Circular concert halls and possible ways to improve their acoustics

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CIRCULAR CONCERT HALLS AND POSSIBLE WAYS TO IMPROVE THEIR ACOUSTICS

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1 INTRODUCTION

The acoustic quality of a concert hall depends on a set of parameters; one of the most important is its shape. It is known that top acoustics are not achievable in too wide a hall. Generally, the circular shape is assumed to be the worst because of a lack of early lateral reflections. This problem is well known but from time to time new circular halls are designed. Acoustic consultants propose many reflectors directing the sound from a stage to listeners and provide an optimal reverberation time. In spite of the acceptable reverberation time and enough sound strength, some measures improving early reflections are needed and usually applied.
In this paper we consider three halls with circular shape and possible ways of correction of their acoustics. First hall is the great hall of the Novosibirsk Opera and Ballet Theatre (NOVAT) for more than 1790 spectators. It was built in 1941 and officially opened after the Second World War in 1945. Today NOVAT is the largest musical theatre in Russia and often called the “Siberian Coliseum” due to its size and beauty. Second hall is the Svetlanov hall of the Moscow International Performing Art Centre opened is 2003. The hall with 1735 seats has the largest organ is Russia. Third hall is a new concert hall in Pyongyang, the Democratic People’s Republic of Korea. The hall belongs to Mansudae People’s Theatre built in 2012. Acoustics of these halls was improved in different ways. A sound amplification system is regularly used in NOVAT. Some years ago the Svetlanov hall was equipped by a digital system to control reverberation time. A set of sound reflectors in Korean hall is going to be installed around a stage and on front walls of a main floor. Results of acoustic adjustment in three halls are discussed here.

2 NOVOSIBIRSK OPERA AND BALLET THEATRE

The history of the Novosibirsk Opera and Ballet Theatre began in the late 1920s, when it was decided to build the Center of Science and Culture in the biggest Siberian city. The architectural idea was to combine different facilities with a theatre, museum, and gallery. It had to be a huge and unique building with a great dome with a diameter of 60 m. After the start of construction in 1931 the design of the building was simplified, only the theatre had to be constructed. Construction work was continued until the beginning of the Second World War in 1941 and restarted at the end of the War. The Novosibirsk Opera and Ballet Theatre (NOVAT) was opened on 12 May 1945.
Until now NOVAT is the largest musical theatre of Russia. Its exterior view reminds of the initial idea due to the dome. The main hall under the dome is circular shaped which is a trail of original concept as well. There are no balconies in the hall; its upper gallery is decorated with copies of antique statues. The theatre is often called the "Siberian Coliseum" because of its size and beauty.
Figure 1 shows a scheme of the hall. A circle with a diameter 41 m determines the hall shape. Only front parts of the side walls are deviated from the circle. The length from the stage front to the back wall is 46 m. The hall has the flat ceiling at an average height of 19 m. The volume is about 28000 m^3. There are 1774 seats in the hall. The volume per one listener is 15.8 m^3.
The volume of the hall is large enough. The halls with comparable volume have usually a capacity of 2000 seats and more[1]. It was a reason of a long reverberation time. After decades of operation the hall was renovated in 2015. During the renovation some sound absorbing materials were installed in the hall. Absorbing panels were mounted on the ceiling and curtains were hung on the

upper parts of back and side walls. The red curtains can be seen in Figure 1 in the niches behind the statues. The reverberation time was reduced to 2 s in the unoccupied hall. Figure 2 demonstrates the change of the reverberation time due to renovation. Now it is suitable for an opera house.

