THE ACOUSTICS OF A MULTIFUNCTIONAL CONCERT HALL IN ZAGREB

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Abstract
This paper presents the design process for a small concert hall with a volume of 2,500 m^3 and a capacity of up to 300 visitors, built in the new building of the Music Academy in Zagreb. The hall is to host recitals, organ music, chamber music, full symphony orchestra performances, operas, drama theatre, cinema projections, and, in addition, serve as a venue for speech-based events. To respond to the set design demands, various solutions for changing the surface geometry of the hall have been implemented into its construction, including the rotating absorptive/reflective cylinders for fine tuning of the acoustical response of the hall. The results of acoustical measurements made in the finished hall are presented in the paper as well. The known limitations of the hall and the solutions implemented to overcome them are discussed.

Keywords: concert hall, multipurpose hall, adjustable acoustics, acoustic measurements

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1 Introduction

The Academy of Music of the University of Zagreb is the oldest and largest college of music in the Republic of Croatia. Its graduates have conveyed and confirmed the Academy's reputation for providing a high level of musical education throughout the world. Through their professional endeavours as musicians, teachers, musicologists, critics etc., they make a significant contribution to the cultivation and development of musical tradition and the general cultural wealth. Nowadays, the Academy of Music is organized into eight departments: Composition and Music Theory; Musicology; Conducting, Harp and Percussion; Voice; Piano, Harpsichord and Organ; String and Guitar; Wind; Music Education. Overall, approximately 150 teachers are responsible for educating about 500 students altogether [1].
Until January 2015, the Academy occupied four buildings in Zagreb. All departments, previously scattered all around Zagreb, moved into the restored and upgraded Ferimport building at Marshal Tito Square, a former office building built in the early 1960s, surrounded by older, 19th century buildings. The Academy signed a 100-year lease contract with the City of Zagreb in 2009. The restoration finished in early 2015, and the total price of the renovation is more than 30 million euro. The new building is shown in Figure 1. The building has almost 12,000 m^2 of gross area (around 9,000 m^2 net

area) where all departments of the Academy are placed, together with the Academy administration, library, rehearsal rooms, studies, and the concert hall. The building has two floors underground and eight above.
Ivica Stamać and Hrvoje Domitrović made the initial acoustic project. More than ten years have already passed from the start of the project and the final interior acoustic design of all acoustically critical rooms in the building was done by the authors of this paper [2], [3].

Figure 1 – The new building of the Academy of Music in Zagreb.

2 The concert hall

The new concert hall has a maximum of 307 seats. Although it is not very big, it is still the only space of such size owned by the Academy of Music. Therefore, it was designed as a multipurpose hall in order to host events that require a relatively large audience, large groups of musicians (orchestras of various sizes) or even actors in opera and drama performances. There are four different setups of the hall. They can be achieved by using two lifting platforms in the audience area between the fixed part of the stage and the fixed part of the audience, as shown in Figure 2.
Setup 1 is used for performances of smaller ensembles, drama theatre, speech events, video projections etc. The stage is limited to its fixed size, and the lifting platforms are positioned to extend the audience area to its maximum size, i.e. both platforms are lowered to level 2, Figure 2 and 3. The area covered by the platforms hosts 4 rows of seats. This setup enables the maximum number of visitors, 294 in the ground floor and 13 additional seats on the small balcony.
Setup 2 is used for opera performances. The first two rows of seats from platform A need to be removed, and the platform is lowered to level 3 in order to form a part of the orchestra pit. Platform B remains at level 2 and forms a part of the audience area, as shown in Figure 2. Additional reflectors are placed on the side walls of the pit, thus providing useful reflections for the orchestra sound to reach the audience. The number of seats in the ground floor is reduced to 246.
Setup 3 is used specifically for performances of big music ensembles, e.g. symphonic orchestras. In order to provide space for that many musicians and choir singers, both platforms are raised to the stage level (level 1), as show in Figure 2. Consequently, four rows of seats have to be removed, thus reducing the number of seats in the ground floor of the audience area to 198.

