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Acoustics of Courtrooms in Portugal

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Abstract:

This paper presents the results of field measurements in 29 courtrooms in Portugal (average volume of 440 m^3) regarding their acoustic behavior to several objective parameters: (RT, EDT, C_{80}, D_{50}, TS, $RASTI$ and $D_{n,w}$). The individual results show, for instance, that the mean measured values in each room for *RASTI* were from 0.39 to 0.74 (with a global mean value of 0.53 for all rooms) and for the *RT* (500/1k Hz) were from 0.5 to 3.6 s (with a global mean of 1.6 s for all rooms). The evaluation of the airborne sound isolation index ($D_{n,w}$) between courtroom and main lobby found values from 17 to 30 dB. These results show an insufficient acoustical behavior for almost all these courtrooms. Two groups of rooms were formed regarding their date of construction: "old" (prior to the 1990s) and "recent" but the statistical analysis did not support the hypothesis that the two groups presented acoustically diverse behavior. However, the only room in this study that was object of acoustic treatment had values considered to be statistically distinct from the others. Simple formulas are presented that relate among the objective acoustic parameters and between the acoustic and the architectural parameters.

1. INTRODUCTION

The courtrooms are special public places where speech must be clearly understood by all. In these spaces in Portugal, speech is emitted in four different directions (judge, defendant, defender attorneys, and prosecution attorneys). These four directions are separated by 90 degrees each (judge and defendant face to face and both parties of attorneys also face to face, but 90 degrees apart from the judge-defendant direction). Therefore the acoustic conditions are very important for the overall quality of these spaces mainly regarding the speech intelligibility.

The goal of this work was to check the overall acoustic conditions of these rooms by the use of objective acoustic parameters concerning their interior conditions: Reverberation Time (RT), Early Decay Time (EDT), Clarity (C_{80}), Definition (D_{50}), Center Time (TS), *RASTI*, and Dn,w (airborne sound insulation of the wall between courtroom and main hall, with a door) [1].

2. METHOD

A. The Sample

The sample of courtrooms used is a group of selected 29 rooms of 25 towns in Portugal (Almeida, Castelo Branco, Celorico da Beira, Covilhã, Figueira de Castelo Rodrigo, Fornos de Algodres, Fundão, Gouveia, Idanha-a-Nova, Mangualde, Mêda, Nelas, Oleiros, Oliveira de Frades, Oliveira do Hospital, Pinhel, Sabugal, Satão, Seia, Sertã, Sever do Vouga, Trancoso, Vila Nova de Foz Côa, Viseu, and Vouzela). These rooms were built from 1946 until 2001 and the summary of their main architectural characteristics is shown in Table 1.

Figures 1 to 4 - Four typical examples of the 29 Portuguese courtrooms tested (Seia, Celorico da Beira, Vouzela, and Fundão).

Table 1 - Main architectural characteristics of the sample of 29 courtrooms used.

Parameter	Volume (m^3)	Floor surface (m^2)	Height (m)	Length (m)	Width (m)	Number of seats
Minimum value	150	46	2.75	8.3	5.0	24
Maximum value	880	173	6.85	15.5	11.5	170
Mean value	440	102	4.20	12.2	8.2	66
Standard deviation	198	30	1.00	2.1	1.6	31

B. Methodology and Equipment

In each room, eight measuring points were used (see Figure 5) except for the *Dn,w* calculation where twelve measuring points were used (six on each side of the tested wall; see Figure 6). For the *RASTI* measurements, two sound source locations were used (*S* for the judge position and *S'* for the defendant position as seen in Figure 6). All measurements were done with three consecutive measures per point. Octave band results from 125 to 2 kHz were used (for *Dn,w* measurements the ISO 140-4 was used). However in the analyses only the average of the 500 Hz and 1 kHz octave band results was used because this is the method usually employed in this type of work by almost all others researchers and also because these bands relate better with the subjective acoustic impression in rooms. The equipment used was a sound level meter B&K 2231 with a filter set B&K 1625, a microphone B&K 1/2", a sound source B&K 4224, software B&K BZ 7109 or 7144, and *RASTI* set B&K 3361.

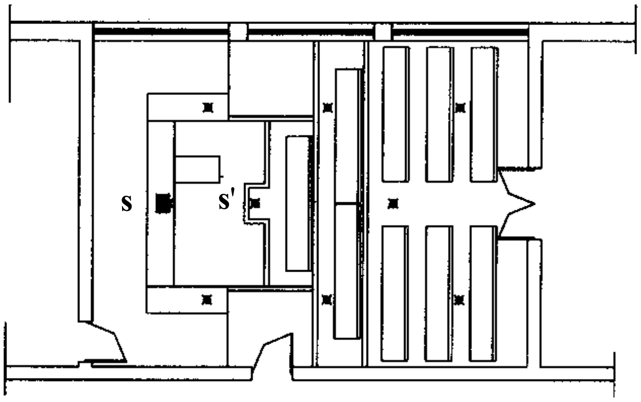

Figure 5 - Standard location of the eight measuring points and sound source (*S*) for the *RT*, *EDT*, *TS*, D_{50}, and C_{80} measurements. For *RASTI* measurements the sound source was also put in the *S'* position (facing *S*): two sets of measurements.