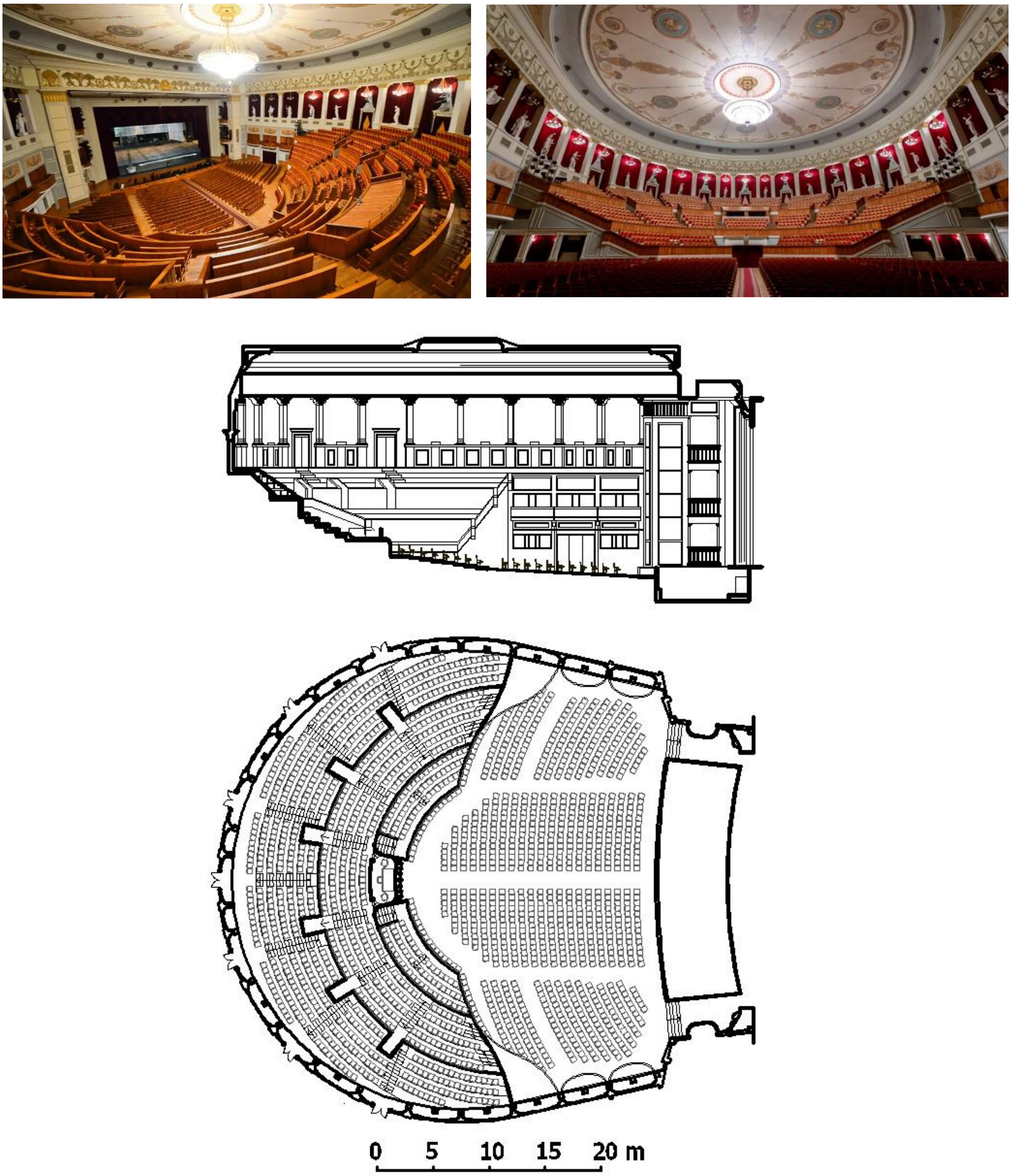

Figure 1. Opera house of the Novosibirsk Opera and Ballet Theatre

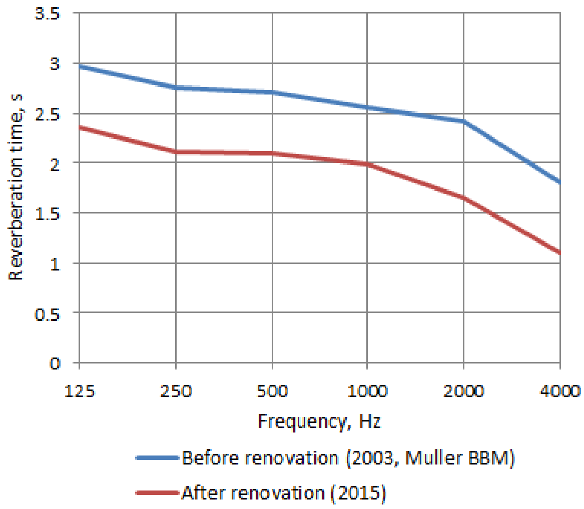

Figure 2. Reverberation time measured without an audience in NOVAT opera house

However, acoustics of the NOVAT hall is not ideal today. Because of the big volume and length the loudness at some seats is not enough especially when singers perform. The loudness of their voices depends on their individual abilities and a balance with the orchestra. The problem for a conductor is to find this balance and it is not always possible. On the other hand, the orchestra sounds good during the ballet performances; neither the listeners nor the musicians criticize acoustics seriously.

