The Design of the Multifunctional Concert Hall of the Academy of Music in Zagreb

Marko Horvat, Hrvoje Domitrović, Kristian Jambrošić
Faculty of Electrical Engineering and Computing, University of Zagreb, Unska 3, Zagreb, Croatia.

Summary
The Academy of Music of the University of Zagreb is an institution with 90 years of history and tradition in education. However, a building suitable for their needs was finished and opened only in 2015. The 12,000 m^2 of available space hosts many music facilities, such as rehearsal rooms, teaching cabinets, two small recital concert halls and a larger multifunctional concert hall. This paper gives an overview of the design process of the multifunctional concert hall with a volume of 2,500 m^3, and variable number of seats for up to 300 visitors. Due to space constraints, it was not possible to build more than one hall of this size in the building. Therefore, it had to be designed to serve several purposes: as a concert hall for chamber music orchestras, organ music and full symphony orchestra performances, operas, but also as a drama theatre, cinema, and a space for speech-based events. For these reasons, the use of elements responsible for changing the acoustics of the hall was proposed and implemented. The complete design process of the hall will be presented. Limitations and the solutions implemented to overcome them will be discussed.

PACS no. 43.55.-n, 43.55.Dt

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 endeavors as musicians, teachers, musicologists, critics etc., they make a significant contribution to the cultivation and development of musical tradition and the general cultural good [1].
The Academy has a long and distinguished history. It is the direct successor of Music School of the Croatian Music Institute, which opened on February 16, 1829. After a dynamic history, 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 over 500 students.
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 1960's, surrounded by older, 19th century buildings. The Academy had 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.

2. Some facts about the new building

The winning architectural project of the new building was developed by architect Milan Šosterič in 2003. The building has almost 11,900 m^2 of gross area (around 8,850 m^2 net area) where not only all departments of the Academy found their place, but also the Academy administration, library, rehearsal rooms, studies, and 3 concert halls. The building has 2 floors underground, a ground floor and 7 upper floors. The visual solution of the building itself is shown in Figure 1.
The initial acoustic project was made by Ing. Ivica Stamać and Prof. Hrvoje Domitrović. More than 10 years have already passed from the start of the project and the final interior acoustic design of all acoustically important rooms in this building was done by the authors of this paper [2].
The building contains a large number of various rooms that had to be treated acoustically. From the 8,850 m^2 net area of the building, around 4,950 m^2 (99 different rooms) were considered acoustically

sensitive. The project of interior acoustics covers the following rooms of the building:

- a concert hall with 300 seats and a stage with polyvalent functionalities (changeable geometry) – 700 m^2
- one audio + one video control room connected to the concert hall
- an electronic recording studio (multimedia studio and sound synthesis) – 190 m^2
- two smaller concert halls for multiple purposes – 220 m^2
- classrooms for theoretical lectures – over 1000 m^2
- rehearsal rooms – 560 m^2

Figure 1. Visual appearance of the new building of the Academy of Music in Zagreb.

The acoustic design of musical facilities has a crucial influence on their functionality and many guidelines are well presented in literature by other authors [3-6]. Nevertheless, designing music facilities is always a challenge. This is especially true for music rehearsal and teaching rooms as many playing techniques depend on the interaction between the room and the player. This interaction mostly depends on room size, but also on its acoustics. More damped rooms require the musicians to play louder, playing errors are more audible. This is often required by music teachers because such rooms help the students prepare for playing in bigger concert halls and in orchestras, although students generally dislike playing in damped rooms.

In case of the new building of the Academy of Music in Zagreb, the challenge was even bigger as there were 99 rooms to take care of, often with very different demands. There are almost no two equal rooms due to the design with non-parallel walls, utilized to avoid the appearance of flutter echo. The demand on changeable acoustics made the challenge even bigger, as well as on the polyvalence of the main concert hall, that can be adapted for performances of any ensemble ranging from a solo player up to a symphony orchestra, or even form an orchestra pit for opera-like performances. This paper describes in particular the design process for the aforementioned concert hall.

