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THE POSIBILITIES OF APPLICATIONS OF INVERSE METHODS IN ACOUSTICAL ANALYSIS OF SACRAL OBJECTS

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Abstract

An acoustic quality of sacral objects depends on many factors. Since there is a lack of a specific method allowing to assess the acoustic quality of sacral objects the methods developed for assessment of acoustic performance of concert halls and auditoriums are being adapted. Acoustic parameters as well as the methods adapted for the acoustic assessment of interiors of sacral buildings are briefly presented in the paper.
The authors are presenting the development of the new index method of acoustic assessment of interiors of sacral structures. The assessment is being done in a complex way by means of a single number – the global index of an acoustic quality, which is the function of several partial indices.
The paper presents the possibilities of applications of inverse methods in acoustic of worship spaces.

INTRODUCTION

Inverse methods are widely applied in recent years. There are various definitions of the notion of inversion some quite strange, such as: “Inversion problem can be treated as a task, in which the answer is known while the question is unknown”, “Inversion is a problem which results and consequences are known while their reason is unknown”. The authors are hereby proposing the application of the inverse method in the acoustic assessment of sacral objects.
The authors performed the tests of acoustic properties of several sacral objects. Due to the lack of a uniform, specific method allowing to assess acoustic properties of sacral interiors, methods developed for concert hall, opera houses and auditoriums

were being used. On the basis of such investigations the index method of acoustic assessment of sacral objects was developed [10]. The assessment is being done in a complex way by means of the single-numbered global index.

SHORT PRESENTATION OF THE INVESTIGATION METHODS APPLIED FOR SACRAL OBJECTS

Since there is a lack of a specific method allowing to assess the acoustic quality of sacral objects the methods developed for assessment of acoustic performance of concert halls and auditoriums are being adapted. Those are Beranek's [2], Ando's [1], RASTI [15] and impulse methods [9]. The classic methods are presented in Fig. 1.