Another disadvantage is great time gap after the arrival of the direct sound. Impulse responses measured in three points are presented in Figure 3. At points 1 and 2 we do not see any reflections after the direct sound during 30 ms. Similar situation was observed on almost all seats on the main floor. The reflections from the flat part of the side wall show the area with the lateral reflection in Figure 3.

There are no lateral reflections in point 3 as well, but the reflection from the ceiling comes in 16 ms after the direct sound. The initial time delay gap (ITDG) is usually quoted for a position near the center of the main floor, halfway between the stage front and the rears wall. The point 3 is close to the central position, so we can define ITDG=16 ms. As known in the best opera houses the ITDG is less than 25 ms. It could be concluded that this parameter is relevant for good acoustic evaluation if there were not the great time delays on the most seats on the main floor.

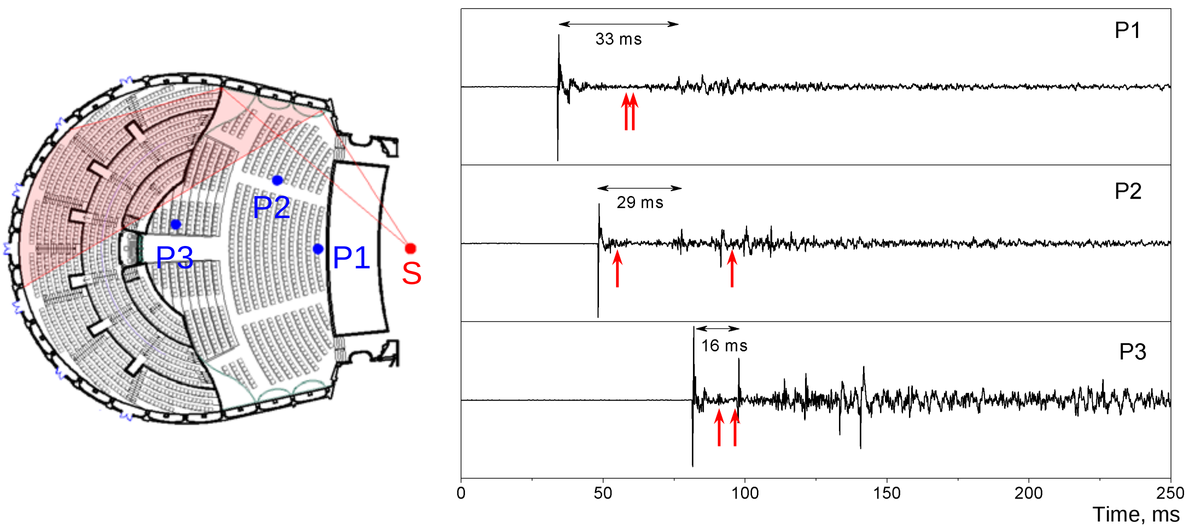

Figure 3. Impulse responses recorded in NOVAT from the nondirectional source (S). Red arrows mark estimated arrival times of the direct sound from two loudspeakers

To solve the problem of low sound strength a sound amplification system is used. Microphones are mounted at a height of 3 m over the stage. Loudspeakers are installed on the left and right of the proscenium. Sound producers adjust the amplification system to achieve sufficient loudness of soloists. Amplified sound provides additional peaks in the impulse response as well. Peak amplitudes are adjustable, whereas their arrival times depend on the loudspeaker location. Red arrows in Figure 3 mark estimated arrival times of the direct sound from two loudspeakers.

3 SVETLANOV HALL

The Moscow International Performing Arts Centre was built in 2002. It accommodates three concert halls placed on three different levels; the biggest one is the Svetlanov hall with 1716 seats. The hall has been designed for both classical and popular concerts. There is an organ, which is the biggest concert organ is Russia. Along with symphonic concerts pop and jazz performances take place there. Therefore, the hall may be considered as a multifunctional space. Views and schemes of the hall are shown in Figure 5.
The reverberation time measured in the unoccupied hall presented in Figure 4. It is slightly lower than the preferred value for symphonic music[1]. Whereas longer reverberation time is required for organ music. The pop and jazz concerts need usually shorter reverberation time[2].
The shape of the hall is not strictly circular, but all disadvantages of the circular shape exist in this hall. Intensity of useful sound reflections from walls is not very high. Moreover, many walls have irregular surfaces, so most of reflections from the walls are almost diffuse.

