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ACOUSTICS OF CHURCHES FROM PORTUGAL AND PERU WHEN THEY WERE ONCE THE SAME COUNTRY

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This paper compares the interior acoustics of Catholic churches of Portugal and Peru, built in the late 16th and early 17th centuries. In situ measured data of Reverberation Time and other parameters are presented and compared controlling for country.

1. Introduction

From 1580 to 1640 Portugal and Peru were the same country. Or, better said, they were ruled by the same king. In 1580 Portugal lost its 437 years-old independence (when the 68 year-old king Henrique died with no direct heir) and the Spanish king became also the king of Portugal (because he was the "closest" relative). For 60 years the Portuguese and the Spanish world Empires were united (until a Revolution in Portugal put the History back on its tracks). King Filipe II, III and IV were then in charge.

During these years many churches were built in Peru; the first half-century of domination and the stage of pacification and acculturation have been consolidated in these years to make away for a cultural boom and evangelization of the natives. The churches were necessary for the presence and physical demonstration of Catholicism in the new territories.

In Portugal, on the contrary, the times were not for the construction of churches (Portugal had lost its dynasty and the control for all its old sources of money). Also, the country had already hundred of churches built during the four centuries before.

In Portugal, in the late 16^{th} century and in the early 17^{th} century, the dominant architectural style was the Late Gothic ("Manueline", a Portuguese flamboyant Gothic), the Renaissance and then the Baroque.

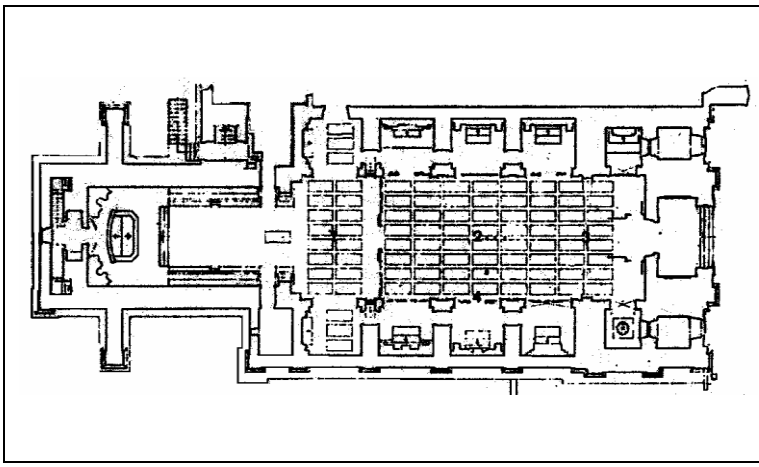
In Peru, this long period, was dominated by the same European architectural styles, often arriving a few years later and staying beyond the time prevailing in Europe. The styles of the Peruvian churches analyzed are Renaissance and Baroque, with constructive and aesthetic influence of the natives.

2. Sample

The sample used -ten churches in each country- is shown in Table 1. Figures 1 to 4 present examples of those churches.

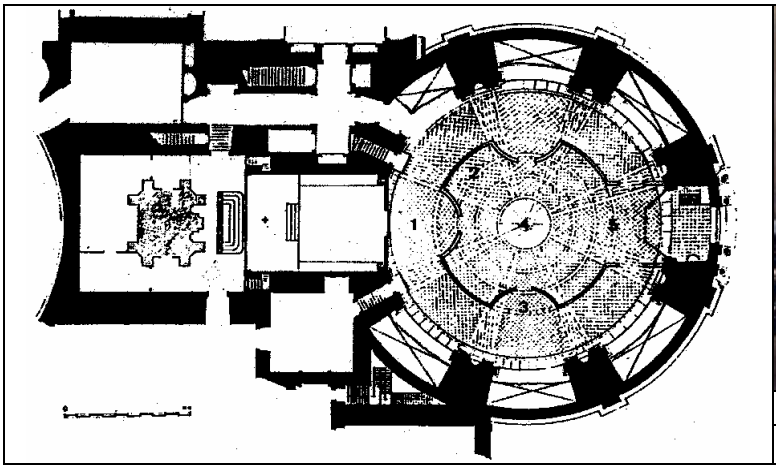
Table 1. Sample of churches in Portugal and Peru used in this study. [1,2,3]

