, ETx increases and Abs DBM decreases, showing the effect of diffusers units rotation (instead of repeating the same way of placing the acoustic lining). This effect is shown by comparing Experiments 5b (regular mounting) and 7 (modulated mounting).

Multi layer perceptron neural network model application

To relate results just from the uniformly distributed condition, establish the input variables set for minimum rms error, and find the importance of each independent variable, a perceptron multilayer neural network (MLP NN) [10] was trained using SPSS™ running on 50 variables combinations between EDT, RT, Diffusers surface extension, ETx, Abs DBM and Mt.

Uniform distribution – Dependent variable: Abs DBM

Considering a test room with constant volume, it was found that the following neural net models best relate inputs with outputs (for minimum training and prediction errors):

Independent variables: EDT and diffusers surface extension. Dependent variable: Abs DBM, with the following conditions:

Training: 6 cases. Test: 4 cases. Total: 10 cases.

Change of scale of the dependent variables: “None” (there was no variable’s scale modification).

This MLP NN run presented the minor errors, both in the training and in the test phase.

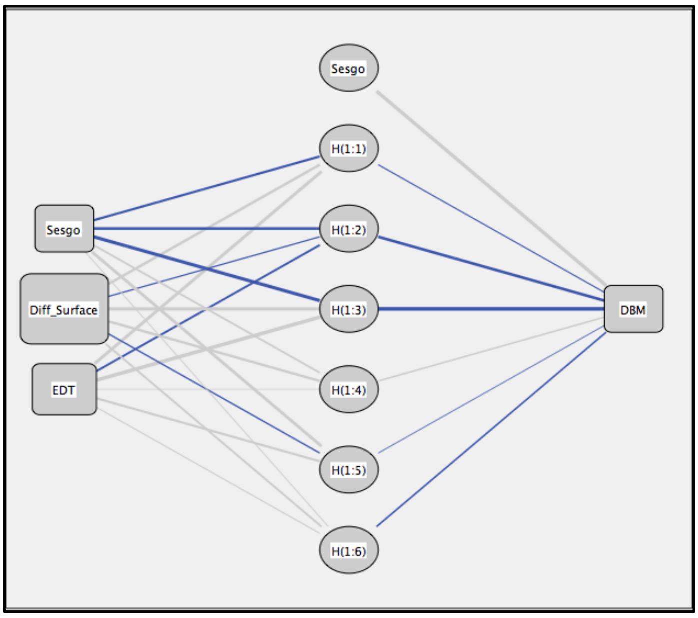
For the training cases, the sum of quadratic errors was 0.198 and the relative error was 0.066.

For the test cases, the sum of quadratic errors was 0.05 and the relative error was 0.097. Total rms error: 0.23.

All other variables combinations (6 NN learning supervised runs per variables combination) produced much larger errors.

The tested MLP NN model scheme is shown in Figure 4, and the corresponding parameters estimation is shown in Table 3.

Figure 4: MLP NN Model scheme. Dependent variable: Abs DBM. Activation function of the hidden layer: hyperbolic tangent. Activation function of the output layer: identity. Grey lines: synaptic weights > 0 (excitation); Blue lines: synaptic weights < 0 (inhibition). Line weights are proportional to the synaptic weights.



Fuente: Elaboración propia.

Table 3: MLP NN Model Parameters estimation for lowest rms error. Dependent variable: Abs DBM. Independent variables: Diffusers Surface extension [m2] and EDT [s].

Predictor		Predicted						
		Hidden Layer 1						Output Layer
		H(1:1)	H(1:2)	H(1:3)	H(1:4)	H(1:5)	H(1:6)	DBM
Input Layer	(Bias)	-0.607	-0.764	-2.998	0.482	0.890	0.257	
	Diffusers Surface extension	0.678	-0.347	1.081	0.655	-0.390	0.485	
	EDT [s]	0.904	-0.505	3.570	0.046	0.524	0.309	
Hidden Layer 1	(Bias)							3.094
	H(1:1)							-0.325
	H(1:2)							-0.779
	H(1:3)							-4.034

	H(1:4)							0.406
	H(1:5)							-0.147
	H(1:6)							-0.408

Fuente: Elaboración propia.

Table 4: Importance of each independent variable, for Absolute Distance Between Models (Abs DBM) as dependent variable. Diffusers surface extension can be seen as the predominant factor for Abs DBM results.

