MEASUREMENTS OF REVERBERATION IN CHRISTIAN ORTHODOX CHURCHES OF THE MODERN HELLENIC PERIOD

G. Xanthoulis AtkinsRéalis UK, National Technical University of Athens
A. Sotiropoulou National Technical University of Athens
I. Karagiannis National Technical University of Athens
I. Konstantopoulos National Technical University of Athens

1 INTRODUCTION

Orthodox churches of the modern Hellenic period, i.e. since the independence of Hellenic nation in early 19th century, are replicas of (historic) Byzantine temples, though normally of much larger scale than their archetypes, in order to accommodate the increasing population of church goers in modern societies. This sort of churches have highly reflecting inner boundaries such as their archetypes, whilst the well known tradition of iconography is conspicuous on their inside envelop. As a result, spare surfaces to host any sound absorptive treatment are limited. Under such circumstances, reverberation, could not be anything but excessive; it follows, that issues of audience noise could possibly be raised and the situation could become even worse whenever insufficient noise protection allows for urban noise penetration in churches. This situation is currently acknowledged by church goers, and church authorities often employ sound amplification during liturgy, in order to "fix the acoustics"!! [1]

With the aim to investigate the above situation, twelve test churches were selected in Athens, so as to be representative of the Orthodox church of the modern Hellenic period. Measurements of reverberation time were carried out. Results are presented and commented below.

2 BACKGROUND

Amongst the earliest attempts to investigate the acoustics of Byzantine churches using modern technology, is the work of Tzekakis [2,3]. In that work, which is summarised in [3], acoustic measurements were carried out in eight churches in Thessaloniki dating between 11th and 14th century; a typical church plan and section, that was involved in that study, is given in Figure 1. Some results from that study which concern cruciform churches, are presented in Table 1. Tzekakis concluded that despite hard (reflective) inner boundaries and relatively large volumes, the measured reverberation times remained reasonably low; this had been the effect of 'complex' church plan, that had been highly segmented by substantial stone supporting walls.

Like interpretation, applies in Karampatzakis results from his reverberation time measurements much later [4]. Those measurements were carried out in eleven (historic) Byzantine churches in Thessaloniki, and results are summarised in [4]. Some of those results which involve cruciform churches are presented in Table 1.

Both the above authors acknowledge that room 'complexity' can have considerable effect on reverberation, mainly in the case of historic cruciform temples, thanks to the temple's own inner morphology.

It was not until recently [5] that Karampatzakis revisited the concept of room boundaries 'complexity' and its connection with total room absorption, with the aim to investigate the acoustics of (historic) Byzantine churches. That author carried out measurements of reverberation time employing virtual

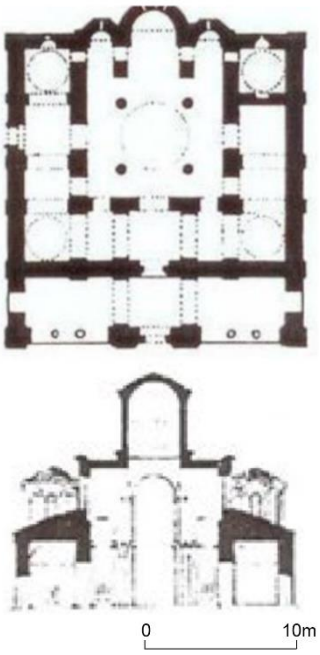

Figure 1. Plan and Section of the Holy Apostles church, used in Tzekakis' study [3]

space simulation. His measurements confirmed that for a temple of given volume, and given hard (reflective) inner boundaries, reverberation could be improved (decreased) by increasing the room boundaries 'complexity'. According to Karampatzakis "..this finding presents a solution to improve the acoustic field in the case of large temples, without introducing absorptive materials, but rather using the potential of 'complexity' as an acoustic design tool".

