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# Experimental Study of the Time of Reverberation of a Sacred Building Having a Cruciform Architecture

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**Abstract.** The response of the interior to the excitation of the pulse noise was registered using the Svan958A spectrum noise analyzer. After that, using the Dirac system, the registered files were analyzed and the time of reverberation of the church of St. John the Baptist, located in the village Verkhnya, Kalush district, Ivano-Frankivsk region, Ukraine with indication of measuring points. Detailed measurements of the investigated object were carried out and on their basis a 3D-model of the church in the SketchUP system was developed, which allowed to determine the recommended reverberation time for this type of interior and the given volume. The conducted researches made it possible to determine the uniformity of sound energy distribution in building having a cruciform architecture.

## 1. Introduction

The main acoustic parameters used to assess the acoustic quality of sacred interiors for many years one of has been the reverberation time [1-2]. The calculated or measured value of the reverberation time can be compared with the values recommended for this type of interior and thus assess whether there will be sufficient language intelligibility and volume in all places where believers may be [3]. Reverberation time is still the main and most frequently used factor that determines the acoustic properties of the sacred interior due to the fact that there is still no single method of assessing the acoustics of this type of interior, and because it is an internal parameter that can be calculated at the design stage and then tested experimentally [4-6].

The evaluation based on the comparison of the measured reverberation time to the recommended one does not fully reflect the acoustic qualities of the interior of a church designed to perform many functions in terms of acoustics. However, this parameter allows an introductory assessment of the ability of the assessed premises to perform its function in terms of acoustics [7].

That is why the task was set to investigate the acoustic properties of the St. John the Baptist church, located in the village Verkhnya, Kalush district, Ivano-Frankivsk region (see Fig. 1).

For this purpose, it is necessary to carry out measurement of the geometrical sizes of a construction along with materials. The next step is to conduct an experimental study of the reverberation time in order to find the uniformity of the distribution of sound energy in the premise of study. The source of impulse noise must be installed at the place where the priest usually conducts the service, and the second option is to install the source where the church choir is located.



