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CHURCH ACOUSTIC REHABILITATION
A CASE STUDY

BY

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Abstract. One of the most important aspects aimed within a church is focused on the capacity of congregation members to hear sounds at an agreeable level. The uneven spread of the sounds throughout the area occupied by the auditors may cause audition problems that can be solved through acoustic rehabilitation solutions. This paper presents a study of a Greek-Catholic church located in Cluj-Napoca. In the church, the analysis of the acoustic field was made both by using empirical and experimental methods. As a basic study of the room acoustic, the behavior of the sound propagation was determined by using the Sabine equation. By applying it, the values of the reverberation time, which is the most important parameter currently in use for the room acoustic description, was established. Also, for a complex study of the reverberation time, acoustic measurements were developed, the resulted data being compared with the admissible one. Therefore, following the obtained values, a correction solution has been proposed in order to achieve the needed acoustical comfort through a judicious dimensioning of the reverberation time.

Key words: church; reverberation time; Sabine equation; acoustic measurements.

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1. Introduction

Churches included in the audition halls category involving complex issues related to the listener's optimal audibility conditions insurance.

The acoustic quality evaluation of a hall constitutes a difficult problem taking into account the complex structure of the sound field which is established in closed spaces of various shapes and the acoustic characteristics of the delimiting surfaces.

In recent years, the acoustic study of churches raised various issues among those who study this domain, the basic preoccupation being focused on the audience which should understand most of the words spoken by the speaker and sung by the choir.

Basically, these problems can be solved by: uniform sound distribution methods throughout the area occupied by the auditors, reduction of noise through absorption treatments, sound intelligibility increasing methods through a convenient distribution of useful sounds into the room, etc.

In the auditorium acoustic evaluation different parameters are utilized, of which the most important is *the reverberation time*.

Reverberation is the effect of sound reinforcement in a closed space, due to the successive sound reflections between the delimiting surfaces of the space. The reverberation time, considered the principal objective parameter of the subjective impression of reverberation, is the time in which the sound level of a room is reduced with 60 dB after the sound source is switched off. It can be determined by measurements or can be estimated by calculation.

In this paper the authors present a study of the reverberation time in order to analyse the existing acoustical conditions inside a church and, if it is necessary to recommend a feasible treatment solution.

2. Space Characteristics

The Greek-Catholic church of “St. Joseph” is located in the city of Cluj-Napoca, Romania. It was built using confined masonry in little more than a year, from August 2009 until October 2010. The holy building is 27 m in length and 8.2 m in width. The height ranges from 6.4 m to 16 m on top of the church tower. Thus, the total volume sums up to 935.5 m^3.

The walls and the ceiling of the church are coated with white plaster, while the floor is fitted with stoneware, covered by a carped disposed along the principal access to the seats. The main furniture in the church is made up of upholstered bench and chairs and can accommodate up to 120 persons.

Fig. 1 – Exterior/interior of the "St. Joseph" church.

3. Analysis Setup

In this paper different acoustical methods have been carried out in order to determine the reverberation time values and to develop a proposal solution for an acoustical improvement of the studied church.

For the acoustic field evaluation, the following steps were proposed to be checked:

a) Calculation of reverberation time using empirical methods (Sabine).
b) Reverberation time measurements.
c) Result interpretation and verification of obtained values.
d) Acoustic rehabilitation proposal.

3.1. Reverberation Time Calculation

The first method applied is based on the Sabine eq., an empirical formula based on the room geometry and on the absorption characteristics of the room delimiting surfaces defined by the relation

$$T = \frac{0.161V}{A}, \quad (1)$$

where: T is the reverberation time, [s]; V – the room volume, [m^3]; A – the total absorption area, [m^3].

The obtained values using the Sabine eq. are presented in Fig. 2.