Acoustical Parameter	**Importance [%]**
Diffusers Surface extension [m^2]	62.8
EDT [s]	37.2

Fuente: Elaboración propia.

This MLP NN model reflects a predominant sensitivity of Abs DBM to Diffusers surface extension. Just another MLP NN model with 9 cases was found, with less rms error (0.139), but showed very few prediction cases; anyway importances did not change much (Diffusers surface extension: 59.3 %; EDT: 40.7 %).

Uniform distribution – Dependent variable: ETx

Independent variables: RT, and diffusers surface extension. Dependent variable: ETx,

and the following conditions:

Training: 5 cases. Test: 5 cases. Total: 10 cases.

Change of scale of the dependent variables: “None” (there was no variable’s scale modification).

This MLP NN run presented the minor errors, both in the training and in the test phase.

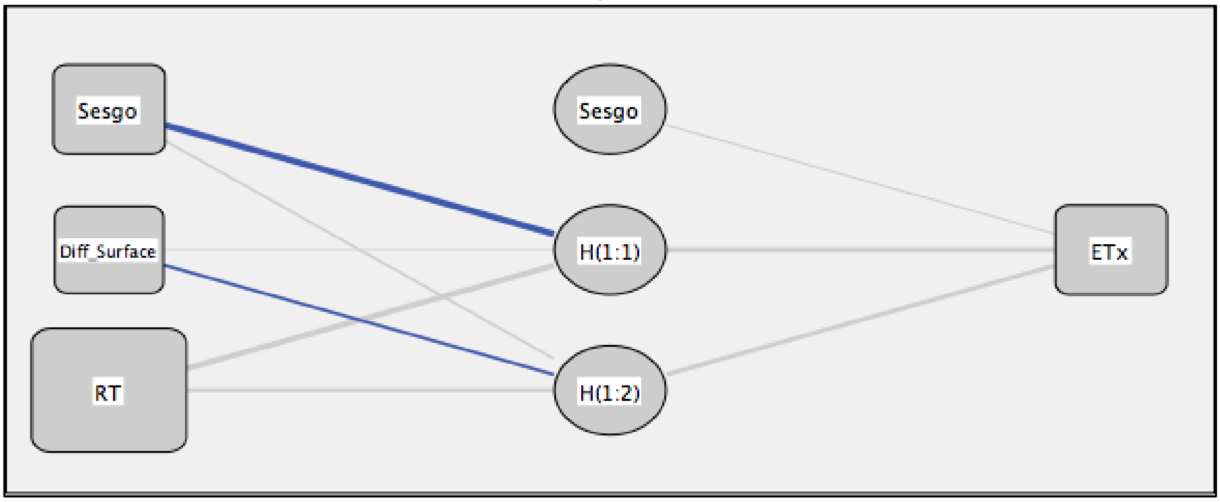
For the training cases, the sum of quadratic errors was 0.022 and the relative error was 0.011.

For the test cases, the sum of quadratic errors was 0.415 and the relative error was 0.098. Total rms error: 0.4271.

All other variables combinations (6 NN learning runs per variables combination) produced much larger errors.

The tested MLP NN model is shown in Figure 3, and the corresponding parameters estimation is shown in Table 5.

Figure 3: MLP NN Model scheme. Dependent variable: ETx. Activation function of the hidden layer: hyperbolic tangent. Activation function of the output layer: identity. Grey lines: synaptic weights > 0 (excitation); Blue lines: synaptic weights < 0 (inhibition). Line weights are proportional to the synaptic weights.



Fuente: Elaboración propia.

Table 4: MLP NN Model Parameters estimation for lowest rms error. Dependent variable: ETx. Independent variables: Diff_Surface extension [m2] and RT [s].

Predictor		Predicted		
		Hidden Layer 1		Output Layer
		H(1:1)	H(1:2)	ETx
Input Layer	(Bias - Sesgo)	-3.367	0.140	
	Diffusers Surface extensión [m^2]	0.052	-0.350	
	RT [s]	3.150	0.451	
Hidden Layer 1	(Bias - Sesgo)			0.116
	H(1:1)			2.398
	H(1:2)			0.483

Fuente: Elaboración propia.

Table 5: Importance of each independent variable, for Expected texture (ETx) as dependent variable. Balance between RT and EDT can be seen as the predominant factor for ETx results.

Acoustical Parameter	**Importance [%]**
RT [s]	68.2
Diffusers Surface extension [m^2]	31.8

Fuente: Elaboración propia.

