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ACOUSTIC ISSUES OF SACRAL STRUCTURES

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In the paper sacral structures treated as speech-music halls were evaluated in terms of acoustic properties. The basic acoustic issues occurring at a planning stage as well as the methods of evaluation of the finished, existing and being modernized interior acoustic quality of sacral structures are discussed. Acoustic requirements refer to some type of liturgical ceremonies, and to cultural activities performed as well in those structures. The current status of church acoustics in structures built in different periods up to 1950 is presented. The methods of evaluation of the sacral interiors acoustic quality are nowadays significantly improved. They are discussed on an example of newly designed churches.

1. Status of the issue

The problem of sacral structure acoustics is a part of room acoustics. Thus it is evident that, the task of the former is twice that of the latter as illustrated after H. KUTTRUFF in Fig. 1 [25]. Figure 2 shows the problem of room acoustics from the viewpoint of designing and estimation of the sacral structure acoustics.

In Poland, the problem of sacral structure acoustics has been neglected contrary to other European countries where suitable attention was paid to this question.

This situation existed even after 1987 when the development of sacral buildings has been intensified. Even now, when the insufficient financial support is the only barrier for investigation, only some of the Universities and Research Institutes deal with this issue. This results in the creating of a number of churches (of different religions) with poor acoustic characteristics, because their designers are not acquainted with the results of acoustic research and pay attention only to architectural forms and functional solutions. They seem to forget that the acoustic characteristics of interiors contribute to the final assessment of the structure quality.

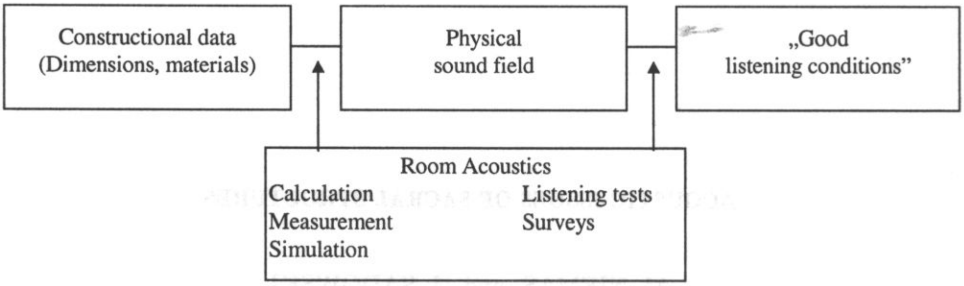

Fig. 1. Tasks and methods of room acoustics [25].

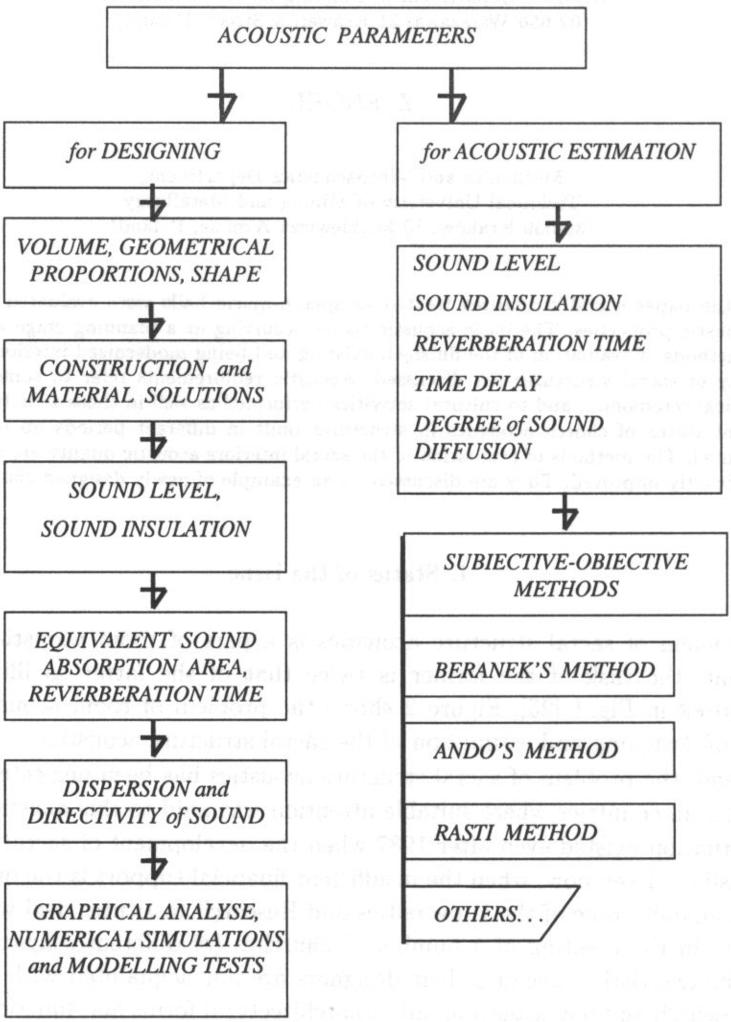

Fig. 2. Problems of room acoustics from the point of view of designing and estimation of the sacral structures acoustic.