3. Functionalities of the concert hall

The new concert hall is the only space of such size owned by the Academy of Music. Therefore, it was designed from the start as a multipurpose hall, to host events that require a relatively large audience, larger groups of musicians (orchestras of various sizes) or even actors in opera and drama theatrical performances. There are three different setups of the hall that can be changed 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 will be 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. 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 will be 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, 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 will be 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), 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.

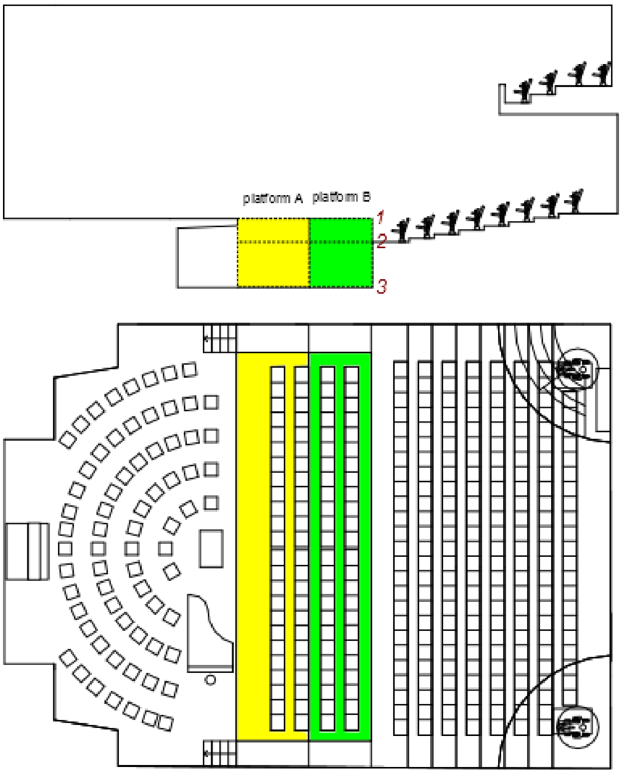

Figure 2. Cross-section and plan view of the concert hall, showing the possible positions (level 1, 2 and 3) of the two lifting platforms, A and B.

The volume of the hall also varies with the setups, namely 2380 m^3 in setup 1, 2540 m^3 in setup 2 and 2330 m^3 in setup 3.

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 performing space, its volume, and to some extent, the number of people in the audience. Optimum values of reverberation time shown in Table I are derived from recommendations found in [6-10]. The table also shows the setup of the hall for each of the listed functions.

The choice of reverberation times of the concert hall for all its uses was limited by the technical solution chosen to provide changeable acoustics, but care was taken to achieve values within the recommended range. The only deviation from this principle occurs for cinema projections in the hall, which require even lower reverberation times than the chosen ones. However, the investors stated that the hall will be used very rarely for this type of events, and it would be very difficult to design a hall with such a great range of reverberation times by means of changeable acoustics. This range directly depends on sound absorption coefficients of the wall, floor and ceiling materials and the range of their change that can be achieved on some of these surfaces. The broader the range of the reverberation time change, the more costly and technically more complex the whole project becomes. For this reason, the reverberation time for cinema projections was chosen to be equal as the one chosen for drama theatre and speech events. Furthermore, the chosen reverberation time is valid for the fully occupied hall, and it only rises when the audience area is only partially occupied.

Table I. The chosen values and ranges of recommended reverberation times at mid frequencies (500 Hz and 1000 Hz), depending on the use of the concert hall.

