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Cinema hall adapted for opera singing – acoustic assessment

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Abstract Room acoustics must be adapted to the intended function, and acoustic requirements vary depending on the type of sound production. Acoustic investigations were carried out in the hall of the Olimpia Academic Music Theater, which was originally a cinema. Acoustic requirements for cinemas are entirely different from those for opera singing. To ensure good acoustic conditions in the interior, an architectural adaptation or introduction of variable acoustics is necessary. The analysed interior was adapted to the needs of opera singing and the cinema function was abandoned. The objective of the research is to evaluate the acoustic quality of the hall for the purposes of an opera house.

Keywords: acoustic adaptation, opera house acoustics, reverberation time in an opera house.

1. Introduction

Buildings often change their function. Interiors intended for cultural purposes – music or spoken word – need to undergo acoustic adaptation to the new intended use. The acoustic requirements vary depending on the type of sound production; a symphonic concert, a musical performance or a performance involving speech will all require different acoustic conditions. Therefore, in cultural venues such as a cinema, theatre, concert hall or opera house, the acoustic requirements have to differ. Rooms where the function changes or where the space is reorganized but the acoustic requirements remain the same are neither architecturally nor acoustically challenging (e.g. transformation from a cinema hall into a lecture hall, or from a conference room into a fashion show room). On the other hand, it is not possible to use the same room without any architectural modifications, hold different events with different acoustic requirements and expect the same level of acoustic success. This is especially true if the room is used for purposes for which the optimal acoustic values differ greatly.

In order to ensure acoustic comfort in one room used for different functions, acoustic adjustments are applied [1-5]. The adjustments are solutions that allow adaptation of the room to the current needs. By adjusting the acoustics, it is possible to successfully combine extreme acoustic requirements in one interior.

This paper addresses acoustic issues found in a hall which operated as a cinema for many years but which is currently used for opera performances. However, the hall is not acoustically regulated and no acoustic adaptation to its new function has been carried out. The aim of this paper is to present the preliminary results of an acoustic investigation of the hall and to assess the hall's functionality for the needs of opera music.

2. Olimpia Academic Music Theatre

The Olimpia Academic Music Theater is housed in a building for years associated by Poznan citizens with the cinema. The current modernist building was constructed after the war. Before that, there had been an impressive Art Nouveau villa by Nazary Kantorowicz, which housed the management of the Pewuka (General National Exhibition) in the interwar period [6]. The post-war building was constructed to be the Cultural Centre of the Civic Militia. From 1957 to 2004, the Olimpia cinema operated there. In the following years, the cinema was replaced by the Viva Theatre, and then a private institution of higher education was founded there. Currently, the building has been taken over by the Academy of Music. A major refurbishment of the building is being planned to facilitate a wide range of cultural activities. Figure 1 shows the building from the entrance perspective, while Figure 2 shows the investigated hall.

The main hall, which was used as a cinema for years, is now mainly used for opera. The internal volume of the hall including the flytower is approximately 4 500 m^3. The hall is designed for 270 listeners including 124 seats in the balcony. For the needs of the orchestra, on the ground floor, the front rows can be removed and the hall can then accommodate 240 people.

Figure 1. View of the building.

