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Acoustical Considerations in the Design of Heydar Aliyev Center Auditorium

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ABSTRACT

The auditorium within the Heydar Aliyev Center serves for an audience of 1200 and incorporates conference, concert and opera use altogether. Confronting the multi-functional performance program of the space together with uncompromising aesthetic considerations, coupled space concept has been adopted as an acoustical and architectural design aid. This paper presents mainly the dependable acoustics attained by the coupling of auxiliary spaces by employing of the right-sized coupled volume connected with proper finishing materials and variable aperture size which consequences in the differentiation of reverberation time within the main volume -namely multi-purpose auditorium- and the coupled room. Fixing the volume and room finishes as for getting the desired energy decay behavior, aperture size has come up to be the essential parameter to concentrate on. The proposed solution for conference, music and inter-related activities is for the best of early and late sound field energy decay control. The proper reverberation times are studied for the main hall alone and coupled space separately to find the results as of the optimum reverberation times over frequency range of the auditorium for performance-specific. Aperture size has an essential role in balancing the reverberation time distributions of the auditorium and coupled space. Stage tower acoustics and thoroughly wooden surfaces of auditorium are studied together with the coupled volume in search of optimum reverberation times for different purposes of coupling spaces. Within this study coupled volume is used as a design tool out of recent acoustical innovations. The form and materials within the main volume is worked out together to get the optimum sound energy decay forms for different activities. Apart from coupled space concept, stage house design, auditorium main back-wall design and side-wall face irregularities are studied within the aim of having an even-distribution of sound field throughout the hall. This paper presents the successful outcomes of a coupled volume design within such a collection of irregular forms out of minimum aesthetic compromises.

INTRODUCTION

Heydar Aliyev Center as a landmark building for the city of Baku, Azerbaijan houses majorly a library, a museum, an auditorium and a multi purpose hall. This paper intends to discuss the acoustical properties and corresponding research on probable acoustical measures and design solutions of auditorium within the limits of architectural and aesthetic considerations. Having the signature of Zaha Hadid the proposed design has an exterior skin as a single continuous surface folding around in defining individual functions of the Center, while providing each element its own identity and privacy (e.g. Figure 1).

Source: (Zaha Hadid Architects, 2010)
Figure 1. Heydar Aliyev Center, cultural plaza

The museum building faces out into the landscape with its glass facade forming the mild rising crest. The other dominating figure of outer skin is the library building. This north structure has a more distinctive inclination rising out up high from the landscape's natural topography.

Source: (Zaha Hadid Architects, 2010)
Figure 2. Heydar Aliyev Center, auditorium

The conference hall building as of the lowest portion of the exterior shell accommodates two major spaces including auditorium (e.g. Figure 2) and multi purpose hall. The outer shell of the auditorium leans into the Cultural Plaza creating the inclination for the seating and connects to the natural slope of the topography. The auditorium and multi purpose hall with their associated facilities have a direct access to the plaza. The auditorium is located in the void created by the outer skin being stretched between volume of the museum and the library tower.

The auditorium serves for an audience of 1200 and incorporates conference, concert and opera use altogether. The visitor main entrances of the auditorium open into the inner galleries (e.g. Figure 3) of the Center, the acoustical characteristics of which are to be presented within the scope of a supplementary research paper [1].

Source: (Zaha Hadid Architects, 2010)
Figure 3. Main lobby, serving auditorium and library

In this further paper, auditorium within the Heydar Aliyev Cultural Center Auditorium is studied for providing the limits of certain acoustical parameters in relation to functions to be held.

ACOUSTICAL DESIGN

The acoustical design of the auditorium in Heydar Aliyev Cultural Center incorporates the challenge of providing multi purpose requirements of the hall. Considering the conference, concert and opera uses to be embraced in one single enclosure, the optimization of the functional needs through the acoustical requirements is of priority.

In brief, the given pre-design concept project has proved not to be efficient for providing the acoustical parameter limits for these three functions. The finishing cloth as announced to be hardwood floor, wall and ceiling material is respected in terms of architectural requirements. However, having this highly reflective material lined out through such single and multi functional space some further precautions are thought to be in the core of major consideration.