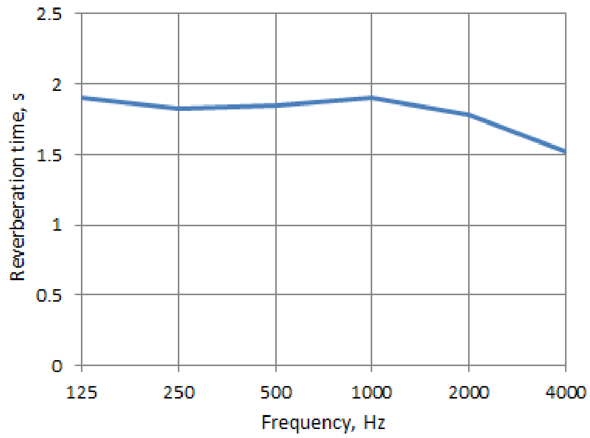

Figure 4. Reverberation time of the Svetlanov Hall

The ceiling does not provide specular reflections as well. Efficiency of sound reflection by the ceiling can be characterized by some factors recently proposed[3]. A nondirectional sound source is placed near the front part of the stage. The sound rays between green lines in Figure 6 fall onto the ceiling, so the sound energy incident on the ceiling is proportional to the angle α_0. Only a part of the ceiling reflects sound towards the audience outside the direct sound field. These rays are marked by red lines; the angle between the lines is α_1. The efficiency factor of ceiling reflecting properties is defined as a ratio of the reflected energy towards the audience to the total energy reflected by the ceiling $\varepsilon_1 = \alpha_1 / \alpha_0$. The angles in Figure 6 have values $\alpha_0 = 59°$ and $\alpha_1 = 6°$, the efficiency factor is $\varepsilon_1 = 0.1$. Only one tenth of the energy incident on the ceiling is reflected to the audience. Concert halls with good acoustics have the efficiency factor values $\varepsilon_1 > 0.5$[3].