Use of the hall	Chosen reverb. time (s)	Range of the recommended values (s)
chamber music (setup 1)	1.6	1.5 – 1.8
symphonic music (setup 3)	1.7	1.7 – 2.0
opera performance (setup 2)	1.4	1.3 – 1.8
drama performance (setup 1)	1.1	0.8 – 1.1
speech events (setup 1)	1.1	0.8 – 1.1
cinema projection (setup 1)	1.1	< 0.6

Besides achieving the optimum reverberation time for each function of the hall, it was important to ensure good communication and intelligibility between the performers on stage, as well as good transmission of sound energy from the whole stage area and the orchestra pit to the entire audience area.

In order to meet these demands on acoustics of such a complex, and yet rather small space for a concert hall, it is necessary to combine all three

typical acoustic elements – sound absorbers, sound reflectors and sound diffusers.
The stage area is quite wide and deep (16 m x max. 12 m) and therefore its side walls have been treated with convex reflectors that prevent flutter echo occurring on the stage because of parallel walls. Moreover, they can be tilted horizontally to the optimal position, depending on the position and number of performers 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.
Above the fixed part of the stage, convex reflectors are used to direct the useful sound energy to the back of the hall, towards the audience. As there is an abundance of stage technique fastened to the ceiling on steel ropes, the reflectors had to be broken into 40 cm strips in order not to obstruct the scenery elements that have to be raised and lowered. There will also be an organ placed in the centre of the front wall of the hall, thus providing additional sound diffusion for the sound sources on stage. Figure 3 shows a visualization of the stage area.

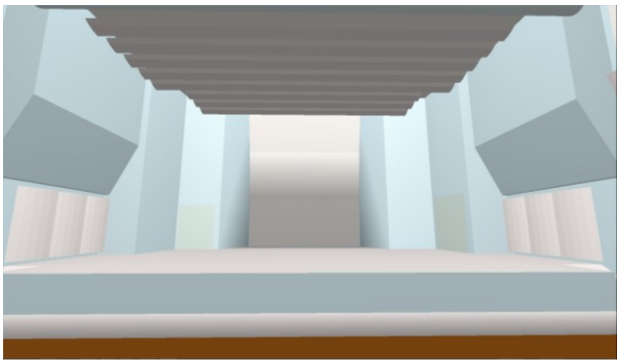

Figure 3. The visualization of the stage area of the concert hall.

The side walls of the audience area were also treated with reflector surfaces angled in a way to provide good sound field distribution throughout the audience area. Above these reflectors, there is a catwalk that extends along the side walls, used by technicians responsible for maintaining all technical equipment mounted in the upper part of the hall.
The back wall is designed as a perforated absorber tuned to low and mid frequencies in order to provide a balanced reverberation time curve and consequently good tonal balance in the hall.
The audience seats are typical concert hall seats, heavily upholstered and with a perforated wooden plate on the sitting surface.
Finally, the most important part of acoustic treatment of the hall in terms of acoustic adaptation of the hall to all of its functionalities is the ceiling above the audience area. Rotary cylinders were designed, with half of the cylinder surface made from fully reflective materials, and the other half from highly absorptive materials. When the reflective side of the cylinders is facing the audience area, their absorption is minimal. Each cylinder can be individually turned so that its absorptive side faces the audience. Any angle of rotation can be selected for each individual cylinder. This way, the amount of absorption facing the inner volume of the hall can be varied in small steps, providing a method of fine-tuning the acoustics of the hall for all of its three basic setups.
Figure 4 shows a visualization of the complete audience area. The 3D wireframe model of the concert hall used to simulate the acoustics is shown in Figure 5.

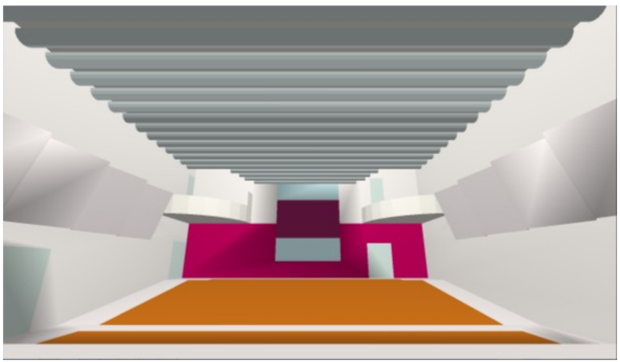

Figure 4. The visualization of the audience area of the concert hall.

