Atmosphere of the sacred – sonic aspect, acoustic investigations of the contemporary church

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Acoustics are one of the main components that constitute the functionality of the sacred building. Designing a church is a real challenge because the interior must be adapted to various acoustic requirements. However, one must bear in mind that one of the goals to be achieved in a religious interior is to create the sense of the sacred. The aim of this paper is to investigate acoustic conditions in a contemporary Catholic church with a view to determining the sound quality of the interior.

The design of a sacred building requires not only visual considerations but also needs to take account of the acoustic aspect. Designing church acoustics is an indisputable challenge as the interior needs to combine extremely different acoustic requirements. Tradition and guidelines provided by church documents highlight the importance of organ music, but the liturgy is also inextricably linked to speech. However, the optimum reverberation time for organ music exceeds two seconds while it should be less than one second for speech. The combination of such radically different requirements in one interior calls for a precise balance between the acoustic design for speech and for organ music.

It must be remembered, however, that a sacred interior should provide a religious ambience – the sense of the sacred – in the sound sphere, which is related to appropriate reverberation time in the interior. It is part of the tradition of religious architecture to have a distinctly reverberant interior, which creates a sense of being in a space immediately associated with the liturgy.

Numerous studies and papers on church acoustics include an array of publications specifically devoted to modern Catholic churches [1–3]. The issue of the reception of acoustics was discussed in the context of an atmosphere of prayer in a sacred space [4] and a range of observations as to the reception of a religious interior in relation to its reverberation properties was presented [5]. Based on the investigation conducted by the author [6–7] as well as studies available in the literature [8–9], it can be concluded that the issue of acoustics is a major problem in sacred buildings. The main concern is reverberant noise, i.e. undesirable strong reverberation, sounds that cause interference with verbal communication. The problem of acoustics in a church does not only refer to the creation of conditions suitable for speech and organ music; the aspect of the sense of the sacred in the sonic sphere is also important. Thus, the question arises in regard to the reception of the sacred in the sonic sphere: when is the object perceived as sacred in terms of acoustics? Then there is also a question of whether meeting acoustic recommendations will ensure the reception of the sacred in the sonic sphere. An acoustic study was conducted in a church exemplary of religious facilities typically situated in multi family housing estates to determine its functionality in the sonic sphere and to discuss the issue of the sacred in relation to acoustics.

In search of appropriate reverberation in churches

The sense of the sacred in the sonic sphere is strictly dependent on the reverberation of the interior. As part of the project for the Church of the Most Holy Trinity in Fatima,

Fig. 1. Św. Jerzy Church in Poznań – view of the building; source: author

Fig. 2. Św. Jerzy Church in Poznań – view of the interior; source: author

acoustic project was also made for the twin chapels located under the church [5]. In the first of them, i.e. the Chapel of the Blessed Sacrament, a great deal of sound-absorbing materials were applied and thus short reverberation time $RT_{500\text{-}100}$ = 0.8 s was achieved. In reference to the second, i.e. the Chapel of the Resurrection, it was decided not to introduce any acoustic arrangement, and the traditional sound-reflecting materials were applied. This design resulted in reverberation time $RT_{500\text{-}100}$ = 2.8 s. Visually, the two chapels remained very similar to each other. Next, believers were asked which chapel they liked better, and the answer was that the Chapel of the Resurrection was definitely more pleasant, while there was "something wrong" with the Chapel of the Blessed Sacrament (the respondents were unaware of the acoustic arrangement). The reverberation in the chapel without an acoustic arrangement gave the effect of the acoustic environment of a small church. However, the reverberation time obtained after the acoustic arrangement created an acoustic climate typical of interiors intended for speech, thus depriving the place of an ambience typical of a sacred facility.