PORTUGAL				PERU			
#	Church name	Year	V(m^3)	#	Church name	Year	V(m^3)
PT1	Golegã	16th c.	5563	PE1	Compañía-Arequipa	1654	10471
PT2	Misericórdia-Évora	1554-1590	3338	PE2	S. Francisco-Arequipa	1687	9777
PT3	S. Francisco-Évora	early 16th c.	18631	PE3	Sta. Catalina-Arequipa	1580	5723
PT4	S. João Baptista-Moura	early 16th c	6300	PE4	Compañía-Ayacucho	1645	8185
PT5	Azeitão	16th c.	1239	PE5	S. Agustín-Ayacucho	1637	5616
PT6	S. Roque-Lisboa	late 16th c.	14207	PE6	S. Francisco Paula-Ayacucho	1613	4466
PT7	Tibães	early 17th c.	8608	PE7	S. Juan de Dios-Ayacucho	1627	5739
PT8	Viana do Alentejo	16th c.	3358	PE8	Recoleta-Cusco	1601	2284
PT9	Vila do Bispo	late 16th c.	1290	PE9	Sta. Clara-Cusco	1622	8393
PT10	Serra do Pilar-V.N.Gaia	1538-1670	11566	PE10	S. Pedro-Puno	1579	11225



View towards the Altar

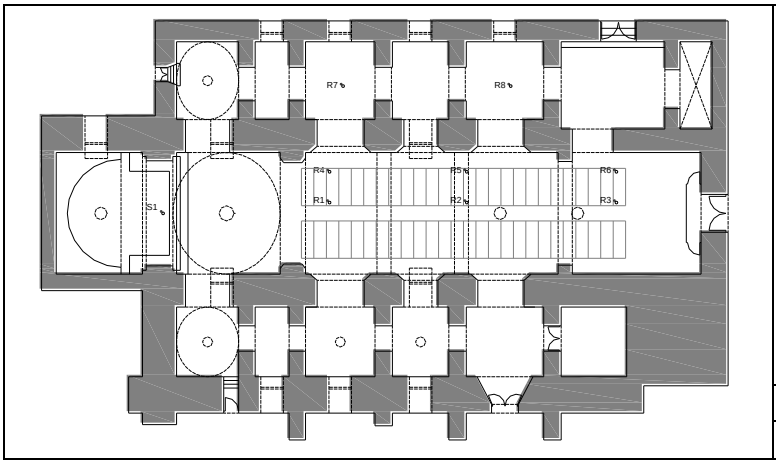
Mosteiro de Tibaes



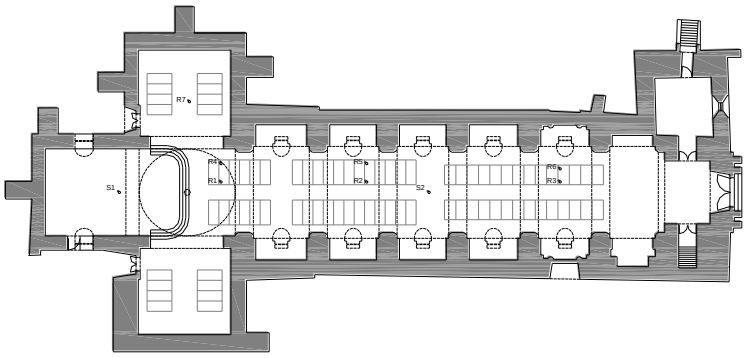
View towards the Altar

Serra do Pilar – Vila Nova de Gaia

Figures 1 and 2 - Examples of churches in Portugal in the sample used [1,2]



View towards the Rear Entrance
San Francisco - Arequipa



View towards the Altar
San Pedro - Puno

Figures 3 and 4 - Examples of churches in Peru in the sample used[3]

3. Results

3.1 Reverberation time and Clarity C_{80}

The Table 2 shows the averaged data (500 and 1k Hz octave bands) for the RT and C_{80} of the churches used in this study [1,2,3].