The challenge has started with fixing the requirements for conference and concert use, or for concert and opera, and for opera and conference uses. No tolerance has given to any visual alteration in architectural design terms. As presented in following sections of this paper the required absorption for the conference use has become above limits for the concert use in a very brief assessment. Considering the design straggles and prospective variable acoustics, the coupled space concept has been found to be the most realistic and manageable manufacturing guide.

The optimization of acoustical functions has lead to certain acoustical parameter up limit corrections. MEZZO Studio has considered three different scenarios of use in the acoustical analysis of the hall. The prospective design solutions are listed as follows;

Table 1. Space configurations for different scenarios

Design Proposal	*Stage shell*	*Pit*	*Coupled room apertures*	*Orchestra*
Conference Use	Lifted and stored in the stage tower	Closed	Closed	Absent
Concert Use	In place	Closed	Open	On the stage
Opera Use	Lifted and stored in the stage tower	Open	Partially open	In the pit

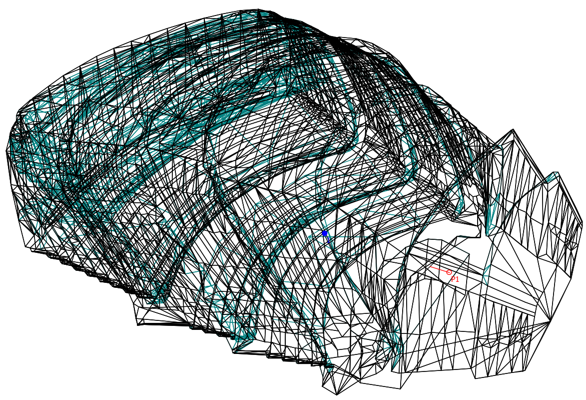
Source: (Çalışkan, 2004) [2]

A different graphical model for computer simulation, comprising 6270 plane surfaces is developed by MEZZO Studio for use with ODEON version 10.02. The model basically made up of 3-D face elements is obtained after simplifying the graphical model supplied by ZHA Architects. In this process of modification the geometry and dimensions in the graphical model is completely preserved in great detail (e.g. Figure 4).

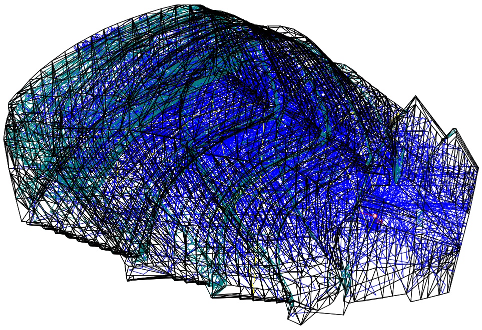
Source: (MEZZO Studio, 2010)
Figure 4. View from Stage, auditorium

Estimated main hall acoustical volume excluding stage is 8215m³. A series of new simulation studies is carried out by MEZZO Studio using this new graphical model and acoustical data obtained by measurements in the laboratory for wooden surfaces.

Recommended ranges for acoustical parameters used in the assessment study are listed in Table 2. Sources and corresponding receivers are defined and located in major locations (e.g. Figure 5). The present condition of the concept design and the proposed alternative acoustical design solutions are discussed in later sections. Ray tracing is used majorly in sound path analysis (e.g. Figure 6).



Source: (MEZZO Studio, 2010)
Figure 5. ODEON acoustical model with source (red) and receiver (blue) positions, auditorium



Source: (MEZZO Studio, 2010)
Figure 6. Ray Tracing, auditorium

Table 2. Space configurations for different scenarios

Parameter	*Recommended range for theatres*	*Just noticeable difference*
T30	1.0 to 1.4s	5% (i.e. about 0.1s)
EDT	0.9 to 1.4s	5% (i.e. about 0.1s)
SPL	Minimum Variations in SPL	2dB
C80	0 to +4dB	1dB
	Recommended range for concert halls	
T30	1.7 to 2.4s	5% (i.e. about 0.1s)
EDT	1.7 to 2.6s	5% (i.e. about 0.1s)
SPL	Minimum Variations in SPL	2dB
C80	-4 to 0dB	1dB
LF	> 0.20	0.05
Strength - G	Less than 10dB variations	2dB
	Recommended range for opera houses	
T30	1.4 to 1.8s	5% (i.e. about 0.1s)
EDT	1.4 to 2.0s	5% (i.e. about 0.1s)
C80	-2 to +2dB	1dB
LF	> 0.15	0.05
Strength - G	Less than 10dB variations	2dB

Source: (Çalışkan, 2004) [2]

The present concept design and acoustical alterations are discussed in following sections for conference, concert and opera uses.