In the year's 1975÷1985 acoustic investigations of the temples were realized at the Technical University of Gdańsk only. The first one was the room acoustical investigation of the Gdańsk-Oliva Cathedral. As the Oliwa Cathedral with its famous organ has become a world known place for church organ music, it requires a thorough acoustical investigation concerning the organ quality, the room acoustics properties and their independence. The results of the acoustical investigations were presented [9].

The next was the room acoustic investigations of the Saint Mary's church in Gdańsk built in the XIV-th century. It is the largest church in Poland. Its internal volume is about 97000 m^3.

Saint Mary's church in Gdańsk, due to the large volume of its interior and poor absorption, presents a serious acoustic problem. Acoustic studies on the properties of this interior and the possible acoustic corrections connected with the installation of the new great organ in the baroque style are described in [8, 39, 50, 51, 52].

Large churches differ acoustically from other multipurpose large halls by the distributed sound reinforcement systems applied for service transmission, as well as by depending on the architectural style and the highly variable sound absorption according to the large church acoustics. Some suggestions, parameters of St. Mary's Basilica in Gdańsk have been given as an example of the acoustic problem of a large church [9, 39].

Irrespective of the period of erecting the church, two groups of acoustic issues are playing an important role, namely the protection of the sacral interiors, and sometimes their vicinity, against external noise and vibrations and the acoustics of the sacral interiors.

The way of the formulation of those issues was connected over centuries with characteristic features of a given period referring to the site planning, culture of the society, building style of this period, structural and material solutions, decorative art, and availability of financial means connected mainly with the public liberality. It was also greatly influenced by historical events, invasions, wars, bondage and discrimination in the different periods of the polish history. All these factors influenced the status of sacral structures, including their acoustics (Fig. 3).

Protection of the sacral structures against noise has been formed naturally over ages and resulted from functional, structural and material solutions of these structures. The acoustics of interiors, however, resulted not only from functional solutions but also from styles governing in particular periods, the use of massive constructions, lack of sound amplification devices. The reverberation time calculated from the known Sabine's formula, and also that measured, was the only important acoustic parameter used for evaluation of the quality of the sacral structures acoustics. It was been for long years the only parameter which could be used for designing purposes as well as for the acoustic evaluation of the realized or modernized interiors. According to shape and interior – decorations, the degree of coupling of particular interiors, number of sculptures (e.g. the saints' statues), the interior form, and also the number, shape and localization of columns as well as other architectural elements a second important factor of the acoustics of interiors has been formed – the index of sound dispersion. This index, influencing the interior acoustic quality, caused that large sacral interiors with a very high reverberation time disadvantageous for its characteristics had pretty good acoustic properties.

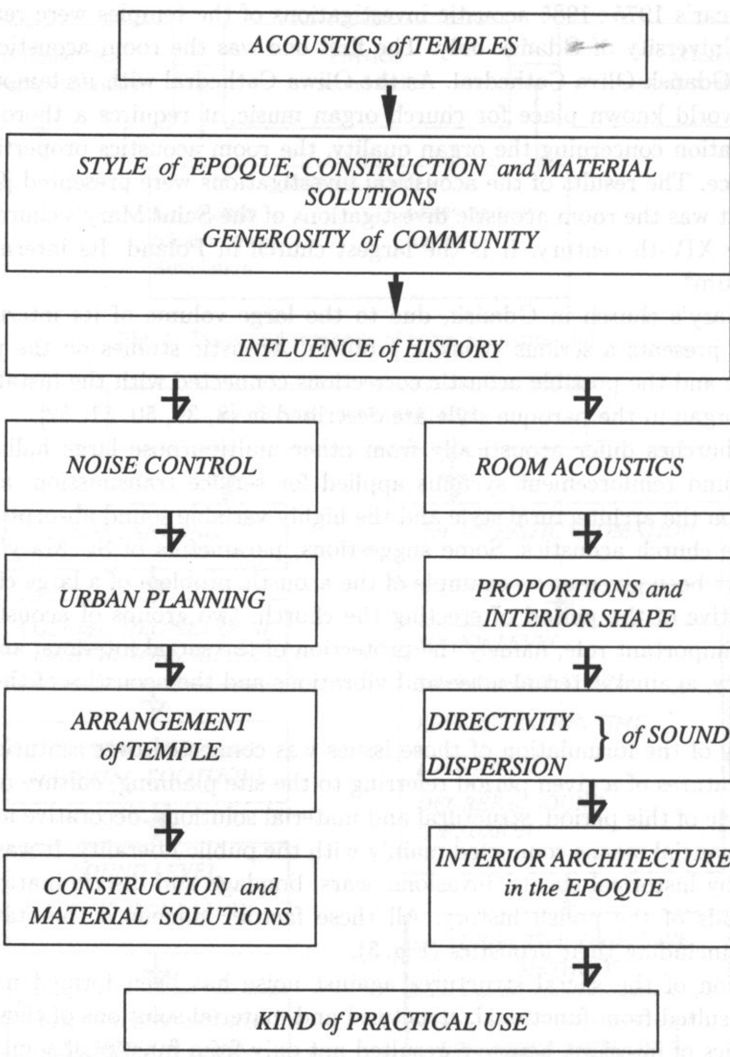

Fig. 3. Factors influencing in status of sacral structures including their acoustics.