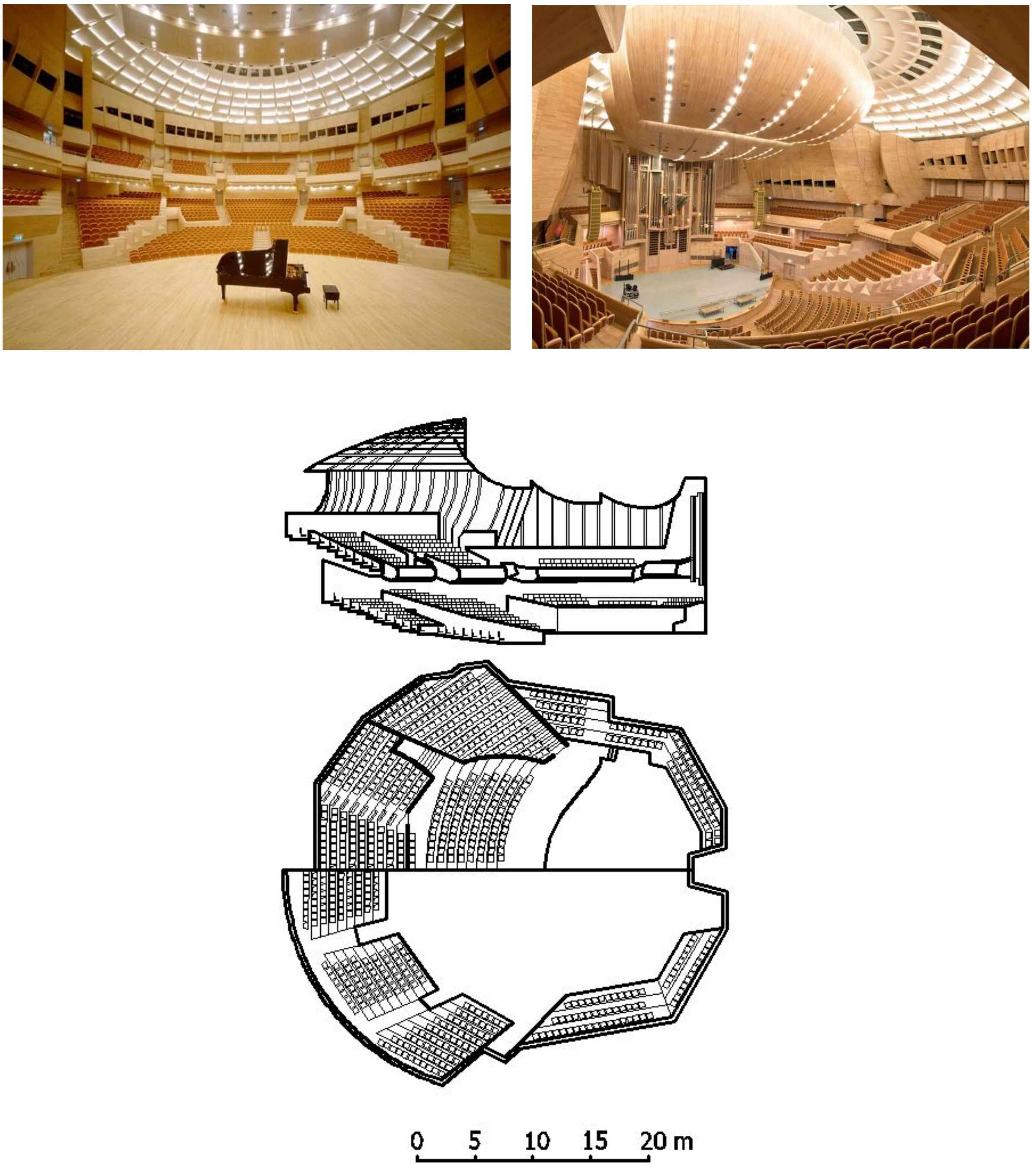

Figure 5. Svetlanov Hall of the Moscow International Performing Arts Center

So the sound field in Svetlanov hall is very diffuse. Due to lack of specular lateral reflections the degree of spaciousness is low. These conditions along with the low reverberation time do not provide fine acoustics for symphonic and organ concerts. Therefore, a number of classical music concerts has decreased in recent years.

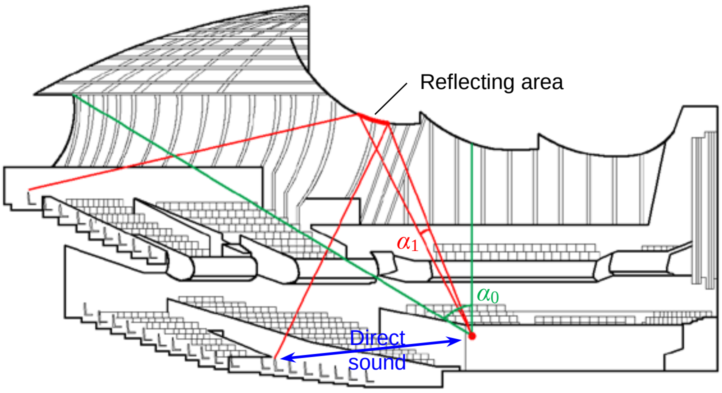

Figure 6. Sound reflections from the ceiling of the Svetlanov Hall

To improve acoustics of the Svetlanov hall it was decided to install an electroacoustical system of controlling of the reverberation time and early reflections. The system consists of 137 compact self-powered loudspeakers spaced overhead and around the perimeter of the hall and 48 miniature microphones placed precisely around the hall to pick up the room's physical response. Signals from the microphones form signals for each loudspeaker by means of digital processors. There are also 16 loudspeakers suspended over the stage at 8m height. They supply critical early reflections for the stage and front seating areas.

Now acoustics of the Svetlanov hall may be adjusted. The reverberation time may be increased up to 2.5 s which is optimal for symphonic and organ concerts. The stage support is improved significantly as well. Overall subjective evaluation given by listeners and musician suggests that the virtual acoustic system changes the hall's acoustics positively.

4 MANSUDAE THEATRE

The Mansudae People's Theatre in Pyongyang, the capital Democratic People's Republic of Korea, was built in 2012. The building has a round shape which defines the shape of a concert hall. Photographs and schemes of the hall are shown in Figure 7. The diameter of the hall is 53 m, the average height is 13 m, the volume of the hall is approx. 27000 m^3.

To make sound field more diffuse the walls are covered by relief surfaces. So the focusing of sound waves is not observed.

