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Sound absorption of 18th-century baroque woodcarving in churches

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Abstract
The use of woodcarving in very large surfaces within Catholic churches was very usual in the 17th and 18th century not only in Portugal and Spain but also in Southern America, and in other European Catholic countries. In Portugal, the town of Porto was even well known for its informal school of woodcarving masters. This paper presents the results for sound absorption coefficients regarding a typical early 18th century baroque woodcarving church piece. A large chestnut-tree wood altarpiece (about 21 m^2) from the Portuguese church of the Monastery of the Saint John the Evangelist of Vilar de Frades (near the northern town of Barcelos) was tested. That "Retable of the Purgatory Souls" was carefully removed from the church during a large renovation program and tested in a reverberant chamber using one-third octave bands from 100 Hz to 5000 Hz. These results show a sound absorption coefficient of about 0.3 and not very dependent on frequency. This paper also presents the acoustic measurements regarding reverberation time done within that church with and without many areas of woodcarving, from 125 Hz to 4000 Hz and without occupancy. [Partly supported by the IPPAR - The Portuguese National Institute for the Architectural Patrimony]

1. Introduction
Retables or altarpieces in Catholic churches are a very old practice. The tradition of erecting a structure behind and above an altar and adorning it with artworks extends back at least to the eleventh century [1].

During the Baroque (17th century) many artists excelled in the creation of large altarpieces using woodcarving, especially in Southern Europe (and Latin America).

From about 1660-1670, all over Portugal there was an increase in the use of gilded woodcarving. In the religious spirit of that time, particularly in Portugal and Spain, the woodcarving with its bright golden surface (gilding), answers efficiently to the needs of the Catholic Church after the Council of Trent (Counter-Reform) that uses it to support the diffusion of the Faith [3].

For instance, in 1789, Agostinho Costa writes about one church in Porto (St. Francis church): "*The church of this convent, has three naves covered from top to bottom with golden woodcarving, what makes it look as a dilated mountain of gold*" [3].

Or, in 1795, the British James Murphy writes about what he saw on a trip to Portugal: "*The churches are large, strong and magnificent buildings (...). It is scarcely credible what riches are lavished on the inside of them; the altarpieces, baldaquins, &c. (...) exhibit a profusion of gilding*" [4].

In Portugal, the northern town of Porto became very well known for its informal school of woodcarving masters. A typical example of a beautiful early baroque retable from this school was chosen to be tested (Figure 1).

Today, many churches in Portugal, Spain, Brazil and other countries have very large areas of their interior covered with woodcarving. However, not many data is available to characterize acoustically those surfaces and very little literature address this problem [2].

The main goal of this study was to measure the sound absorption coefficients of a very large altarpiece, typical of the baroque woodcarving in Catholic churches in Portugal and Spain, that could help acousticians in their design work concerning renovation work in churches.

2. Measurements in Reverberant Chamber

2.1 The Sample

The tested sample in this study was a large chestnut-tree wood altarpiece with 20.5 m^2 (with sculptures and florid ornaments) from the Portuguese church of the Monastery of Saint John the Evangelist in the village of Vilar de Frades (north of Porto, near the town of Barcelos).

That particular piece (Figure 1) is named as the "*Retable of the Purgatory Souls*" and it is a typical example of the baroque from the Portuguese "*Joanino*" period. It was made about 1720-25 by an unknown author. For our study, it was carefully removed from the church during a large restoration program supervised by the state owned Portuguese National Institute for the Architectural Patrimony (IPPAR, Oporto Regional Office).

2.2 Methodology

The altarpiece was carefully reassembled (horizontally) on the floor of a reverberant chamber for sound absorption measurements (Figures 2 to 5).

Figure 1 (left): Altarpiece sampled - *Retable of the Purgatory Souls* (c. 1723).
Figure 2 (right): Entrance of a piece of the Retable in the reverberant chamber.

Figures 3, 4, 5 and 6 (top left to bottom right): Assembling and measurement of the altarpiece in the reverberant chamber.

The altarpiece was tested in the 320 m^3 reverberant chamber of the IDIT - *Instituto de Desenvolvimento e Inovação Tecnológica* (in Santa Maria da Feira, near Porto) using one-third octave bands from 100 Hz to 5000 Hz, according to EN 20354 (ISO 354) using a B&K 2231 sound level meter with a 1/2 inch B&K 4165 microphone and a B&K 4224 sound source (Figure 6).

2.3 Results

Table 1 and Figure 7 show the averaged sound absorption coefficients (α) from the 27 measurements done in the reverberant chamber and considering two situations for the calculation of the total area (S) of the Retable under study:
- Situation I: the total area in the horizontal plan ($S = 20.5$ m^2);
- Situation II: the total exposed wooden area including all lateral surfaces ($S = 28.5$ m^2).