2. Development of investigations of the room acoustics phenomenon

For a long time, the reverberation time of rooms was the most important factor of room acoustic estimation and design. Very important was the fact that it could be calculated with reasonable accuracy from room data by the simple Sabine's formula (1).

$$T = 0.161\frac{V}{A}, \quad \text{s} \tag{1}$$

where V – the room volume in m^3, A – equivalent sound absorption area, m^2.

(1) See H. Kuttruff [25], 1991: $T = 0.163\ V/A$.

Suppose the enclosure consist of N different walls, floors, partitions with areas $S_1, S_2, ..., S_N$ etc. and with absorption coefficients $\alpha_1, \alpha_2, ..., \alpha_N$ etc. Then:

$$A = (S_1 \cdot \alpha_1 + S_2 \cdot \alpha_2 + ... + S_N \cdot \alpha_N). \tag{2}$$

In large auditoria ($V \geq 1000\,\mathrm{m}^3$) not only the wall and floor absorption but also the attenuation of sound in air should be included. This is achieved by adding a term 4 mV in the brackets of Eq. (2): m is the attenuation constant of air.

The reverberation time has been introduced into room acoustics by W.C. SABINE (1923) whose work on reverberation and other topics marked the beginning of scientific room acoustics. It can easily be measured, and nowadays it is known for many concert halls, theatres and other auditoria. Basically, reverberation has the tendency to blur the sounds produced in a hall, in particular to impair the intelligibility of speech. It might seem therefore that reverberation should be avoided as far as possible [25].

V.O. KNUDSEN (1932) after dividing the church buildings into three groups as country churches, village churches and city churches has given reverberation times optimal for the church auditorium [22] (Table 1).

Table 1. Optimal values of reverberation times for church auditoriums according to V.O. KNUDSEN [22].

Reverberation time for churches, s	Volume [m^3]					
	1000	2000	4000	8000	16000	32000
Roman Catholic churches	1.5	1.6	1.7	1.8	1.9	2.1
Protestant and Jewish churches	1.3	1.4	1.5	1.6	1.7	1.8
Christian Science churches	1.1	1.2	1.3	1.4	1.5	1.6

In 1956 E. MAYER and R. THIELE [29] have carried out acoustical measurement in 31 different rooms ($V = 550$ to $22000\,\mathrm{m}^3$):

1. Measurements of the reverberation time as a function of frequency.
2. Recording of the reverberation curves with the "impulse glide method".
3. Measurements of sound pressure as a function of frequency and calculation of the frequency irregularity.
4. Recording of the directional distribution of the sound at 2 kHz and calculation "directional diffusiveness".
5. Recording of the reflections of a short pulse and measurement of the "50% energy part".

The results of these measurements show that only the methods 4 and 5, developed according to the geometrical conception of room acoustics, give more information for the judgement of the hearing conditions of a certain place in the room, than the reverberation time does. The subjective significance of the observed phenomena has still to be cleared in detail by means of hearing tests carried out by suitable electroacoustical methods. For this purpose the measured directional distributions and time sequences of the sound reflections will be very useful.

D. FITZROY (1959) [12] observed that when the average absorption was approximately the same in all the directions, the accepted formulas were quite close; thus was confirmed by his experience. But when the distribution of absorption was unequal in terms of direction and in the average absorption per square foot – as, for example, in an all – over ceiling acoustical treatment with little absorption on the side and end walls – the reverberation times, measured by Fitzroy was much longer than the Sabine and Eyring formulas predict [22, 23]. D. Fitzroy gave a reverberation times formula which in the case of nonuniform distribution of absorption seems to be more accurate than the Sabine or Eyring formulas [12, 37]:

$$T = \frac{S_x}{S}\left[\frac{0.161V}{S\ln(1-\alpha_x)}\right] + \frac{S_y}{S}\left[\frac{0.161V}{S\ln(1-\alpha_y)}\right] + \frac{S_z}{S}\left[\frac{0.161V}{S\ln(1-\alpha_z)}\right], \mathrm{s} \tag{3}$$

where V – volume of the room, m^3, $S\ln(1-\alpha)$ – equivalent absorption area of the room, m^2, S_x, S_y, S_z – areas of the walls and floors in direction x, y, z, $\alpha_x, \alpha_y, \alpha_z$ – absorption coefficients of the walls (floor) in direction x, y, z.

In Poland Andrzej RAKOWSKI (1968) and Jerzy SADOWSKI (1959, 1971) described some factors governing the acoustical quality of concert halls. The quality parameters proposed by several authors for room acoustic are discussed in the view of practical demands. The opinions of musicians on some well known concert halls and opera houses are quoted and technical parameters of halls are given [35, 37, 38]. Jerzy SADOWSKI (1971) has published a book [37] (in Polish) with the chapter 21 entitled "The Temple". It was the first book in Poland giving the guidelines of acoustical designing of temples. Some remarks on the reverberation time criterion and its connection with the acoustical properties of a room are given in the publication "Materials from the conference on measurements of reverberation phenomena in halls". The conclusion concerning the reverberation time given by Witold STRASZEWICZ (1968) was as follows: "The results of experiments lead to the conclusion that reverberation time is significant only for classification of the auditoriums as more or less reverberant. The determination of the relation between the results of the reverberation time measurements and the subjective judgement of acoustical quality prove to be difficult. The difficulty results mainly from the spatial character of the reverberation effect and from the general adoption of field diffusity as the basis of the classical measurement methods." It seems that we should dispense with the assumption and try to determine the characteristic field parameters in conditions more resembling those of the normal use of a given interior [46].