There are curtains in the hall for changing the reverberation time. In the right photo in Figure 7 the curtains of pink colour are lowered; they can be seen between the last row of seat and the ceiling with lamps. In the left photo the curtains are raised; the walls of white colour are open. The reverberation time was measured with the curtains raised and lowered in the unoccupied hall. The measured values are presented in Figure 8. Without curtains it is 2.2 s which is good for symphonic music. However, taking into account sound absorption by the audience the optimal reverberation time is slightly longer.

Subjective evaluation of the listeners and musicians indicated unsatisfactory acoustic conditions in the centre of the hall. Impulse responses were measured in different seats with a nondirectional sound source placed at the stage front in accordance with ISO-3382. Great time delay gaps between the direct and reflected sound were detected. In the scheme of the hall in Figure 8 red points mark the seat where the impulse responses were measured; the numbers near the red point indicate the time delay between the direct sound and the most intensive reflection. In the centre of the hall its values are 37-74 ms. Obviously there are no lateral reflections. The reflections from the ceiling are diffuse due to the ceiling form and not intensive as well. The delay times on the side seats are much smaller; its values are 11-31 ms.

There are no walls on the sides of the stage. So the stage support is provided only by the ceiling. But the reflections from the ceiling are not enough for good support. Usually side reflectors are used near the stage like in the Svetlanov hall (Figure 5).