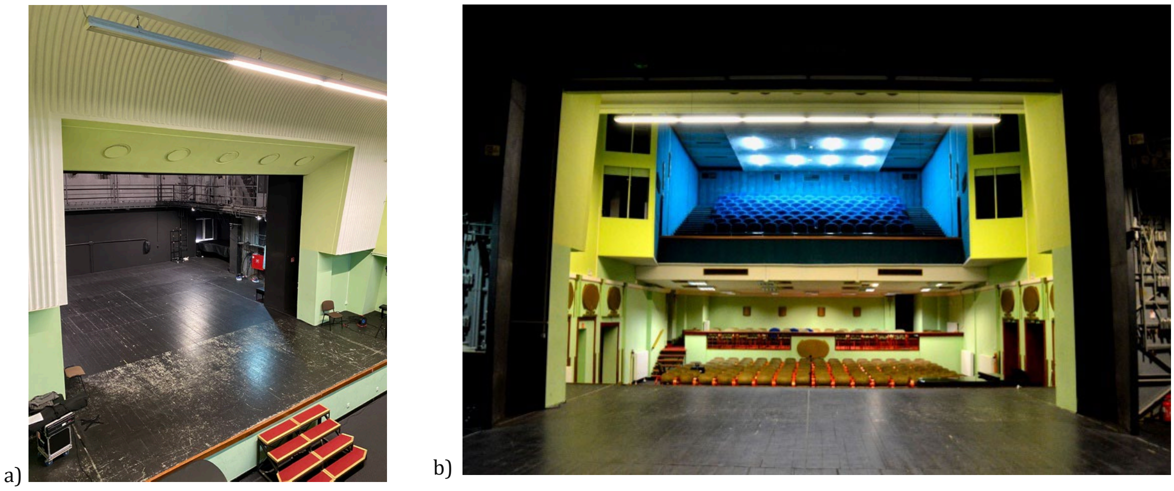

Figure 2. Hall interior: a) view towards the stage, b) view of the hall from the stage.

3. Measurements

The acoustic investigations were carried out using a gunshot, and DIRAC programme with sound card Brüel & Kjær ZE-0948 USB. The measurements involved parameters: T_{30}, EDT, T_S, C_{80}, C_{50}, D_{50}, STI and RASTI. The sound source was placed on the stage. The microphones were located in selected points in the auditorium at the height of 1.1 m. The background noise level in the facility under investigation did not exceed 35 dB. All the investigations were conducted without an audience. Figure 3 presents a view of the hall with the marked sound source "S" and measurement points, which are marked with digits. The assumed measurement methodology is compliant with recommendations for investigations provided for in PN-EN ISO 3382-1:2009, PN-EN ISO 3382-2:2010, PN-B-02151-4:2015-06.

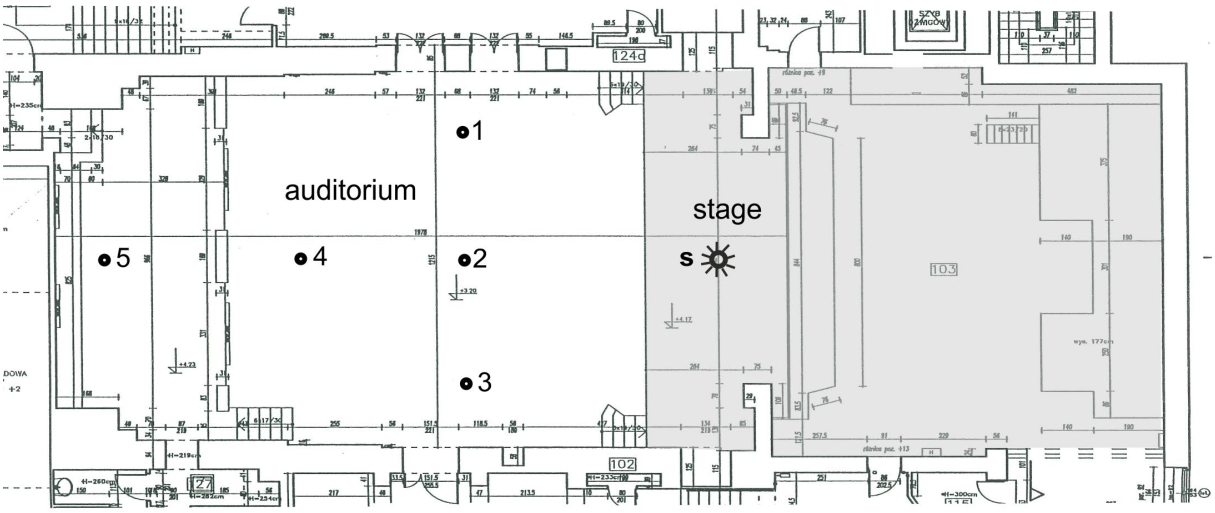

Figure 3. View of the hall with the marked sound source and position of the measurement points.