In last years, after 1990 have been some investigation results published, which are very useful for the evaluation of the room acoustic phenomenon.

The K. ŚRODECKI and A. ŚLIWIŃSKI (1991) carried out investigations in rooms of various shapes. They have demonstrated that the employment of autocorrelation and cepstrum functions enables the assessment of certain acoustical properties of rooms, i.e. of the degree of sound scattering, the possibilities of the occurence of acoustically unfavourable phenomena such as the sound colouration or echo, influencing in general a property of the room called by the authors the reverberation quality [45].

It is widely known that the measured value of reverberation time does not characterise itself the nature of the reverberation process. Thus the temporal diffusion can, together with reverberation time, be one of the basic parameters describing the acoustic properties of a room independently of many other criteria used in room acoustics.

The investigations carried out by K. ŚRODECKI (1994) [44] suggested further problems to be solved including comprehensive studies on the effect of a room on the colouration change in the signal propagated in the room by employment of the cepstrum function.

The results of L. Gerald MARSHALLS (1994) investigations show, that the importance of the early reflection portion of a sound decay process in the auditoriums is well established. Curves showing early/late sound energy rations (ELR) in the early reflection period comprise a useful way of examining energy – time data within that period. The L. Gerald MARSHALLS (1994) paper on auditorium measurements and the analysis procedure using ELR data in a period between 20 and 200 ms after the arrival of the initial signal is presented in [27]. A measurement and analysis procedure based on the early/late sound energy ratio is a potentially useful way for evaluating the acoustic response of the auditorium. The ELR procedure described in Gerald MARSHALL's paper [27] was developed for evaluating the acoustics of large spaces, such as auditoriums, concert halls, theatres, churches and so forth.

Curve C_x, shows theoretical ELR values for a pure exponential decay based on a decay time equal to that of the measured curves:

$$C_x = 10\log(e^{13.82t/RT} - 1), \tag{4}$$

where t is the ratio dividing time in seconds.

This is the theoretical equivalent of the measured without – direct – signal curve, C_{t0}, and can serve as a useful reference. For this purpose, the difference between C_{t0} and C_x is illustrated in Fig. 4.

Gilbert A. SOULODRE and John S. BRADLEY (1994) have examined the relative importance of the various subjective parameters to the overall preference of these sound fields. A series of experiments were conducted to evaluate several acoustical measures as predictors of subjective judgements. Subjects were asked to rank binaurally reproduced sound fields in terms of loudness, clarity, reverberance, bass, treble, envelopment, apparent source with, and overall preference. The binaural impulse responses were measured in several North American Concert Halls and were chosen so as to cover a range of RT, EDT, C80, G, IACC, and LF values [43] as possible as broad. The results of these tests were then correlated with the various 1/1 octave band objective measures to find the best predictor of each subjective parameter. New objective quantities correlating with loudness, clarity, bass and treble judgements were found.

The reconciliation of speech and music in sacral rooms may be realized by the distributed column sound system. This is not subject of this paper. Some information's are given by David L. KLEPPER (1993) [21].

The diffuse-field theory is used by designers to predict sound fields in rooms of every type. The fact that the theory is based on assumptions, which may limit its applicability, is often forgotten. If the theoretical assumptions do not hold in the case of a particular room for which predictions are to be done, the predictions may not be accurate.

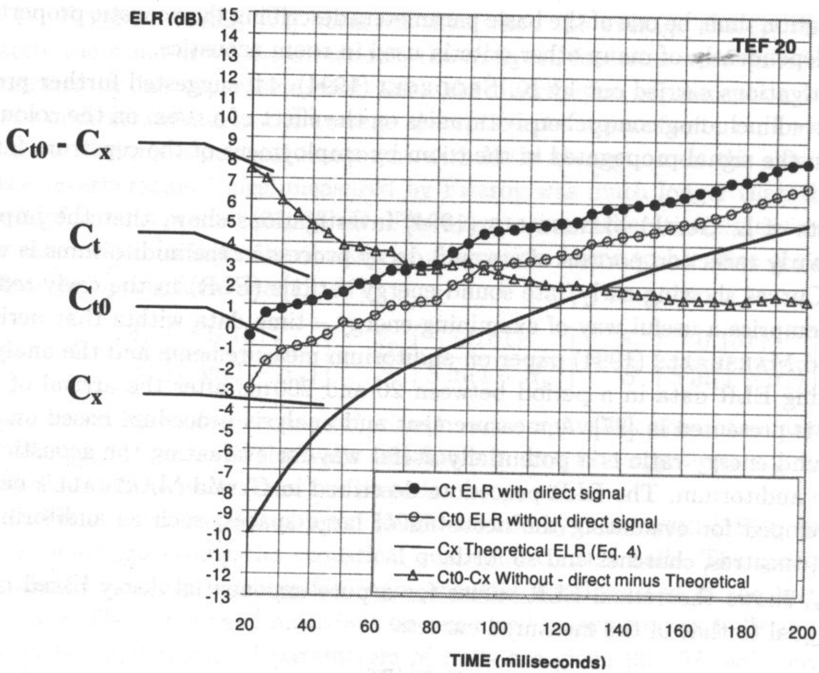

Fig. 4. ELR data curves [27].