3 EXPERIMENTAL DESIGN AND PROCEDURE

The test churches, were replicas either of cross-in-square domed temples, or of multiple-aisle domed Basilicas, and are listed in Table 1 [6,7,8]. Measurements were carried out in the octave bands 125 Hz to 4000 Hz. Byzantine chant comprises male vocal sound, it is monophonic without musical instruments, and it is meant to be within the vocal capabilities of the average Christian church prayer. It follows that, by and large, the mid frequency region (mean of 500 Hz and 1000 Hz) is appropriate for use in the analysis.

Unfortunately, in the case of Byzantine chant, there are no optimal reverberation values available in the relevant literature nor optimal frequency spectrum. The values measured in historic Byzantine temples by Tzekakis [3] and by Karampatzakis [4] (Table 1) could be used, by and large, as reference values. Nevertheless, Cremer and Müller [9] proposed optimal reverberation time as a function of church volume, based on acoustic measurements in Roman catholic churches.

Acoustic measurements were carried out in the unoccupied churches, using omnidirectional loudspeaker source in the "solea" i.e. the standard position of the preacher. Reverberation time was derived analysing the recorded impulse responses using the computer software DIRAC by B&K.

Table 1. Basic details of Orthodox churches

	No.	Name	Date	Style	Volume [m^3]	RT_{mid} [s]
Present study, Athens	1	Hagia Eirini Galatsiou	1982	Cross-in-square domed	7445	5.50
	2	Hagia Sofia N. Psychicou	1968	Cross-in-square domed	5345	4.87
	3	Hagia Triada Holargou	1981	Cross-in-square domed	4645	4.42
	4	Hagios Therapon Zografou	1964	Domed Basilica Three-aisle	6150	3.47
	5	Hagia Foteini N. Smyrnis	1940	Cross-in-square domed	4810	3.81
	6	Hagios Panteleimon Acharnon	1970	Cross-in-square domed	21289	9.05
	7	Hagia Triada Ampelokipon	1930	Cross-in-square domed	3965	3.39
	8	Hagios Vasileios Exarcheion	1935	Domed Basilica Three-aisle	4800	2.90
	9	Hagios Georgios Karytsi	1849	Domed Basilica Three-aisle	2500	2.15
	10	Chrysospileotissa	1863	Domed Basilica Three-aisle	5930	3.35
	11	Hagia Eirini Aiolou	1850	Domed Basilica Three-aisle	3403	3.05
	12	Hagios Nikolaos Chalandriou	1862	Cross-in-square domed	2359	2.31
Tzekakis' study [3], Thessaloniki	A	Hagios Panteleimon	1314	Cruciform	2880	2.47
	B	Churh of Holy Apostles	1315	Cruciform	1575	1.71
	C	Katholikon Monastery of Vlattadon	11^{th}–14^{th} century	Cruciform	835	1.45
	D	Church of Prophet Elias of	1293	Cruciform	2250	1.87
Karampatzakis' study [4], Thessaloniki	I	Hagia Sophia	7^{th} century	Cruciform	15250	2.50
	II	Church of Panagia Chalkeon	1028	Cruciform	1290	1.41
	III	Church of Saint Catherine	13^{th} century	Cruciform	1230	1.43

4 RESULTS, DISCUSSION

Reverberation results are listed in Table 1. Also, reverberation values have been plotted vs room volume in Figures 2,3,4.

Two distinct groups of churches have been identified from the analysis. Namely, those which belong to 19^{th} and early 20^{th} century which were found to have reverberation reasonably low. By contrast the remaining churches which are relatively recent exhibited excessive reverberation, despite the fact that the two groups of churches have comparable volume with each other, and their inner boundaries are hard and reflective. According to the analysis, this result applies in the mid-, as well as in the low- and the high- frequency region.