A fourth setup not planned from the beginning is used as well. Since the fixed part of the stage is not particularly big, platform A is often raised to level 1, thus extending the size of the stage and reducing the size of the audience by 2 rows of seats. This was also one of the setups measured in this paper.
The volume of the hall also varies depending on its setup, namely 2380 m^3, 2540 m^3 and 2,330 m^3 in setups 1, 2 and 3, respectively.

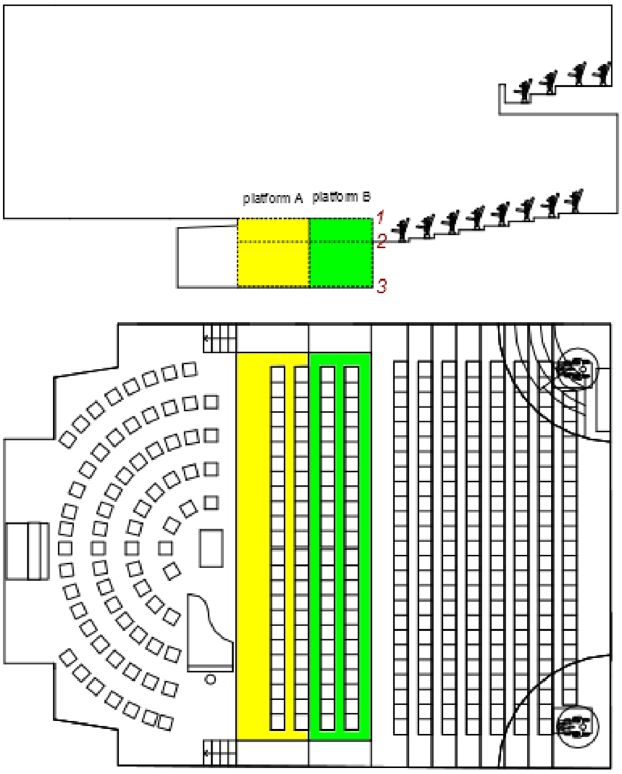


Figure 2 – Cross-section and plan view of the concert hall, showing the possible positions (level 1, 2 and 3) of the two lifting platforms, A and B.

Figure 3 – Interior of the concert hall during a musical performance (setup 1).

The first obvious criterion of the acoustic quality of the hall is the reverberation time. Its optimum values depend mostly on the specific use of the performance space, its volume, and to some extent on the number of people in the audience. Optimum values of reverberation time shown here were derived from recommendations found in literature [4-8]. More precisely, the chosen reverberation times at mid frequencies (500 Hz and 1 kHz) were 1.6 s for chamber music (setup 1), 1.4 s for opera performances (setup 2), 1.7 s for symphonic music (setup 3) and 1.1 s for drama performances, speech events and cinema projections (setup 1).
These reverberation times should be achieved by using variable acoustic elements on the ceiling above the audience area of the hall. Rotary cylinders were designed for this purpose, with half of the cylinder surface made from hard and fully reflective materials, and the other half from highly absorptive ones. When the reflective side of the cylinders is facing the audience area, their absorption is minimal, but they exhibit high diffusion. Each cylinder can be individually rotated in a way that its absorptive side faces the audience. This way, the amount of absorption facing the inner volume of the hall can be varied in small steps, thus providing a method to fine-tune the acoustics of the hall for all of its four basic setups. Figure 4 shows the acoustic cylinders, above which some HVAC pipes are installed. During the measurements, it became clear that these pipes are heavily insulated with mineral wool that behaves as a strong absorptive element, which was not known nor was it taken into account during the acoustic design of the hall.

Figure 4 – Rotating cylinders on the ceiling (lower part of the figure) for changeable acoustics.