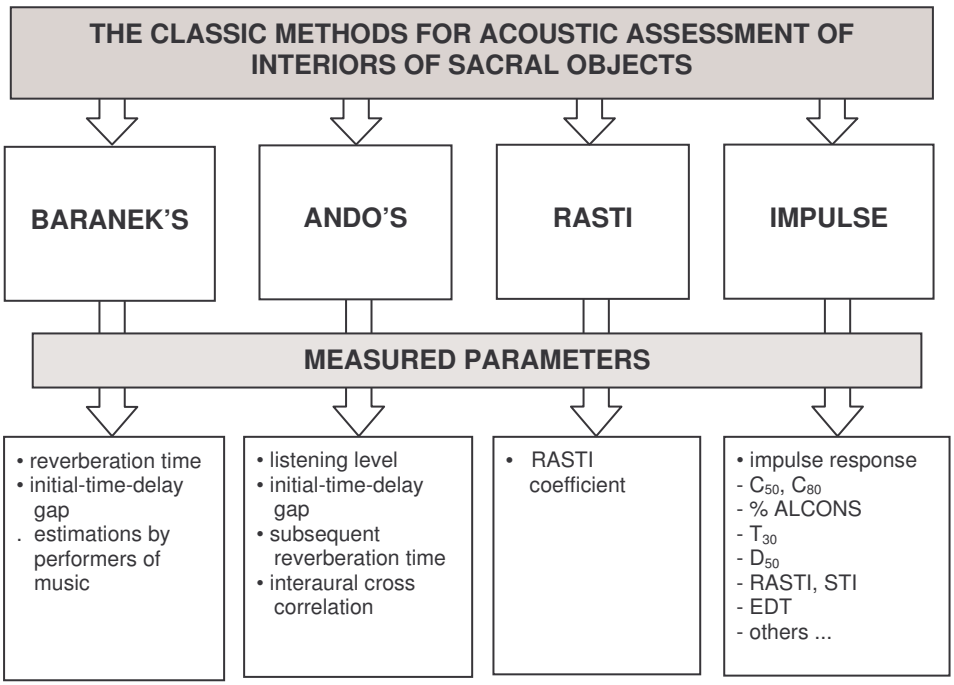

Figure 1 - Classic methods adapted for acoustic assessment of sacral objects

One of the first method was the Beranek's scale based on a comparison of acoustic characteristic of more than fifty concert and opera halls in the world. This type of assessment concerns mainly the suitability of concert and opera halls for the selected types of music. In this method the points are allocated for various properties such as: reverberation time at the given frequency bands, initial-time-delay gap, volume of the hall, the distance between a listener and a singer or a director. The remaining features are estimated according to the perception of persons taking part in the assessment procedure. The sum of those points classifies the concert hall into the certain category. This is entirely subjective method since music perception of persons assessing the acoustic quality is not adequate to impressions of common listeners.

The method proposed by Y. Ando is an example of a modern method of assessment. It is based on the subjective preference scale. The following four independent parameters were selected by Ando: listening level, early reflections after direct sound, subsequent reverberation time and the interaural cross correlation. The Ando's scale of the acoustic quality of concert halls is nowadays the most compact one and takes into consideration acoustic parameters, probably the most important for the music reception by humans. However, for performing the measurements and establishing the preferred values the application of very sophisticated measuring tools is necessary, what causes that the method is not widely used.
The advantage of the Ando's method is the possibility of its application not only for the already existing buildings but also at the stage of their designing, while the Beranek's method is applicable for existing structures only.
The RASTI method (Rapid Speech Transmission Index) is supplementing the above methods in the field of the intelligibility of speech. It is based on the connection between the transmission function of the system modulation and the intelligibility of speech. The RASTI index and the subjective assessment of the intelligibility of speech are linked by corresponding formulations [15], [9].
The impulse method, based on the determination of an impulse response of the interior of the hall followed by the calculation of parameters essential for the acoustic performance of that interior, is also sometimes utilized. Such parameters are, among others: reverberation time, clarity, clarity index, early decay time. Comparing these measured values with the optimal ones we can assess the intelligibility of speech (RASTI and STI indices) and the conditions for the music perception.
The assessment of the acoustic performance of a sacral structure can be also performed in a traditional way by measuring the reverberation time, uniformity of loudness and the level of external disturbances.
Many references and data concerning the investigations of acoustic parameters in sacral object can be found. Investigation of acoustic properties by means of methods adapted for sacral objects have been performed in the Chair of Mechanics and Vibroacoustics, AGH, for many year. There were the topics of several Master of Engineering Degree Theses.

GLOBAL INDEX OF ACOUSTIC QUALITY OF SACRAL OBJECTS

The analysis of adapted methods performed in [9] indicates clearly that none of them considers sufficiently the specificity and uniqueness of interiors of churches. Information are often incomplete, have to be supplemented and do not allow to assess explicitly the acoustic properties of such objects. This was the reason that prompted the authors to develop – on the bases of the adapted methods – the uniform index method of the acoustic assessment of sacral buildings [10].
The proposed index method was developed on the bases of analysis of factors decisive for acoustic properties of interiors and analysis of methods adapted for the acoustic assessment of worship places [9], [10]. Investigations were preceded by acoustic measurements performed in several churches. Acoustic properties are being

determined in a complete way by means of just one number – the index of acoustic quality of sacral objects, W_{JAS}. The global index W_{JAS}, as the function of several partial indices, is determined by the formula:

$$W_{JAS} = \frac{\sum_{i=1}^{n} W_i \eta_i}{\sum_{i=1}^{n} \eta_i} \tag{1}$$

where: W_i - *i-th* partial index, η_i - weight of the *i-th* partial index.

Five partial indices presented in Fig. 2 were proposed for the assessment of the sacral objects acoustic quality. However, the possibility of introduction of new indices is not excluded.

