



Index assessment of the acoustics of Orthodox churches in Poland



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ABSTRACT

This work describes the problem of acoustics in architectural objects related to Christianity in Poland, especially Orthodox churches, and to a lesser extent, Roman Catholic churches. Ensuring adequate acoustic environments in spaces of religious worship is a difficult task, especially as churches differ from other public facilities, due to sacred and emotional factors. Alongside the issue of the proper acoustic design of worship interiors, due to the wide range of acoustic production, including music and speech, a significant problem is the difficulty of making a uniform assessment of acoustic parameters.

The index method for the acoustic assessment of Orthodox churches, adapted from a method dedicated to Roman Catholic churches which was developed within the scope of earlier research, was proposed in the article. Acoustic tests conducted in Orthodox churches in Poland together with surveys and geometric measurements, as well as the architectural style along with other distinguishing features, were presented. The obtained results were compared to the subjective tests conducted in advance for the same architectural objects with the index assessment. The proposed index method for determining the single-number assessment was verified in two Orthodox churches from outside Poland in the index values for the geometric models the design stage, is featured.

1. Introduction

The problem of acoustics in places of religious worship is grounded in the history, tradition and customs of a given denomination. Verbal and musical forms accompany almost every confession and create, alongside architecture, an important element of identity. Over the centuries, distinct architectural styles have been correlated closely with musical styles. Acoustics also played a crucial role in shaping these tastes [1]. This paper addresses the problem of acoustics in architectural objects related to Christianity in Poland, especially Eastern Orthodox churches and Roman Catholic churches. Although these denominations share a number of characteristics, it does not seem obvious whether the results of research conducted on Roman Catholic churches may be projected onto Eastern Orthodox churches and vice versa and, if so, to what extent. Besides the numerous works on acoustics in Roman Catholic churches [2–7,23], there are only a few devoted to the acoustic properties of Orthodox churches [8–10].

Special attention is given to the acoustics of Roman Catholic churches in Poland in works devoted solely to this problem [11,1]. These works discuss the acoustic aspects of Roman Catholic churches in great detail. What is more, one of the authors of the present paper has developed a single-number index for the assessment of Catholic churches [12]. The suitability of this index has been confirmed by a series of

experiments and calculations published in the literature on the subject [13–15].

Eastern Orthodox churches belong to a group of sacral buildings dominated undoubtedly by one form of transmission, which is singing. This applies to both large churches with professional choirs and smaller buildings where only the participants of services sing. In all Orthodox liturgies, the priest also sings out a large portion of the service. The only spoken part is the sermon and general information addressed at the congregation. Such proportions in the mode of transmission are the major determinant of the expected parameters of the church's acoustic field. Orthodox music is dominated by multi-vocal pieces. Even in local churches, songs are performed in a four-part harmony. In most cases, Orthodox liturgy is performed in the archaic Old Church Slavonic language. Orthodox churches in Poland have been poorly researched in terms of their acoustic properties. The very few works on the subject result mostly from the studies of the other co-author of the present paper [16,17]. Despite the characteristics of Orthodox churches outlined above, it must be noted that, in Poland, they are rooted in a similar cultural spectrum as Polish Roman Catholic churches. This work attempts to implement a single-number index in the assessment of Orthodox churches in Poland. The next chapters present the methods and results of acoustic tests conducted in Orthodox churches, followed by the main premises of the single-number index in the assessment of

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acoustics in Orthodox churches, as well as a detailed acoustic assessment executed with the use of the index.

2. Acoustic tests in Orthodox churches

2.1. Method of measurement

Measurements of the acoustic parameters in Orthodox churches in Poland were performed over the years 2011–2015 in over 20 diversified interiors. Surveys and geometric measurements were performed and the architectural style was analysed along with other distinguishing features. The EASERA software and scripts in the MATLAB environment were used to determine the spatial impulse response. Measurements were taken in compliance with the ISO 3382-1 standard [18], however, due to the characteristics of the interiors and technical capabilities, some simplifications were adopted. Instead of an omnidirectional source, an active JBL EON 515 column loudspeaker was used. Its parameters were examined thoroughly in advance. Its maximum level is 132 dB SPL and has a frequency response of 42 Hz–18 kHz with a ± 3 dB margin. Its horizontal and vertical coverage (-6 dB) is $100^\circ \times 60^\circ$, which is similar to human mouth directivity. It was determined that the parameters calculated were erroneous. The error margin for such buildings with a strong dispersion of the acoustic field is certainly smaller than the scatter of results that depends on the location of measurement points. Another difference in reference to the standard lies in the density of the measurement grid and the number of sound source locations. In the majority of cases, the column loudspeaker was located between the iconostasis and the exaltation altar. This is the place where most musical concerts take place and where the priest speaks or sings. In each of the buildings under examination, measurements were taken from several characteristic locations:

- behind the exaltation altar (front rows, where the concert is located),
- in the centre of the church (in no less than two spots),
- under the main dome,
- under the matroneum,
- at the back of the church,
- in aisles (in at least three spots),
- in other locations as required by the layout of the church.