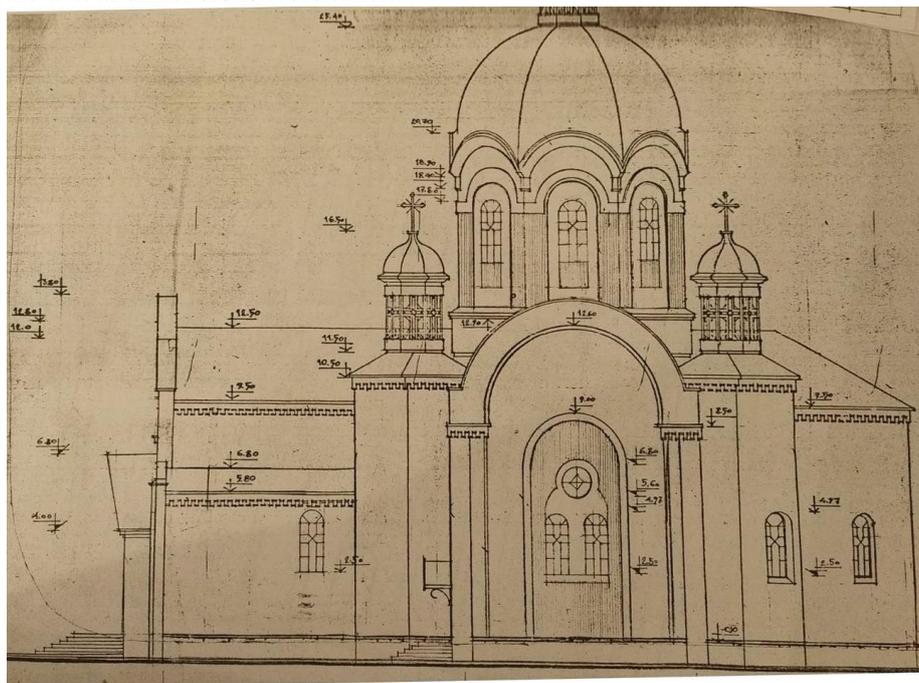


**Figure 1.** Photo of the object of study.

## 2. Construction of a 3D model of the church

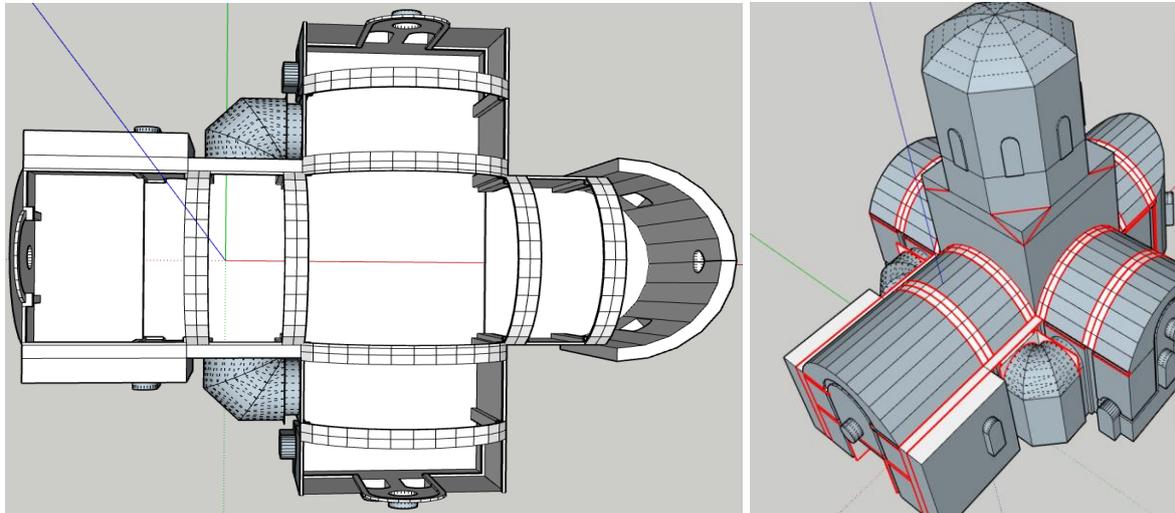
In the literature, the recommended reverberation time is very often tied to the volume of the interior [7]. To accurately determine the volume of the interior, it was proposed to develop a 3D model in the SketchUP system. The developed model made it possible to determine precisely the volume and this can also be used to build an acoustic model of the church when exporting to room acoustics modeling systems, such as CattAcoustic in order to further acoustically adapt the church premises [8]. The model can also be used to test the accuracy of acoustic modeling systems, but it is necessary to specify the absorption coefficients used in the materials of the church decoration. Most often, the model has discrepancies with experimental data due to inappropriate setting of sound absorption coefficients of materials.

At the initial stage, it was proposed to develop a model according to the drawings (see Fig. 2.), but the test showed that the actual dimensions do not always correspond to the drawing, so using the laser rangefinder the actual dimensions were taken.



**Figure 2.** Church drawing (side view).

A 3D model of the church was designed according to the actual dimensions, which is presented in Fig. 3. The church is made of brick and covers an area of 397 m<sup>2</sup> with a volume of 4070 m<sup>3</sup>. The height of the dome is 22.5 m.



**Figure 3.** 3D model of the church

### 3. Description of measurement conditions

The signal for the tests and experiments was an impulse noise. Balloons are used as a source of pulsed noise, which fully meet the requirements for pulsed noise sources. The source of pulsed noise was installed at a height of 1.5m and 1.2m from the floor [9]. A capacitive omnidirectional measuring microphone SV22, set at a height of 1.2m, and a noise meter spectrum analyzer SVAN 958A were used to record the response of the interior [10, 11]. The equipment was calibrated before the experiment. All experiments were performed at a temperature of 19 °C and a relative humidity of 49%. The recorded signals were processed using an algorithm implemented in the Dirac 5.0 system. As a result of its work, the reverberation time was determined in the octave ranges from 125 to 8000 Hz. The photo of the experiment is presented in Fig. 4.