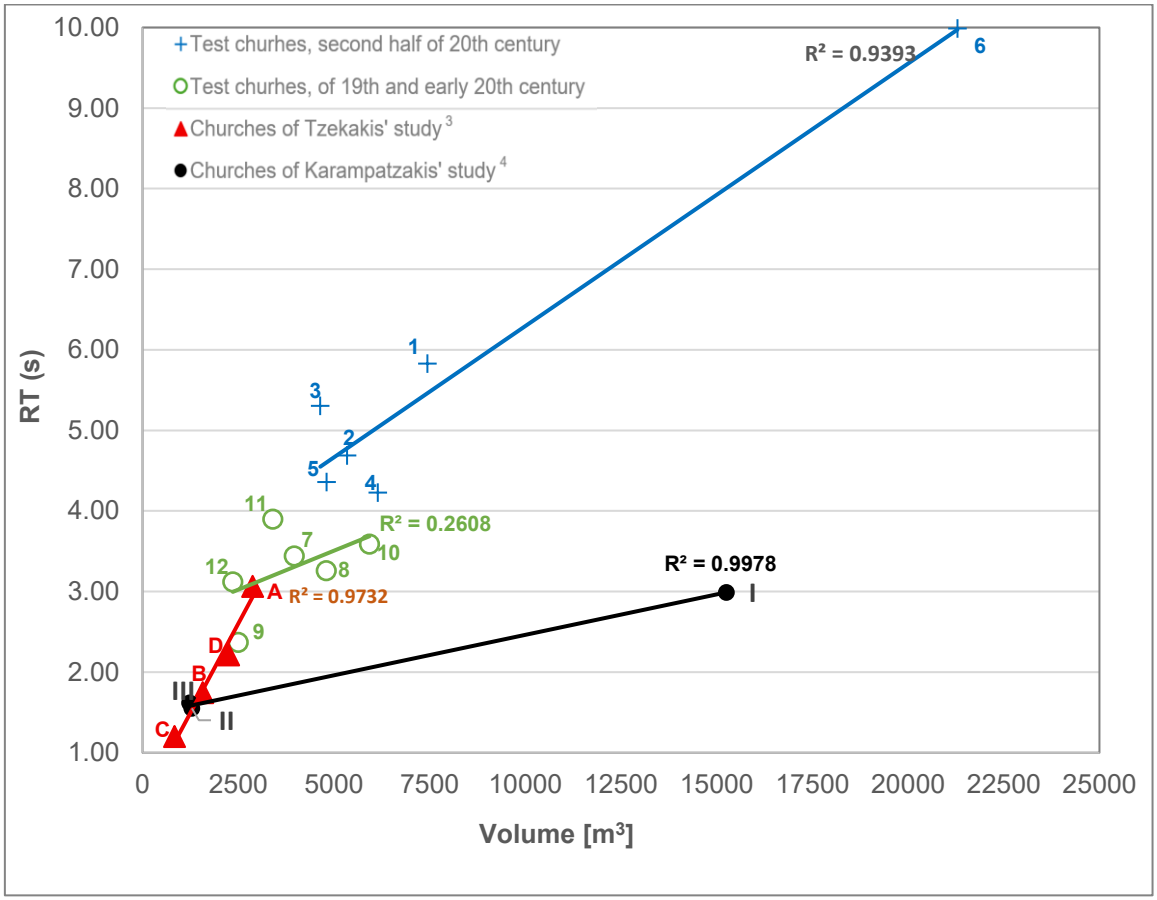

Figure 2. Measured Reverberation Time (RT) vs church volume at low frequencies (mean 125-250 Hz). *Numbers refer to church identity (Table 1)*

An explanation to the above finding can be seen in the concept of room boundaries 'complexity' (see Section 2 above). In particular, the relatively early group of churches are made of stone which involves massive structural elements with complex joints between each other; also the church volume is clearly subdivided due to the relatively dense arrangement of the supporting stone columns. The increased room 'complexity' in this case, gives rise to relatively high total room absorption which, in turn, results in relatively low reverberation time. This interpretation is also coherent with Tzekakis' conclusions [3] from his reverberation measurements in historical Byzantine churches (see Section 2 above).
Unlike churches of the early period, relatively recent churches are made of the "20th century new material" namely reinforced concrete. Owing to this material's advanced capabilities, structural components involve less massive and relatively fine profiles and can span large openings resulting in churches of almost uninterrupted huge volumes. Apparently, the group of relatively recent churches have 'less complex' inner boundaries, which give rise to relatively low room absorption, and excessive (measured) reverberation times. The above effect is clearly illustrated in the contemporary church of Hagia Triada Holargou in Athens, which is made of reinforced concrete (Figure 5). This church is approximately as large as the early 20th century Hagios Vassileios Exarcheion (figure 6); Nevertheless this (Hagia Triada) is almost by 50% more reverberant (RT = 4.42 s) than Hagios Vassileios (RT = 2.90 s).