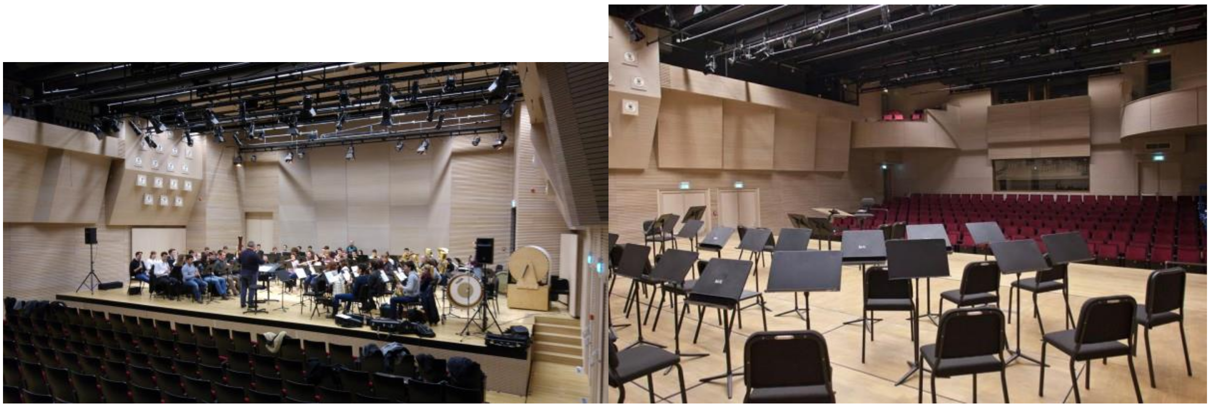


Figure 5 – Left: the stage of the concert hall (setup 4). Right: the audience area of the concert hall.

The stage area is quite wide and deep (16 m by max. 12 m). Its parallel side walls have been treated with convex reflectors that prevent flutter echo from occurring on the stage. Moreover, the reflectors can be rotated around the vertical axis to the optimal position, depending on the number of performers and their position on the stage. Additionally, the higher part of the side walls (above 2.3 m) is used as an air-conditioning plenum with a number of ventilation nozzles. As it was allowed for these surfaces to be tilted vertically, their lower parts were used as reflectors to improve the communication between the members of the orchestra, as shown in Figure 5.
The side walls of the audience area were also treated with reflector surfaces angled in a way to provide an even sound pressure distribution throughout the audience area. Above these reflectors, a catwalk extends along the sidewalls. It is used by technicians responsible for maintaining all technical equipment mounted in the upper part of the hall. The back wall is designed as a panel absorber tuned to low frequencies in order to provide a balanced reverberation time curve and consequently good tonal balance in the hall. The seats in the audience area are typical concert hall seats with heavy upholstering, chosen to minimize the difference in acoustical conditions in the empty and the occupied hall.

3 Measurements and results

To determine and evaluate the present acoustical conditions in the hall, a series of impulse response measurements has been made. The chosen positions of the sound source and the microphones are shown on the floor plan of the hall in Figure 6.
The omnidirectional sound source was placed at two positions on the stage marked with yellow dots. The microphones have been placed on 18 positions in the audience area and on the stage. Taking into account the high degree of symmetry of the hall with respect to its main axis stretching along the length of the hall, it was decided that only half of the audience area would be measured, similar to [9].