CONCEPT OF ACOUSTICALLY COUPLED ROOMS

This section is added to give brief information on above mentioned design solution namely 'Acoustically Coupled Rooms/Spaces'. Architectural acousticians have been increasingly interested in halls that incorporate coupled-volume systems because of their potential for creating desirable effects in meeting conflicting requirements. Those requirements could either be having a variable sound field within the hall for speech and music or maintaining a variable reverberance for different music performances. Inclusion of a reverberant auxiliary room (or rooms) connected to the primary space has proven to be a useful technique in the design of concert halls and multipurpose auditoria [3,4].

Some important cases of halls worldwide that utilize coupled room system and so the double decay phenomena as part of their acoustical design are as follows; Festival Hall in Tampa, FL; the Great Hall in Hamilton, Ontario; Lucerne Concert Hall in Lucerne, Switzerland; the Myerson-McDermott Hall in Dallas, TX; Verizon Hall in Philadelphia, PA; Bass Performance Hall, Fort Worth, TX; Symphony Hall, Birmingham, UK.

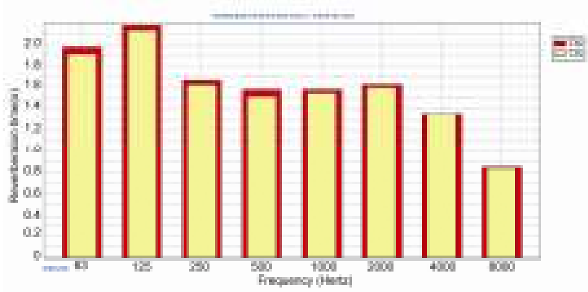
A coupled-volume system is typically defined as two or more spaces that are joined by a common acoustically transparent surface, known as a coupling aperture. In a coupled-volume system, if the times required for sound decay in each space are unequal, there will be an excess energy in one of the spaces during the decay process when compared to the other one. This leads to energy transfer from the energy surplus room to the energy deficient room, which can produce a sound decay proper for desired acoustic qualities within a space. Designers are attracted by the coupled volume concept, because it proposes a compromise between the competing acoustic conditions for both reverberance and clarity [5].

There are mainly two types of acoustical coupling which are source-area coupling (stage house coupling) and distributed coupling (reverberation chambers). In source-area coupling source is in the auxiliary room and auxiliary room is the stage and stage tower above. Distributed coupling employs the volumes above ceiling or behind side walls and source is away from the room as it is on the stage.

In acoustical coupling, to provide a sound field that is variable, longer, distinct, and performance-piece-specific depends on certain architectural parameters. Geometric volume, form, materiality and aperture size are variables that affect reverberation of sub-room and consequently energy flow to the main room. Achieving desired energy decay for performance-specific purposes necessitates an intensive study on those variables. Reserving certain amount of volume at the upper parts of the Heydar Aliyev Center Auditorium (above ceiling in between auditorium shell and roof/wall main structure) and aperture in desired dimensions (as removable ceiling panels on ring T3 in this design) are architectural measures that will enable acoustical designers to work with coupled rooms.

PRESENT CONDITION

The concept project is initially assessed for its acoustical performance. No additional coupled volume or stage back house is added to the main hall as in architectural drawings provided by the design team in this first phase. Wooden curved surfaces with no rectilinear corners are composing the core concept of this project. Considering the wooden wall and ceiling sections are forming the principal surfaces to carry acoustical meaning, the real-size measurements are of priority for accurate results to be obtained from simulations. For that reason, the sound absorption coefficient tests are hold in a laboratory set-up for 50mm perforated wood samples and the results are used in acoustical simulations. The estimated global estimate reverberation times for the initial design concept with no modifications for specific functions (conference, concert and opera uses) are displayed in Figure 7.