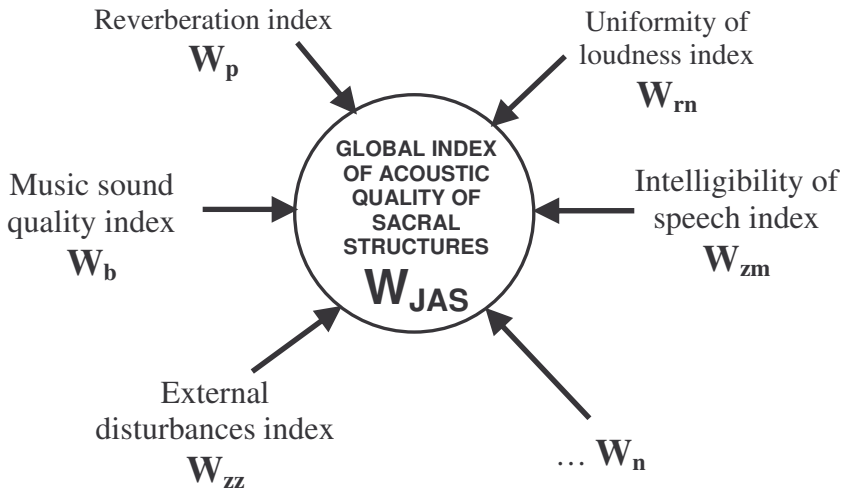

Figure 2 - Global index of the acoustic quality of sacral objects [5]

The global index W_{JAS} - for five partial indices, developed so far - is given by the following formula [10]:

$$W_{JAS} = \frac{W_p \eta_1 + W_{zm} \eta_2 + W_{zz} \eta_3 + W_{rn} \eta_4 + W_b \eta_5}{\eta_1 + \eta_2 + \eta_3 + \eta_4 + \eta_5} \tag{2}$$

where: W_p - reverberation index, W_{zm} - intelligibility of speech index, W_{zz} - external disturbances index, W_{rn} - uniform loudness index, W_b - music sound quality index, $\eta_1 \div \eta_5$ - weights of partial indices.

Verification of the proposed method was performed in five Roman catholic churches.

The measurements of the impulse responses were performed in the measuring points of the tested interiors [10]. The measurements of the external disturbance levels as well as of the acoustic pressure levels for the sound source being placed near the altar were also accomplished. The acoustic parameters were estimated from the impulse response. On these bases the values of individual partial parameters were assessed for each church. The data are presented in Table 1 and in Fig.3. The global index was calculated for each church. They were also classified according to the tentative scale developed in [10].

Table 1. Comparison of acoustic properties of sacral objects by means of partial indices and the global acoustic index [6]

Church of:	V [m^3]	W_p	W_{zm}	W_{zz}	W_{rn}	W_b	W_{JAS}	Assessment of acoustic properties
Reformati Fathers, in Wieliczka	4450	0.88	0.33	0.37	0.26	0.48	**0.56**	Satisfactory
Holiest Sacred Heart, in Kraków	2750	0.94	0.34	0.4	0.53	0.6	**0.66**	Good
St. Sebastian, in Strzelce Wielkie	1650	0.88	0.49	1	0.2	0.67	**0.71**	Good
St. Paul Apostle, in Bochnia	22000	0.39	0.21	1	0.78	0.21	**0.47**	Bad
St. Clemente, in Wieliczka	6380	0.94	0.32	0.57	0.21	0.49	**0.62**	Satisfactory

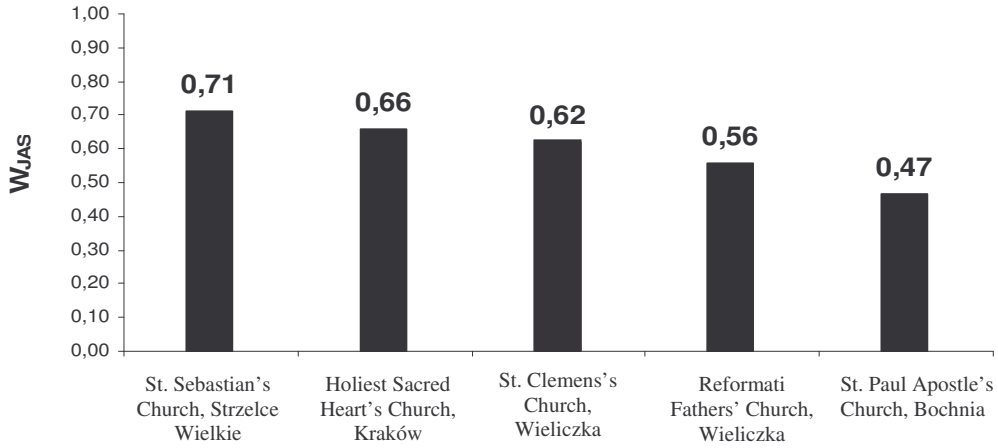

Figure 3 - *Comparison of an acoustic performance of five Roman-catholic churches assessed by means of the global index W_{JAS} [6]*