In large interiors, the number of measurements was increased proportionally. In order to record the spatial properties of the acoustic field and to perform subjective listening tests, measurements were taken with the use of a Soundfield ST350 first-order ambisonic microphone. Acoustic parameters were calculated based on the pressure signal, with its frequency response being measured and characteristic linear within the acoustic range with a scatter no bigger than ± 2 dB.

2.2. Architectural and acoustic characteristics of Orthodox churches – measurement results

Based on the measurements taken, over 20 measurement reports were compiled. Some interiors were very similar, both in terms of geometry and fittings, but also, obviously, in terms of their acoustic parameters. Therefore, a statistical analysis was performed by means of the Principal Component Analysis (PCA). The method allows the objects to be reduced by calculation of orthogonal variables, which constitute a linear combination of input parameters. The efficiency of the PCA analysis is defined by the sum of variances of input data described by subsequent orthogonal components calculated. Based on initial analyses, the 11 most diversified interiors were selected for further analysis. The reduction enables a simplification to be created, especially in the case of the subjective listening tests, to which the results of acoustic parameters are compared. In Table 1, the basic parameters of the measured buildings are compiled.

id 1: The Church of the Intercession at Fili in Zdynia (Table 1) was erected in 1786 or 1795, as a Greek Catholic parish church. It is considered to be a younger variation of the western-Lemko type. It is an oriented, three-nave, rectangular, wooden, log frame structure. From the west, it is adjacent to a pole frame structure bell tower.

id 2: St Basil the Great's Church in Konieczna was erected in the years 1903–1905. Architecturally, the building is similar to the previous one. Additionally, from the west, it is adjacent to a three-storey tower with straight walls and no protruding elements. It is topped with a large onion-shaped helm roof without a lantern. A square nave was topped with a wooden barrel vault. The reverberation time in both churches is short and comparable to the reverberation times of wooden Catholic churches built in that period [11].

id 3: St Peter and Paul's Church in Siemiatycze was erected in the years 1865–1866, based on a typical official design of an Orthodox church for small towns. It is a brick oriented church built on a rectangular plan. The interior of the church is covered with a ceiling, except for the nave, which is covered with a faux groin vault. The rich fittings of the church cause significant dispersion of the acoustic field.

id 4: Holy Trinity Khram (the Orthodox counterpart of a cathedral church) in Sanok was erected in the years 1784–1789 as a Greek Catholic church, a municipal parish church. The church is an oriented, two-part structure built of crushed stone on a rectangular plan with a dominant spacious nave. The characteristics of the reverberation time and the values of the majority of the acoustic parameters calculated are similar to medium-sized Catholic churches [11], which confirms the Latin architectural influence on buildings erected at that time.

id 5: The Dormition of the Mother of God Church in Hrubieszów was erected in the years 1873–1875 and constitutes the most monumental example of Orthodox church architecture amongst parish churches within the Kingdom of Poland. The twelve-domed church was erected on a cross plan with a separate division into three parts. The frequency characteristics of the reverberation time achieve their highest values for low frequencies (BR). The value of the sound strength G is low in comparison to the other buildings under examination.

id 6: The Nativity of Mary Church in Włodawa was erected in the years 1840–1843 as a Greek-Catholic municipal parish church and is a classical example of a Russian Revival style, which developed as an attempt to find a national Russian architectural style. It is an oriented building on a cross plan, with a square nave topped with an onion dome on a cylindrical tholobate. The church is characterised by high values of the base parameter BR and sound strength G, while the reverberation time is relatively short.

id 7: The Orthodox parish church in Tomaszów Lubelski was erected in 1890 in the Neo-Russian style. The body of the church was designed on a cross and dome plan. The acoustic parameters of the church are characterised by a very high value of the base index BR and medium reverberation time.

id 8: Hagia Sophia in Białystok was consecrated in 1998. From the architectural point of view, the church is a direct reference to the temple most important for eastern Christianity - Hagia Sophia in Istanbul. The designer's aim was to create a miniature copy (1:3). The reverberation time of Hagia Sophia in Białystok is long. The maximum of the frequency characteristics of the reverberation time is achieved for medium frequencies, which results in a low value of the base parameter BR, which may be considered untypical for such large and well-reverberated buildings.

id 9: The Holy Trinity cathedral church in Hajnówka was designed by Aleksander Grygorowicz and erected in the years 1981–1983. The reverberation time of this church is relatively long for buildings of this size. The recognised acoustic advantage of the church in Hajnówka is also confirmed by the Festival of Orthodox Church Music held there annually, which is an important reference point for the analysis and interpretation of test results.

id 10: The Resurrection of Jesus Church in Siemiatycze was erected in the years 1999–2009. It is an oriented building of yellow clinker

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