**Figure 4.** Reverberation time measurement.

### 4. Comparison of the results of the experiment with the recommended values of the parameters

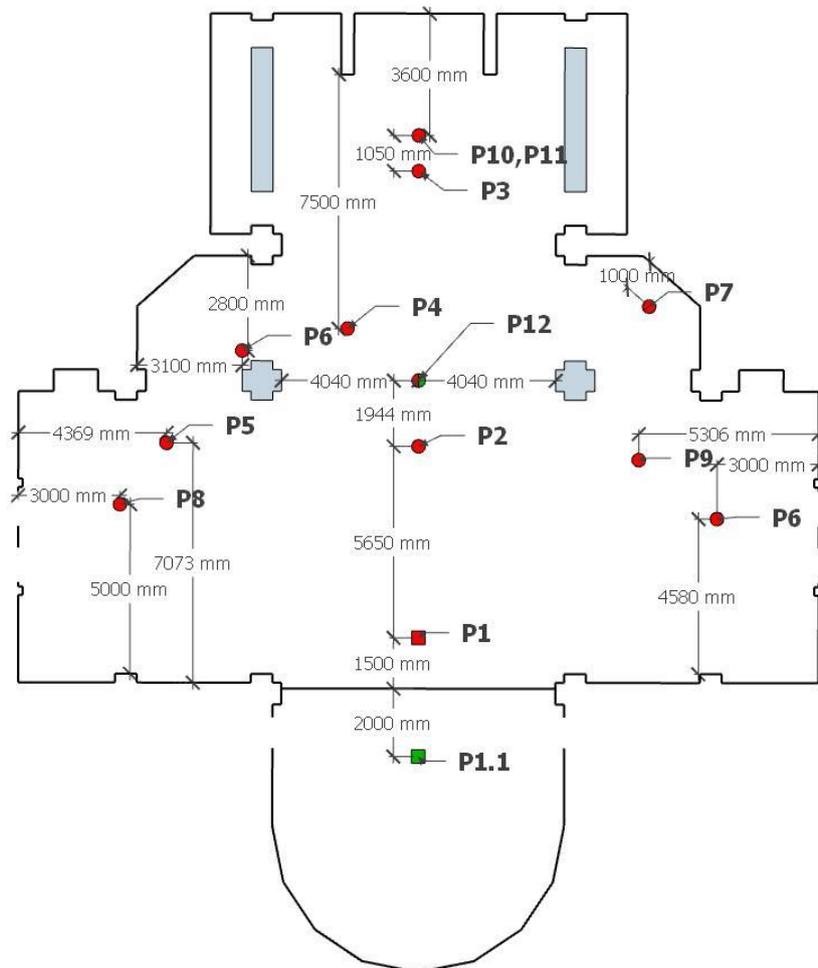
To compare the values of the acoustic parameters obtained as a result of the experiment with the recommended values, the average values of T<sub>30</sub> (T<sub>30</sub> – the reverberation time for 60 dB of room decay, based on a straight line curve fit between the -5 dB to -35 dB points on the Schroeder curve [9]) for 500 and 1000 Hz were determined (see Table 1.).