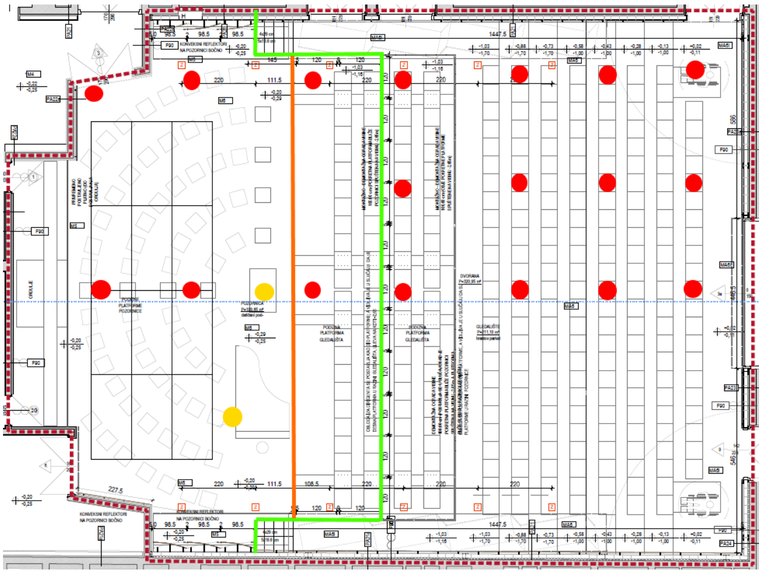


Figure 6 – Floor plan of the concert hall. Green is the stage border for setup 4, and orange for setup 2.

The hall was measured in setup 4 (corresponding to the average of the stage sizes in setups 1 and 3), and in the opera setup (setup 2), as shown in Figure 7. The average reverberation time for all microphone and source positions is shown in Figure 8. Reverberation times for both the concert setup

(C, setup 4) and the opera setup (O, setup 2) are shown. The cylinders can be rotated to have their absorptive (abs.) or reflective side (ref.) turned towards the audience, as stated above. The corresponding reverberation time curves were shown in the same figure in order to compare the influence of the variable acoustic elements. Figure 9 shows the measured early decay time, and Figure 10 the clarity C_{80} for the same setups.

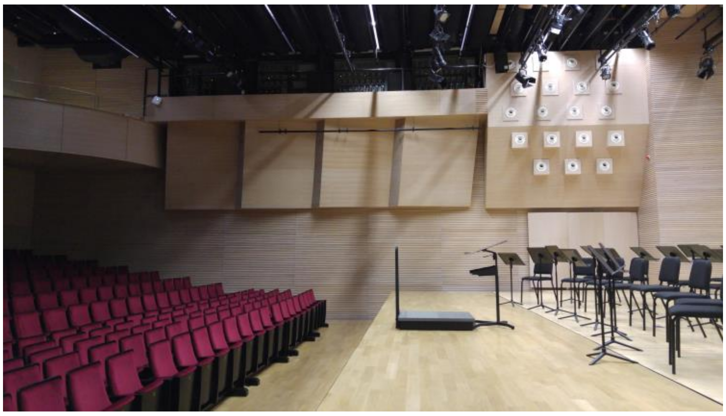


Figure 7 – Top: stage size of setup 4. Bottom: stage size and orchestra pit of setup 2.

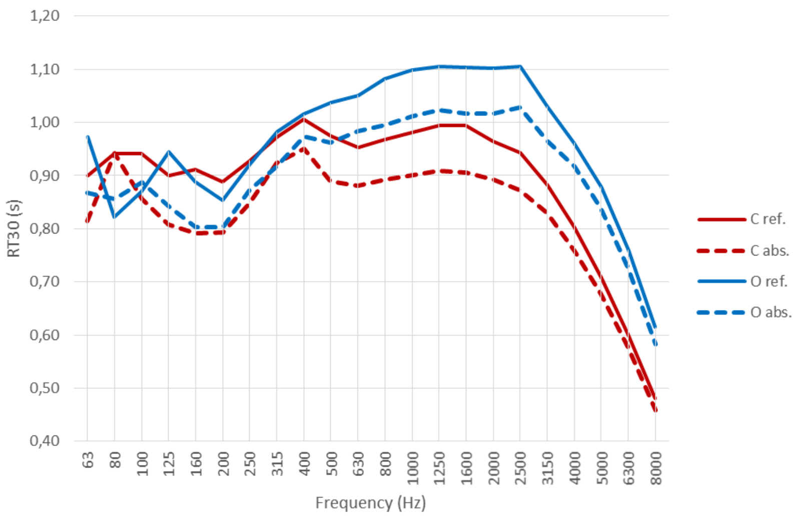


Figure 8 – Reverberation time of the concert (C) and opera setup (O) for both cylinder positions.

