SUBJECTIVE ACOUSTIC EVALUATION OF BYZANTINE CHANT IN ORTHODOX CHURCHES OF MODERN GREEK PERIOD

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1. INTRODUCTION

Byzantine chant is a genre of religious music, which originated in the period of the Byzantine Empire as a development of oriental and western musical influences. Byzantine chant together with reciting are major components of Byzantine liturgy; the latter was developed through centuries, hand by hand with Byzantine religious architecture.

Orthodox churches of the modern Greek period are replicas of original Byzantine churches, though of much larger scale than their archetypes in order to accommodate the increasing population of church goers in modern societies. This uncontrolled replication has, occasionally, resulted in edifices of poor sound; the latter, unfortunately, is often amplified, in order that natural acoustics is … "improved"!

So far, worship spaces in ottoman architecture[1,2], as well as in modern western world[3], have been approached with respect to their acoustical performance. However the acoustics of orthodox churches of the modern period has only recently been the object of scientific research[4,5,6,7].

With the above in mind, the present work aims at identifying, using auralised signal, independent subjective acoustic qualities in five orthodox churches of modern Greek period. Although results from this research area do not tell the designer how to build a good church, they can form a firm basis for further research in this direction.

2. REVIEW OF PAST WORK

Few scientific studies have been reported in the literature to investigate the acoustics of Byzantine churches. Examples are the work of Tzekakis[8,9] and Karampatzakis[10], respectively. Also, scientific studies to investigate the acoustics of orthodox churches of the modern Greek period, are few[4,5,6]. All the above studies involve physical acoustic measurements. Furthermore, amongst the fewest studies, referring to subjective acoustic evaluation of liturgy in churches of the modern Greek period, is the work by Sotiropoulou et al[7]. In that study live liturgy is used, therefore there are involved limitations that are associated with non-acoustic influences of the real environmental complexity, The present study involves subjective acoustic evaluation experiments, and employs auralised sample of Byzantine chant from a number of churches.

3. EXPERIMENTAL DESIGN AND METHODS OF ANALYSIS

Five orthodox churches (Fig. 1 to 5) of modern Greek period, in and around Athens, were chosen for the present experiment. One of these churches, namely "Hagios Therapon" was common with the earlier study of Sotiropoulou et al[7] that had involved live liturgy evaluations of natural (unamplified) sound. Liturgy from the five churches was simulated in the following way. An anechoic recording of Byzantine chant (without rhyme) was edited using Voxengo's "pristine space" Plug-in and then Steinberg's "Nuendo 4" as a host application, in order to be adjusted to the impulse response of each test church. The final sample was exported as a WAVE file (.wav 44100Hz 16bit). For each church, one sample signal was produced (Byzantine chant), that was 15 mins long.

Physical acoustic measurements had been performed previously, in the test churches[4,5,6]. Impulse response was recorded in various test positions within each church (Fig. 1 to 5). For each church, the auralised signal referred to a typical position in the middle of the main space. Acoustic measurements employed the computer software "Dirac" developed by B&K and were made according to relevant standards.

Furthermore, in the subjective evaluation experiments, the semantic differential method[11] was employed, in which subjective responses are measured by semantic rating scales, in this case bipolar and continuous. The scale judgments were analysed by factor analysis[12]. Factor analysis suits the basic hypothesis of this study, namely, that the labels employed in the rating scales refer to a much smaller number of independent concepts. Comments on the identity of factors, their interpretation and their relative importance, are found in references[13,14].

The present list of rating scales was taken from Sotiropoulou et al's[7] study, in which the derivation of scales had been based on English resources (Table 2). The rating scales were presented to the experimental subjects in English as well as in Greek, in order to minimise misinterpretations.

4. EXPERIMENTAL PROCEDURE AND RESULTS

The subjective experiments involved the following churches: "Hagia Eirini Galatsiou", "Hagia Triada Cholargou", "Hagia Sofia Neou Psychikou", "Hagia Triada Ampelokipon" and "Hagios Therapon Zografou" (Table 1 and Fig. 1 to 5).

