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Acoustic parameters of chosen Orthodox churches overview and psychoacoustic estimation of their use for choral music

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A lot of acoustic research was done for Roman Catholic churches and because of some differences in traditions and culture comparing to Orthodoxy, it is not the best idea to use its acoustic estimators for Orthodox churches. The article shows results of measurements in some Orthodox churches in Poland and the proposal of psychoacoustic tests using the convolution technique, which would allow formulating the new acoustic outlines for Orthodox churches. The research has been done especially considering choral music, which is inseparable part of East Christians culture, so as a test sounds, there were Orthodox choir sound samples recorded in anechoic chamber convoluted with impulse response of measured churches.

1 Introduction

Roman Catholic churches acoustics is the point of interests of many scientific groups [1-5]. On the other hand, there are no many investigations conducted at Orthodox Churches, which should induce to focus on that subject. In the Orthodox Church singing is a major element of service and religious tradition in general. A situation is the same in large cathedrals with professional choirs as in small local churches where all the parishioners sing during services. Even a priest, deacon and psalmist sing while reading (it is a kind of recitative). The only spoken parts are the sermon and current information. These proportions determine expectations of acoustic field in orthodox churches. This work shows results of measurements in some Orthodox churches in Poland and the proposal of psychoacoustic tests using the convolution technique, which would allow formulating the new acoustic outlines for Orthodox churches

2 The research methodology

To classify orthodox churches considering their acoustic values, measurements of some popular interiors were made. The first step of research is a typical impulse response parameters calculation. Because of the fact that there are many objective parameters that describe room acoustic (RT, EDT, TS, IACF, IACC, C50, C80, C10 ..., LF, G, BR, ST1, D50, STI, RaSTI, AlCons, LA ... [1,6]) only the essential ones for this research were chosen. T20 and EDT are considered as reverberating overall parameters. Energy ratio position-related assessment are: C50 for speech and C80 and ST for music. To compare speech intelligibility RaSTI and AlCons values are being used [7]. But it is not enough only to list chosen values and compare them. There are acoustical criteria for churches (table 4, [1]) but most of them are for Roman Catholic and Protestant Churches which have different acoustics requirements and aesthetics compared to orthodoxy. Another solution is to use concert hall and opera criteria but intuitively it is also not a best idea. For a better estimation which considers orthodox choir music as major medium psychoacoustics, listening tests were done. Choral music samples were recorded in anechoic chamber and convoluted with measured impulse responses in churches.

2.1 Numerous room-criteria investigations

Measurements were made using one-way loudspeaker, RME Fireface 800 audio interface, omni-directional microphone and EASERA software. As a test signal there was MLS and SWEEP-sine 16 [bit], 48 [kHz] sequence.

The first and the most important object measured was Holy Trinity Orthodox Cathedral in Hajnowka (figure 1). It is very famous for its great acoustics and well-known because of the international festival "Hajnówka's Orthodox Church Music Days". This great cultural event is organized annually in May. Every year the festival hosts more than a thousand singers from various countries representing Christian music of different traditions such as eastern Greek and Slavonic, western, Syrian and others.

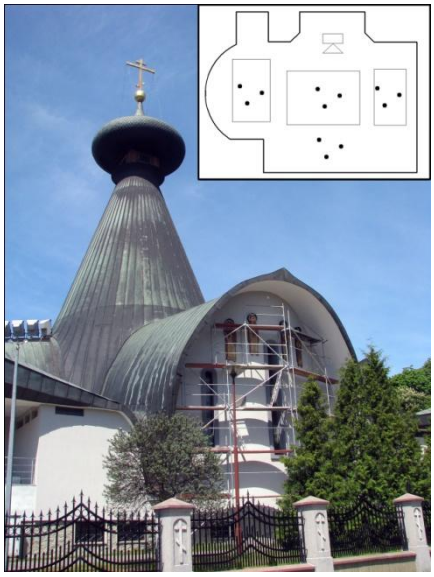

Figure 1: Picture and measuring point scheme of Holy Trinity Orthodox Cathedral in Hajnowka (Poland)

It has one large dome and is complex in shape. It represents a modern architecture which refers to Byzantium style. It has a marble floor and smooth walls covered by frescos. There are many stained glass windows and ornaments. There are hardly any sitting places or other sound absorbent materials.