4. Results of the measurements

Reverberation is quantitatively determined by reverberation time, a primary parameter used to assess the acoustic quality of an interior. It is correlated to a great extent with numerous acoustic parameters used to assess individual acoustic aspects of an interior. Reverberation time RT is the primarily defined acoustic parameter in an interior. It is the time after which the sound pressure level drops by 60 dB after the continuous sound source is switched off. It is defined on the basis of the sound decay curve. The measurements are made in octave bands. In practice, the measurement involves the range of 5 to 35 dB below the initial level and is multiplied by two. The average reverberation time RT = 1.44 s, while the recommended RT = 1.3-1.8 s, depending on the volume of the interior. The bigger the volume, the longer the RT should be. Reverberation time for mean frequency $RT_{(500\text{-}1000)}$ = 1.57 s (see Fig. 4). In comparison, in recognized opera houses around the world, reverberation time for the frequency of 500-1000 Hz for a hall without an audience is: Milan, Teatro alla Scala 1.35 s; London, Royal Opera House 1.3 s; Vienna Staatsoper 1.8 s; Paris, Opera Garnier 1.2 s; New York, Metropolitan Opera House 1.7 s [7].

In terms of other cultural institutions, Poznań has one opera house, i.e. the Grand Theatre in Poznań. The reverberation time RT investigated by the author in this opera theatre is 1.47 s for an empty stage, while for mean frequencies $RT_{(500\text{-}1000)}$ =1.48 s [8]. Thus, these values are similar to those reached in the Olimpia Academic Music Theatre.

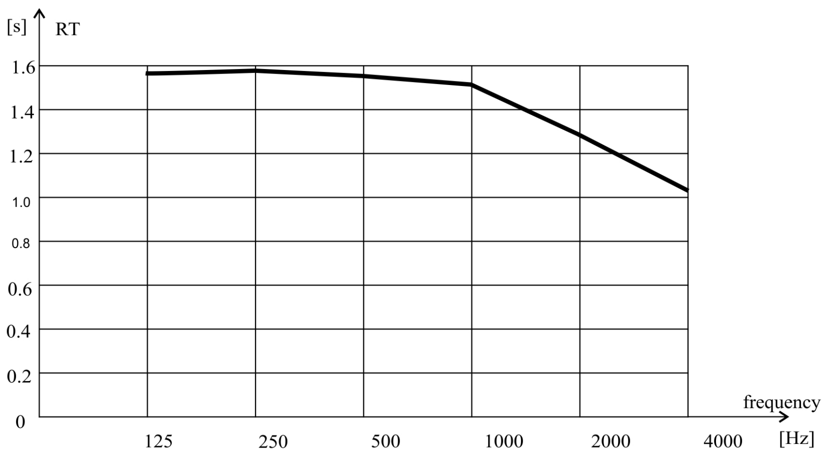

Figure 4. Frequency characteristic of average reverberation time RT.

Early decay time EDT is defined as six times the value of the time after which the sound pressure level drops by first 10 dB after the stationary sound source is switched off. It is determined from the slope of the straight line approximating the time decay curve in the range from 0 to -10 dB. EDT reflects subjectively experienced reverberation of an interior better than RT. An average EDT value equals 1.26 s. Figure 5 presents the frequency characteristic of early decay time.