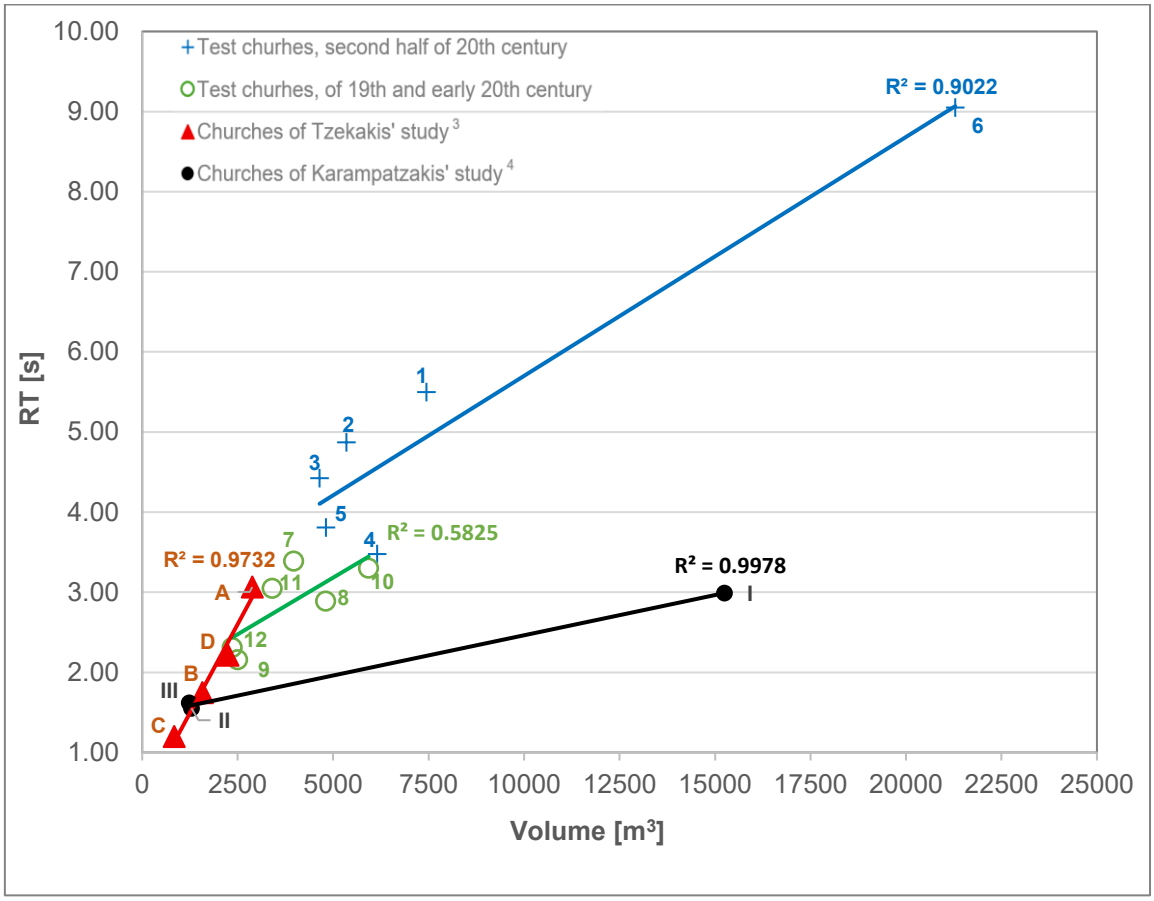

Figure 3. Measured Reverberation Time (RT) vs church volume at mid frequencies (mean 500-1000 Hz). *Numbers refer to church identity (Table 1)*