The MLP NN model reflects a predominant sensitivity of ETx to RT (68.2 %), and to Diffusers surface extension (31.8 %).

Uniform distribution – Dependent variable: Diffusers Surface extension

Considering that an increase of the acoustic diffusers surface extension would lead to an increase of the degree of diffusion of the sound field, another MLP NN was developed with diffusers surface extension (*Diff surface*) as dependent variable. For the smallest rms error result model, the independent variables showed to be Abs DBM and EDT, and their importance over Diffusers surface extension were 41.7% and 58.3%, respectively.

Afterwards, was found the mathematical relation between *Diffusers surface extension* and both variables, separately. With this information, an equation for the approximation of the sound field diffusiveness was developed as shown in eq 5, eq 6, eq 7 and eq 8, resulting in a parameter, SFD, that varies between 0 (minimum) and 1 (maximum).

$$Diffusers\ surface\ extension\ \propto \frac{1}{Abs\ DBM} \qquad (5)$$

$$Diffusers\ surface\ extension\ \propto\ EDT^3, (6)$$

As MLP NN models are based in summation of weighted stimuli [10], an approximation for sound field diffusiveness calculation, *d*, could be inferred trough (7):

$$d\ \propto \frac{0.417}{Abs\ DBM} + 0.583\ \cdot\ EDT^3, (7)$$

Where:

- *d*: is the sound field diffusiveness,

- *Abs DBM*: is the absolute DBM value,
- *EDT*: is the early decay time.

As larger diffusers surface extension produces larger sound field diffusiveness, d is bounded between 0 and infinite. For this reason, the final equation for sound field diffusiveness, SFD, bounded between 0 and 1, is:

$$SFD = \frac{d}{1+d}, (8)$$

At this point, a clarification should be made: our proposal considers the sound field diffusiveness is not a state but a process; a process that takes the room from its deterministic state to it´s stochastic one. The duration of this process is the mixing time (Mt [ms]). That is why SFD is maximum when this process is identical to the ideal one, regardless of its duration.

Discussion

Every non anechoic room, even without diffusers coatings, evidences its sound field diffusiveness through certain Abs DBM, ETx and Mt values.

Measuring RT30, EDT and Mt, and then calculating ETx and Abs DBM it is possible to find a sought value of sound field diffusiveness.

As sound field diffusiveness may be quantified, any array of diffusers - absorbers - reflective surfaces may be evaluated to match a targeted acoustic texture condition.

The efficiency of any diffuser coating (design, surface, modulation, location) could be evaluated through differential analysis in a high anisotropic test room with a medium-low reverberation time value, between the empty condition and the installed condition.

Future work may include systematic room acoustic texture measurements with different room volumes and the use of very anisotropic test rooms to evaluate changes in the sound field diffusiveness through systematic diffusers surface extension variations. Also, perceptual test for different SFD values has to be evaluated.

CONCLUSIONS

Results from the MLP NN model show a relation between the diffusers surface extension, RT and EDT, Abs DBM and ETx, for constant room volume, without normalizing the training variables.

Abs DBM showed to be more sensitive to diffusers surface extension, while ETx to RT30. Taking into account the errors from MLP NN models, Abs DBM would be the more precise descriptor for sound field diffusiveness between both.

As diffusers surface extension increased, in the uniformly distributed condition, Abs DBM and Mt tended to be reduced and ETx to increase, for constant RT and EDT conditions (see Table 1), resulting in an increase in the sound field diffusiveness.

As RT gets reduced, ETx showed a decrease, for constant diffusers surface extension [m2] and room volume; on the other hand, an increase of ETx and a reduction in Abs DBM were achieved through increasing diffusers surface extension [m2].

Placing the acoustic diffusers near the sound source showed to be a good option to attain large values of ETx and reduced values of Abs DBM with the smallest diffuser surface extension posible, though constraining the location of the speaker. The modulated diffusers distribution, experiment 7, showed improved results compared with the non-modulated experiment, for the same diffusers surface extension.

An equation is then proposed to allow the quantification of the sound field diffusiveness, (see SFD, eq. 8).

When calculating sound field diffusiveness, it seems not only the diffusers surface extension is important, but also diffusers efficiency (scattering), their location in the room, EDT, RT30, room volume [m3], sound source and receiver locations. Evidence shows that there is a certain equilibrium that maximize sound field diffusiveness, and is far away from coating all room surfaces, 100% extensions, with acoustic diffusers. More test is needed with high anisotropic rooms and different room volumes.

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