Murray HODGSON (1996) [17] gives an objective review of what is known about the applicability of the diffuse field theory. His paper is based on the work by Kuttruff and on his own, comparing the predictions of the diffuse-field theory and the ray-tracing models. It considers two versions of the diffuse-field theory – the Eyring and Sabine versions and the prediction of both the sound decay/reverberation time and the steady state sound pressure level. It discusses applicability with respect to the following room acoustical parameters: room shape, surface absorption (spatial distribution and magnitude), surface reflection, fitting density. The author discussed how to apply the experimental results to real rooms.

Spatial information about sound fields for the room-acoustics evaluation and diagnosis were given by A. ABDON and R.W. GUY (1995) [1].

3. Acoustic requirements for sacral structures

Multiple functions of churches as well as traditionalism and ritualism and the eagerness for obtaining the architectural beauty greatly influence the construction. Almost all sacral buildings are based on the longitudinal, circular, and Greek or Roman cross maps (these are the basic forms). There are also structures, which include several forms mutually coupled. For churches with a simple construction, the acoustic requirements are easier to meet than for complicated spatial forms for which obtaining the assumed (required) acoustic properties is more difficult because these requirements should be met not only for the entire auditorium but also for each of the area individually. The detailed requirements for a sacral structure should be known to design correctly the church or evaluate acoustic terms in it.

Churches designed correctly in the acoustic terms should meet many requirements of which the most important ones are:

- conditions for undisturbed pray and meditation in the interior;
- relatively low level of sound level from external noise;
- good conditions of organ music, songs, chorus, speech listening;
- good speech intelligibility and music texts;
- proper interior volume, reverberation time (characteristics in the frequency domain and value of the reverberation time);
- uniformity of sound amplification;
- proper sound quality.

Good listening conditions in churches should not depend on the site of the sound emission beginning. Sacral interiors should be designed in a way that ensures the dissipated acoustic field. According to [37], the sound level from external noise in churches should not, exceed 25 – 35 dB to ensure undisturbed conditions for prayer and separation from the exterior world in the interior.

Table 2 presents information on the reverberation time of selected sacral interiors erected in different periods according to the various styles typical of them. High discrepancies in the reverberation time and its characteristics are seen.

Table 2. Reverberation time values in interiors of selected churches [34].

No	Name of church and localization	Volume $\cdot 10^3$ [m^3]	Reverberation time T [s]					
			125 [Hz]	250 [Hz]	500 [Hz]	1000 [Hz]	2000 [Hz]	4000 [Hz]
1.	Church of St. Mark in München	6	2.8	3.2	3.9	3.8	3.0	2.0
2.	Church of St. Matthew in München	9	3.7	4.0	5.9	5.8	4.9	2.0
3.	Church of St. Thomas in Lipsk	18	2.4	3.3	4.1	4.0	3.2	1.8
4.	Chapel of Blessed Kinga at Wieliczka	7.5	5.7	5.6	5.6	5.3	4.7	2.8
5.	Basilica of Our Lady in Gdańsk	100	10.7	11.1	11.4	10.5	6.9	3.7
6.	Church of Sts. Peter and Paul in Cracow	24	5.4	5.6	5.7	5.3	4.0	2.5
7.	Church of St. Charles in Tallin	19.2	4.0	4.0	5.6	6.0	5.0	3.0
8.	Church of Our Lady in Cracow	9.5	12.9	9.8	7.7	5.3	4.4	3.5

As was mentioned above, the sacral interior acoustics is greatly influenced by the architectural style of the churches, which to great degree determine the acoustic quality of the sacral structure. The church of Saint Roch in Białystok, built before World War II, and the Orthodox Church in Hajnówka (Figs. 5 and 6) built in the nineties, may be examples of churches differing from the traditional structures of the XVII and XVIII centuries.

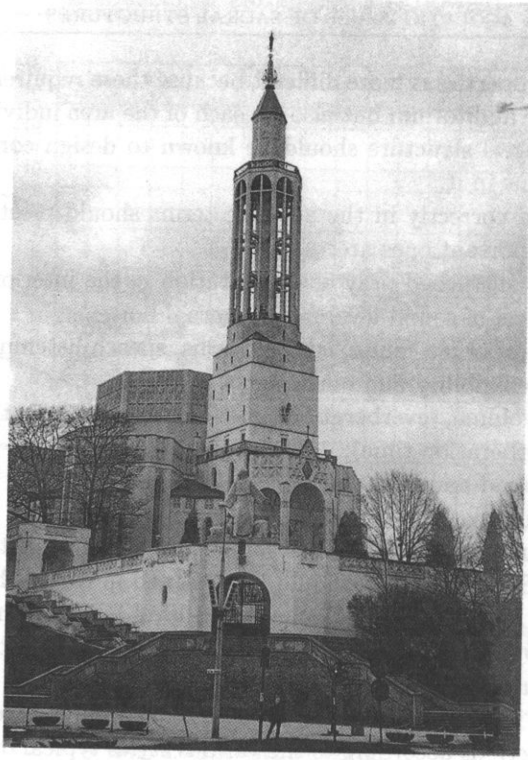

Fig. 5. Church of St. Roch in Białystok [32, 33].