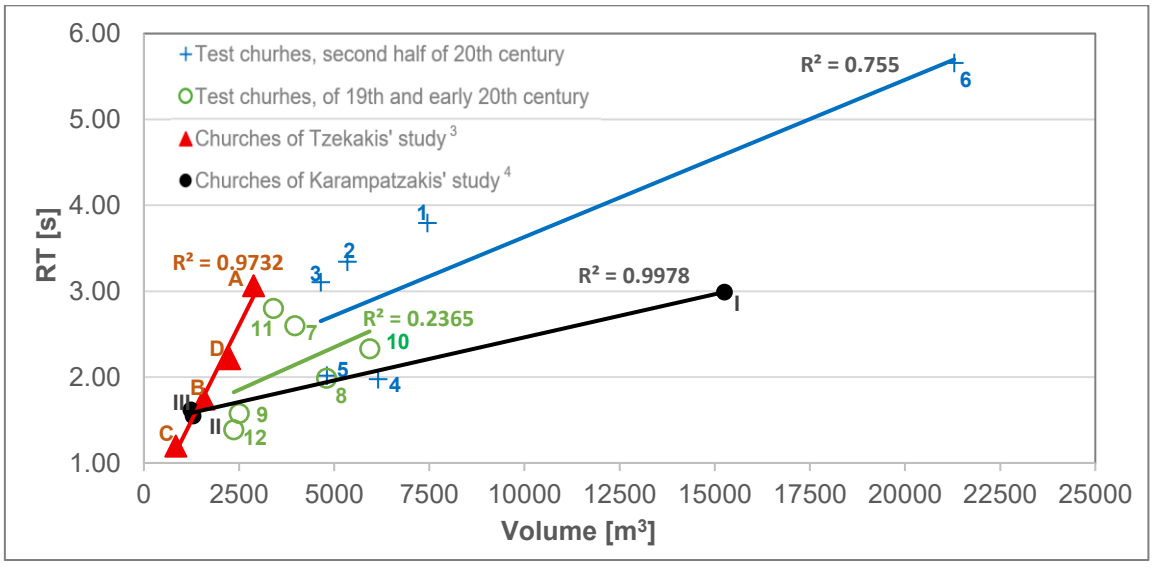

Figure 4. Measured Reverberation Time (RT) vs church volume at high frequencies (mean 2000-4000 Hz). *Numbers refer to church identity (Table 1)*