**Table 1.** Statistical results T30 for 500 and 1000 Hz.

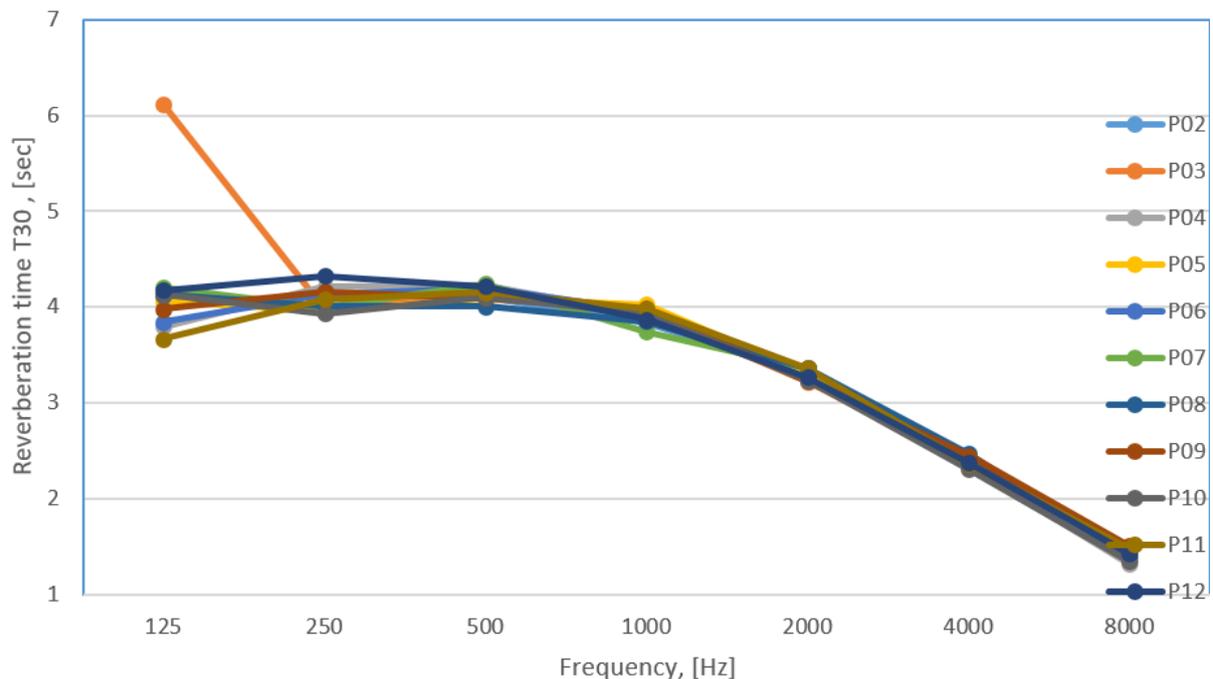
Frequency	500 Hz	1000 Hz
Number of experiments	11	11
Minimum	4,007	3,741
Maximum	4,244	4,029
Average value	4,142	3,91
Recommended value	3,54	3,54

The recommended value of the reverberation time for Catholic churches according to Kulowski [3] with a volume of  $4070 \text{ m}^3$  marked as the average time from the graphical ratios  $T(V)$  is 1.82 sec. Where  $T$  is the reverberation time and  $V$  is the room volume. As we can see, the church does not meet the requirements, but it is difficult to clearly assess this due to the large discrepancy between the recommended reverberation time for churches. The tolerance range is  $\pm 20\%$ , except for the frequency 125 Hz (50% of the tolerance up) and 4000 Hz (40% of the tolerance down).

In order to investigate how the reverberation time changes depending on the observation point, as well as near the walls, in the middle and on the balcony, several measuring points were selected. The layout of the points where the measurements were carried out is presented in Fig. 5

**Figure 5.** Layout of measuring points.

The graph (Fig. 6.) shows that the recurrence is at a high level. Only at low frequencies does point 3 differ from all the others, and this is due to the fact that it was almost under the balcony and the delayed sound energy coming from under the balcony was added, because it is the low frequencies that are poorly attenuated in the air.



**Figure 6.** The results of determining the reverberation time for 11 different locations of the noise source and noise meter.

As mentioned earlier, for a church space of 4070 meters<sup>3</sup>, the recommended reverberation time should be 1.82 seconds, and in our case, the average values for 500 and 1000 Hz are 4.1 seconds and 3.9 seconds, respectively. The first measurements were made without people because they would create additional noise. If we take into account the absorption surface of people and carpet, which was taken from the floor, we can assume that the acoustics of this church is rather good, but to confirm this fact it will be necessary to conduct additional simulations and use these results later to calibrate the model.

## Conclusions

Studies of the reverberation time of the church have shown that the problem of sacred objects is their large volume, which in turn leads to an increase of the reverberation time. This fact is useful since the choir sings in churches most of the time, but it comes to the preaches, the intelligibility of the priest language is rather poor. Experiments have shown that the room distribution of echo time is uniform, but it is too large and the quality of speech transmission is therefore low.

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