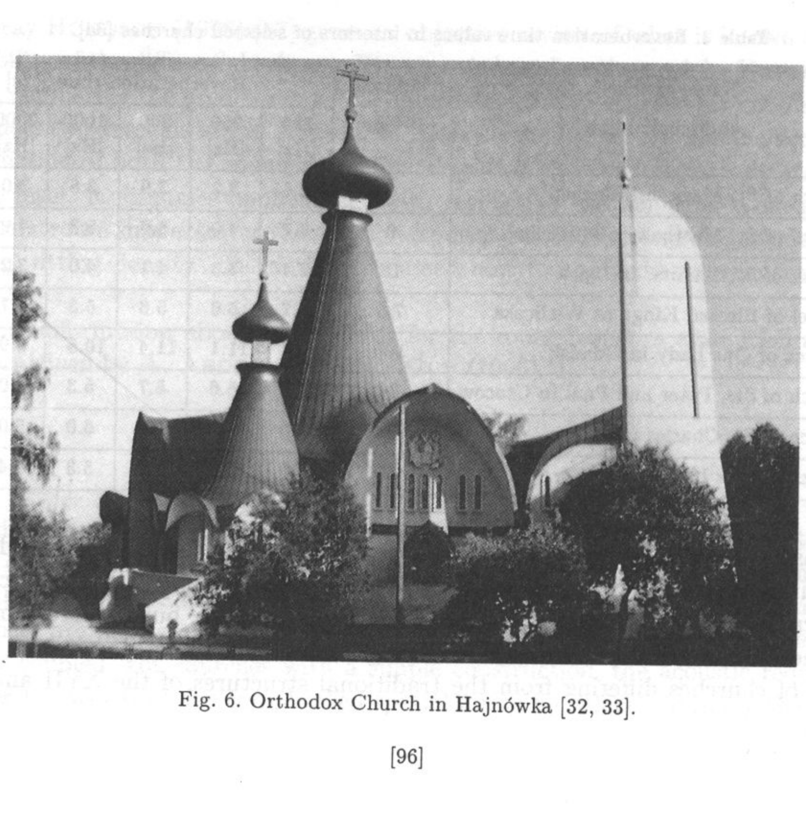

Fig. 6. Orthodox Church in Hajnówka [32, 33].

It is difficult to characterize the acoustic quality of those structures because they were not subjected to acoustic research up to now. Most certainly, the search for new architectural styles of churches observed during the last 20 years should include the acoustic requirements if the acoustics of those churches is to meet their function. There are examples of churches built in last years with of good architecture and particularly bad acoustic quality. Due to this it worthy to investigate the issue of church acoustics on examples of the sacral structures built in the last years.

4. New evaluation methods of acoustic characteristics of sacral structures

The evaluation of a sacral interior in terms of its acoustic characteristics is connected mainly with the impression made on believers (listeners) through speech, chorus or songs. This impression depends not only on the predisposition and individual characteristics of the listeners but also mainly on the acoustic characteristics of the sacral interior and the absence of external noises. It is therefore required to use evaluation methods, which combine an objective evaluation of interior acoustics (measurement or calculation), with subjective evaluation of the listeners.

Up to now no evaluation methods referring exclusively to the sacral interiors were elaborated and modified methods used of the evaluation of the auditorium acoustic properties are applied for this purpose. From amongst those methods of evaluation of the interior acoustic characteristics that have been used recently, the newest one are the methods of digital recording and processing of sound signals. They enable the recording and analysis of a response of the interior to external excitation and afterwards the estimation of the autocorrelation function, the interior impulse response, and the determination of the modulation transfer function.

Application of the autocorrelation function method and the modulation transfer function for evaluation of the quality of the sacral interior acoustics is however in a beginning phase and is limited only to several foreign research centers. Nevertheless the results of investigations are very promising. Objective measurements of sacral interior characteristics enable also the evaluation of the structure of reflections reaching the listener that depend to a great degree on the acoustic characteristic of the interior. It influences crucially the quality of the sound impression in the interior. The important parameters are: EDT – Early Decay Time, D_{50} – deutlichkeit, C_{80} – clarity, L – liveness, t_s – center time, Δ – time diffusion, RASTI – speech intelligibility.

A relationship between the above mentioned parameters of the acoustic field and the subjective attributes of the sound impression in the interior like reverberationess, reverberation quality, tone quality, intimacy, clarity and speech intelligibility was found. Thus it is possible to evaluate the acoustic properties of the investigated interior in terms of impressions made on the listener. For the evaluation of acoustic characteristics of the interiors, including sacral ones, the following methods are applied:

- **BERANEK's** (basing on analysis of the reverberation time and the first reflection);
- **ANDO's** (based on analysis of the impulse response of the interior);
- **RASTI** (based on analysis of the modulation transfer function).