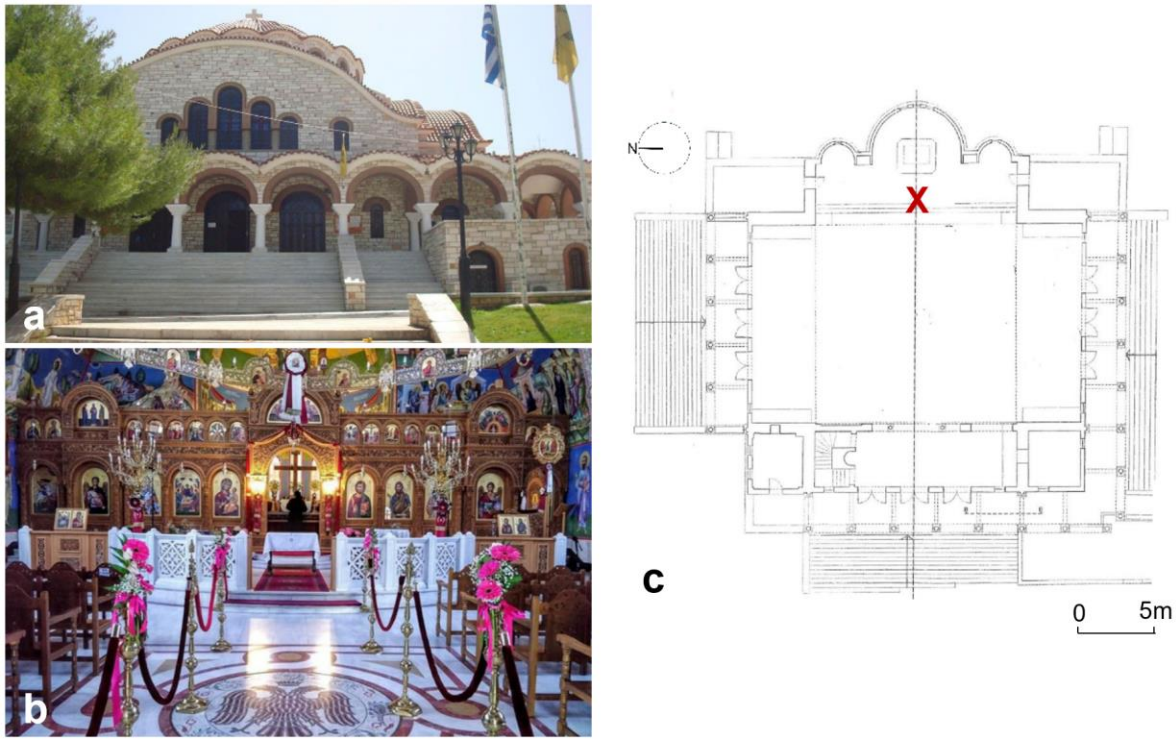

Figure 5. Test church of Hagia Triada Holargou, Athens: a) outside view, b) inside view, c) church plan, *loudspeaker source in solea (X)*

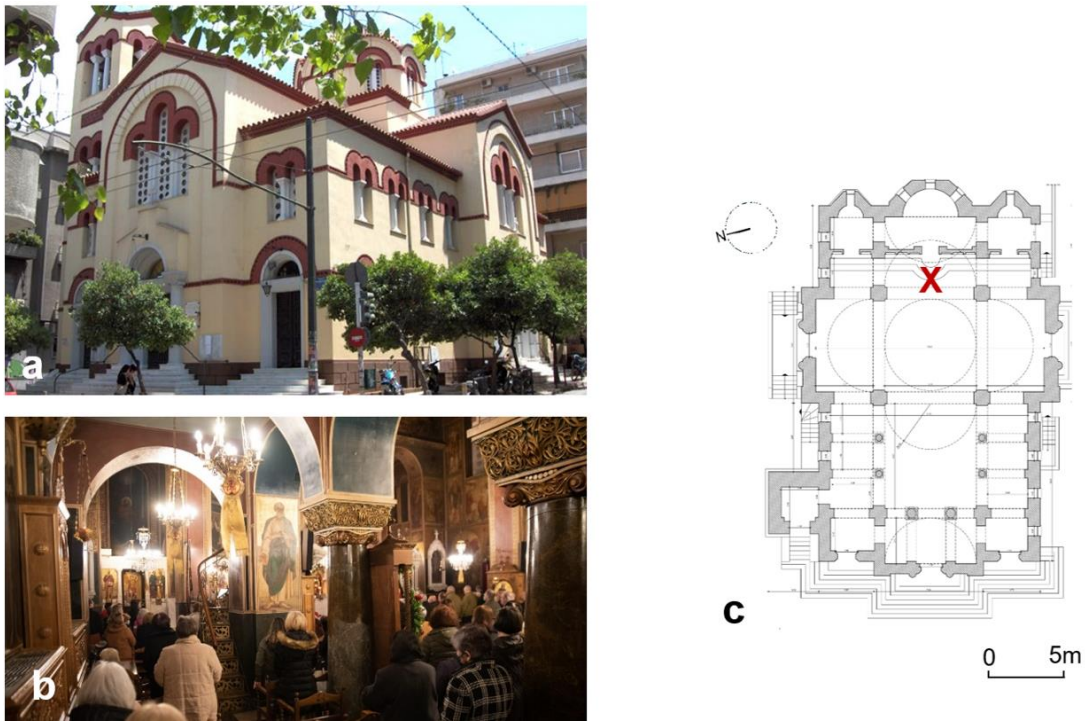

Figure 6. Test church of Hagios Vassileios Exarcheion, Athens: a) outside view, b) inside view, c) church plan, *loudspeaker source in solea (X)*