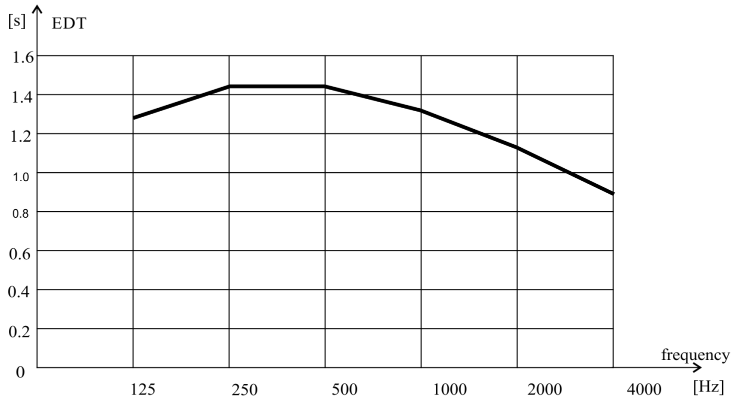

Figure 5. Frequency characteristic of average early decay time EDT

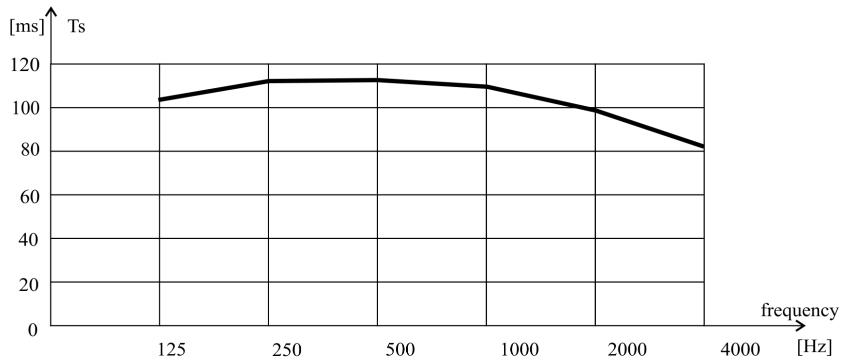

Figure 6. Center time T_S in the frequency function.

Another parameter, i.e. center time T_S, is a coordinate on the time axis of the center of gravity of the echogram. It is used to assess sound clarity of music. Figure 6 shows the frequency characteristic of center time; mean T_S = 103.4 ms, while the recommended T_S = 70 – 90 ms [9].

Clarity C_{80} is used to assess the sound quality of music and defines the ability to differentiate between details of a received piece of music. In the logarithmic measure, it is the ratio of sound energy which arrives at the measurement point within the first 80 ms to the sound energy arriving there after 80 ms. In accordance with the guidelines available in the literature, C_{80} was averaged for 0,5; 1; 2 kHz. In the investigated interior, C_{80} assumes values from -1.12 to 2.05 dB, while the recommended value for opera houses is from 3 to 7 dB [10]. The values closest to the recommendations are in point no. 2. In comparison, in recognized opera houses around the world, clarity C_{80} for a hall without an audience is: Milan, Teatro alla Scala 2.9 dB; Vienna Staatsoper 2.3 dB; Paris, Opera Garnier 3,7 dB; New York, Metropolitan Opera House 1,3 dB [7].

Speech intelligibility is also a key component of acoustic functionality of the interior. The investigation involved parameters C_{50}, D_{50} and STI, which are used to assess speech intelligibility. Index C_{50} 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 equal to 0,15; 0,25; 0.35; 0.25 for each band respectively, and thus obtained results are added up. It is recommended that thus calculated C_{50}> -2 for speech without an amplifying system. According to (Marshall, 1996), when C_{50} ranges from -7 to -2, it indicates poor speech intelligibility, while C_{50} < -7 indicates bad speech intelligibility. The investigated interior reaches C_{50} values in the range from -0.03 to -5. For points no. 1-3, recommendations are met.

Another parameter used to determine speech intelligibility is clarity D_{50}, which is the ratio of energy reaching the listening position in 50 ms to the total energy of the impulse response. The recommended value of D_{50} should be at least 0.4 [11]. As with C_{50}, these recommendations are met for points 1-3.

Parameter STI ranges from 0 to 1, where 0 means no speech intelligibility and 1 means complete intelligibility. The parameter ranges from 0.51 to 0.63, meaning that speech intelligibility is fair to good.

5. Discussion

5.1. Stage, flytower and orchestra pit

The critical area that defines the opera theatre is the stage with its flytower (stagehouse) and orchestra pit. The stage is the largest area in the entire theatre and both the centre of the life of the theatre. It is the most important element of the stagehouse known as the flytower or flyloft. We can say that a theatre has a flytower when the ceiling above the stage is more than 1.5 metres above the ceiling of the proscenium (the proscenium is the area between the curtain and the orchestra pit, or, if the orchestra pit is covered, between the curtain and the auditorium).