The L.L. BERANEK*'s method* [6]

The first method of evaluation of auditoriums in acoustic terms was developed by the American acoustician L.L. BERANEK [6]. His evaluation scale was based on the comparison of acoustic characteristics of 54 large concert and opera halls all over the world. The method rest on points given from measured or calculated values of the reverberation time, delay time of the first reflection, the distance of the listener from the source, the kind of music performed, and the level of external noise. The halls were classified according to the on number of points obtained as follows:

A^+	– excellent	(90 – 100) points
A	– very good to excellent	(80 – 90) points
B^+	– good to very good	(70 – 80) points
B	– sufficient to good	(60 – 70) points
C	– sufficient	(50 – 60) points

Halls with a score below 50 points are not suitable for music or speech performance due to their bad acoustic quality.

The method of subjective preference acc. to ANDO [3]

For the evaluation of the acoustic field, a scale was elaborated based on the law of comparative values. Comparative tests of the subjective preference were performed according to totally independent objective parameters and in this way the optimal parameter values were obtained. Having a linear scale of preferences for each individual parameter, it is possible to apply the rule of superposition to calculate the total evaluation of the hall acoustics on the general scale of preferences.

Four parameters selected for evaluation, called the *preference factors*, are as follows:

- listening level (S_1),
- time delay (S_2),
- subsequent reverberation time (S_3),
- IAAC – maximum value of the interaural cross correlation function $f_{lr}(t)$ (S_4).

The RASTI *method*

The speech intelligibility in auditoriums, churches, etc. is of importance and serves to evaluate the acoustic quality of the interiors. Evaluation of the speech quality by the identification and evaluation of the interior effect on the sound signal received by the listeners is determined by the RASTI method (Rapid Speech Transmission Index). This method is a modification of the STI method (Speech Transmission Index) and is based on 9 measurements taken in 2 octave bands with middle frequencies of 500 and 2000 Hz. The value of the RASTI factor is calculated as follows:

$$\mathrm{RASTI} = [(S/N)_{\mathrm{app}} + 15]/30, \tag{5}$$

where $(S/N)_{\mathrm{app}}$ – sound signal to interference noise ratio.

5. Investigation of selected sacral structures

The authors of his paper performed many investigations of the acoustic properties of sacral structures. Very interesting results were obtained for the Chapel of the Blessed Kinga in the Salt Mine at Wieliczka. At the end of last century a chapel for 400 seats and 1000 standing places was established in a chamber of 7500 m^3.

The chapel is characterized by very good acoustic conditions; concerts of various types are often organized in this chapel. Table 3 and Fig. 7 present the reverberation time values in a frequency domain.

Table 3. Results of measurements of the reverberation time in the Chapel of the Blessed Kinga obtained by the Schroeder method [11].

Freq. [Hz]	p1-Q1 [s]	p2-Q1 [s]	p3-Q1 [s]	p4-Q1 [s]	p1-Q2 [s]	p2-Q2 [s]	p3-Q2 [s]	p4-Q2 [s]	Avg. RT [s]
125	5.0	5.6	6.1	5.9	5.9	5.5	5.5	5.8	5.66
250	5.6	5.5	5.4	5.6	5.7	5.9	5.8	5.5	5.63
500	5.6	5.4	5.5	5.6	5.8	5.9	5.7	5.7	5.65
1000	5.3	5.0	5.3	5.3	5.4	5.6	5.3	5.4	5.33
2000	4.6	4.4	4.5	4.5	4.9	5.2	4.6	4.7	4.68
4000	2.9	2.7	2.7	2.7	3.0	3.0	2.9	2.8	2.85

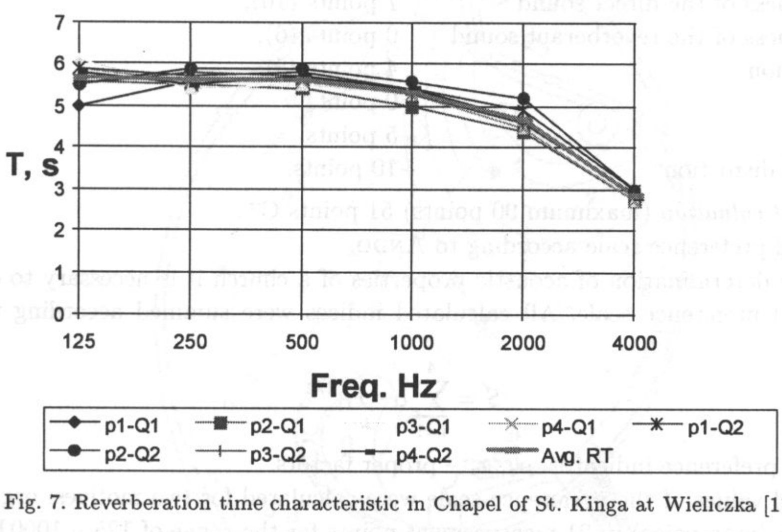

Fig. 7. Reverberation time characteristic in Chapel of St. Kinga at Wieliczka [11].

The results of the investigation obtained for the Sts. Peter and Paul Church in Cracow are presented in Table 4.

The results of investigation obtained for the modern St. John Kanty Church in Cracow are presented below. This church is the first one for which a complex evaluation was made using the methods described in point 3.

Table 4. Results of medium values of the reverberation time for the Church of Sts. Peter and Paul in Cracow [24].