No	Name	Area of Athens	Year of completion	volume (m^3)	Seating capacity	R.T. [s]
1.	Hagia Eirini	Galatsi	1982	7445	300	5,50
2.	Hagia Triada	Cholargos	1981	4645	150	4,42
3.	Hagia Sofia	Neo Psychiko	1968	5345	250	4,87
4.	Hagia Triada	Ampelokipi	1930	3965	*No Data*	3,44
5.	Hagios Therapon	Zografou	1952	6150	250	3,47

Table 1: Basic details of test churches *RT: Reverberation Time (mean 500Hz, 1KHz)*

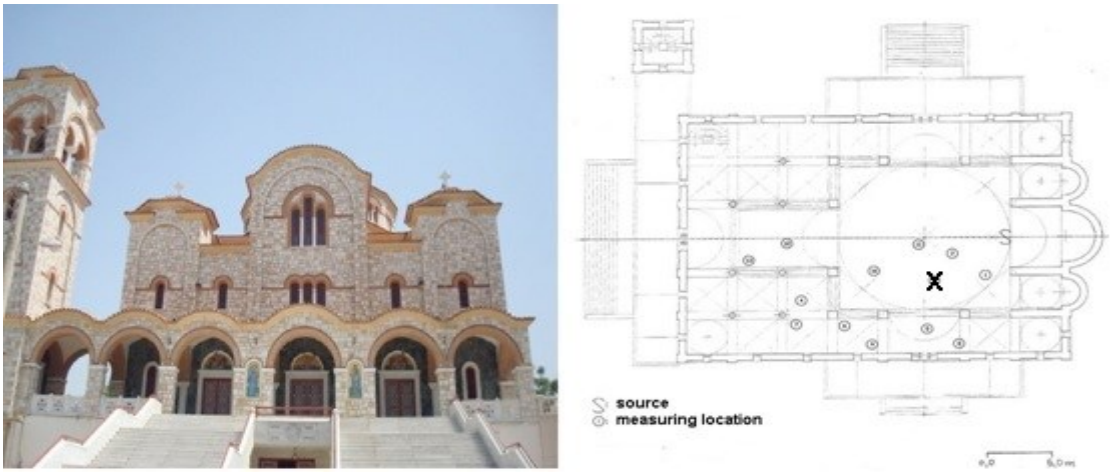

Figure 1: Outside view and plan of Hagia Eirini *(test church No1) Auralised sample location is marked with an* **X**

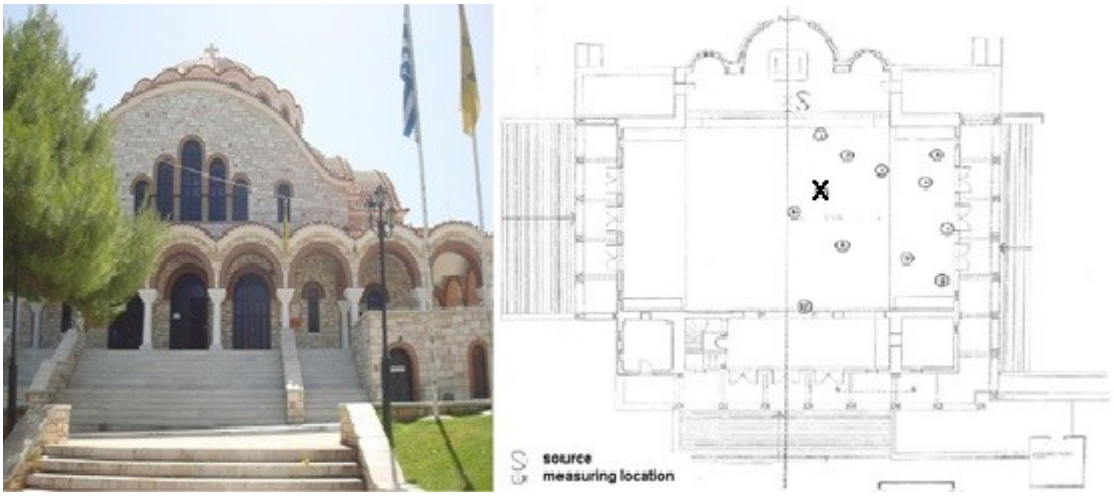

Figure 2: Outside view and plan of Hagia Triada (*test church No 2) Auralised sample location is marked with an* **X**