Table 2. RT and C_{80} data (average 500-1k Hz) from the sample of churches in Portugal and Peru used in this study. [1,2,3]

PORTUGAL				PERU			
#	Church name	RT (s)	C_{80} (dB)	#	Church name	RT (s)	C_{80} (dB)
PT1	Golegã	3.6	-5.0	PE1	La Compañía-Arequipa	3.2	-14.6
PT2	Misericórdia-Évora	2.3	-2.1	PE2	S. Francisco-Arequipa	2.5	-19.3
PT3	S. Francisco-Évora	5.0	-6.5	PE3	Sta. Catalina-Arequipa	3.3	-19.4
PT4	S. João Baptista-Moura	6.6	-7.7	PE4	Compañía-Ayacucho	3.8	-18.0
PT5	Azeitão	2.3	-1.6	PE5	S. Agustín-Ayacucho	3.6	-17.8
PT6	S. Roque-Lisboa	3.8	-4.6	PE6	S. Francisco Paula-Ayacucho	2.6	-9.1
PT7	Tibães	2.7	-3.6	PE7	S. Juan de Dios-Ayacucho	3.3	-7.9
PT8	Viana do Alentejo	3.1	-2.7	PE8	Recoleta-Cusco	2.2	-3.2
PT9	Vila do Bispo	1.8	0.1	PE9	Sta. Clara-Cusco	2.0	-3.2
PT10	Serra do Pilar-V.N.Gaia	7.8	-8.2	PE10	S. Pedro-Puno	3.3	-16.0

By observing the values of RT in the churches of Peru, there is a great homogeneity as they vary between 2.0 s and 3.8 s, while the churches of Portugal have a RT between 1.8 s and 7.8 s while for C_{80} reverse situation occurs, that is, lower interval in the case of the Portuguese churches –between 0.1 dB and -8.2 dB, and for the Peruvian churches the variation is between 3.2 dB and -19.4 dB. However, the relationship between RT and C80, as seen in the figure 5, indicate more significant R^2 values among the churches of Portugal (R2=0,96) than for the churches of Peru (R^2=0,50), existing in the latter case a wide dispersion related to the regression line obtained, indicating an independence degree between those two acoustics parameters.

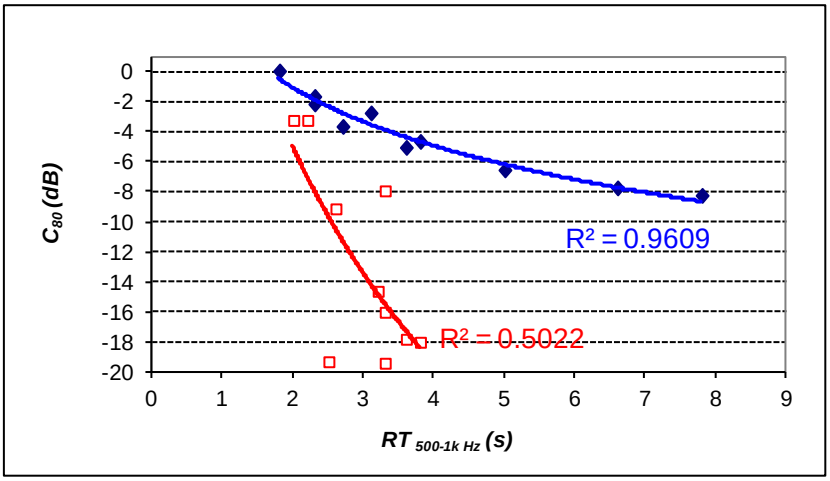


Figure 5 – Average RT and C_{80} data for each church, controlling for the country (blue dots and line for Portugal and red open squares and line for Peru)

When individually analyzed, the relationship between these two acoustical parameters and two basic architectural parameters such as maximum height and volume, of each temple, as shown in figures 6 to 9, again, the churches of Peru have very low R^2, nothing significant for both acoustic parameters, while for the churches of Portugal are obtained significant values of R^2, especially considering the C_{80} with the two architectural parameters. This wide dispersion of the samples from the churches of Peru may be due to two considerations: the different physical configurations of the samples (during this period the new European architecture were just consolidating this type of construction) like narrow nave, three naves, or wide nave with transept; and building materials used: *sillar* (porous volcanic stone) in the churches of Arequipa, stone in churches from Cusco and Puno, and adobe (earth) in the churches of Ayacucho.