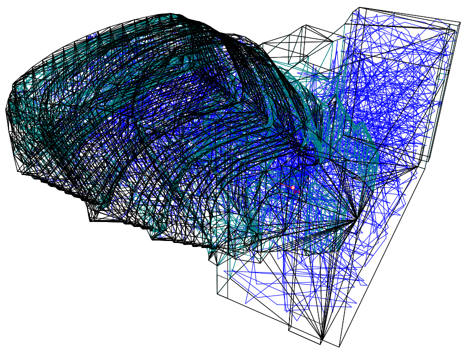
Source: (MEZZO Studio, 2010)
Figure 7. Estimated global reverberation times for present condition

Global estimates indicate average mid frequency reverberation time of 1.57s and average low frequency reverberation time of 1.93s. The original design without any acoustical intervention does not function for multi-purpose functions including conference, concert and opera uses altogether. Thus, the coupled space concept is chosen to be the most effective variable acoustics solution and presented for applicable activities in following sections.

CONFERENCE USE ANALYSIS

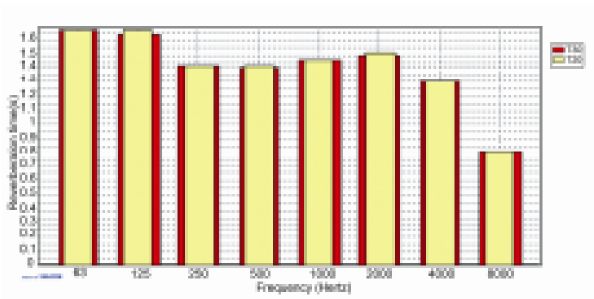
Conference performances involving activities related to speech is known to be the initial use of this multi-purpose auditorium. For that reason, the hall is designed for speech performances initially. Adjusting the excessive reverberance due to highly reflective wood surfaces and extreme volume is the first goal for providing sufficient speech intelligibility. The Auditorium is initially tested with its present condition as given in previous section. Adding absorptive materials to the rear wall and increasing the amount of absorption supplied by the seating area is helpful to some extent but not totally fulfill the requirements. The need for another design solution is ended up by using the advantage of stage tower as a sound attenuation center of the hall.

The removable ceiling panels on the stage shell that are assumed to be raised in opera/ballet performances are removed for conference use as well. By opening the panels on stage shell, stage tower is coupled to the main hall. Stage tower has to be made totally absorptive for decreasing the excessive reverberance of the hall. Leaving the backstage floor area as similar to the stage floor, rest of the surfaces including walls and ceilings are covered with highly absorptive materials made up of rock wool with geo-textile facing.



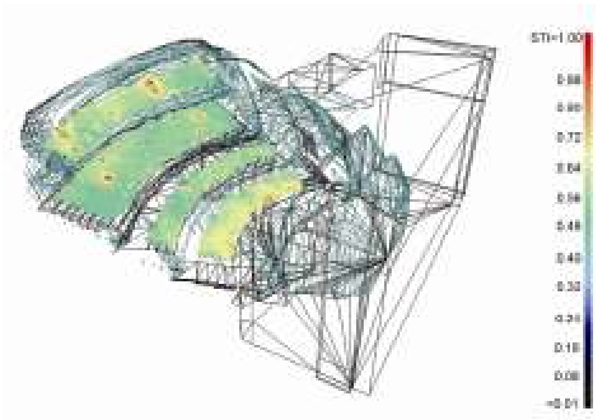
Source: (MEZZO Studio, 2010)
Figure 8. Ray tracing of conference use acoustical model

A different graphical model for computer simulation, comprising 8426 plane surfaces is developed by MEZZO Studio. Estimated acoustical volume for conference use including stage tower is 18729m³. The room consists of 10 different finish materials. Ray tracing of the model for conference use is given in Figure 8.



Source: (MEZZO Studio, 2010)
Figure 8. Estimated reverberation times for conference use