The proscenium houses numerous galleries, platforms, lifts and, in larger theatres, open rooms for storing decorations. The flytower has multiple functions. It is the space that primarily houses the stage set hung on battens. Large theatres can store decorations for up to three productions simultaneously. The flytower renders it possible to quickly change the scenery that is lowered onto the stage. There is also a curtain. As a fire safety precaution, a so-called safety curtain is also placed in there, which can separate the auditorium from the stage if necessary. The flytower area also accommodates lighting.

Auditoriums in opera theatres are wider and deeper than in drama theatres. Among other things, this is because, the opera stage, in addition to soloists, needs to offer enough space for a large chorus, ballet and extras. It is not uncommon that horses, camels or elephants appear on the stage. It is also significant that it is often large groups of extras or chorus that move on stage while the solo singer stays in one place. Particularly dramatic works may feature a large group scene where ballet, chorus, extras and animals may need to appear on stage at the same time.

The pace of appearance on stage is dictated by the music and music cannot be changed. Thus, large opera productions require not only a large acting space but also a spacious area next to the stage in the form of the backstage and wings. Opera stages often employ equipment packed with technology; the scenery is expensive and enormous due to the nature of the opera performance. As opposed to staging in drama theatres, an empty stage in an opera production will not pass muster. Flytowers in opera theatres are generously equipped with technical tools, light bridges, lifts, numerous multi-level galleries and often storage rooms for technical equipment or decorations.

The space of the flytower is several times larger than the auditorium. The ratio of the internal volume of the flytower to the internal volume of the auditorium was calculated for selected opera houses. The results show how many times the flytower is larger than the auditorium (see Tab. 1). In the Olimpia Academic Music Theatre, the ratio of the flytower to the auditorium falls within the range found in professional opera theatres whose architecture was consciously designed to include this function. Thus, from the functional point of view, it is possible to use the stage for opera performances.

Table 1. Ratios of the internal volume of the flytower to the internal volume of the auditorium for selected opera houses.

Opera house	Flytower Volume m^3	Auditorium Volume m^3	Proportion
Olimpia Academic Music Theatre	2781	1709	1.63
Grand Theatre in Poznan	11300	5000	2.26
Opera Nova in Bydgoszcz	12500	9100	1.37
Grand Theatre de Bordeaux	13000	4500	2.9
Magyar Állami Operaház in Budapest	18300	9500	1.93
Festspielhaus in Bayreuth	30100	10600	2.8

The orchestra pit is the space between the stage and the auditorium. It is a feature found in opera or musical theatres. Multi-purpose halls with adjustable acoustics also have an orchestra pit. However, the orchestra pit is not found in drama theatres, where the speech function is predominant. In the interior under investigation, the orchestra pit is not in use. Due to its technical condition, it is closed off from above by the stage and is used as an acting space. The orchestra is situated on the ground floor when the front rows are removed. This arrangement resembles open pits. Unlike orchestra pits that are situated partly below the stage (sunken pit open), this type of pit is quite uncommon. Open pits prove successful in classical operas where the composition of an orchestra is not very extended. For large orchestras, the problem is not only the extent of the space occupied by the musicians but also the sound level generated mainly by the brass and percussion sections. In addition, the disadvantage of such an arrangement is that the visible orchestra and the conductor partly interfere with the perception of the performance.

5.2. Interior finishes

When designing an opera house, the acoustic impact of all components that make up the interior architecture is key. Thus, appropriate proportions of the hall, the shape and texture of the walls, the ceiling and the auditorium, together with the choice of the finishes, play an important role. In cinemas, short reverberation time must be ensured so the interior is highly muffled. Sound absorptive materials are mounted on the ceiling, the walls and the floor. The seats are also heavily upholstered. Such a solution ensures that the reverberation is reduced and thus the acoustics of the hall do not affect the sound image coming from the loudspeakers [12]. Depending on the room's volume, basic mid-frequency RT values (at 500 Hz) are recommended to be within 0,2 s and 0,6 s.