Figure 3: Outside view of Hagia Sofia *(test church No 3)*

F**igure 4:** Outside view of Hagia Triada *(test church No 4)*

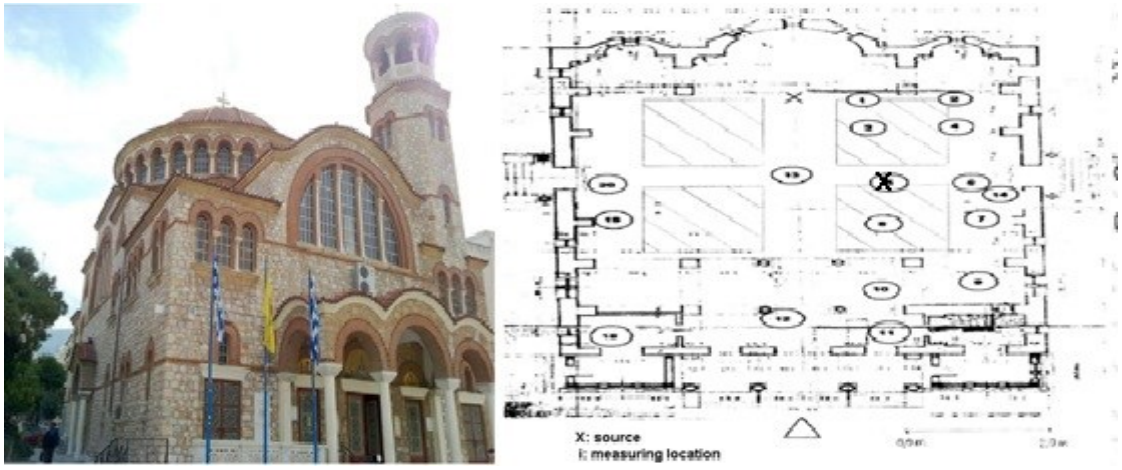

Figure 5: Outside view and plan of Hagios Therapon *(test church No 5) Auralised sample location is marked with an* **X**

A group of fifty (50) ordinary church goers made their evaluations in a typical domestic living room, using headphones (closed-back technology professional headphones AKG-K271). Three subjects at a time, made their evaluations using three sets of headphones, respectively. For each test church, subjects were presented with the appropriate signal (sample chant), and were asked to express their acoustic experience of listening to the sound, by putting a mark at an appropriate distance from the poles, on each of the nineteen (19) rating scales. For each test church, subjects made their evaluations while listening to the auralised signal; this practically lasted for, no more than five minutes, for each assessor. Subjects were twenty to thirty years old, and were instructed to evaluate qualities of the sound, not those associated with the musical content of chant.

The raw scale judgements from the five church evaluations were pooled together and were analysed according to factor analysis[12]. The “principal factoring with iterations” method was used for the extraction of initial factors, and the “varimax” method was used for the orthogonal rotation of factors. Results are shown in Table 3.

5. DISCUSSION

Results from the present evaluations of auralised chant, confirmed the hypothesis of this study; namely, that the labels employed in the rating scales, refer to a much smaller number of independent acoustic qualities of orthodox churches of modern Greek period. This result is in agreement with earlier findings from live Byzantine liturgy evaluations[7]. This result is also in agreement with findings from earlier subjective acoustic evaluations, performed through recordings and/or in live concerts, concerning halls of i) classical music[13,14,15], ii) opera[16,17], iii) jazz music[18,19], and iv) rock music[20].

The present Factor I, namely DISTINCTNESS / PREFERENCE accounted for a relatively high percentage of the total variation of subjective data (Table 3); i.e. this was a relatively strong factor. Also, “preference” and “pleasantness” of the overall acoustics of the test chant, was determined by this factor. In particular, “preference” was determined by scales such as “distinct”, “harmonious”, “balanced”, etc. which loaded highly on Factor I and apparently they all referred to a common sound quality. Obviously, the label “distinct” in this case referred to a

sound that was exquisite / sublime, rather than to a clear sound. This interpretation is supported by the fact that: the test signal had no rhyme, and Byzantine chant alone comprises sounds sustained enough, so that clarity could have well been of no concern, in the present tests. Furthermore, Factor I was, by and large, in agreement with the first of two Factors of an earlier study[7] that involved live evaluations of unamplified Byzantine liturgy.