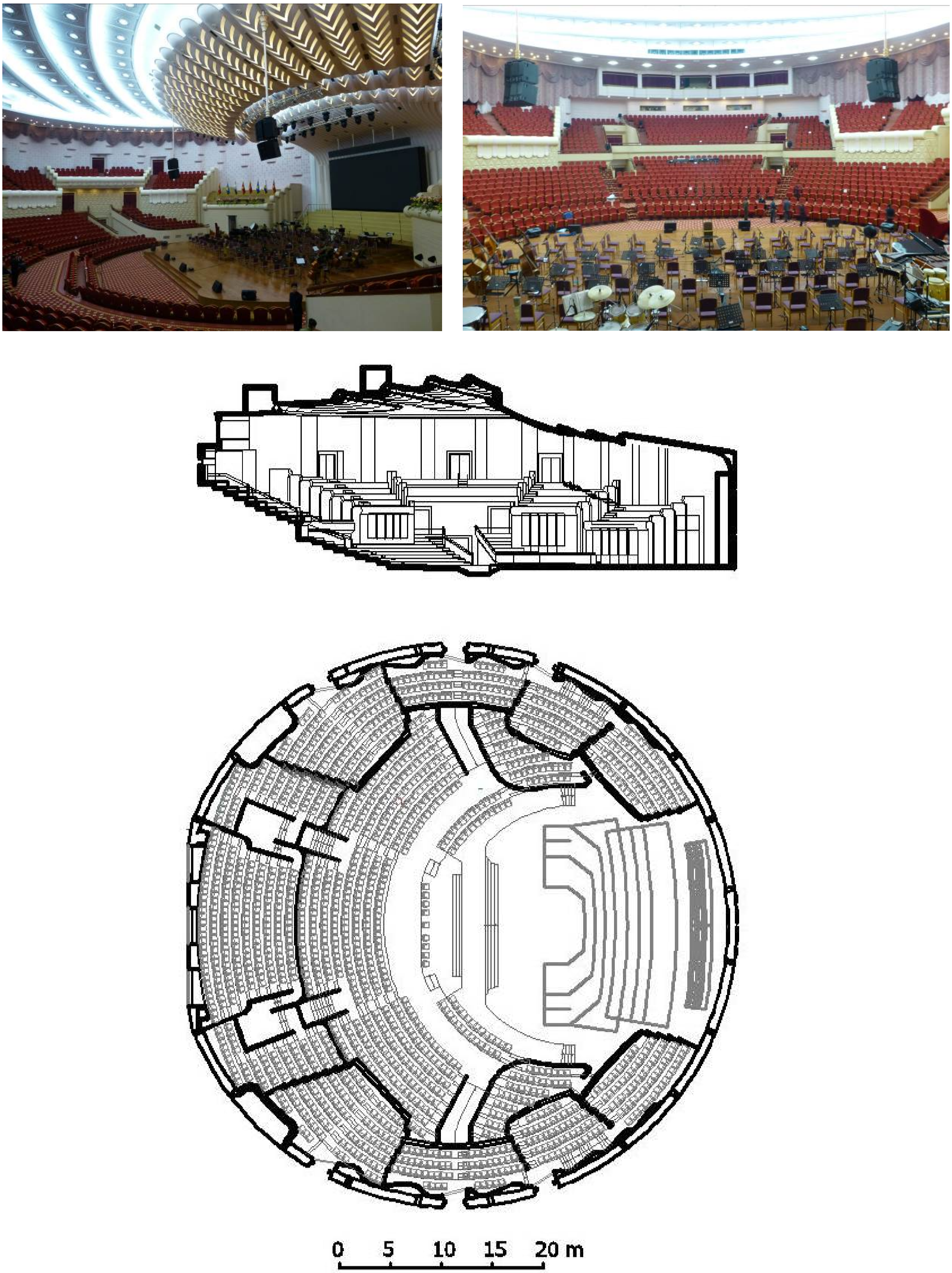

Figure 7. The concert hall of the Mansudae People's Theatre, Pyongyang

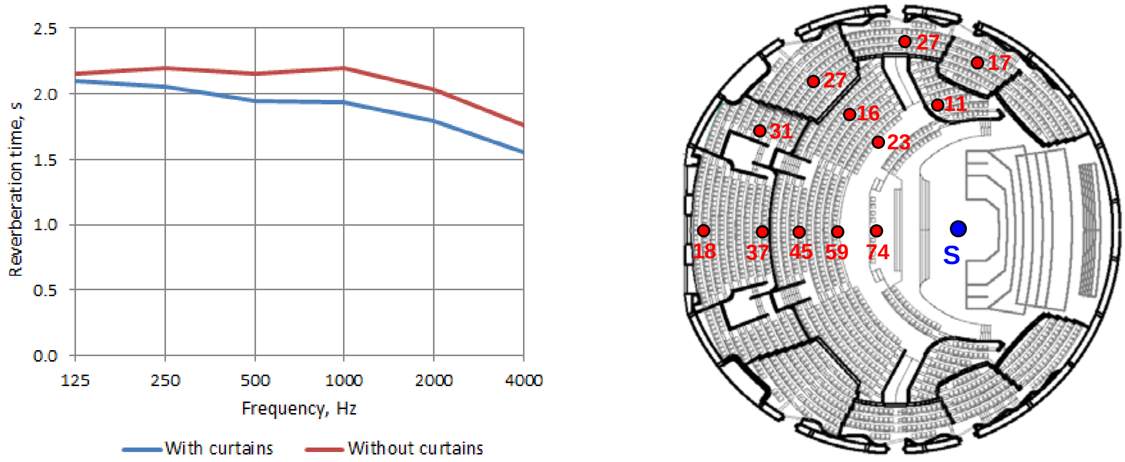

Figure 8. The reverberation time in the unoccupied hall (left) and the time delay gap, ms, between the direct sound and the most intensive reflection (right)

To improve acoustic conditions in the main floor some corrections of the hall space has been proposed. First of all, the reflecting walls of approx. 6 m height should be constructed along the centre part of the hall. Location of these walls is shown in Figure 9 by blue lines. The profile of the walls is similar to the existing layout of the hall. It proposes to minimize the construction works.
In order to provide a good visibility at the side seats the audience area has to be raised. This area may be separated into two parts marked by red colour in Figure 9. Other side seats don't seem very comfortable and their location does not influence acoustics.