Table 1: Acoustic parameters of Holy Trinity Orthodox Cathedral in Hajnowka (Poland)

	T20 [s]	EDT [s]	C50 [dB]	C80 [dB]	ST [dB]	RaSTI	AlCons [%]	other
Avarage value - $\overline{x}$	3,5	3,3	0,9	1,3	-7,6	0,6	9,6	close to source
Standard deviation - σ	1,3	0,6	1,6	1,5	2,1	0,05	2,2	
Avarage value - $\overline{x}$			-11,0	-7,6	28,5	0,3	30,2	far from source
Standard deviation - σ			3,7	1,5	1,6	0,02	3,3	

The results which are shown in table 1. illustrate significant differences related to source distance. It could be a result of a huge dome under the central part of church.

The second measured object was Saint Martyr Dmitry Orthodox Church in Hajnowka (figure 2) has a very traditional East Slavic structure. It has a regular shape based on Greek cross and the interior is devoid of ornaments, sitting places or any other items that cause sound diffusion or absorption. It also has also marble floor and smooth walls with some frescos. It is smaller than a cathedral of Holy Trinity but its acoustic estimators (table 2) are quite similar. Reverberation time is a little bit longer and energy ratio parameters are much lower than in a previous church. In both cases analyzed parameters are different from church criteria (table 4) and have nothing in common with opera or concert hall recommended acoustic assessments.

Figure 2: Picture and measuring point scheme of Saint Martyr Dmitry Orthodox Church in Hajnowka (Poland)

Table 2: Acoustic parameters of Saint Martyr Dmitry Orthodox Church in Hajnowka (Poland)

	T20 [s]	EDT [s]	C50 [dB]	C80 [dB]	ST [dB]	RaSTI	AlCons [%]	other
Average value - $\overline{x}$	4,0	3,6	-3,2	-2,2	-1,4	0,4	15,3	close to source
Standard deviation - σ	0,4	0,2	0,7	0,7	0,2	0,05	8,7	
Average value - $\overline{x}$			-7,3	-5,0	32,1	0,3	27,2	far from source
Standard deviation - σ			3,3	2,6	5,4	0,05	9,9	

The third was Orthodox Church of Saint Nicholas (figure 3) in Bialowieza (Poland) which is the oldest and the smallest of all measured objects. It was built in 1894 by Tsar of Russia Alexander III in small village of Bialowieza Forest one of the oldest ancient woodland where he used to hunt. It is regular in shape and it is very similar to Saint Martyr Dmitry Church but also it is few times smaller. Its acoustic parameter is different from previous churches and in contrast to them, they meet the recommended acoustic criteria for churches (table 4).

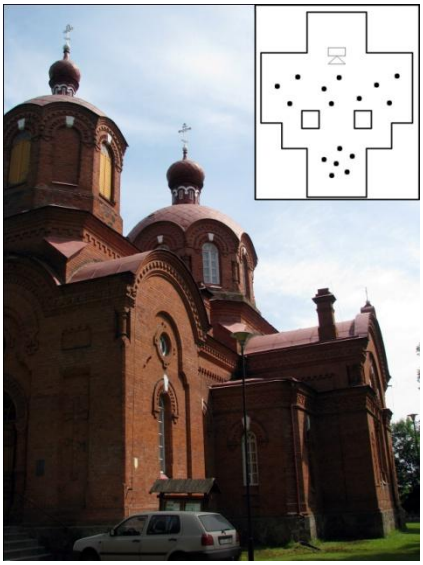

Figure 3: Picture and measuring point scheme of Saint Nicholas Orthodox Church in Bialowieza (Poland)

Table 3: Acoustic parameters of Saint Nicholas Orthodox Church in Bialowieza (Poland)