Factor II was named DEPTH / FULNESS, after the scales “deep”, “full”, “long” etc. that emerged with high loadings on this.

Last, Factor III, namely SUBJECTIVE INTENSITY was loaded highly by scales such as “intense”, “live” etc. This Factor (III), by and large, was in agreement with factor STRENGTH of an earlier study[7] that involved live evaluations of unamplified Byzantine liturgy.

For each subjective factor, an analysis of variance test was applied to the factor scores (Table 4). Results showed that, for all factors, there were significant differences between churches, i.e. the mean church subjective judgments were the effect of some systematic objective influence(s). The identification of these influences in terms of physical room acoustic criteria can be the object of future studies.

1	Clear	-Blurred
2	Intense	-Calm
3	Toneless	-Harmonious
4	Live	-Dead
5	Empty	- Full
6	Pleasant	- Unpleasant
7	Cold	- Warm
8	Rich	- Poor
9	Shallow	- Deep
10	Soft	- Rough
11	Far	- Near
12	Weak	- Mighty
13	Distinct	- non distinct
14	Dull	- Special
15	Harmonious	- Dissonant
16	Wide	- Restricted
17	Balanced	- Unstable
18	Long	- Short
19	Preferred	- non Preferred

Table 2: List of opposite labels used at the poles of present rating scales

Factor	Associated scales	Factor loadings	Pctg. Variance (%)
I.DISTINCTNESS/ PREFERENCE	Distinct - non distinct	0,79	26,80
	preferred - non preferred	0,78	
	pleasant - unpleasant	0,73	
	harmonious - dissonant	0,70	
	balanced - unstable	0,70	
	dull - special	- 0,62	
	far - near	- 0,56	
	cold - warm	- 0,55	
II.DEPTH/FULNESS	shallow - deep	0,78	15,15
	long - short	- 0,68	
	empty - full	0,62	
	wide - restricted	- 0,60	
	rich - poor	- 0,55	
III.SUBJECTIVE INTENSITY	Intense - calm	0,73	9,43
	live - dead	0,63	
	soft - rough	- 0,59	
	Cumulative percentage variance:		51,38

Table 3: Results of factor analysis of data from all test churches. *Listed loadings are above 0.55*

Factor	F-ratio	significance
I. DISTINCTNESS/ PPREFERENCE	2,02	0,00
II. DEPTH / FULNESS	2,33	0,00
III. SUBJECTIVE INTENSITY	3,20	0,00

Table 4: Comparison of subjective factor scores between test churches

6. CONCLUSIONS

Three independent subjective qualities were produced, for the first time from acoustic evaluations of auralised Byzantine chant in orthodox churches of the modern Greek period. Preference, in present study, was found to be associated with “distinct”, “harmonious”, “balanced”, “special” etc. sound. These results, by and large confirm earlier findings from evaluations with live (unamplified) Byzantine liturgy. The present results illuminate some of the ways, ordinary church goers describe their acoustic experience of listening to Byzantine chant. These results can be useful in further work in order to identify, first, subjectively significant physical room acoustic criteria, and ultimately, design principles and techniques for the architecture of orthodox churches.

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8. REFERENCES

[1.] Fausti P., Pompoli R. and Prodi N. ‘Comparing the acoustics of mosques and byzantine churches.’Dipartimento di ingegneria engineering, Università di Ferrara, Italia.

[2.] Hammad R.N.S. Technical Note; (1990) ‘Rasti Measurements in Mosques in Amman, Jordan’.*Applied Acoustics*, Vol. 30, pp. 335-345.

[3.] Lubman D. and Wetherill E.A. (eds) (1983) ‘Acoustics of worship spaces’. In 106th Meeting of Acoust. Soc. Am, San Diego, CA, USA, 7-11 Nov. Am. Inst. Physics publ., N. York.

[4.] Daskalopoulos P. and Kyriakopoulos P. (2010) ‘Acoustics in Greek orthodox churches’. (in Greek) Diploma thesis supervised by assoc. professor A.G. Sotiropoulou, Sch. of Civil Eng., Tech. Univ. Athens, Athens.