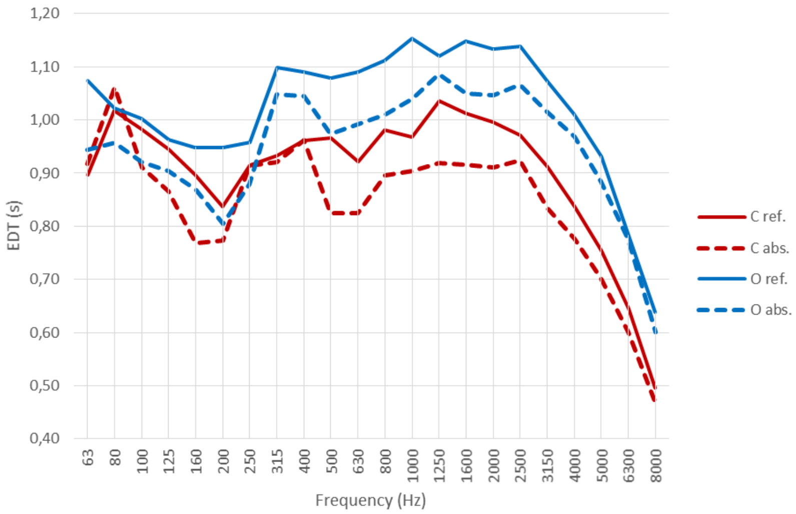


Figure 9 – Early decay time in the concert (C) and opera setup (O) for both cylinder positions.

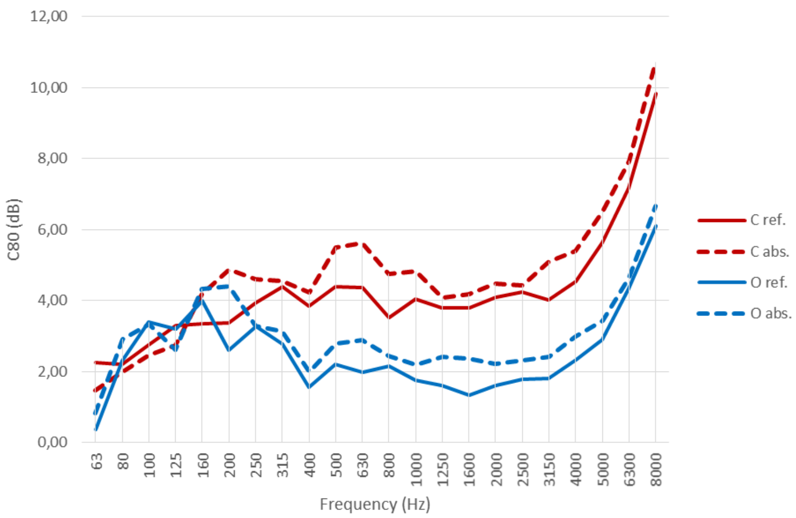


Figure 10 – Clarity C_{80} in the concert (C) and opera setup (O) for both cylinder positions.

In order to examine closely the spatial distribution of the C_{80} parameter, its values were extracted for each measurement point for the centre frequencies 125 Hz and 1000 Hz. The contour maps of the C_{80} parameter for the audience and the stage area are shown in Figures 11 to 14. The maps have to be interpreted as the C_{80} distribution over the hall area depending on the position of the rotating cylinders. For the concert hall setup, the sound source was located in the middle of the stage (the middle yellow dot in Figure 5), corresponding to a position between column 3 and 4 in Figures 11 and 12. For the opera setup, the sound source was located in the middle of the orchestra pit opening, corresponding to the middle of column 3 in Figures 13 and 14.

From these figures, it becomes obvious that the absorptive side of the rotating cylinders influences the C_{80} distribution by decreasing the spread of the C_{80} values throughout the stage and the audience. The diffusivity of the cylinders on their reflective side causes the blurring of the sound image of the orchestra over the whole audience area. Although the results of the average reverberation time (Figures 8 and 9) do not differ much with the position of the cylinders, the C_{80} parameter, as well as the overall auditory impression in the hall confirm that the absorption side of the cylinders absorbs most of the reflections from the hall volume below them. By doing so, they improve the precision of the sound image from the stage. The average C_{80} values are somewhat higher for the cylinders rotated to their absorptive side (Figure 10).