	T20 [s]	EDT [s]	C50 [dB]	C80 [dB]	ST [dB]	RaSTI	AlCons [%]	other
Avarage value - $\overline{x}$	1,9	1,8	0,0	1,4	-0,9	0,5	9,0	close to source
Standard deviation - σ	0,1	0,2	1,4	1,4	2,7	0,04	1,5	
Avarage value - $\overline{x}$			-9,3	-5,7	34,7	0,4	19,8	far from source
Standard deviation - σ			0,3	0,4	1,0	0,03	1,8	

All measured churches frequency distribution of reverberating time is typical. There is longer time for low bands and very short for high frequencies. Disproportion is more apparent for Saint Martyr Dmitry Church in Hajnowka than other two measured churches.

Table 4: Preferred acoustic parameters for churches [1,7]

	RT [s]	C50 [dB]	C80 [dB]	ST [7] [dB]	RaSTI	AlCons [%]
close to source	1,5÷3,5	2÷10	3÷8	-12÷-15*	0,6÷1	0÷10
far from source			0÷5			

2.2 Psychoacoustic estimation of different acoustic climates

In order to evaluate new acoustic standards and recommendations for orthodox churches psychoacoustic listening tests were conducted. The greatest difficulty was to obtain samples of choral music recorded in the free field. Orthodox choral music is quite complex and multi-voice (typically 4 voices). For this research the recording of chamber orthodox choir was provided in an anechoic room at AGH University. The choir consisted of 8 singers (2 in each voice). The choir was recorded using multichannel recording system (figure 4). There was a problem with hearing between choir members which are used to singing in strongly reverberating field of churches and concert halls.

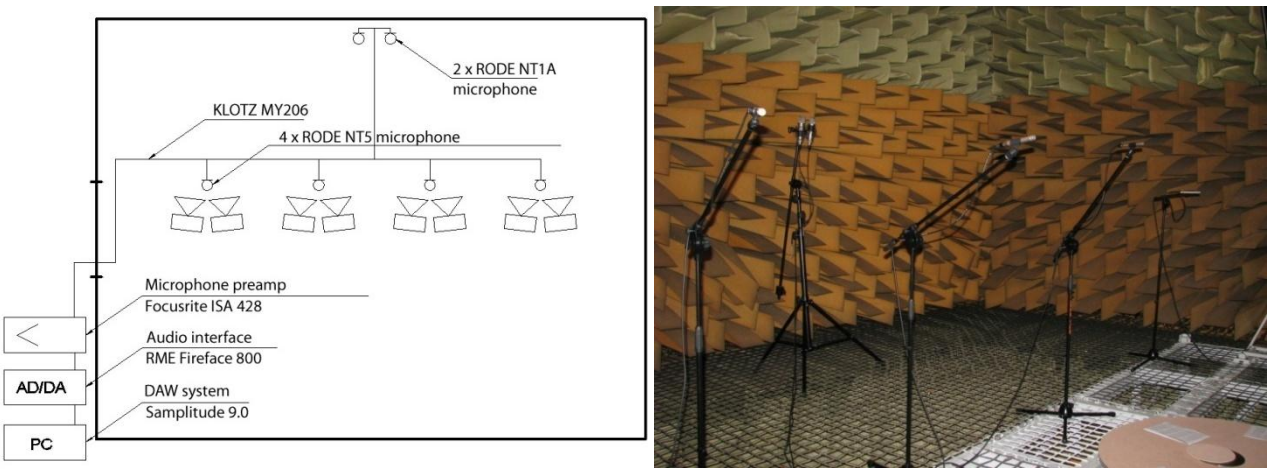

Figure 4: Scheme of recording channel in anechoic room and a used system photo
(singers are presented by loudspeakers)

Recorded and mixed samples were convoluted with measured impulse responses and used to subjective listening tests. Convolutions were calculated using *Room Simulator* the *Samplitude*'s 9.0 *VST* (Virtual Studio Technology) plug-in. The tests were performed on group of 35 people with different music experience including students of academy of music, acoustic engineering and without any acoustical experience. Every listener worked with headphones and could listen to samples and rate them as long as he/she wanted. Listeners had three criteria to judge: feeling of space, timbre and

general impression. The results are calculated and shown as graphs (figure 5) which indicate that listeners definitely preferred churches with longer reverberation time. In all cases Saint Nicholas church had the lowest rates. On the other hand, Holy Trinity Cathedral in Hajnowka was highly rated considering all criteria. These results are confirmed by opinions of directors, composers and singers from all over the world who take part in "Hajnowka's Orthodox Church Music Days". It is also noticeable that the general impression which was the most important and obligatory to rate by listeners is correlated with other parameters.