Another example of the search for optimal acoustic conditions and of the ambiguity in determining them is noticeable at Duke University Chapel. This university chapel, built in 1930–1932 in the neo-Gothic style, with its internal volume of ca. 28 000 m^3, was originally finished with absorptive porous ceramic tiles (*Akoustolith*). The surface covered with it was ca. 2 300 m^2. The reverberation time for 500 Hz was 3 seconds. In 1969, a decision was made to install a new pipe organ and also to increase the reverberation time. The acoustic tiles were coated with a sealant, and the value of RT_{500} = 6,75 s was obtained after putting four layers of the sealant. The first two layers allowed reverberation time RT_{500} to reach 4.0 s, but the value turned out to be insufficient for the designers who aimed to ensure acoustic conditions found in the largest Gothic cathedrals. The initial reverberation time RT_{500} = 3 s was compliant with the contemporary requirements (Fig. 4.); however, in this specific case, speech clarity was impaired because only the newly built instrument was taken into account and the creation of an interior for the needs of organ concerts was a priority. The sound amplification system obviously needed to be replaced because it did not serve its purpose in such a reverberant interior [10].

Investigations

A specific example will show how the issues of reverberation and a religious ambience are put into practice in the sound sphere. A contemporary church, Św. Jerzy Church, built in 1992–1999 in Poznań and located in a housing estate of blocks of flats, was selected. The internal volume is 4 000 m^3 (note: internal volume of an average contemporary church in a housing estate of blocks of flats is ca. 3 500–7 500 m^3). This aisle church was designed by Włodzimierz Wojciechowski, Bogdan Celichowski and Wojciech Kasprzycki. It is a garrison church dedicated to the police forces of Wielkopolskie province, and has been the only religious church for the police in Poland. Figure 1. shows the outside of the church while Figure 2. shows its interior.

The acoustic investigations were carried out using an omnidirectional sound source, and the DIRAC programme with the Brüel & Kjær ZE-0948 USB sound card. The e-sweep signal was generated, and the measurements involved parameters that are regarded in the literature as primary to assess acoustic properties of a sacred interior: RT, T_s, C_{80}, C_{50}, STI. A gunshot was an additional sound source, and a control measurement was carried out in selected points. The measured acoustic parameters were compared with values recommended for churches. The sound source was placed in front of the altar. The microphones were located in selected points in the pews at the height of 1.1 m. Figure 3. presents a view of the hall with themarked sound source "S" and measurement points, which are marked with numbers. The background noise level in the facility under investigation did not exceed 35 dB. All the investigations were conducted while people (believers) were absent. The assumed measurement methodology is compliant with the recommendations for investigations in churches [11–13]. Thus obtained results may be compared with the recommended values.

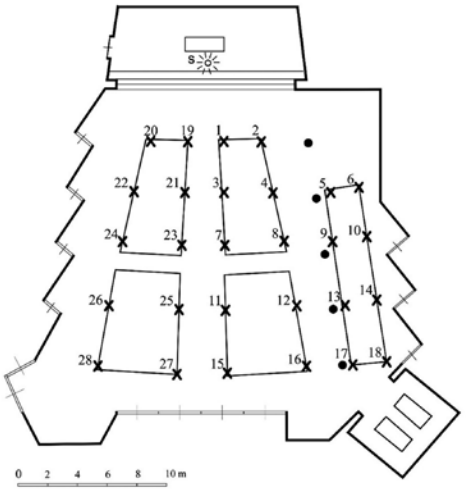

Fig. 3. View of the church with the marked sound source and position of the measurement points; source: author

Results of the investigations

Reverberation is defined quantitatively by reverberation time, i.e. the basic parameter used to assess the acoustic quality of an interior. It is, to a high degree, correlated with many acoustic parameters used to assess specific acoustic aspects of an interior. The results of the investigations were compared with the recommendations available in the literature.

Figure 4. depicts a graph illustrating the recommended reverberation time for churches depending on their internal volume [14]. The dark grey colour represents recommended reverberation time for churches with frequent organ music performances. The light grey colour represents reverberation time for churches where speech is dominant.

The results of the reverberation time measurements are shown in Figure 5. The average reverberation time RT= 2.6 s, while the recommended value is RT = 1.3–2.7 s. The value of mid-frequency RT is even higher and amounts to $RT_{500\text{-}1000}$ = 2.9 s. For churches of this internal volume, the recommended reverberation time RT for interiors with a pipe organ is from 1.7 s to 2.7 s. If the interior accommodates an electronic instrument and speech prevails, the recommended RT value is from 1.3 s to 1.7 s (Fig. 4.). In the investigated church, RT falls within the upper range of the recommended values, but because there is no pipe organ, reduction of RT is recommended.