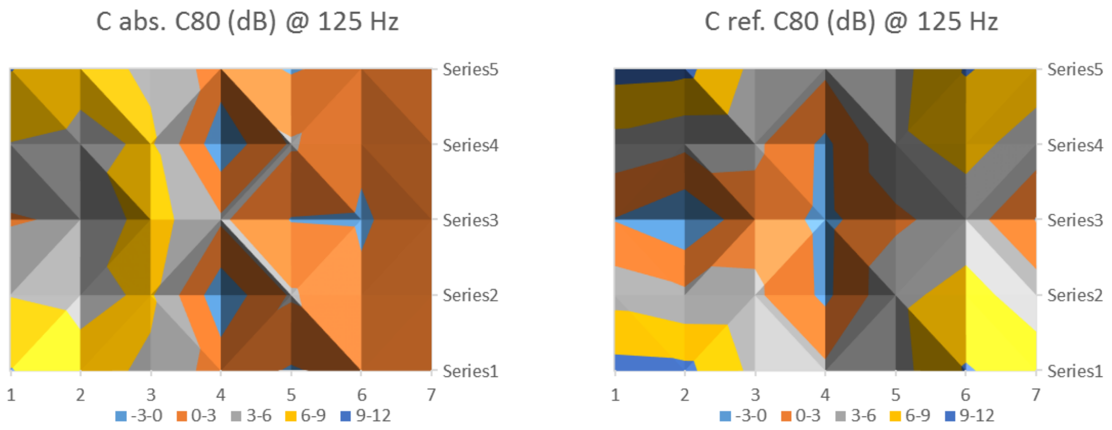


Figure 11 – Clarity C80 at 125 Hz of the concert setup (C) for both cylinder positions.

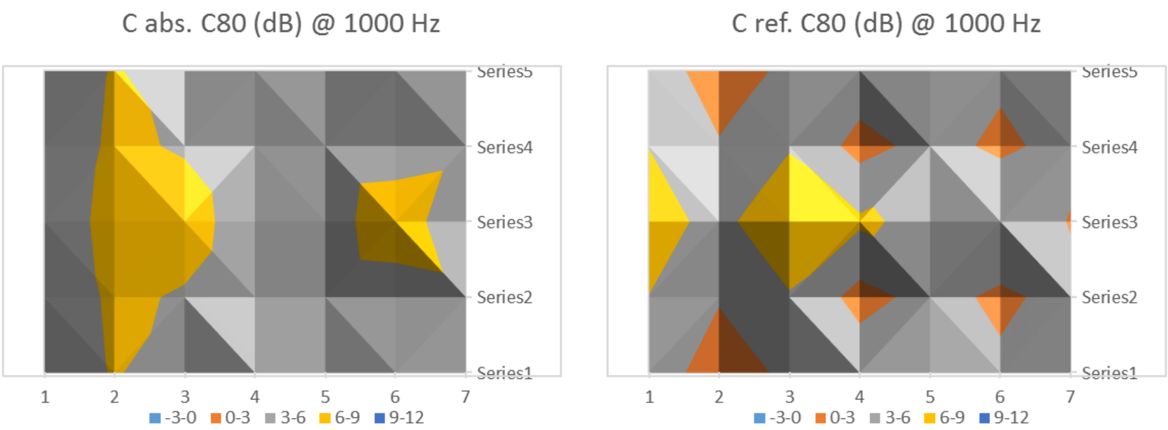


Figure 12 – Clarity C80 at 1000 Hz of the concert setup (C) for both cylinder positions.