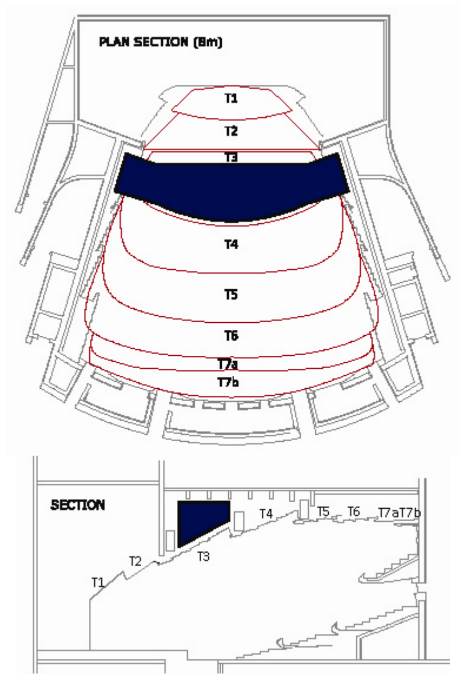
This acoustical precaution helped greatly to decrease overall reverberation by around 0.3s (e.g. Figure 8) throughout the full octave frequency range. Certain amount of diffusion on the rear wall that can be obtained through various diffuser designs is also kept in place for minimizing probable echoes caused by the large concave surfaces of rear wall. On the rear wall as long as opening area is 30% of total area a lot many different alternatives of diffusers can be worked until it satisfies architectural design group. With all the precautions taken the Auditorium has come to a point that minor later tunings on materials will help for the performance needs together with a good electronic sound amplification design (e.g. Figure 9).



Source: (MEZZO Studio, 2010)
Figure 9. STI distribution map, for conference use

CONCERT USE ANALYSIS

Maintaining sufficient absorption in the hall for speech purposes, the challenge has come to adjust it for music performances. The geometrical restrictions of the hall eliminate some of the variable acoustics solutions. The most reasonable solution in terms of acoustics and implementation is found to be applying coupled space concept for concert performances.

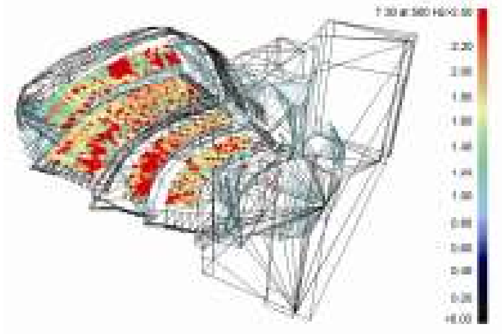


Source: (MEZZO Studio, 2010)
Figure 10. Location of the coupled volume above ceiling

On concert use all of the materials applied for conference use are kept in place and orchestra members as a surface is added on to the stage. The removable ceiling panels that are raised for opera and conference use are closed as stage acoustics necessitates good reverberant field, satisfactory ensemble values and enough reflections from the covering stage shell. To increase the reverberance to desired limits for concert performances and satisfying clarity at the same time is normally a challenging requirement for acoustical designers. Coupled space/room design is the best approach for handling those two conflicting requirements. Coupling some volume (in between auditorium shell and roof-side wall structure) into the main (e.g. Figure 10) hall with an aperture (removable ceiling panels) has ended up with a very good decay curve in full octave bands and conformed acoustical design targets for concert use.

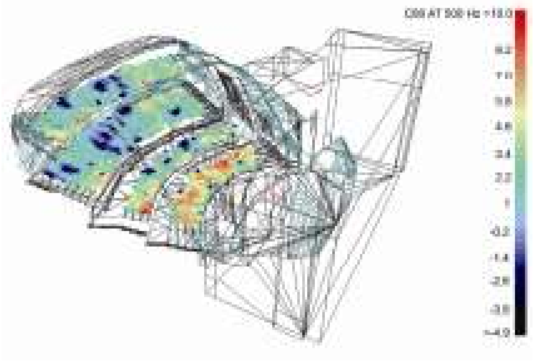
The reverberation time of the coupled room has to be higher than the main hall for providing extra energy fed to the main hall. The volume and aperture size are studied for obtaining acoustical coupling within two rooms. The coupled room surfaces are left mostly reflective for achieving the desired target reverberation time. After working on various designs the mid frequency reverberation of the coupled room is fixed in 3.71s in best alternative. In this design, the auxiliary volume is added to the main hall over ring T3 as shown in architectural drawings (e.g. Figure 10). The room has a height around 5 m and a length around 25m located centrally above ring T3. 1m gap from roof surface and auditorium shell surface is left for probable construction limitations. The acoustical volume of the room is estimated to be 600m³. The aperture opening is in the center of aperture surface and of area around 19m² with a width of 2m. The aperture size and volume is approximately calculated in this initial study.

Estimated acoustical volume of the graphical model for concert use excluding stage tower and including coupled room is 18326m³. The room consists of 11 different finish materials. Some cases of the acoustical simulation results of this first coupling alternative for concert use are presented below.



