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Acoustic Investigations of the Contemporary Churches in Poznań

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Abstract

The paper discusses acoustic issues of contemporary churches. Church interiors should be designed so as to obtain intelligibility of speech and simultaneously take organ music into account. It is a tough task as acoustic parameters required for speech and organ music are entirely different. Analysis of the issue was carried out on the basis of investigations in five contemporary churches in Poznań. In total, seven interiors were investigated as two of the churches were two-storeyed. The acoustic investigations were conducted by means of an omnidirectional sound source, a SVAN 945A Sound Level Meter and the DIRAC programme. *RT, Ts, C80* and *C50* were measured. The acoustic parameters were compared with values recommended for churches. The investigations allowed to draw clear conclusions concerning the influence of architecture of the interior on acoustic parameters.

Keywords: church acoustics, acoustic investigation in church.

1. Introduction

Acoustics of the interior are tightly connected with the architecture of the building. Architecture of many churches promotes the occurrence of excessive reverberation, which limits intelligibility of speech. In result, the main function of the sacral interior, i.e. the conduct of liturgy, is considerably hindered. In addition, it is crucial to realize that acoustics in church interiors is a complex issue as it is difficult to combine entirely different acoustic requirements in one interior. The basis of a Roman Catholic liturgy is intelligibility of speech; however, liturgy involves organ music. Acoustic requirements for speech differ diametrically from those for organ music. Depending on the main function designed for a sacral interior, the recommended reverberation time takes different values, contingent on the cubature (Fig. 1).

In literature dealing with the issues of church acoustics, there are books like "*Czynniki akustyki w architektonicznym projektowaniu kościołów*" by Dominika Wróblewska and Andrzej Kulowski [10] and *"Podstawy akustyki obiektów sakralnych"* by Zbigniew Engel, Jacek Engel, Krzysztof Kosała and Jerzy Sadowski [4]. *Worship Space Acoustics* by Mendel Kleiner, David Lloyd Klepper and Rendell R. Torres [8] discusses issues of religious buldings of different faiths.

The issue of reverberance was described, among others, in the papers mentioned below. "*Akustyka wielofunkcyjna wnętrz sakralnych*" by Kosała K., Kamisiński T. [9] discusses the issue of excessive reverberance on the example of the St. Paul's Church in Bochnia. On the basis of measurements and acoustic simulations, acoustic treatment was suggested. *Acoustic properties of the selected churches in Poland* by Z. Engel, K. Kosała [5] presents a new method of acoustic assessment of religious buildings by means of the global index of the acoustic quality. The paper describes the application of the indexing

method for five Roman Catholic churches. *Acoustical characterization of the underground chapels of the new Holy Trinity church in the Fatima shrine* by Carvalho A. P. O., Nascimento B. F. O. [3] discusses acoustics of chapels of the Church of the Holy Trinity in Fatima. Acoustic measurements were taken and acoustic properties of the chapels were compared with typical religious buildings in Portugal. *Acoustic rehabilitation of middle twentieth century Portuguese churches* by Carvalho A. P. O., Cruz M. T., Pereira G. C. G. [2] describes the issue of too long reverberation time and poor intelligibility of speech in two churches from the first half of the 20th century. After investigations, acoustic treatment was suggested. *The improvement of acoustic situation in two modern churches* by Horvat M., Domitrovic H., Jambrosic K. [7] describes acoustic treatment of two newly built churches in Croatia. Results of the investigations were presented for each stage of the applied acoustic treatment.

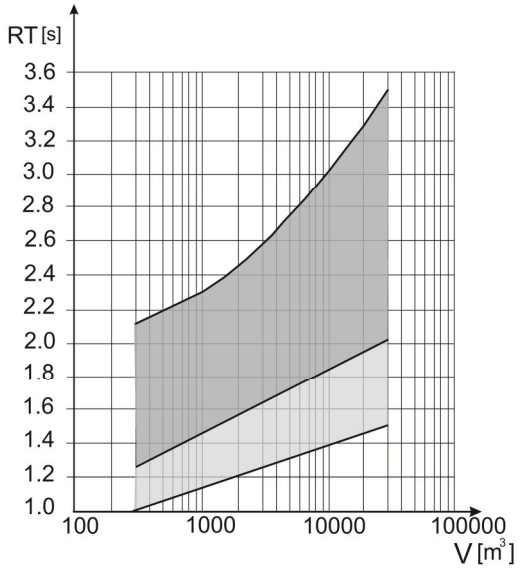

Figure 1. Range of optimum reverberation time for churches [6]

2. Description of the investigations

Acoustic problems of interiors were presented on chosen examples of contemporary churches in Poznań. The acoustic investigations were conducted by means of an omnidirectional sound source, a SVAN 945 A Sound Level Meter and the DIRAC programme. The Brüel & Kjær ZE-0948 USB Audio Interface was used.The e-sweep signal was generated and *RT, Ts, C80* and *C50* were measured. The measured acoustic parameters were compared with values recommended for churches. In total, seven interiors were investigated as two of the buildings were two-storeyed. The churches under investigation were compared in Table 1.