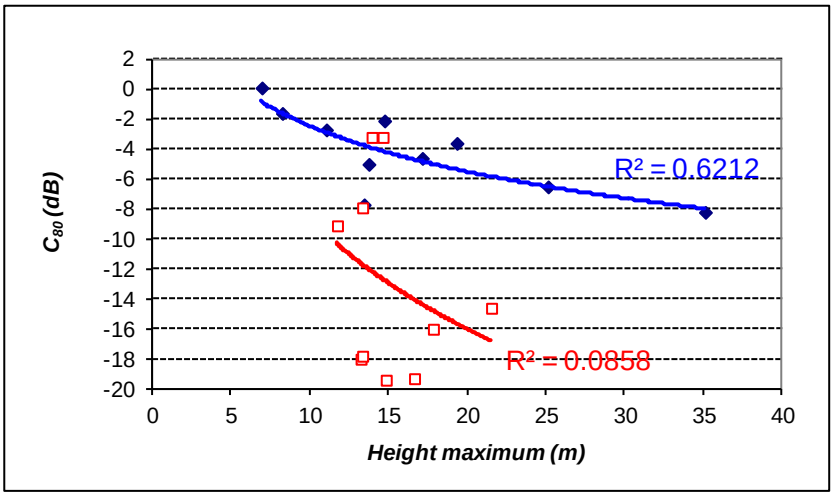


Figure 6 – Average C_{80} and Maximum Height data for each church, controlling for the country (blue dots and line for Portugal and red open squares and line for Peru)

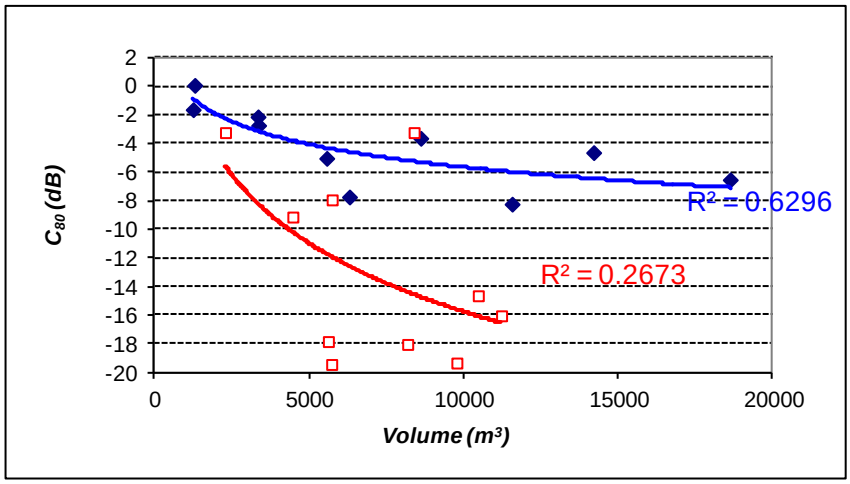


Figure 7 – Average C_{80} and Volume data for each church, controlling for the country (blue dots and line for Portugal and red open squares and line for Peru)

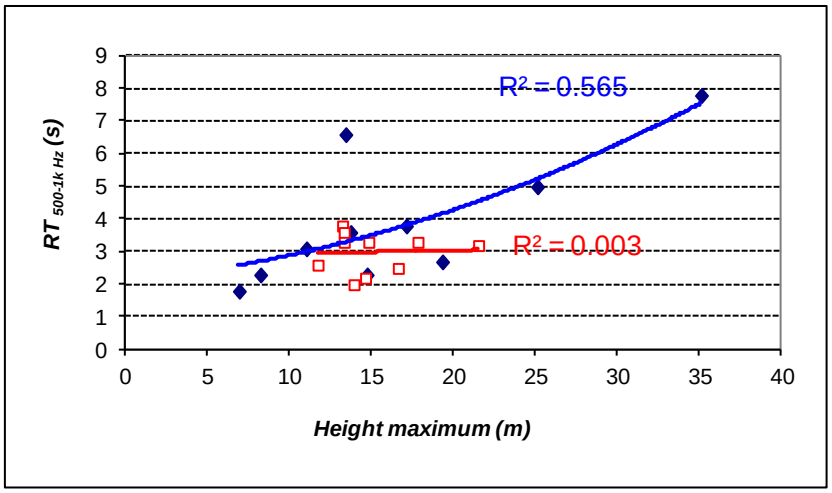


Figure 8 – Average RT and Maximum Height data for each church, controlling for the country (blue dots and line for Portugal and red open squares and line for Peru)