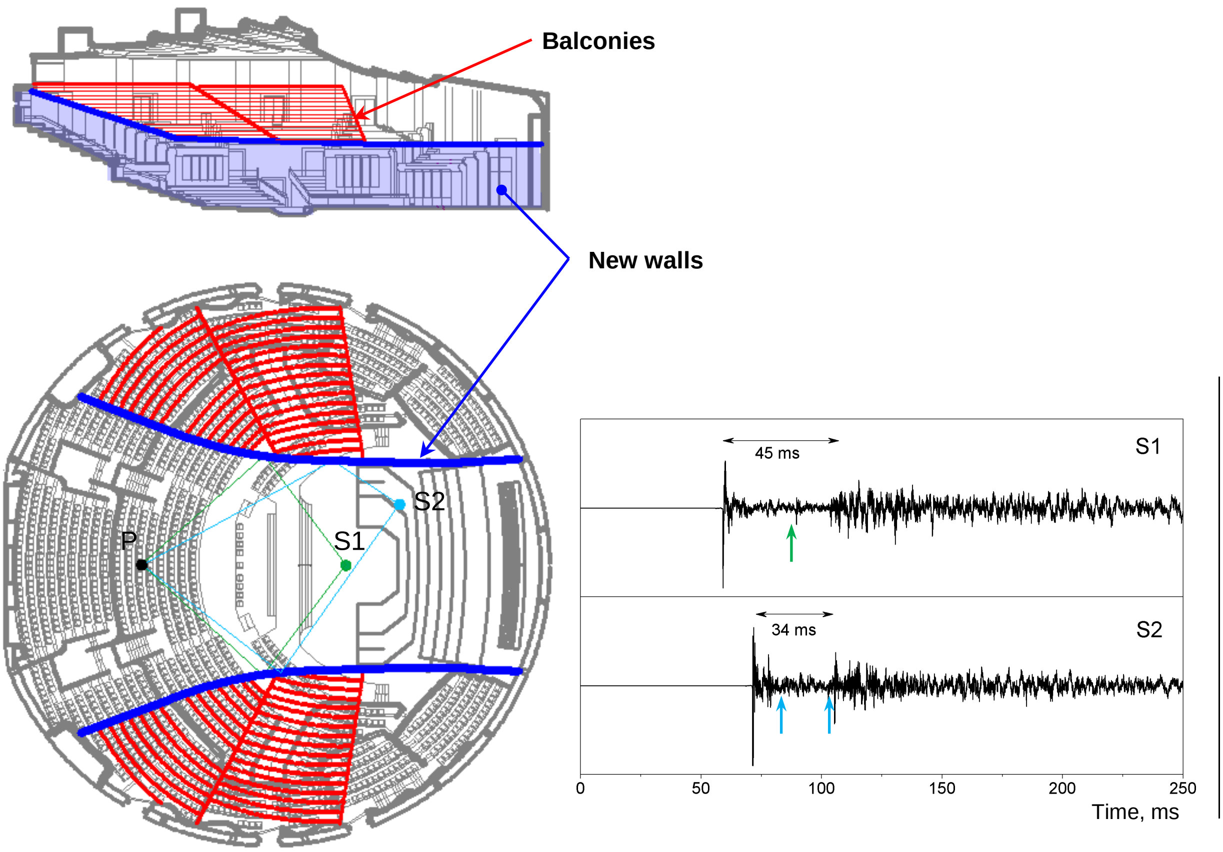

Figure 9. Proposed changes of the concert hall and expected sound reflections

First of all, new walls have to direct sound from the stage to the main floor. Figure 9 shows examples of sound rays reflected by the walls for the center point P. There are two sound rays marked by green color from the source at the position S1. The green arrow shows expected arrival time of these rays on the impulse response measured in the hall. The initial time delay gap should be reduced to 30 ms. Additional peaks in the impulse response for the source position S2 are expected as well; they are marked by blue color in Figure 9. The time delay has to become about 10 ms.

5 SUMMARY

Three cases of round and almost round concert halls have been considered. The halls built in different time have different architectural design but similar acoustic problems. After several years of operation, it became clear that acoustics had to be improved. In all cases different possibilities were considered and analyzed, but their own way was chosen for each hall. Given examples cover all the real possibilities of changing the acoustics used in practice today.

The simplest way is to use a sound amplification system. It raises the sound strength and provides early but not lateral reflections if loudspeakers are installed near a proscenium. One can say that the acoustics ceases to be natural. But sometimes it is better to sacrifice natural acoustics and achieve a better acoustic experience for listeners.

The second way is more complicated but also involves the use of electroacoustic systems. Today there are technologies sometimes called “virtual acoustics systems” which propose to control the reverberation time and early reflections. They are often used in multifunctional halls to rise the reverberation time from the values suitable for amplified music up to the values optimal for classical music. In the example given here the virtual acoustic system slightly increases the reverberation time, provides intensive early reflections and improves the stage support.

The third way to correct acoustics is the most traditional but the most difficult. The concert hall with poor shape may be reconstructed. To change acoustics significantly the reconstruction should be radical; it is not sufficient to install some reflectors and to reshape walls locally. However, this way will allow approaching the acoustic conditions typical for good concert halls with natural acoustics.

In any case it is much harder to improve acoustics of the constructed hall than to build it correctly.

6 REFERENCES

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