Table 1: Averaged sound absorption coefficients (α) from the 27 measurements in the two situations of calculus (*I* - considering the total altarpiece area in the horizontal plan, $S = 20.5$ m^2; *II* - considering the total wooden exposed area including all lateral surfaces, $S = 28.5$ m^2).

Frequency (Hz)	100	125	160	200	250	315	400	500	630
α, I (if S=20.5 m^2)	0.42	0.44	0.33	0.38	0.40	0.35	0.33	0.33	0.33
α, II (if S=28.5 m^2)	0.30	0.31	0.24	0.27	0.29	0.25	0.24	0.24	0.24

Frequency (Hz)	800	1k	1250	1600	2k	2500	3150	4k	5k
α, I (if S=20.5 m^2)	0.32	0.32	0.33	0.36	0.35	0.38	0.38	0.42	0.53
α, II (if S=28.5 m^2)	0.23	0.23	0.24	0.26	0.25	0.27	0.27	0.30	0.38

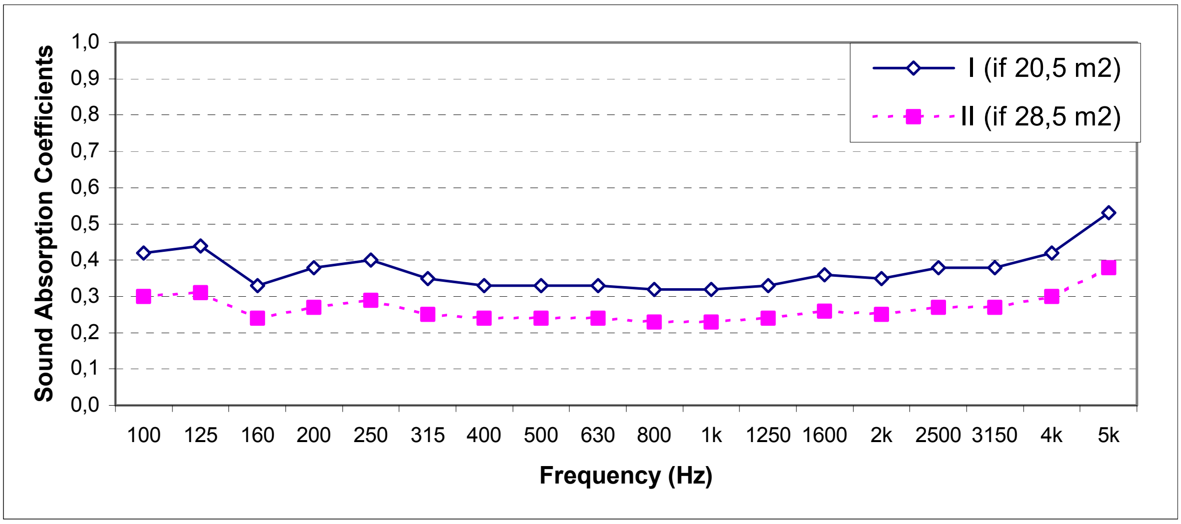

Figure 7: Averaged sound absorption coefficients (α) from the 27 measurements in the two situations of calculus (*I* - considering the total altarpiece area in the horizontal plan, $S = 20.5$ m^2; *II* - considering the total exposed wooden area including all lateral surfaces, $S = 28.5$ m^2).

3. In Situ Experimental Measurements

To check the acoustic effect of the altarpiece in its home church environment, acoustic measurements regarding reverberation time were also done (March-May, 2001) within the Vilar de Frades church (without occupancy) in three situations: with and without the presence of the sampled retable and also without the presence of a second similar retable. Octave band measurements were done from 125 Hz to 4000 Hz using a B&K 2231 sound level meter, a 1/2 inch B&K 4165 microphone, and a B&K 4224 sound source. Four measuring positions were used within the church (two measurements in each position). The averaged results achieved are present in Table 2 and Figure 8.

Table 2: Averaged reverberation time values (*RT*) and standard deviation within the Vilar de Frades church in three situations: *I* - With the tested retable in its home location; *II* - Without the tested retable; *III* - Without a second similar retable.