Regarding the frequency spectrum of the measured reverberation times, it is clear that: a) there is relatively low reverberation time in the high frequency region (Figure 4), which apparently, has been the effect of the air absorption, and b), the relative increase of reverberation in the low frequency region, confirms absence of any bass absorption in the (hard) reflecting envelop of the church (Figure 2).

5 CONCLUSIONS

Evidence is provided in this study, of the difference between: on the one hand, churches of 19th and early 20th century (early group) and, on the other hand, churches of 20th century till present days (recent churches), regarding control of reverberation time. The early group of churches were found to have reasonably low reverberation thanks to relatively high room 'complexity' associated with traditional stone structure employed. By contrast, the recent group of churches were found to have excessive reverberation, owing to their relatively low room 'complexity' associated with modern building materials and techniques (reinforced concrete) employed.

The present findings a) cast some light on the question of excessive reverberation in present days Hellenic Christian Orthodox churches, b) confirm transferability of virtual church simulation results to the real Orthodox church situation, and c) provide a challenge for the architect to experiment with new forms, that can improve acoustical quality in contemporary Orthodox churches.

Acknowledgements

Thanks go to the Present and Former Deans, Professors Heleni Vlachogiannis and Paris Pandouvakis respectively, for support. Appreciation is expressed to civil eng. Mr Panayiotis Segos for useful discussions. Part of the present study has been produced in the context of Diploma thesis of Ioannis Konstantopoulos, in the School of Civil Eng. of Tech. Univ. of Athens.

6 REFERENCES

1. J. Kilaidoni, A. Sotiropoulou and G. Karagiannis, Classical auditoria in the Mediterranean of universally acknowledged acoustics: evaluating electroacoustic amplification, Proc. 11th International Conference on Auditorium Acoustics, IOA, Vol. 45, Pt. 2, Athens (2023).
2. E.G. Tzekakis., 'Reverberation time of the Rotunda of Thessaloniki', J.A.S.A 57(5), 1207-1209. (May 1975).
3. E.G. Tzekakis., 'Data on the acoustics of Byzantine churches of Thessaloniki', Acustica 43, 275-279. (1979)
4. P. Karampatzakis, Acoustic measurements in 11 Byzantine churches in Thessaloniki, (in Greek), Proc. 4th National Conference HELINA. Xanthi (2008).
5. P. Karampatzakis, Connection between iconography and reverberation performance of Byzantine temples: Experimental investigation, Proc. 11th International Conference on Auditorium Acoustics, IOA, Vol. 45, Pt. 2, Athens (2023).
6. M. Karpodini, Acoustical design of Greek Orthodox churches, (in Greek), Diploma Thesis, (supervised by assoc. prof. A. Sotiropoulou and Dr eng. I. Karagiannis), School of Civil Eng., Tech. Univ. Athens. (2011).

7. P. Daskalopoulos and P. Kyriakopoulos,The acoustics of Greek Orthodox curches, (in Greek), Diploma Thesis, (supervised by assoc. prof. A. Sotiropoulou and Dr eng. I. Karagiannis), School of Civil Eng., Tech. Univ. Athens. (2010).
8. I. Veltsistas and S. Rouvas, Acoustical measurements in contemporary Greek Orthodox Churches, (in Greek), Diploma Thesis, (supervised by assoc. prof. A. Sotiropoulou and Dr eng. I. Karagiannis), School of Civil Eng., Tech. Univ. Athens. (2011).
9. L. Cremer and H.A. Müller. Principles and applications of room acoustics, Vol. 1, Applied Science Publishers, London and New York (1982).