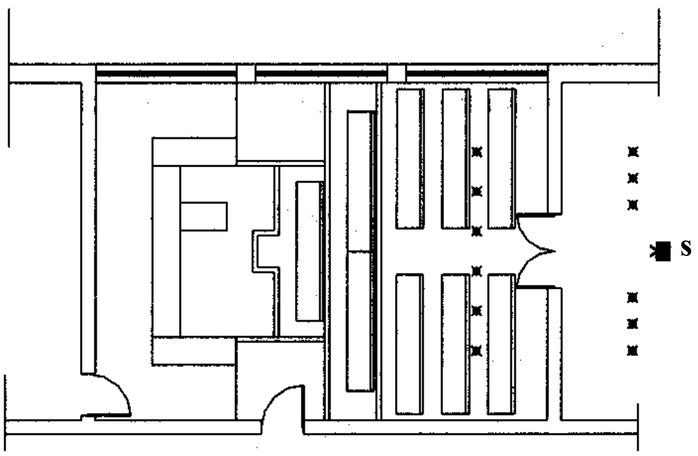

Figure 6 - Standard location of the twelve measuring points and sound source (*S*) for the *Dn,w* airborne sound insulation measurements.

3. ANALYSIS

A. General Comments

The Table 2 shows the summary of the results found in the 29 courtrooms sampled for the seven parameters tested. The results show that the majority of the courtrooms do not have good acoustical conditions for this type of place as set in Table 7. The individual analysis show that about 70% of the rooms do not have a *RT*, *EDT* or D_{50} within the set limits of Table 7. For the C_{80}, *TS* and *RASTI* values, about 50% of the rooms fall short of these proposed limits. For instance, a 3.6 s mean *RT* value was found in one room what is a totally inadequate value for a courtroom.

Table 2 - Summary of results regarding the 29 average values (500/1k Hz except for *RASTI* and *Dn,w*) for each courtroom.

Parameter	*RT* (s)	*EDT* (s)	C_{80} (dB)	D_{50}	*TS* (ms)	*RASTI*	*Dn,w (dB)**
Minimum	0.46	0.42	-3.3	0.21	30	0.39	17
Maximum	3.55	3.56	4.5	0.82	253	0.75	30
Median	1.46	1.44	1.1	0.41	100	0.53	22
Mean value	1.58	1.53	1.0	0.43	110	0.53	22
Standard error	0.67	0.66	2.2	0.14	48	0.09	3

* wall between courtroom and main lobby (with a door closed)

B. Relationships Among Acoustical Parameters

Using the 29 averaged values in each courtroom and for each objective acoustic parameter some good simple models were found to relate among pairs of parameters as seen in Table 3 (Figure 7 shows a graphical example). Very high values of R^2 (about 0.9) were found for many relationships. Therefore some of the formulas shown in Table 3 can be used with confidence to predict other acoustical parameters (averaged room value).

Table 3 - Relationships found between pairs of objective acoustic parameters with the correlation Pearson coefficient (R^2).

MODEL	R^2
$EDT = 0.0176\ RT^2 + 0.9201\ RT + 0.028$	0.99
$C_{80} = 0.7616\ RT^2 - 5.9588\ RT + 8.207$	0.93
$D_{50} = 0.5347\ RT^{-0.7178}$	0.92
$TS = 71.5413\ RT - 3.1$	0.98
$RASTI = 0.0456\ RT^2 - 0.2882\ RT + 0.854$	0.95
$C_{80} = 0.7933\ EDT^2 - 6.0732\ EDT + 8.13$	0.94
$D_{50} = -0.3077\ \ln(EDT) + 0.534$	0.93
$TS = -1.1932\ EDT^2 + 77.078\ EDT - 4.9$	0.99
$RASTI = 0.0455 \times EDT^2 - 0.2873\ EDT + 0.846$	0.97
$D_{50} = 0.3536\ e^{0.1435\ C80}$	0.96
$TS = 2.0477\ C80^2 - 24.8356\ C80 + 123.6$	0.95
$RASTI = 0.4888\ e^{0.0704\ C80}$	0.95
$TS = 390.1681\ e^{-3.1617\ D50}$	0.96
$RASTI = -0.2329\ D50^2 + 0.8195\ D50 + 0.227$	0.97
$RASTI = 9\text{x}10^{-6}\ TS^2 - 0.0039\ TS + 0.837$	0.98