The best acoustic performance among the tested churches characterises – according to the index method – the Holiest Sacred Heart's Church in Kraków and the wooden, antique St. Sebastian's Church in Strzelce Wielkie, while the worst – the modern St. Paul Apostle's Church in Bochnia.

INVERSION AND THE GLOBAL INDEX

The simplified schematic presentation of the acoustic assessment of the sacral object interior is given in Fig. 4.

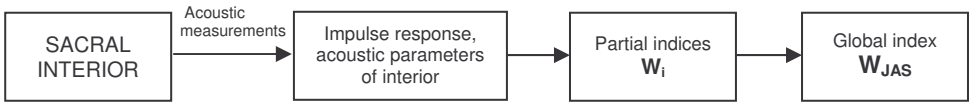

Figure 4 - Schematic presentation of the acoustic assessment of the sacral object by means of the global index

After the estimation of the interior impulse response and other parameters the partial indices are determined from the corresponding dependencies and finally the global index is calculated. The inverse problem is presented in Fig. 5.

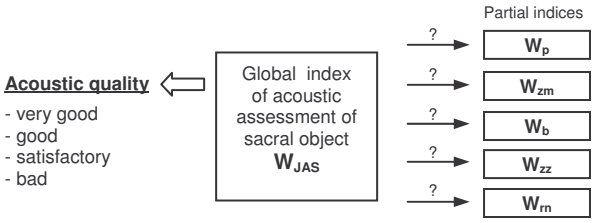

Figure 5 - Determination of partial indices at the assumed global index

The value of the global index is assumed. According to the index method [10] the index values are within the range: 0 to 1. Zero value means the worst acoustic quality, while 1 the best ones. The properties of the sacral object are estimated by means of the tentative scale developed on the basis of measurements performed in several sacral objects.
In this case the inversion means finding the values of partial indices, which ensure the proper acoustic quality of the interior, having assumed the global index value.
Development of the geometric model of the investigated sacral object will be useful (Fig. 6) in solving the problem.
Having the geometric model the simulation investigations can be performed by application of the available software, e.g. RAYNOISE, ODEON, etc. Acoustic parameters of the investigated object, from which partial indices as well as the global index can be determined, are being obtained as the result of simulations.

Model parameters such as: geometry of the room, materials in the interior, distribution of receivers and sound sources, dimensions of the absorbing surface – representing the faithful filling the church - can be changed in a cost-free way.

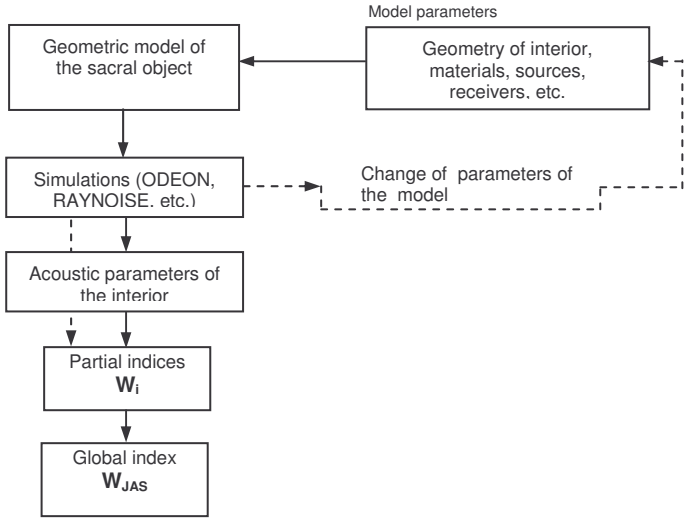

Figure 6 - Determination of partial indices by means of simulation investigations of the model

By changing the parameters of the model and obtaining the values of acoustic parameters it is possible to select the values of partial indices in such a way as to get the assumed value of the global index.
Those investigations can be utilised for performing acoustic improvement of the sacral building interior, which is characterized by a low value of the global index estimated in the real object.
Application of inversion in the index method assessment can be also useful at designing new sacral objects, where at the assumed global index, partial indices – determining individual properties - are looked for.