Freq. [Hz]	RT [s]	σ(RT) [s]
125	5.4	0.583
250	5.6	0.473
500	5.6	0.331
1000	5.3	0.310
2000	4.0	0.363
4000	2.5	0.281

Table 5. Averaged reverberation time for the Church of St. John Kanty in Cracow [34].

Freq. [Hz]	125	250	500	1000
RT [s]	14.3	12.8	11.6	10.3
σ(RT) [s]	0.13	0.24	0.10	0.30

The general evaluation according to the BERANEK's method obtained for this church is as follow:

Intimacy	40 points (40),
Liveness	0 points (15),
Warmth	15 points (15),
Loudness of the direct sound	7 points (10),
Loudness of the reverberant sound	0 points (6),
Diffusion	4 points (4),
Echo	0 points,
Noise	−5 points,
Tonal distortion	−10 points.

General valuation (maximum 90 points) 51 points C+.

General preference scale according to ANDO.

For the determination of acoustic properties of a church it is necessary to establish the general preference scale. All calculated indices were summed according to below formula:

$$S = \sum_{i=1}^{4} \alpha \cdot |x_i|^{3/2}, \tag{6}$$

where S – preference indicator, α_i, x_i – proper factors.

General values of the preference scale were calculated for two motives: organ music and speech (man voice) in 21 measurement points for the range of 125 – 1000 Hz in the octave bands and taken in isolines. The diagrams created in this way [34] illustrate the evaluation of the interior acoustic according to the ANDO's method for speech and organ music. Figure 8 presents the evaluation isolines according to ANDO for organ music for the selected frequency and Fig. 9 presents the evaluation isolines according to the RASTI method.

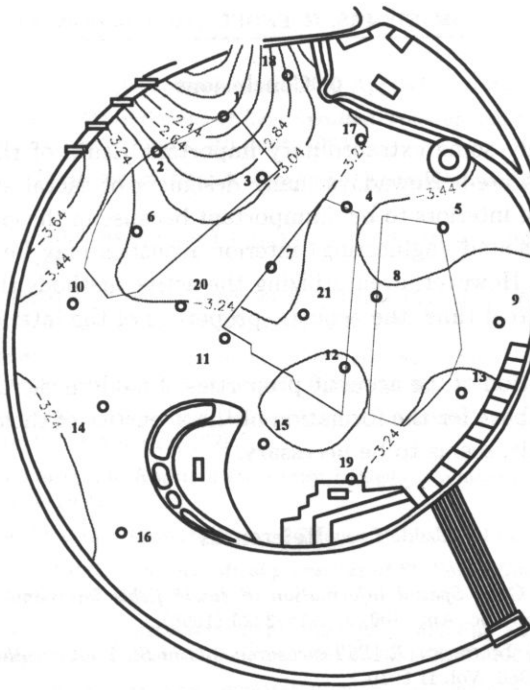

Fig. 8. Isolines of general evaluation of the interior of the St. John Kanty Church in Cracow according to the ANDO method for organ music at a frequency of 250 [Hz] [34].

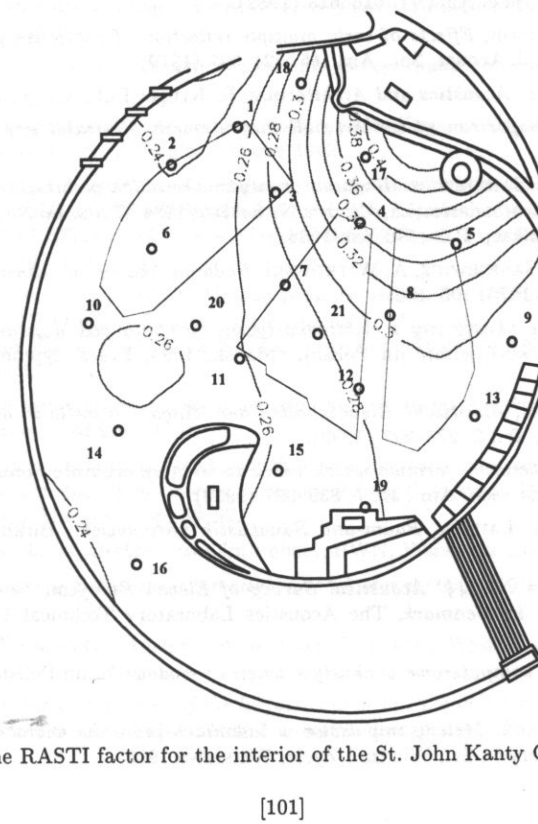

Fig. 9. Isolines of the RASTI factor for the interior of the St. John Kanty Church in Cracow [34].

6. Conclusions

In this paper only some extraordinary important issues of the acoustics of sacral structures were presented. Nowadays many designers of sacral structures believe the acoustic properties of interiors to be unimportant because in the era of the development of electroacoustics (sound engineering) interior acoustics may be improved by proper sound amplification. However, even utilizing the active methods that enable the amplification control in a real time, the acoustic properties of the interior play an important role.

Further investigation of the acoustic properties of modern sacral structures aimed at the elaboration of a base for the formation of the acoustics of those structures in terms of the designing needs, seems to be necessary.

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