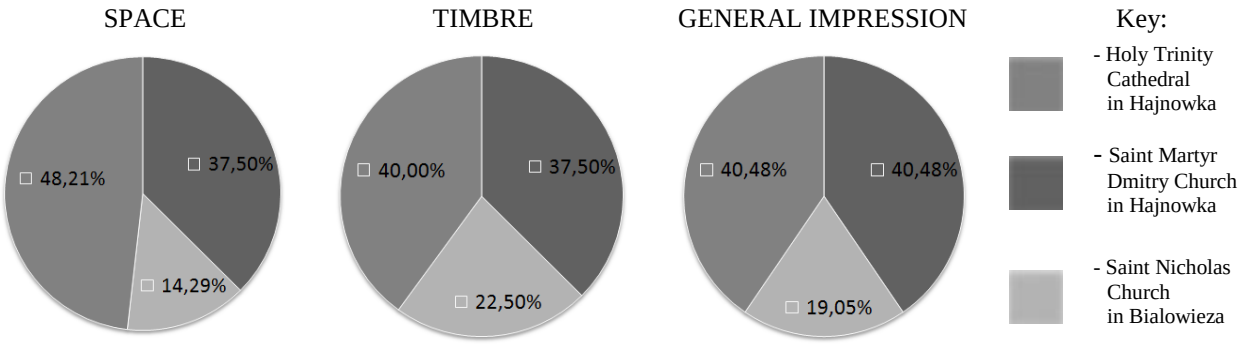

Figure 5: Listening test results

3 Conclusions and the course of changes

The research shows that existing criteria (table 4) do not agree with subjective feeling of listeners (figure 5) and specialists-musicians. It seems that there is a need to develop original acoustic outlines for Orthodox churches which have different requiems and esthetics. These researches should be continued with improved methodology. These preliminary investigations have shown that:

- Impulse response recording channel should be proper both for measurements and for convolution to listening test (or as a filter for audio mixing). It should be considered using a source and a microphone with directional characteristics close to human body properties. Obviously, it should also be checked if acoustic estimators measured in this way are not too much different from those measured in a traditional and normalized way using an omni-directional source and a microphone.

- There is a need to examine much more churches of different style, size, region or different by some other criteria. Especially to focus on objects from Poland, Ukraine, Russia and Belarus. Orthodox churches in this countries are quite similar and have the same origins and many common traditions. Moreover, there is a lack of this kind of research in general [8]. Actually, there is a lot of research done in Serbia [9][10] so there is a possibility of comparing it to its acoustic parameters but Balkans culture is too different from East-Slavs to treat these churches as the same category.

- Recording in anechoic room should be done with headphones monitoring for all singers to improve pitch and tempo accuracy. There should also be a priest, lector or other solo recitative part recorded to consider speech intelligibility.

- The SWEEP sine signal technically caused better S/N ratio than MLS signal. This quality induces researchers to use not only one way speakers but two or three way with flat frequency characteristics and high efficiency.

There is also an idea to record a few impulse responses with different source acoustic axis direction and position, and during the mixing process to convolute particular tracks with impulse responses from different points (for example to record impulse responses using source positions corresponding with choir voices location during performance).

4 Summary

According to obtained result, the existing acoustic criteria should be extended by Orthodox churches as a separate indoor category. Increasing popularity of choral music and (in particular) of East-Christians choral music show that this subject is worth of interest. New outlines for this area would be useful for architects during church design process and for sound engineers. It could be helpful to choose an appropriate indoor for recording or to choose optimal room filter during audio mixing process.

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