Table 1 Investigated churches

	**1** and **1a.** Visitation of Blessed Virgin Mary Church (two-storey church) **1**. Upper church - cubature = 19000 m³ **1a.** Lower church – cubature = 4800 m³
	**2.** Church of the Blessed Virgin Mary Mother of the Church Cubature = 6700 m³
	**3 and 3a.** Christ the King church (two-storey church) **3.** Upper church - cubature = 4600 m³ **3a.** Lower church – cubature = 315 m³
	**4**. Church of the Nativity Cubature = 4800 m³
	**5.** Church of the Ascension Cubature = 4800 m³

Table 2 shows the comparison of reverberation time *RT* and centre time *Ts*. Fig 2. shows the comparison of reverberation time *RT* in the frequency characteristics. The recommended values in all tables were taken from the book [10].

Table 2 Comparison of reverberation time and centre time

Name of the church	***RT* [s]**			***Ts* [ms]**	
	mean	500-1000 [Hz]	recommended mean	mean	recommended
1. Visitation of Blessed Virgin Mary Church – upper church	5.9	7.1	1.5-3.3	410	120 - 180
1a. Visitation of Blessed Virgin Mary Church – lower church	3.8	4.1	1.3 -2.7	298	60-100 organ music to 180
2. Church of the Blessed Virgin Mary Mother of the Church	2.7	3.2	1.3-2.8	196	70 – 120 organ music 120 -180
3. Christ the King church – upper church	3.3	3.8	1.3 -2.7	248	60-100 organ music to 180
3a. Christ the King church - lower church	1.6	1.6	1.3 -2.7	135	60-100 organ music to 180
4. Church of the Nativity	5.0	5.4	1.3 -2.7	367	60-100 organ music to 180
5. Church of the Ascen-sion	2.9	3.2	1.3 -2.7	194	60-100 organ music to 180

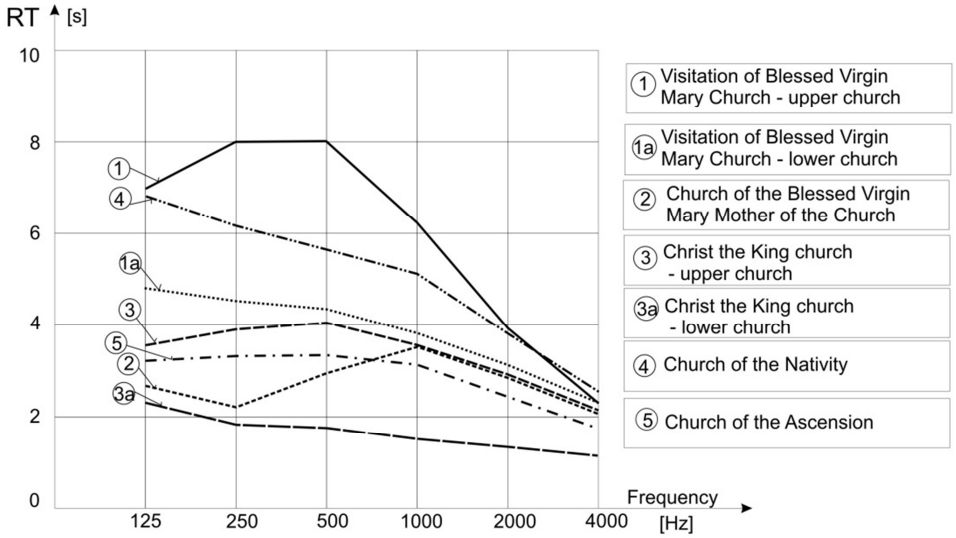

Figure 2. Frequency characteristics of averaged reverberation time in the investigated churches

In most of the investigated cases, reverberation time was too long. Most notably, church No 1 (of cubature equal to 19000 m³) had a considerably exceeded reverberation time. The measured reverberation time was $RT = 5.9$ s, whereas the recommended reverberation time for a church of this cubature equals $RT = 1.5 – 3.3$ s. Reverberation time close to the recommended value occurred in churches No 2, 3a and 5. To asses the clarity of music sound, centre time *Ts* is applied; *Ts* is the center of gravity along the time axis of the squared impulse response [1]. *Ts* close to the recommended value occurred in churches No 2 and 5.