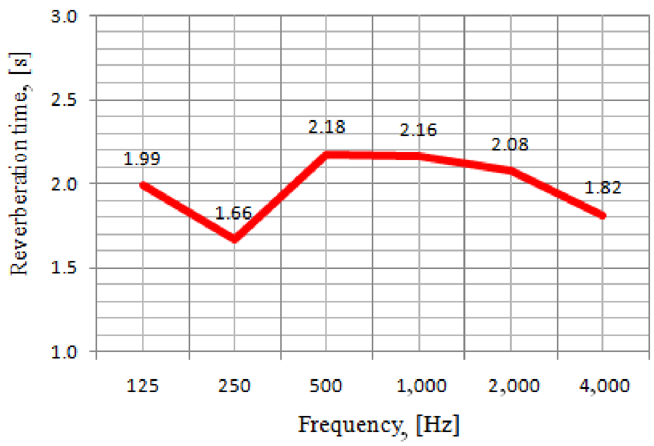


Fig. 2 – Reverberation time (Sabine eq.).

3.2. Reverberation Time Measurement

For a complete study of the room and because the absorptive characteristics of the delimiting surfaces can not be established entirely, a measurement method has also been performed.

Fig. 3 – Reverberation time (acoustic measurements).

The measurements for reverberation time, set according to the International standard ISO 3382-1 requirements, were made by using a special acoustic equipment (Bruel & Kjaer Sound and Vibration Meausurement) composed of

a) pulse sound & vibration analyser;
b) building acoustic software;
c) OmniPower Sound Source;
d) microphones;
e) power amplifier;
f) sound level calibrator.

The measurements were taken inside the emptied church. According to International Standards ISO 3382-1, the reverberation time can be computed using two different methods: interrupted noise and integrated response to the impulse. In this case, the preferred method was “interrupted noise”, method comprising an omnidirectional sound source generating white noise which is a random signal (or process) with a flat power spectral density. The omnidiretional sound source is composed of 12 speakers placed in such a way as to allow a spherical distribution of the sound.

According to ISO 3382-1, the height of the sound source acoustic centre was established at 1.5 m above the floor.

Reverberation time measurements, presented in Figs. 3 and 4, were executed in two stages, depending on the position of the omnidirectional source:

a) in front of the altar, S_1;

b) at the height of 3 m in the choir area, S_2.

The choice in positioning the receivers was made according to ISO 3382-1 which establishes a minimum of 6 microphone positions for a space accomodating 500 people. In order to better cover the area destined to the auditorium there have been chosen 9 positions for microphones, placed at 1.2 m above the floor.

For each microphone position, summarized in Table 1 and Fig. 4, two different readings were made, the final result being an average of the two.

Table 1
Microphone Positions

Relative position	ISO 3382 requirements	Selected value, [m]
Microphone–microphone	> λ/2	> 2
Microphone–reflecting surface	> λ/4	1

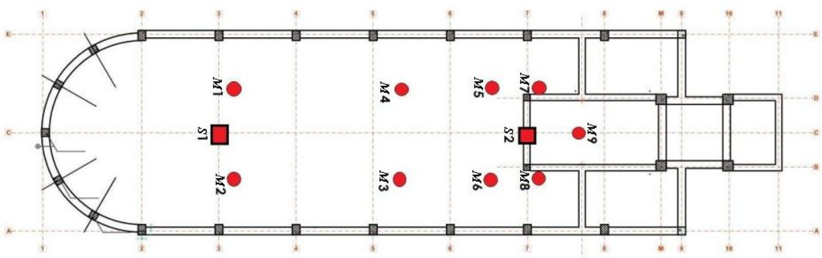


Fig. 4 – Sound sources/microphones positions.

The emitted noise was computed by the analyser unit using information gathered by the microphones. The output data is a sloped decay curve which is used to calculate the reverberation time.

In Figs. 5 and 6 an average of the reverberation time computed values with the sound source placed in the established positions were performed.