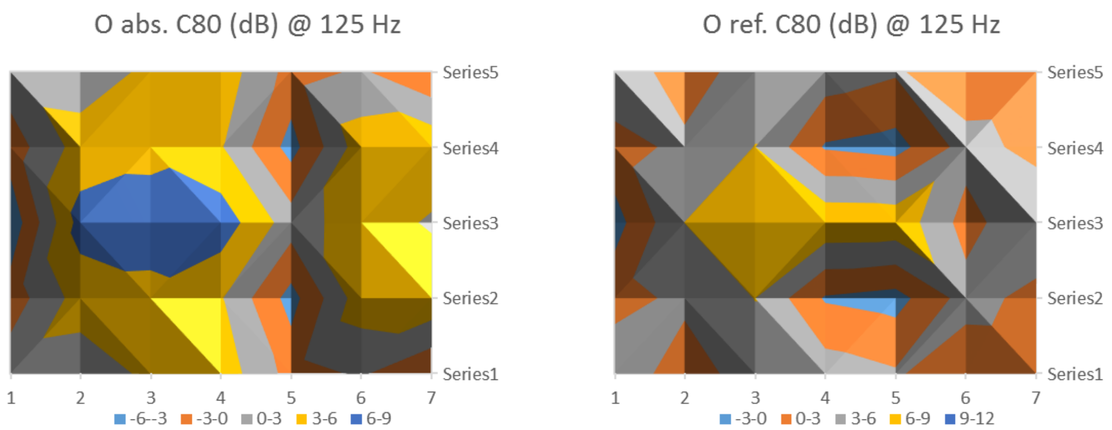
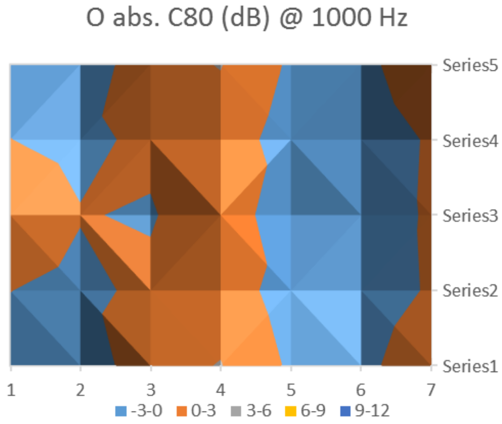


Figure 13 – Clarity C80 at 125 Hz of the opera setup (O) for both cylinder positions.



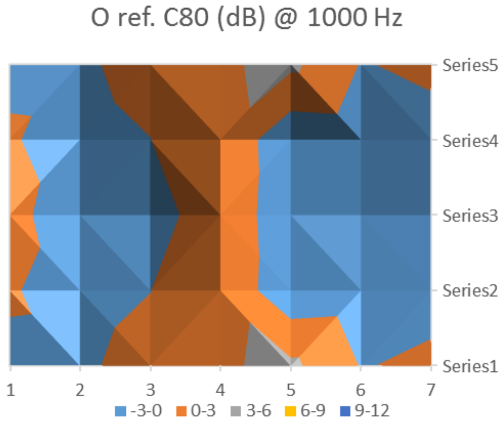


Figure 14 – Clarity C80 at 1000 Hz of the opera setup (O) for both cylinder positions.

4 Conclusions

This paper presents the results of acoustic measurements in the new multifunctional concert hall within the Music Academy of the University of Zagreb. As the hall itself is used for many events that require different acoustical conditions, a set of rotating cylinders has been mounted on its ceiling and can be used for adjusting its acoustical characteristics.

The main difference between the hall acoustics designed in the project and the one measured in the finished space is the presence of a high amount of thermal insulation on the ceiling of the hall that causes additional and unwanted sound absorption. Consequently, the effect of the variable acoustic elements was reduced and lower than designed reverberation times were measured. Still, using the rotating cylinders, the acoustic image of the orchestra and the soloists on the stage can be fine-tuned, as perceived in the audience area. This was confirmed both by measurements and by extensive listening in the audience and the stage area.

The finalization of the interior acoustics of the hall will include removing the excess absorption on the ceiling by covering it with reflective elements. Moreover, although the stage is not very big regarding its surface nor is its ceiling very high, a moveable orchestra shell will be designed. The shell will be installed above the stage area when required in order to further improve the clarity and brilliance of the sound, as heard in the audience.

Acknowledgements

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