Frequency (Hz)	125	250	500	1k	2k	4k
I - *RT* (s) with retable	4.04	3.85	3.93	3.60	3.30	2.81
II - *RT* (s) without retable	3.63	4.09	3.82	3.78	3.24	2.67
III - *RT* (s) without 2 retables	3.87	3.83	3.94	3.71	3.23	2.80
Standard deviation (s), Sit. I	0.25	0.17	0.13	0.07	0.02	0.08
Standard deviation (s), Sit. II	0.24	0.19	0.09	0.07	0.08	0.24
Standard deviation (s), Sit. III	0.32	0.15	0.11	0.04	0.02	0.09

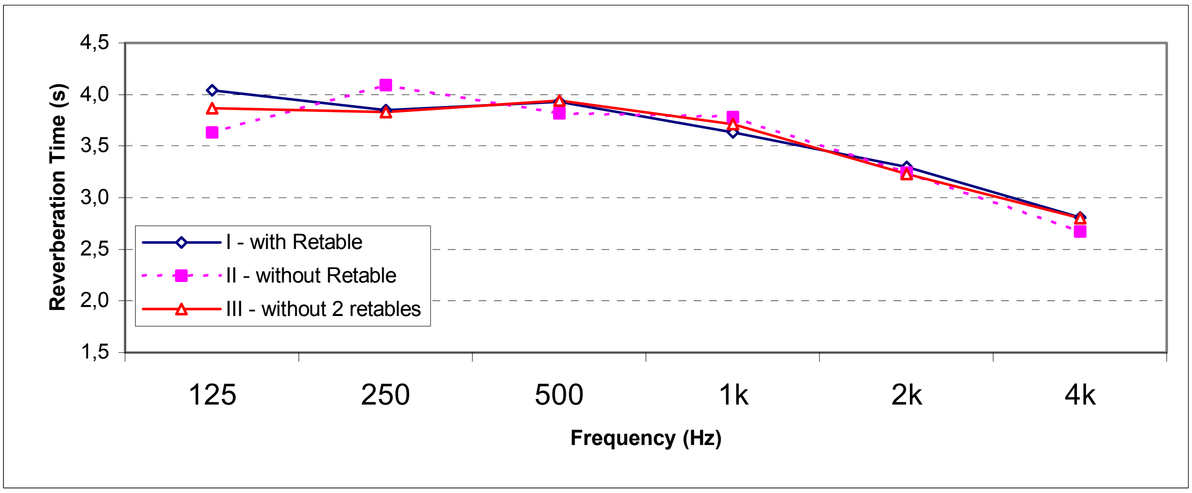

Figure 8: Averaged reverberation time values within the Vilar de Frades church in three situations: *I* - With the tested retable in its home location; *II* - Without the tested retable; *III* - Without a second similar retable.

4. Conclusion

The sound absorption results achieved in the reverberant chamber measurements show a nearly constant behavior in the entire range of the sampled frequency-bands (100-5000 Hz). Those values can be a little overestimated because the volume of the reverberant chamber with the retable is smaller than without it. However, the volume of the retable is very small (about 3%) when compared with the chamber's volume (320 m^3).

In the very low end of the frequency range there is a very small increase in the sound absorption coefficient values consistent with a panel absorber effect. In fact, the measured α values (about 0.3-0.4) are very similar to the ones available in the literature for thin wood panels with large space behind [5, 6]. However, the expected typical decrease in the α values for panel absorbers, with the increase of frequency is not shown for the tested retable. It seems that other effect gradually appears with the increasing of frequency that overrides it.

In the highest sampled frequency bands (above 2 kHz) there is a small increase in the α values. This general behavior for the measured α values in the high frequencies that moves apart from the panel absorber traditional behavior can be explained perhaps by:

- Some "porosity" effect or "resonance" effect, caused by the small air spaces formed in the woodcarving surface by its design;
- An "increased" area *S* of the real exposed wooden surface given by the presence of the protuberances of wood originated by the retable's design (very small sculptures and florid ornaments) that may play an important absorptive role only for small wavelengths. The frequency range of the additional sound absorption would correspond to the wavelengths of the prominent pieces of the retable that lead to an increased absorption and that also causes a significant increase in diffusion.

Those sound absorption coefficient values in the high frequencies are about 3 to 4 times higher than the ones that should be expected in thin wooden surfaces (acting as panel absorbers).

The in situ measurements within the home church of the tested retable did not give usable results because no statistically significant differences were found (therefore no intend was made to calculate the in situ α values). There weren't conclusive differences between the values with and without the two similar altarpieces in their home locations. The main reasons for this situation are:

- The very small area of the altarpieces when compared with the total interior surface area of the church (one altarpiece is less than 2% of the total interior area of the church);
- The altarpieces were positioned in deep lateral chapels that may act as coupled spaces for many of the frequency bands sampled;
- There was also one minor change in the church's interior between the two first sets of measurements (situations *I* and *II*) by the reinstallation of a medium size organ near one of the nave's walls. For this fact, a third situation was measured (*III*).

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