Center time Ts is used to assess sound clarity of music. Figure 6. shows frequency characteristic of center time; mean T_s = 182.6 ms, while the recommended T_s= 70–120 ms [15].

Clarity C_{80} is also used to assess the sound quality of music and defines ability to differentiate between details of a received piece of music. Clarity C_{80} was averaged for 0.5; 1; 2 kHz [16]. Also, following the guidelines for

Table 1. Comparison of the parameter C_{80}

C_{80} [dB]				
First row	Recommended	Last row	Recommended	General recommendations
-0.1 0.5 1.5 1.0	3 to 8	-1.8 -3.4 -3.3 -3.9 -4.3	3 to 8	<-3 Organ music

investigations of religious buildings [1], C_{80} was determined for the first and the last rows (Table 1).

In the interior under investigation, clarity reaches values from 1.5 to–4.3 dB. The results show that in some measurement points, the values are favourable for organ music. According to the guidelines for churches, C_{80} values for the first and the last rows should be from 3 to 8 dB [15]. In the investigated church, the mean value for the first row is 0.7 dB, which is by no means the optimal value, but it is still not much below the recommendations. The value of this parameter is less favourable for the last rows, where it is – 3.3 dB.

Clarity C_{50} is employed to evaluate speech intelligibility, and it is defined analogously to C_{80}. Measurements are used to calculate the weighted value of clarity C_{50}. Octave bands 0.5; 1; 2; 4 kHz are multiplied by the weighting factor that is equal to 0.15; 0.25; 0.35; 0.25 for each band respectively, and thus obtained results are added up. When C_{50} ranges from -7 to -2 dB, it indicates poor speech intelligibility, while C_{50} < -7 dB indicates bad speech intelligibility [16]. In the investigated interior, C_{50} is from 0.03 to -7.4 dB. In particular, acceptable values are reached in the measurement points located in the first rows while the points that are far from the sound source display poor or bad speech intelligibility.

Another parameter that allows assessment of speech intelligibility is STI. For the front rows, both for the female and the male voice, it reaches the value of 0.48, which means fair speech intelligibility, while the back rows register the value of 0.39, which means poor speech intelligibility.

Conclusion

The sense of the sacred is intertwined with appropriate interior reverberation. The recommended reverberation time values in a Catholic church (Fig. 4.) range from values appropriate for speech (RT = 1.0 s; V = 300 m^3) to values acceptable for organ music (RT = 3.5 s; V = 30 000 m^3). According to standard PN-B-02151-4, in interiors intended exclusively for speech, the expected reverberation time should be even shorter (from RT = 0.6 s for classrooms with internal volumes up to V = 250 m^3) [13]. For organ music, considerably longer reverberation time is often expected than the recommended RT = 3.5 s for churches with the largest internal volume. The example of the Duke University Chapel adaptation

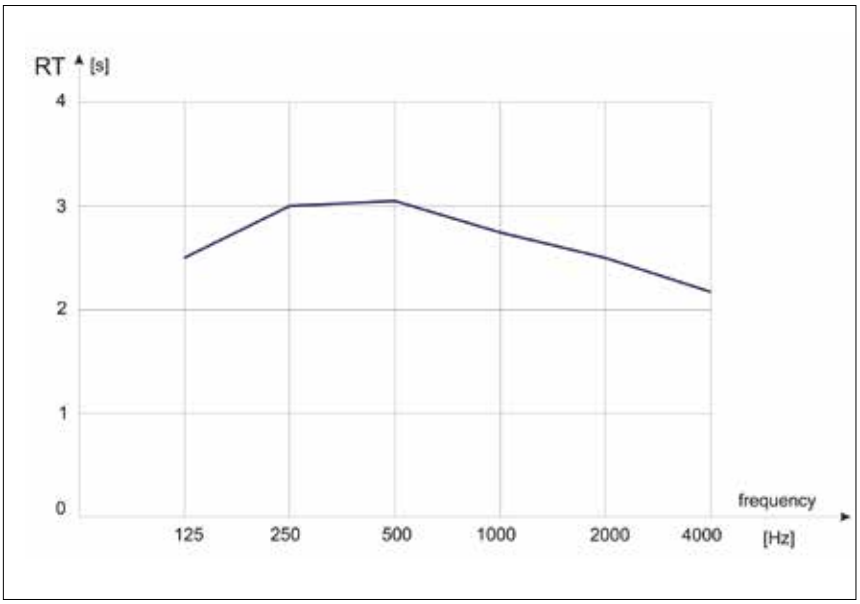

Fig. 5. Frequency characteristic of average reverberation time RT; source: author