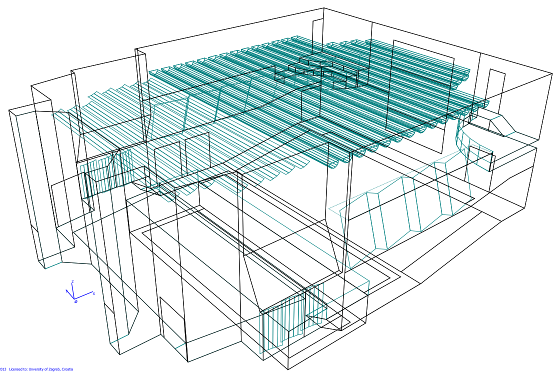

Figure 5. The 3D wireframe model of the concert hall used in acoustic simulations.

4. Simulation of the concert hall's acoustics

The acoustic conditions in the concert hall were simulated using the Odeon 12 software [11]. All setups have been checked against the aforementioned criteria. Reverberation times were calculated, as well as the clarity parameters C_{50} and C_{80}, lateral energy fraction *LF* and speech intelligibility *STI*. To achieve optimal audience coverage with sound energy coming from the stage, the reflector angles have been tested with Odeon reflector coverage calculator. Dynamic transition of early reflection of sound energy has also been tested, with multiple sources defined on stage, to avoid flutter echo problems.
The reverberation time range achievable with changeable acoustics for the fully occupied hall in setup 1 is shown in Figure 6. The difference in reverberation time between the fully occupied and empty hall has also been investigated, because this situation will be experienced by the students on a regular basis. They will rehearse in empty hall, and perform regular concerts in front of an audience. These variations are shown in Figure 7 and 8. The reverberation time ranges in the hall for setups 2 and 3 are shown in Figures 9 and 10.

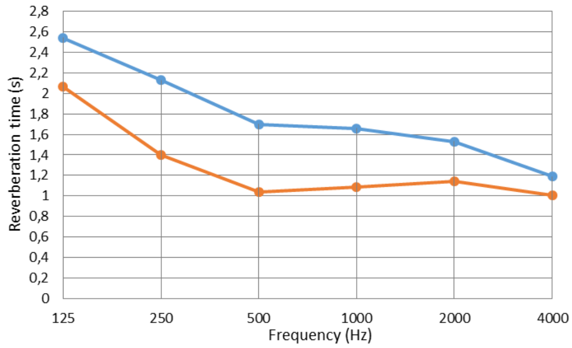

Figure 6. The range of reverberation time in setup 1.

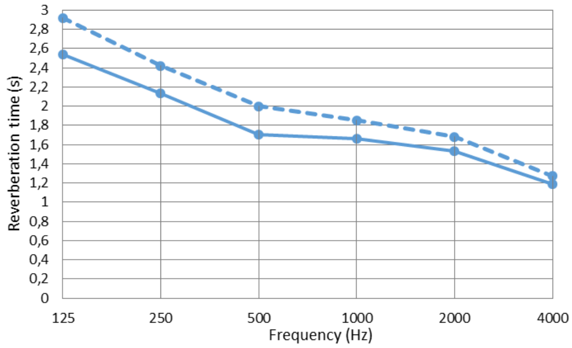

Figure 7. The variation of reverberation time between a fully occupied (full line) and empty hall (dotted line) in setup 1 with maximum reverberance.