Source: (MEZZO Studio, 2010)

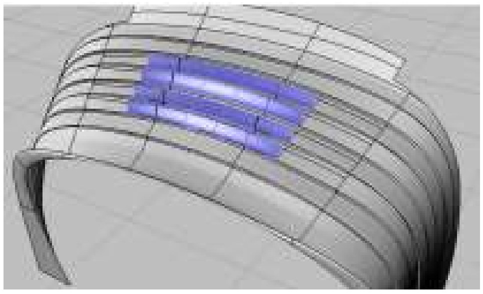
Figure 11. T30 distributions at 500Hz, concert use



Source: (MEZZO Studio, 2010)

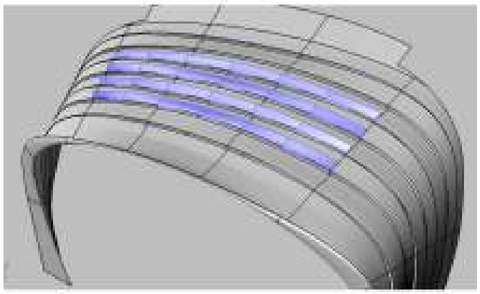
Figure 12. C80 distributions at 500Hz, concert use

A single big opening is not the only solution. On the contrary, having multiple apertures with smaller areas could help for a better diffusion and flow of surplus energy from coupled room into the main hall. Coupled space aperture alternatives distributed around coupling area are studied (e.g. Figure 13 and 14). Going too down in the width of aperture may have ended up with a resonance at a certain frequency resulting in coloration and lessen the effect of acoustical coupling.



Source: (SANSET IKOOR, 2010)

Figure 13. Coupling room aperture alternative proposed by SANSET IKOOR



Source: (Zaha Hadid Architects, 2010)

Figure 14. Coupling room aperture alternative proposed by Zaha Hadid Architects

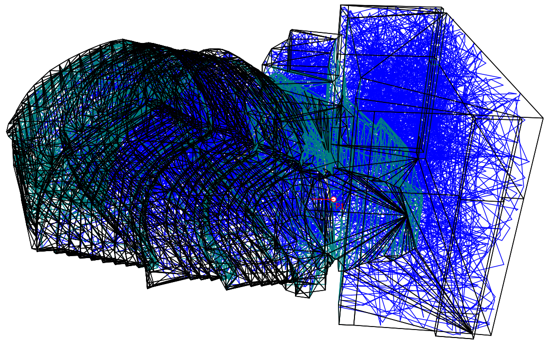
The aim of this initial proposal is to estimate the approximate amount of volume and aperture area that provides required acoustical characteristics for different scenarios of use. At any limitation or different expectation of architecture or implementation, the volume, aperture size/dimensions and locations could be adjusted by a further detailed study on other alternatives.

OPERA AND BALLET USE ANALYSIS

Source: (MEZZO Studio, 2010)

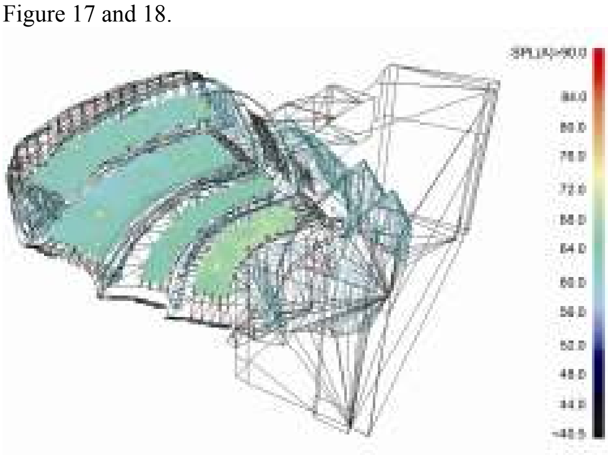
Figure 15. View from back seats, opera use

For opera and ballet function the pit cover is opened and an orchestra surface to represent the orchestra is added into the pit. The shell is removed exposing the stage tower (e.g. Figure 15). All other materials applied for conference use is kept in place. Initially, aperture of the coupled room is kept closed. The auditorium with full audience is found to be too dead for an opera performance as the reverberation time is low around 1.40s in mid frequency bands. Later, the coupled room is added to the main hall. Opening aperture surface fully, resulted in excessive reverberance. Finally, an aperture size of 4m² is found to be efficient in adjusting hall reverberation for opera performance in this design (e.g. Figure 16).