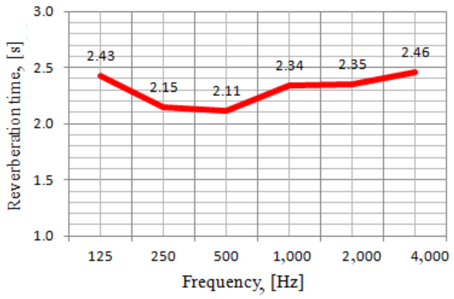


Fig. 5 – Reverberation time (acoustic measurements – S_1).

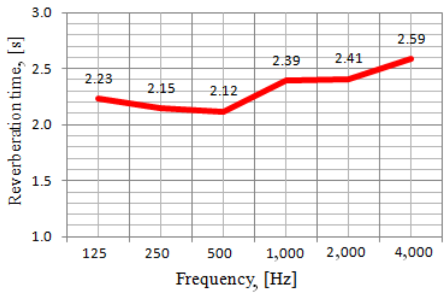


Fig. 6 – Reverberation time (acoustic measurements – S_2).

3.3. Results Analysis

Depending on the various types of music and speech produced inside and on the room volume a mean value of the reverberation time is chosen. From Fig. 7 for choral music/organ and room volume of 935.5 m^3 the mean reverberation time, noted T_m, is of 1.5 s.

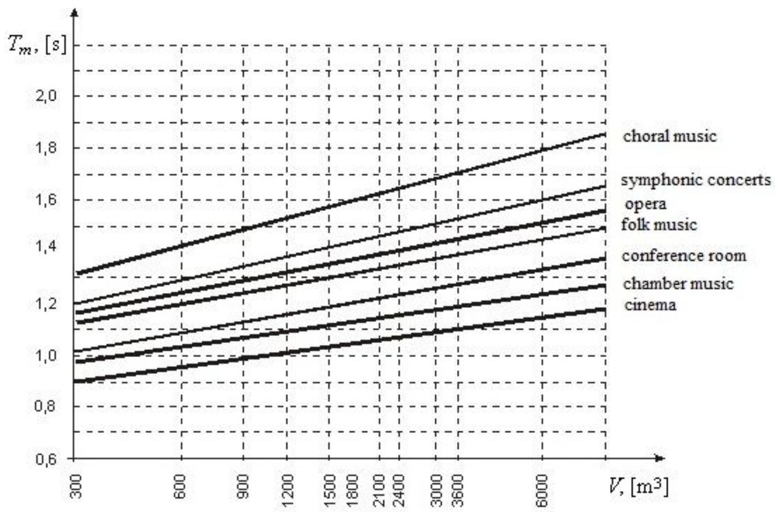
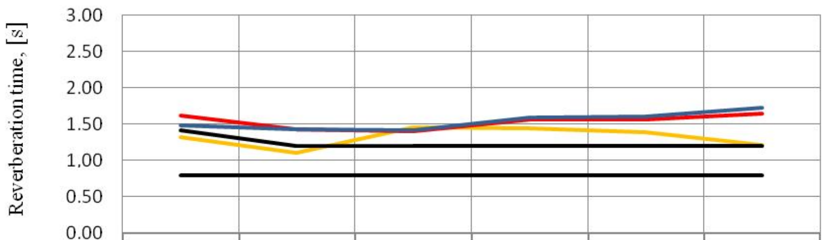


Fig. 7 – Reverberation time (mean values) (STAS 9783/0-84).

Therefore, it is checked whether the ratio between the calculated values and the mean reverberation time is situated between the admissible values.

The result is a graph, shown in Fig. 8, representing the reverberation time variation values with frequency, which must be within the recommended domain established according to the STAS 9783/0-84 requirements.



Frequency,[Hz]	125	250	500	1,000	2,000	4,000
$T_f(S_{eq})/T_m$	1.33	1.11	1.45	1.44	1.38	1.21
$T_f(S_1)/T_m$	1.62	1.43	1.41	1.56	1.57	1.64
$T_f(S_2)/T_m$	1.49	1.44	1.41	1.59	1.60	1.73
T_{min}	0.8	0.8	0.8	0.8	0.8	0.8
T_{max}	1.41	1.2	1.2	1.2	1.2	1.2

Fig. 8 – Reverberation time values compared with the admissible limits.