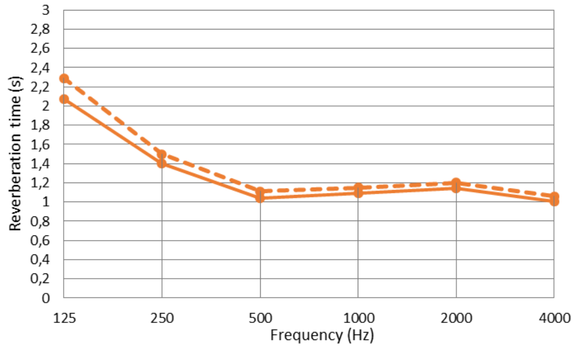

Figure 8. The variation of reverberation time between a fully occupied (full line) and empty hall (dotted line) in setup 1 with maximum damping.

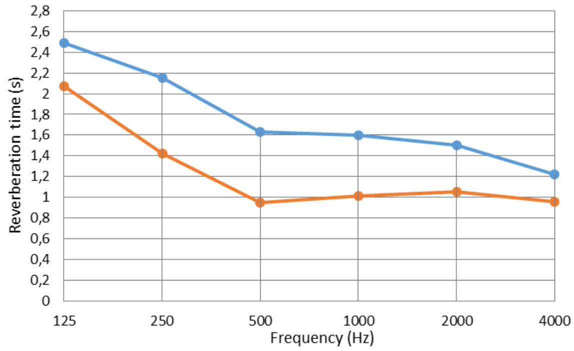

Figure 9. The range of reverberation time in setup 2.

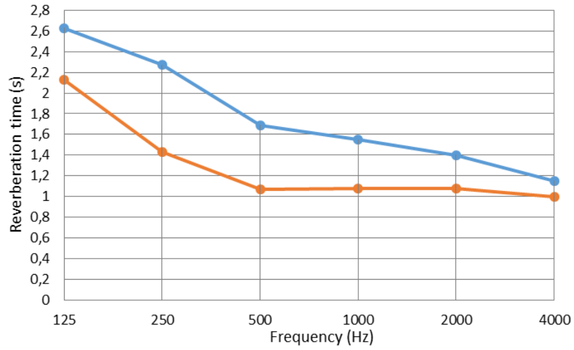

Figure 10. The range of reverberation time in setup 3.

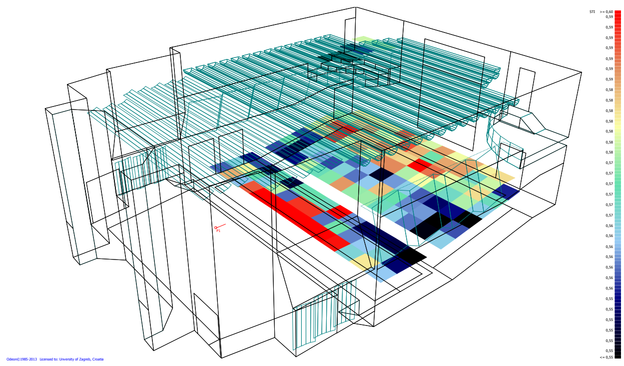

Figure 11. The spatial distribution of *STI* over the audience area for setup 1 with maximum damping.

Finally, Figure 11 shows the range of the *STI* parameter throughout the audience area for setup 1, with maximum sound absorption (the drama theatre setup). Figure 12 shows the frequency-dependant values and the range of the clarity parameter C_{80} for music performances and the hall configured in setup 1, averaged over the entire audience area, for maximum reverberance.

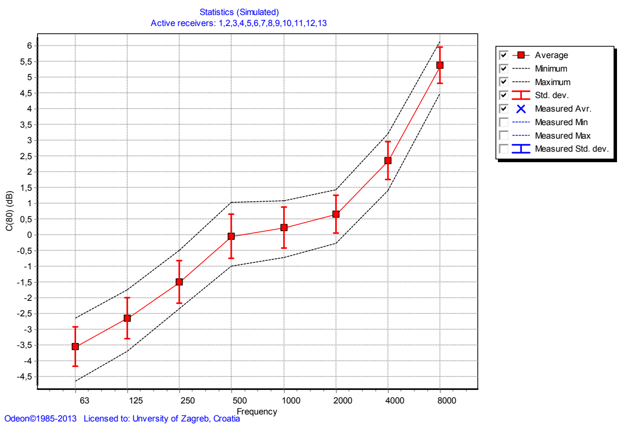

Figure 12. The average values of C_{80} for setup 1 and maximum reverberance.