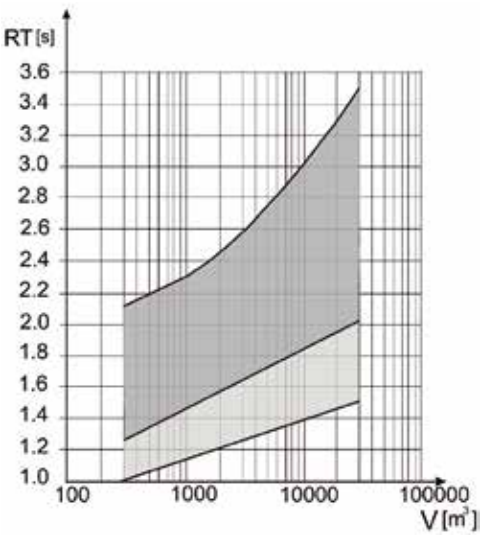

Fig. 4. Range of optimum reverberation time for churches; source: [14]

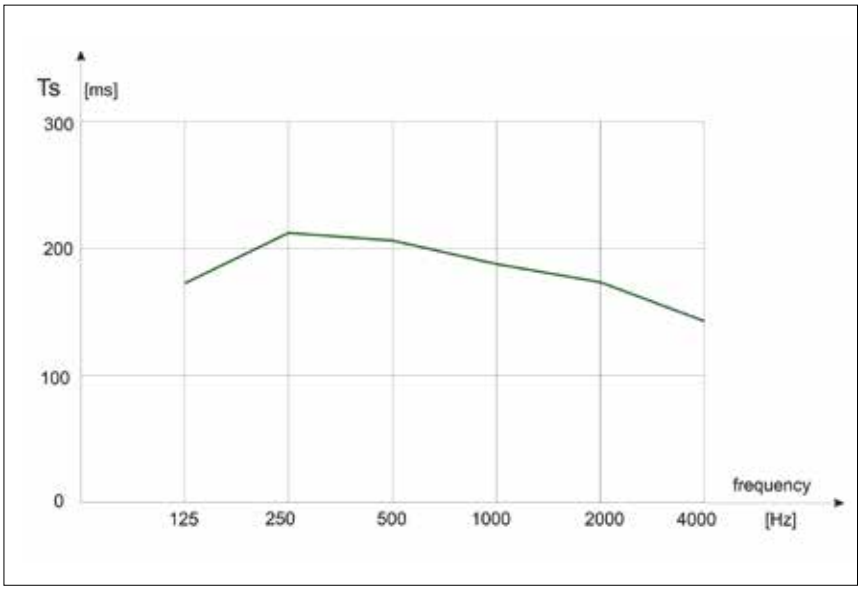

Fig. 6. Center time Ts in the frequency function; source: author

referred to above is an apt illustration of this; only RT values exceeding 6 s were considered appropriate for the reception of organ music. However, such an extreme example of interior adaptation is not suitable to ensure the proper functionality of a sacred building. In churches, reverberation time reduction is essential, and it is conditioned by the key verbal function of the liturgy.

The example of the twin chapels in the Church of the Most Holy Trinity in Fatima shows that the sense of the sacred is related to the persistence of sound in an interior, which is associated with longer reverberation time. In the Chapel of the Blessed Sacrament, $RT_{500\text{-}1000}$ = 0.8 s, which is optimal for speech, does not ensure a sense of the sacred in the sonic sphere. Therefore, it will not be optimal to design a sacred interior to obtain shorter recommended RT values (the light grey range on the graph in Fig. 4.). Even if the interior houses no organ, it is better to choose values from the recommended ranges for churches with organs (dark grey range on the graph – Fig. 4.).