From Fig. 8 it is observed that the admissible limits are exceeded by the reverberation time values obtained through empirical and experimental analysis, which recorded approximately close values. Thus, an acoustic rehabilitation of the interior space is proposed.

3.4. Acoustical Treatment

A sound-absorbing correction solution proposal consisting of 12 × 12 mm perforated gypsum boards delivered with an acoustic canvas placed on their opposite side in order to increase the sound absorption was made. Based on the

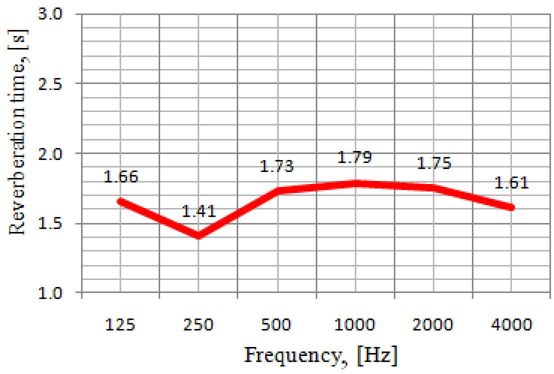


Fig. 9 – Reverberation time values after rehabilitation.

Sabine eq., the reverberation time values were recalculated. From the obtained results an area of 31 m^3 sound absorbing material was put on the back wall of the church in order to reduce the reverberation time values.

The new values of the reverberation time are presented in Fig. 9.

In Fig. 10 the resulting values (T/T_m) fit between the set limits according to STAS 9783/0-84 were represented too.

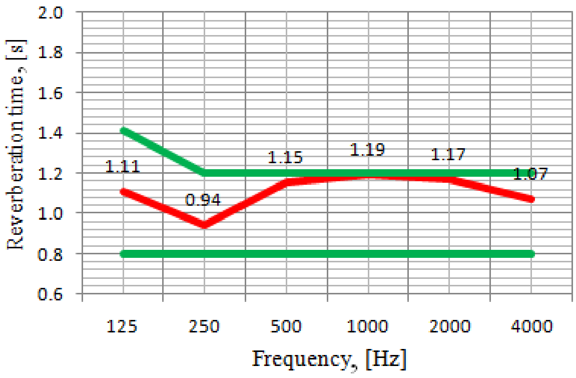


Fig. 10 – Reverberation time compared with the admissible limits.

4. Conclusions

In churches, a favourable transmission of the sound level during liturgy through the entire area occupied by the auditors is an essential requirement in the understanding process of the spoken or sung words.

Research of this paper shows that the reverberation time values of the studied space were sufficiently high to influence the communication activity.

A reduction of the registered values was realized through the implementation of a perforated gypsum board system which ensures reverberation time adequate values.

Comfortable acoustic levels must be met in every hall in order to optimize the sound transmission and listening conditions that are essential for every member of the audience.

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REABILITAREA ACUSTICĂ A UNEI BISERICI

(Rezumat)

Unul dintre cele mai importante aspecte care trebuie urmărite într-o biserică este ca nivelul sunetelor percepute de auditori să fie unul adecvat. Răspândirea inegală a acestora poate determina probleme de audiție care pot fi rezolvate doar prin aplicarea unor soluții de reabilitare acustică. Studiul prezentat a fost efectuat într-o biserică greco-catolică amplasată în oraşul Cluj-Napoca. În cadrul bisericii, analiza câmpului sonor a fost realizată prin metode empirice şi experimentale. Într-o prima etapă a studiului a fost utilizată ecuația lui Sabine, prin aplicarea căreia s-au stabilit valorile timpului de reverberație, considerat cel mai important paramentru folosit în evaluarea acustică a unui spațiu. Suplimentar, s-au realizat măsurători ale timpului de reverberație, valorile obținute fiind comparate cu cele admisibile. Pe baza rezultatelor obținute s-a propus o soluție de reabilitare acustică în scopul îmbunătățirii confortului acustic interior.