5. Conclusion

This paper describes the design process of the interior acoustics of the new concert hall of the Academy of Music in Zagreb.

Although the size of the hall is quite small (up to 300 visitors), its polyvalent use was the main challenge in the acoustic design process. In the architectural sense, the contradictory demands were solved by providing 3 setups that could alter to some extent the volume and the acoustical conditions in the hall.

The results show that it is possible to achieve good acoustical conditions in the hall for all intended purposes. The only discrepancy from the optimum conditions occurs if the hall is used for cinema projections. In this case, to achieve optimal acoustic conditions would require too costly a solution.

The reverberation times in the hall at middle frequencies can be varied from 1.1 to 1.6 s in fully occupied state, and from 1.2 to 1.9 s in empty hall, if setup 1 for smaller orchestras is chosen. For the opera setup 2, reverberation time can be varied from 1.0 do 1.6 s, thus including the optimum value of 1.4 s. Moreover, the exact reverberation time can be tuned using the rotating cylinders that define the variable part of acoustic absorption in the hall. Finally, setup 3 is intended for performances of big ensembles, and with minimum absorption of the cylinders, a target reverberation time of 1.7 s can be achieved.

The “fine-tuning” of the sound field was achieved by introducing reflector surfaces on side walls and the ceiling of the stage area, as well as on side walls and ceiling of the audience area (the cylinders turned to their reflective side). All reflecting surfaces are designed to be convex or flat in order to maximize sound diffusion and prevent unwanted focusing of sound.

Other acoustic parameters have been simulated as well, such as clarity (C_{50} and C_{80}), lateral energy fraction (*LF*) and speech transmission index (*STI*). Acoustic simulations show a very favourable range of these parameters, as one of the main prerequisites to be met for the hall to be acoustically satisfactory. At the same time, it can be acoustically tuned to different tastes of both performers and conductors, especially if different acoustics is wanted during rehearsals of orchestras, compared to live performances in front of an audience.

The simulations are to be verified upon the completion of the hall, and the relevant data will be published.

References

[1] University of Zagreb, Academy of Music, http://www.muza.unizg.hr/

[2] K. Jambrošić, H. Domitrović, M. Horvat: Acoustical Design of New Music Facilities of the Music Academy in Zagreb. Proc. Tecniacustica 2013, 1381-1390

[3] Building Bulletin 93: Acoustic Design of Schools. A Design Guide. Architects and Building Branch, London, 2003, http://www.bb93.co.uk/

[4] Planning guide for school music facilities, Wenger Corporation, 2008, http://wengercorp.com/

[5] K. Jambrošić, H. Domitrović, M. Horvat, A. Petošić: Evaluation of the Acoustical Characteristics of the Largest Concert Hall in Croatia. Proc. Euronoise 2012, 118-123

[6] M. Long: Architectural acoustics. Elsevier Academic Press, 2006

[7] ISO 3382-1:2009 Acoustics - Measurement of room acoustic parameters - Part 1: Performance spaces

[8] L. Beranek: Concert halls and opera houses: music, acoustics and architecture. Springer-Verlag, New York, 2004

[9] T.D. Rossing: Springer Handbook of Acoustics. Springer Science+Business Media, LLC New York, 2007

[10] M. Barron: Auditorium Acoustics and Architectural Design. Spon Press, New York, 2009

[11] Odeon Room Acoustics Software, http://www.odeon.dk/