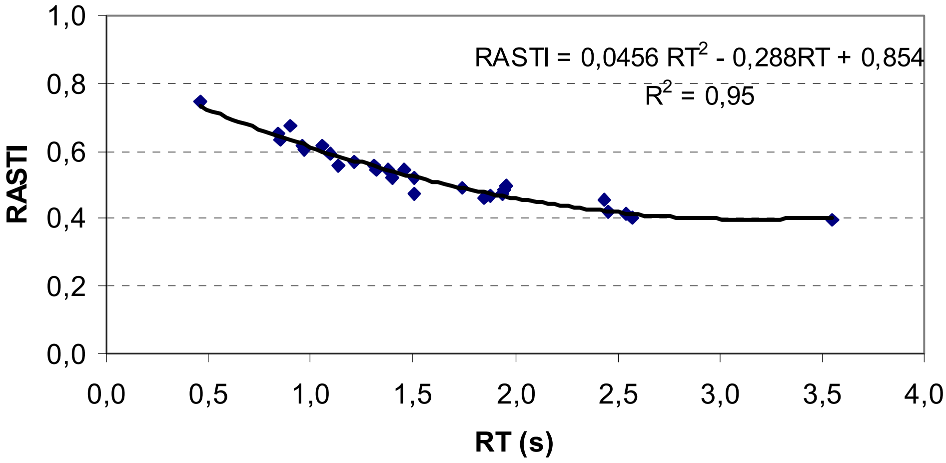

Figure 7: Example of a regression model for the relationship between the *RASTI* and the *RT* room averaged values (500/1k Hz).

C. Relationships Between Acoustical Parameters and Architectural Features

Simple models

The Table 4 displays simple models to predict the mean value for the tested objective acoustic parameters using an architectural feature of the room (Figure 8 shows a graphical example).

It was found that about 55% of the variance in the acoustic parameters is explained by the Height (or Volume) of the room, being these the two most important architectural features.

Table 4 - Best simple models to predict objective acoustic parameters (mean values using the averaged values for the 500 Hz and 1 kHz octave bands) with one architectural feature with the correlation Pearson coefficient (R^2) found (H - height, m; V - Volume, m).

MODEL	R^2	MODEL	R^2
$RT = 0.2296\, H^{1.3129}$	0.52	$RASTI = 1.0419\, H^{-0.4875}$	0.53
$EDT = 0.2125\, H^{1.3437}$	0.52	$RT = 0.0025\, V + 0,500$	0.52
$C_{80} = 0.2407\, H^2 - 3.7599\, H + 12.31$	0.56	$EDT = 0.0025\, V + 0.452$	0.54
$D_{50} = 1.6078\, H^{-0.9743}$	0.51	$TS = 0.178\, V + 31.5$	0.53
$TS = 14.441\, H^{1.3787}$	0.52		

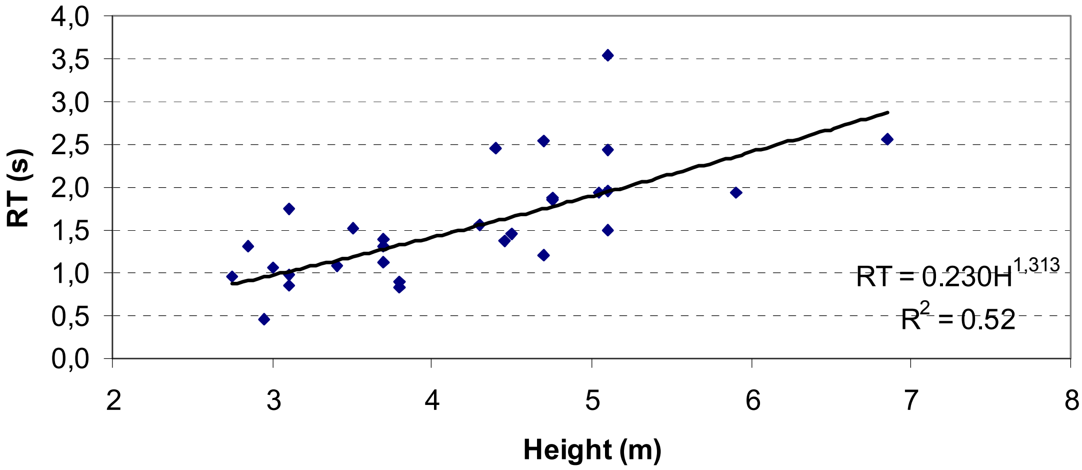

Figure 8: Example of a regression model for the relationship between the *RASTI* and the *RT* averaged values (500/1k Hz).

General linear models

To improve the simple models of Table 4, general linear models were tested and the results are shown in Table 5 (if better than the ones of Table 4). Using two or three architectural features the variance explained by the models increases now to about 61 or 62% (except the C_{80} where no improvement was found).