[5.] Karpontini M. (2011) ‘Acoustic design in Greek orthodox churches’. (in Greek) Diploma thesis supervised by assoc. professor A.G. Sotiropoulou, Sch. of Civil Eng., Tech. Univ. Athens, Athens.

[6.] Rouvas S. and Veltsistas I. (2011) ‘Acoustics in Greek orthodox churches’. (in Greek) Diploma thesis supervised by professor G. Poulakos, and assoc. professor A.G. Sotiropoulou, Sch. of Civil Eng., Tech. Univ. Athens, Athens.

[7.] Sotiropoulou A.G., Vlachos G., Stamos A., Achamnos P. (2013) ‘Subjective acoustic evaluation of Byzantine live liturgy in churches of modern Greek period’. Echopolis 2013: Sounds, noise and music for re-thinking sustainable building, city and eco-neighbourhood: Proceedings of the International Conference Echopolis 2013, 29 Sept.- 3 Oct., Athens.

[8.] Tzekakis E. (1975) ‘Reverberation time of Rotunda of Thessaloniki’. J. Acoust. Soc. Am., Vol. 57, No. 5, pp. 1207

[9.]Tzekakis E. (1979) 'Data of the Acoustics of Byzantine Churches of Thessaloniki'. Acustica, Vol. 43, pp. 275.

[10.]Karampatzakis P. (2009) 'Acoustical measurements in eleven byzantine churches in Thessaloniki'. In 4th Conference of the Hellenic Institute of Acoustics (HELINA), Oct. 2008, Xanthi, Greece. Proceedings of the Conference, N. Barkas (ed), HELINA, Thessaloniki, pp. 44-56.

[11.]Osgood C.E., Suci G.J. and Tannenbaum P.H. (1957) 'The measurement of Meaning'. University of Illinois Press, Urbana Il.

[12.]SPSS Inc.. Advanced Models 12.0, Prentice Hall (2003).

[13.]Sotiropoulou A.G., Hawkes R.J. and Fleming D.B. (1995) 'Concert Hall Acoustic Evaluations by Ordinary Concert-Goers: I. Multi-dimensional Description of Evaluations'. *Acustica,* Vol. 81, pp. 1-9.

[14.]Hawkes R.J. and Douglas H. (1971) 'Subjective acoustic experience in concert auditoria'.*Acustica,* Vol. 24, pp. 235-250.

[15.]Wilkens H. (1977) 'Multidimensional description of subjective evaluations of concert hall acoustics'. (in German) *Acustica*, Vol. 38, pp. 10-23.

[16.]Laoudis P.S. (Oct. 2010) 'Subjective acoustic evaluations in opera auditoria'. (in Greek) Diploma thesis supervised by assoc. professor A.G. Sotiropoulou, Sch. of Civil Eng, Tech. Univ. Athens, Athens.

[17.]Sotiropoulou A.G., Poulakos G., Cambourakis G., Velesiotis D. (2013) 'Subjective acoustic evaluations of opera houses'. Echopolis 2013: Sounds, noise and music for re-thinking sustainable building, city and eco-neighbourhood: Proceedings of the International Conference Echopolis 2013, 29 Sept.- 3 Oct., Athens.

[18.]Sotiropoulou A.G., Savvopoulou A., Karagiannis J., and Tzouvadakis J. (2011) 'Subjective Evaluation of Acoustics in Jazz Clubs'.*Acoustics Bulletin,* Vol. 36, No. 5, pp. 24-31.

[19.]Sotiropoulou A.G., Poulakos G., Karagiannis J., and Tzouvadakis J. (2008) 'Subjective Evaluation of the Acoustics of Jazz Music Auditoria; Multi-dimensional Description of Evaluations'. In 7th International Conference on Auditorium Acoustics, Oslo, Oct. 3-5.Proceedings of the Institute of Acoustics, Vol. 30, Part 3, pp. 326-332.

[20.]Sotiropoulou A.G., Tzouvadakis J., Karagiannis J., Savvopoulou A. (2013) 'Subjective acoustic evaluations in live rock music concerts'. Echopolis 2013: Sounds, noise and music for re-thinking sustainable building, city and eco-neighbourhood: Proceedings of the International Conference Echopolis 2013, 29 Sept.- 3 Oct., Athens.