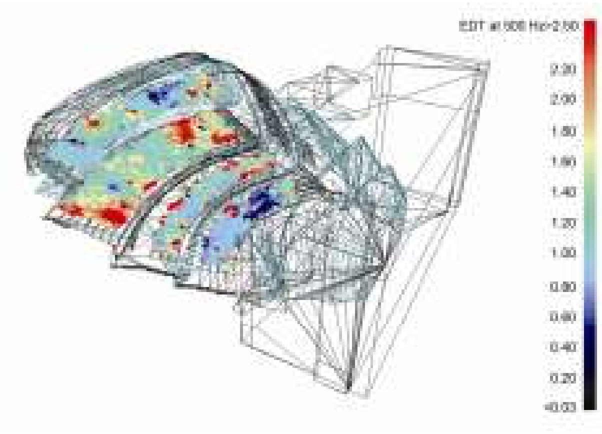


Source: (MEZZO Studio, 2010)
Figure 16. Ray tracing model, opera use

Considering the case that main aperture will have to be segmented to be raised for implementation purposes, aperture for opera use could easily be operated independently. The estimated acoustical volume of opera use graphical model including stage tower and coupled room is 20567m³. The room consists of 12 different finish materials. Some cases of the acoustical simulation results of opera use are presented in Figure 17 and 18.



Source: (MEZZO Studio, 2010)
Figure 17. SPL(A) distribution maps, opera use



Source: (MEZZO Studio, 2010)
Figure 18. EDT distributions at 500Hz, opera use

CONCLUDING REMARKS

The global reverberation times obtained from acoustical simulation of the auditorium at mid frequencies in anticipated conference use indicate an average mid frequency reverberation time of 1.43 s in terms of T30 with relatively smooth distribution within the Auditorium. This value is very close to the targets specified in Table 2. Even with a single source on the stage and a background noise rating of NR-25 as specified in the HVAC noise specs, an average STI of 0.58 is calculated. This representative average figure corresponds to almost good speech intelligibility rating. With a proper sound reinforcement system design and loudspeaker placement the speech intelligibility could be improved and managed as depicted by Long [6]. The average clarity figures in the Auditorium conforms the target specification for the conference use as well as the distribution of A-weighted sound levels complies with the requirement of maximum 10 dB difference within the hall.

For concert use, with assignment of absorption to the performers on stage and exposing the coupled volume increases global estimated reverberation times expressed in terms of T30 to levels just over 2 s at mid frequencies. This is the ideal value falling at the midst of the range specified in Table 2. This allows almost all kinds of classical music performances. On the other hand, reverberation times at low frequencies are increased with an apparent improvement of the warmth of the hall. The bass ratio that came out in this configuration is 1.30 which is the ideal value for this size of halls. Brilliance at 2000 Hz is lowered with a corresponding ratio of 0.85 which is less than the ideal figure of 0.93.

Brilliance at 4000 Hz comes out to be a bit lower with a ratio of 0.70 whereas the corresponding ideal figure is 0.84. These two outcomes can be attributed to the high absorption coefficients of the heavily upholstered seating at high frequencies. Early lateral energy fraction figures need improvement due to their lower values than the targeted ones for concert use. This outcome can be attributed to the location of the coupled space over the auditorium ceiling. Such spaces located on both sides of the hall like the ones in Myerson-McDermott Hall in Dallas would definitely have higher values for lateral energy fraction. This alternative can be tried in further studies, if the concept is approved by the design group.

In opera-ballet use, the orchestra shell is removed and the pit is opened with the performing orchestra as for practical performance reasons. Stage tower acoustical design is kept as it is solved for conference use. Absorptive treatment in the form of 100 mm thick, black porous cloth coated rock wool boards of density of 48-52 kg/m3 are applied onto the interior wall surfaces of the stage tower to handle excessive reverberation. This first attempt is ended up with a lower value for opera use in mid frequency range by around 1.40 s. Later, the coupled room (reverberation chamber) is added to the main volume by opening of 1/4 of aperture area specified for concert use. The segmented movable ceiling panel concept makes it possible to change aperture area size for two different scenarios of use.