Table 5 - Best general linear models to predict objective acoustic parameters (mean value using the averaged values for the 500 Hz and 1 kHz octave bands) with some architectural feature with the correlation Pearson coefficient (R^2) found (*H* - height, m; *L* - length, m; *W* - width, m; *V* - Volume, m; *S* - surface floor, m^2; *A* - total absorption, m^2).

MODEL	R^2
$RT = 2.520 - 0.127\,L - 0.159\,W + 0.00437\,V$	0.61
$EDT = 2.335 - 0.114\,L - 0.156\,W + 0.00427\,V$	0.62
$C_{80} = 0.2407\,H^2 - 3.7599\,H + 12.305$ (*)	0.56
$D_{50} = 0.757 + 0.00138\,A - 0.0947\,H$	0.54
$TS = 171.96 - 8.76\,L - 11.21\,W + 0.312\,V$	0.61
$RASTI = 0.546 + 0.00179\,S - 0.000538\,V + 0.000832\,A$	0.61

(*) Best simple model of Table 4

D. Analysis Controlling for Date of Construction

Two groups of rooms were formed concerning their time of construction: "old" rooms (before 1990) and "new" rooms (see Table 6). The hypothesis that the acoustical parameters had different mean values for each of these groups was statistically tested. The statistical analysis using *SYSTAT®* did not supported the hypothesis. However, the only room in this 29-room study that had been object of acoustic treatment had values considered to be statistically distinct from the others.

Table 6 - Summary of the analysis regarding the mean values for the two groups of courtrooms controlled by date of construction with ± 1 standard error.

Type	Number of rooms	*RT* (s)	*EDT* (s)	C_{80} (dB)	D_{50}	*TS* (ms)	*RASTI*
Old rooms	15	1.69 ± 0.74	1.65 ± 0.72	0.7 ± 2.2	0.41 ± 0.12	117 ± 42	0.52 ± 0.08
New rooms	13	1.54 ± 0.54	1.49 ± 0.54	1.1 ± 2.1	0.43 ± 0.14	107 ± 51	0.53 ± 0.08
Room with acoustic design	1	0.46	0.42	4,5	0.82	30	0.75

4. DESIGN RULES

In the pursuit of the best dimensions for courtrooms, a set of ideal values was defined (see Table 7) and they were used to propose the range of ideal values for the main architectural parameters. Table 8 shows these ranges of values regarding ideal values for the height, volume and surface floor. These values were found using the relationships presented in Tables 4 and 5.

Table 7 - Ideal conditions for courtrooms (average of 500 / 1k Hz octave bands, except *RASTI* and *Dn,w*).

Parameter	*RT* (s)	*EDT* (s)	C_{80} (dB)	D_{50}	*TS* (ms)	*RASTI*	*Dn,w (dB)**
Ideal conditions	0.8 to 1.2	0.7 to 1.1	≥ 1.0	≥ 0.55	≤ 100	≥ 0.55	≥ 27

* wall between courtroom and main lobby (with a door closed)

Table 8 - Ideal values for the main architectural features in courtrooms determined using the relationships found in this study (if no specific acoustic project is considered).

Architectural feature	Height (m)	Volume (m^3)	Surface floor (m^2)
Ideal values	3.0 to 3.4	< 280	< 230

5. CONCLUSION

This work was centered in a selected 29 room sample and found that the majority of courtrooms in Portugal does not have the best of acoustical conditions for their specific function: speech.

The direction of the sound source in the *RASTI* measurements (*S* or *S'* in Figure 5) was found not very significant for the results in the vast majority of rooms. Only in 3% of the spaces the effect of sound source orientation in the averaged *RASTI* values was higher than 10%. Nevertheless, in almost all rooms (93%) a slight increase in the mean *RASTI* value was found when the sound source was in the judge position (*S* in Figure 5).

Simple formulas were found for the relationships among objective acoustic parameters and also to predict the mean room values using some of the main architectural features. In this case, relationships were found that could explain about 60% of the variance in the measured mean values.

No statistical evidence was found to support the hypothesis that old rooms (built before 1990) behave acoustically better than the new ones (if without acoustic design). However, the only room in this study that had been object of acoustic treatment had values considered to be statistically distinct from the others.

It was also found that, on average, the possible use of an absorptive ceiling (with an increase of about 0.7 in the absorption coefficients) would provide an increase of about 70 m^2 in the total sound absorption and this would decrease the mean *RT*, on average, on about 0.6 s. This effect alone, could correct almost all problems (about 85%) relating to high *RT* values.

A set of ideal values for the objective acoustic parameters was proposed and a desired range for the main architectural features (height, volume and surface floor) was defined that can be useful in the design of new courtrooms.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Carlos A. Monteiro, *Caracterização acústica de salas de audiências de tribunais* [in Portuguese] (M.Sc. thesis, University of Porto, 2003).