In the investigated Św. Jerzy Church, RT = 2.6 s is close to extreme recommended values. Since the interior has no organ, reduction of the reverberation time to RT = 1.7–1.9 s would be recommended. Although organ music is never performed in the interior, reduction of reverberation to the value recommended for churches with a predominantly verbal function (i.e., around 1.3 s) will not provide a sense of the sacred in the sonic sphere.

A distinctly reverberant interior that builds a sense of space unequivocally associated with the liturgy is part of the tradition of sacred architecture. Thus, excessive reduction of reverberation time not only has a negative effect on the reception of organ music but also is not conducive to creating an acoustic ambience, ascribed to, in cultural terms, an interior with a liturgical function.

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PRAWIDŁOWY SPOSÓB CYTOWANIA
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Abstract: Acoustics are one of the main components that constitute the functionality of the sacred building. Designing a church is a real challenge because the interior must be adapted to various acoustic requirements. However, one must bear in mind that one of the goals to be achieved in a religious interior is to create the sense of the sacred. The aim of this paper is to investigate acoustic conditions in a contemporary Catholic church with a view to determining the sound quality of the interior. Acoustic investigations were conducted in Św. Jerzy Church in Poznań. An ominidirectional sound source, the DIRAC software and the Brüel & Kjær ZE-0948 USB sound card were used. The e-sweep signal was generated and parameters that are referred to in the literature as basic were measured to assess the acoustic properties of the religious interior. The acoustic parameters were then compared to the recommended values. The most important parameter used in the assessment of the sound quality of a sacred interior is reverberation time RT. A lot of contemporary churches exceed its recommended value, the result of which is reverberant noise. The RT value in the investigated church falls within the recommended range but because the interior houses no pipe organ, the value should be lowered. Shorter reverberation time will ensure better speech clarity while the sense of the sacred will be retained. Designing a religious facility should take account of its acoustics as early as at the conceptual stage; one should remember that aural impressions will influence the reception of the acoustics of the interior.

Keywords: church acoustics, sacred buildings, reverberation time, reverberant noise

Streszczenie: SACRUM W SFERZE DŹWIĘKOWEJ – BADANIA AKUSTYCZNE WSPÓŁCZESNEGO KOŚCIOŁA. Akustyka jest jednym z głównych elementów funkcjonalności obiektu sakralnego. Projekt akustyczny kościoła jest wyzwaniem, ponieważ wnętrze musi być przystosowane do różnych wymagań akustycznych. Jednocześnie należy pamiętać, że we wnętrzach sakralnych ważne jest uzyskanie wrażenia *sacrum* w sferze dźwiękowej. Celem pracy jest zbadanie warunków akustycznych we współczesnym kościele katolickim, aby określić jakość dźwiękową wnętrza. Badania akustyczne przeprowadzono w kościele pod wezwaniem św. Jerzego w Poznaniu. Zastosowano wszechkierunkowe źródło dźwięku, program DIRAC wraz z kartą dźwiękową Brüel & Kjær ZE-0948 USB. Generowano sygnał e-sweep i wykonano pomiary parametrów uznawanych w literaturze za podstawowe do oceny własności akustycznych wnętrza sakralnego. Zbadane parametry akustyczne odniesiono do wartości zalecanych. Najważniejszym parametrem w ocenie jakości dźwiękowej wnętrza sakralnego jest czas pogłosu RT. Wiele ze współczesnych kościołów ma znacznie przekroczoną wartość tego parametru, co skutkuje hałasem pogłosowym. W badanym kościele otrzymany czas pogłosu RT mieści się w górnym zakresie wartości rekomendowanych, jednakże ze względu na brak organów należałoby zmniejszyć jego wartość. Krótszy pogłos pozwoli na uzyskanie lepszej zrozumiałości mowy przy zachowaniu wrażenia *sacrum* w sferze dźwiękowej. W projektowaniu obiektu sakralnego ważne jest, aby już od fazy koncepcyjnej projektu mieć na uwadze jego akustykę, pamiętając że wrażenia dźwiękowe będą wpływały na odbiór architektury wnętrza.

Słowa kluczowe: akustyka kościoła, obiekty sakralne, czas pogłosu, hałas pogłosowy