Table 3 shows results of measurements of clarity index *C80*. This parameter is applied to determine quality of the music sound. In the logarithmic scale, it describes the ratio of the energy of the sound reaching the measuring point within first 80 ms to the energy of the sound reaching it after 80 ms [6]. According to recommendations given in literature [10], *C80* was averaged for 0.5, 1, 2 kHz. Apart from the rear part of church No 1a, the investigated churches had conditions suitable for organ music.

Table 4 presents results of measurements of clarity index *C50*. By analogy, the index is defined like *C80*. The measurements allow to calculate the weighted value of clarity index *C50*. Octave bands 0.5, 1, 2, 4 kHz are multiplied by the weighting factor equal to 0.15, 0.25, 0.35 and 0.25 for each band respectively; thus obtained results are added. In all examined churches, index *C50* did not reach recommended values. It was at its closest to the recommended value in church No 3a, while it was particularly unfavourable in the rear part of church No 1a.

Table 3 Comparison of clarity index *C80*

Name of the church	***C80* [dB]**				
	first row	recommended	last row	recommended	general recommendations
1. Visitation of Blessed Virgin Mary Church – upper church	-2.6 -4.5 -8.2	>0	-5.9 -7.3 -8	-1 to1	organ music -8 to -3 oratorio music -3 to 6
1a. Visitation of Blessed Virgin Mary Church – lower church	-1.8 -2.3 -3.3	>0	-17.3 -18.6 -17.9	>2	symphonic and oratorio music -3 to 6 organ music < -3
2. Church of the Blessed Virgin Mary Mother of the Church	-2.5 -1.4 -0.4	>0	-3.5 -5.1 -5.3	>2	symphonic and oratorio music -3 to 6 organ music < -3
3. Christ the King church – upper church	-2.0 -4.8 -6.2	>0	-5.3 -6.0 -5.3	>2	symphonic and oratorio music -3 to 6 organ music < -3
3a. Christ the King church – lower church	-0.7 0.3	3 to 8	-1.7 -1.6	-	> 6 electronic organ
4. Church of the Nativity	-4.5 -5.0 -5.6	>0	-8.4 -8.2 -8.0	>2	symphonic and oratorio music -3 to 6 organ music < -3
5. Church of the Ascension	-1.3 -3.3 -0.4 -3.6	>0	-4.6 -4.0 -4.1 -3.6	>2	symphonic and oratorio music -3 to 6 organ music < -3

Table 4 Comparison of clarity index *C50*

Name of the church	***C50* [dB]**		
	mean	range of variation	recommended
1. Visitation of Blessed Virgin Mary Church – upper church	- 8.6	-2 to -13	> -2
1a. Visitation of Blessed Virgin Mary Church – lower church	- 15.4	-3.8 to -41	> -2
2. Church of the Blessed Virgin Mary Mother of the Church	-8.1	-4.3 to -17	> -2
3. Christ the King church – upper church	-7.9	-2.9 to -12	> -2
3a. Christ the King church – lower church	-3.7	-2.7 to -5.5	> -2
4. Church of the Nativity	-8.6	-5.8 to -10.5	> -2
5. Church of the Ascension	-5.4	-0.6 to -8.0	> -2

3. Conclusions

The interiors of the examined churches show prominent lack of acoustic adaptation. Acoustic conditions in the churches result from the applied building materials with low sound absorptive coefficient. They are materials typical of the Polish religious buildings, i.e. brick, concrete, plaster, stone and glass. If the acoustic conditions are close to the recommended values, it is owing to either a small cubature of the building or the application of truss roof construction with a suspended ceiling. Church 3a with a small cubature is actually used as a chapel, while churches 2, 3 and 5 have suspended ceilings mounted on bottom chord of the truss. In church No 2, thin aluminium plates tiles were applied; the way of mounting ensures penetration of the sound to the spaces between the bars of the trusses. In church No 5, a construction of plaster-cardboard tiles was attached to the truss; among the tiles, there are several centimetres spaces. This way of mounting ensures penetration of the sound to the space between the ceiling and the roof. In both churches, such ceiling constructions boost sound absorption in contrast with a monolithic reinforced concrete ceiling in church No 4. Church No 3 also has a suspended ceiling mounted on trusses, but the church's timber construction tightly cuts off the interior from the space between the bars of the trusses, which results in the decrease of sound absorp-

tion. It is recommended that churches with considerably exceeded reverberation time (1, 1a and 5) undergo acoustic treatment.

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