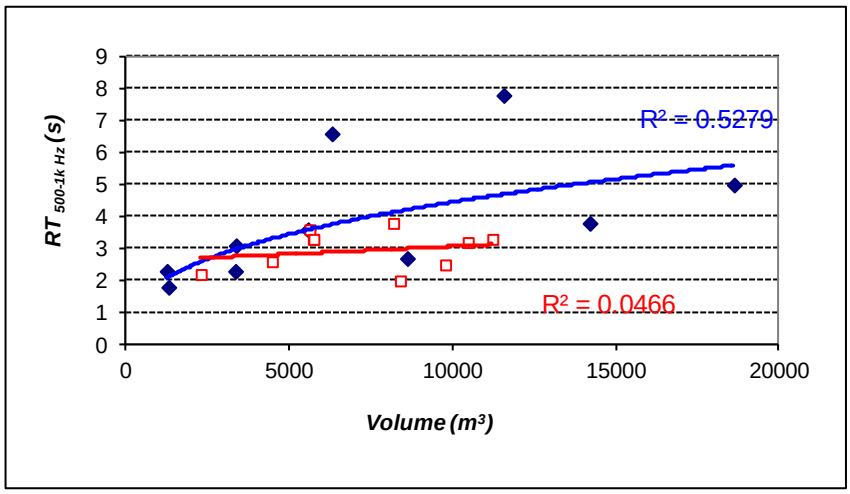


Figure 9 – Average RT and Volume data for each church, controlling for the country (blue dots and line for Portugal and red open squares and line for Peru)

A similar statistical analysis between the physical characteristics of maximum height and volume in churches can again prove that even though the churches of Peru have a smaller dispersion about the regression line, $R^2 = 0.29$ is lower than that obtained for churches in Portugal: $R^2 = 0.78$,

as shown in figure 10. In analyzing comparatively the Portuguese churches and those Peruvian churches made of stone or brick (acoustically rigid materials), even when the sample is smaller, there is a noticeable improvement in the correlation established between the two categories, for example, the R^2 values when interacting RT with C_{80} (R^2 = 0.97), RT with Maximum Height (R^2 = 0.96) and C80 with Maximum Height (R^2 = 0.99). The relations between the RT and C80 with the Volume also increase the values of R2 but to a lesser extent. Probably the difference in materials and construction procedures between both types of churches belonging to the same historical period and architectural styles, could explain the difference in sound quality of churches from Portugal and Peru.

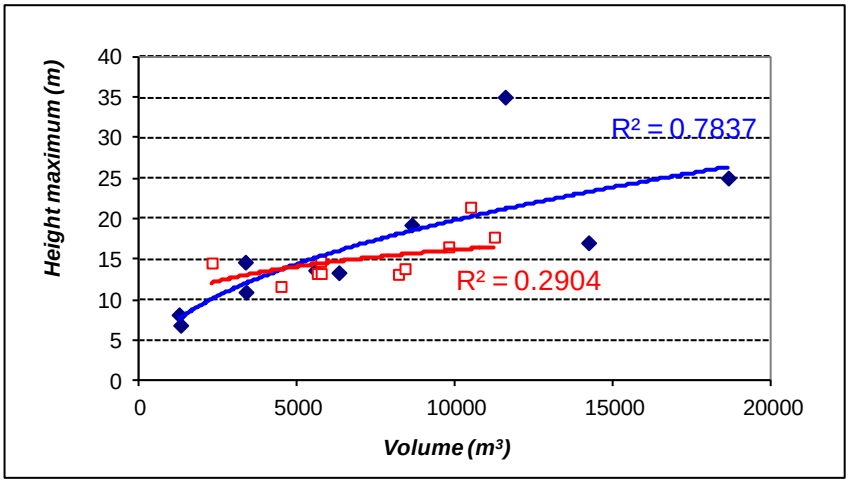


Figure 10 – Average Maximum Height and Volume data for each church, controlling for the country (blue dots and line for Portugal and red open squares and line for Peru)

4. Conclusions

Ten churches in Portugal and ten churches in Peru were compared, whereas in the period 1580-1640, when they were built, were part of a same country, even though they belong to different continents, but maintaining the same patterns of architectural styles of the time.

Statistical analysis of dispersion and regression lines between the acoustic parameters RT and C_{80} and the architectural parameters Maximum Height and Volume determine differences in their R^2 values being lower for the churches of Peru than the churches of Portugal in all cases. This condition could be due mainly to different building procedures and materials typically used in churches in Peru.

ACKNOWLEDGEMENTS

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