The added volume of coupled room has increased reverberation times and ended up in a very smooth transition of double decay in non-exponential energy curves. The reverberation time of 1.65 s falls into the recommended range of 1.4 s to 1.8 s at low frequencies. Best acclaimed opera houses in the world are known to have mid frequency reverberation times of 1.6 s to 1.8 s. The bass ratio is calculated to be 1.18, quite favorable for opera and ballet performances. The brilliance at 2000 Hz is ideal since the ratio of reverberation times is equal to 0.93 whereas this subjective property is just a little short at 4000 Hz with a ratio of 0.79, that is, lower than the ideal value of 0.84. The distribution of sound levels within the auditorium also complies with the requirement of level differences to be less than 10 dB. Clarity aspect also conforms to the targeted values.

A design proposal is presented above for the improvement and adjustment of acoustical characteristics of the Auditorium in Heydar Aliyev Center to manage three different scenarios of use anticipated by MEZZO Studio. The proposal involves adoption of coupled space concept by forming a volume of specific size with definite aperture dimensions within the space over the auditorium ceiling. The motivation behind the proposal is the proven record of coupled space concept in some well known halls built in recent years all over the world. It is believed that this choice is attractive in halls like the one in Heydar Aliyev Center because any possible loss in visual appearance due to flexible passive reverberation control approaches cannot be tolerated.

In the proposal the hall is firstly tuned to acoustical requirements of speech-centered conference use as 70% of use has dictated to be for speech-oriented performances in the program. Major differences from the present design concept lie in the assignment of heavily upholstered seating for the audience area and removal of orchestra shell from the stage. For reverberation control the stage tower required to be treated with absorptive material. These attempts have yielded relatively flat reverberation time profile with frequency, well suited for the conference use.

The sound reinforcement system is crucial in the management of sound intelligibility as carefully selected and placed loudspeaker systems are instrumental to increase the contribution of direct sound in the total sound heard. The other factors affecting the sound intelligibility are the reverberation time and background noise levels. A noise rating of NR-25 which is considered to be high for the specified functions has been assigned previously for HVAC noise in the hall. This adversity would reduce signal-to-noise ratios within the hall.

When the orchestra shell is placed on the stage with the pit closed, the resulting mid frequency reverberation times along with the bass ratio perfectly match to the requirements of a concert hall for symphonic music. However, there is a need for fine tuning for the improvement of lateral energy fraction figures. When the pit is opened with the performing orchestra for opera-ballet use and the stage tower is exposed after removing the stage shell, the inclusion of the coupled space above the ceiling increases the mid frequency reverberation times to the ideal levels. Bass ratio is improved resulting in the favorable warmth characteristics for this mode of functioning.

Consequently, upon evaluations of initial simulation results for the Auditorium for three different uses, the coupled space solution is demonstrated to be feasible though it still needs fine tuning and optimization of matching between reverberation times of the hall and coupled space(s). The proposed acoustical design alternative is considered as a state of art approach in design of multipurpose auditoria. It is well suited to cases where visual appearance of auditoria is desired to be the same for all possible uses.

REFERENCES

1 Z. Sü-Gül and M.Çalışkan, “Acoustical Design of Inner Galleries in Heydar Aliyev Center” *Proceedings of 20th International Congress on Acoustics, ICA 2010,* 23-27 August 2010, Sydney, Australia.
2 M.Çalışkan, “Architectural Acoustics”, Lecture Notes, (IZOCAM Isolation Education Center, 2004)
3 J.C.Jaffe, “Selective Reflection and Acoustic Coupling in Concert Hall Design, in Music & Concert Hall Acoustics” *Conference Proceedings from MCHA 1995,* (Academic Press, New York, 1995), pp.85-94.
4 R. Johnson, E. Kahle, and R.Essert, “Variable Coupled Volume for Music Performance, in Music & Concert Hall Acoustics” *Conference Proceedings from MCHA 1995* (Academic Press, New York, 1995), pp.372-385
5 Z. Sü, *Systematic Investigations on Energy Decays in Acoustically Coupled Spaces Using Scale-Model Technique,* (Master’s Thesis, RPI, July 2006, Troy, NY, USA)
6 M.Long, *Architectural Acoustics*, (Elsevier Academic Press, 2006)

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