CONCLUSIONS

The authors introduced the global index of acoustic assessment of the sacral objects quality. The verification of this index was done in five selected churches. This index is the function of several partial indices. The possibility of application of the inversion method based on finding the individual values of partial parameters, when the global index value is assumed, is presented in the hereby paper. The simulation investigations performed on the model of the church are the tools assisting in problem solving.
Research concerning the inverse method application in the assessment of acoustic quality of sacral objects is being presently continued by the authors. It is hoped, that such research will be utilized in the near future at designing new sacral structures and at acoustic improvements of objects with bad acoustic quality.

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REFERENCES

[1] Ando Y., "Concert Hall Acoustics", Springer Verlag, Berlin, Heidelberg, New York, Tokyo (1985).

[2] Beranek L, "Music, Acoustics and Architecture", R. Kruger Publ. Corp., N. York, (1979).

[3] Engel Z., Engel J., "Akustische Eigenschaften der Kinga-Kapelle in der Salzgrube Wieliczka", Proc. DAGA '92, Berlin, Teil 2. pp. 225-227 (1992).

[4] Engel Z., Kosała K., "Reverberation Indices in Acoustic Assessments of Sacral Structures". Archives of Acoustics, Vol. 29. pp 45-59. (2004).

[5] Engel Z., Kosała K., Engel J., "Problems of Sound Quality in Sacral Object". Proc. Forum Acusticum, Budapest, Hungary, 29 Aug – 2 Sep, 2393-2397, (2005).

[6] Engel Z., Kosała K., "Acoustic Properties of the Selected Churches in Poland". Mechanics, Vol.24, No. 3., 173-181, (2005).

[7] Engel Z, Pleban D., Stryczniewicz L. "Investigation of Emission Sound Pressure Using Inversive Method". Archives of Acoustics 27, 4, 277-290, (2002).

[8] Fürjes A.T., "Applications of inverse methods in room acoustics". Proc. Forum Acusticum, Budapest, Hungary, 29 Aug- 2 Sep, 2377-2380, (2005).

[9] Kosała K., "Metody oceny akustycznej pomieszczeń sakralnych". M.Eng. Thesis, supervised by Prof. Z. Engel, Kraków, (2001).

[10] Kosała K., "Zagadnienia akustyczne w obiektach sakralnych", Ph. D. Thesis, supervised by Prof. Z. Engel, Kraków, (2004).

[11] Kuttruff H., "*Room Acoustics",* Publishers Ltd London, (1991).

[12] Nelson P.A. "A Review of Some Inverse Problems in Acoustics". International Journal of Acoustics and Vibration, Vol. 6., No 3, 118-134, (2001).

[13] Nelson P.A., Yoon S.H. "Estimation of Acoustic Sources Strength by Inverse Methods. Part 1: Conditioninig of the Inverse Problem". JSV 233, 643-668, (2000).

[14] Niemas M., Sadowski J., Engel Z. "Acoustic issues of sacral structures". Archives of Acoustics 23,1,87-104, (1998).

[15] "RASTI Technical Review", No. 3, Brüel&Kjaer, Naerum, (1985).

[16] Sadowski J., "Akustyka architektoniczna", PWN, Warszawa, Poznań, (1976).

[17] Tarantola A. "Inverse Problem Theory". Methods for Data Fitting and Model Parameter Estimation. Elsevier, Amsterdam, (2002).

[18] Tichonow A. N., Arsenin V.Y. "Solution of IU-posed Problems". Wiley, N. York, (1977).

[19] Wavefield Inversion. Edited by Armand Wirgin. Springer Wien New York, (1999).