Thus, the acoustic requirements and interior design for the two functions differ considerably. In the analysed interior, sound absorptive materials are found on the walls of the balcony area and the balcony balustrade. Similarly, the heavily upholstered armchairs or the soft carpet on the floor (see Fig. 7) are sound absorptive. Clearly these are remnants of the cinema function of the hall as such materials are not used in opera houses but are typical of cinemas. In contrast, sound reflective walls are on the ground floor, under the balcony near the stage and on the ceiling. In terms of acoustic impact, the current solution refers to opera houses with boxes which, apart from diffusing sound, also have sound absorptive properties.

Figure 7. View of the interior of the hall from the balcony;
sound absorptive finishes are marked with yellow arrows.

The measured RT reverberation time is 1.44 s and is within the recommended values for opera theatres. The results obtained are mainly due to the influence of the flytower, the effect of which is similar to that of a reverberation chamber. The flytower was empty during the investigation. The presence of a stage set on the stage and storage of the set in the flytower will significantly reduce the current reverberation time.

The measured EDT value is 1.26 s. When the EDT is less than RT, this is caused by strong early reflections or strong direct sound reaching the audience. This can also occur for highly sound absorptive floor combined with highly sound reflective walls [13]. In the investigated interior, sound is absorbed by the carpeted floor, while the walls are finished with sound reflective plaster.

5.3. Comfort for singers

Acoustics have a significant impact on singing comfort. In general, singers prefer a space that provides a feeling that of amplified sound, i.e. the effect is full sound, which ensures confidence, security and comfort during performances. On the contrary, an interior in which the sound lacks fullness, i.e. a dry acoustic interior with short reverberation time, undermines the creation of the sound. This phenomenon is confirmed by the natural propensity of many people for singing in a place where they can easily hear themselves [14]. As Forsyth observes, '*The urge to sing in the shower or to wheep in a tunnel, the ability of even unmusical people to sing in tune in a reverberant space – these suggest a relationship between music and the acoustics of a hard surfaced enclosure* [15]. Thus, singing comfort is high provided that the singer can clearly feel the reverberation and therefore the sound amplification.

In the investigated hall, the singer on the stage feels voice amplification through the reverberant flytower. Provided that the stage set does not involve too many elements and the composition of the orchestra is small, the singing comfort is very good. As the amount of sound absorptive material on stage increases, the sense of voice amplification will decrease. Additionally, as the composition of the orchestra grows, the singer will have a sense of their voice being drowned out. In opera theatres with a sunken pit open, the effect of the singer's voice being drowned out is offset by placing the orchestra deeper in relation to the level of the auditorium. Thus, sound between the singer and the musicians in the orchestra is well balanced.

6. Conclusions

Changing the use of a hall is a multi-faceted acoustic challenge, especially if the existing function undergoes a complete makeover. The discussed investigation involved a hall that that had been used as a cinema for many years and was later adapted for the needs of opera performances.

In general, the investigated hall meets the basic acoustic requirements expected for an opera performance. The basic parameter, i.e. reverberation time RT, is 1.44 s, which falls within the range of values recommended for an opera theatre. Also the value of the reverberation time for mid-frequencies 500-1000, which is $RT_{(500\text{-}1000)}$ = 1.57 s, falls within the range found in highly acclaimed opera theatres. Thus, the reverberation time corresponds to the current function of the facility.

The remaining parameters that enable an assessment of the acoustic quality for opera music functions indicate a need to refine the acoustics. In contrast, parameters for speech intelligibility are close to the recommendations or are met for measurement points close to the stage.

The investigated hall is planned to undergo a major refurbishment. The investigation revealed that refurbishment is necessary. The primary need is to restore the function of the orchestra pit. In addition, it is necessary to replace the absorptive materials on the walls of the balcony area for sound diffusive textures. The issue of the sub-balcony area and the question of how to deliver the sound from first reflections to that area requires further investigation. It is obvious that the hall has great potential, especially that it has a professional stagehouse. The current proportions of the flytower to the auditorium correspond to those found in opera houses. Thus, as a temporary hall, the Olympia Academic Music Theater fulfils its function at an acceptable level.

Additional information

The author declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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