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5aAAa3. New opera house in Astana: A recent opportunity to use a room acoustic scale model
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The acoustic design of the New Opera House in Astana (Kazakhstan) currently under construction was carried out by Biobyte in Milan, Italy (Enrico Moretti and Maria Cairoli) assisted by Gade & Mortensen Akustik, Denmark (Anders Gade). In order to predict the acoustic consequences of the room geometry and decide on details in the design such as diffusion treatment of curved surfaces, it was decided to build a 1:20 scale model, in which several room acoustical parameters were measured. However, the scale model also provided an opportunity to compare the performance of scale model testing and room acoustic predictions by two computer simulation programs which were also used for predictions in the design process. Therefore, besides information about the adequacy of the diffusion treatment to avoid focusing from concave surfaces (an aspect which is not well described by computer simulation) we obtained data on measurement accuracy or rather deviations - between the results from the scale model (DIRAC) and the two different room acoustic prediction programs (CATT and ODEON). These results will be presented and discussed in the paper.

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INTRODUCTION

The New Opera House in Astana, the recent capital city of Kazakhstan, is going to be inaugurated at the end of the year.

Biabyte, a company of acoustics and theatre consultants, worked closely with the architects ABDKR (Rome), to develop the design brief and the project details for the building. A 1:20 scale model was built and tested assisted by Gade & Mortensen Akustik, Denmark (Anders Gade).

A fundamental request of the client (the contractor company Mabetex, in charge with the Kazakhstan government) was that the theatre, with 1280 seats, had to be one of the most beautiful semi-classical opera houses in the world, also from the acoustic point of view.

The acoustic quality in particular had to be similar to that one of the most important Italian baroque theatres like Teatro alla Scala.

The extension of an historic theatre in a new project represented a big challenge for the specialists, especially because the auditorium has to be applauded as excellent throughout the world.

![Auditorium view - from the architects rendering](image)

In the May 2010, a very ambitious program was announced. Ambitious for the amount of rooms planned, for the realization time schedule, and also considering the program of only few months to complete the design by the architects and by all engineers and professionals.

DESIGN PROCESS

The room form and finishes were developed by the team, integrating the functional, aesthetic and acoustic requirements in a homogenous and harmonious manner. The preferred internal dimensions and balcony geometries were discussed at an early stage so that the desired auditorium and stage volumes respected the right proportions.

The acoustic analysis of the developing design was carried out using Odeon and Catt room acoustics Software models.

According to the classical theatre design, it was decided that the form of the new theatre had to be a more traditional opera house than most of the modern theatres with few deep balconies.

In order to better predict the acoustic consequences of the room geometry and to quantify the design details such as diffusion treatment of curved surfaces and to check the absence of echoes, a 1:20 scale model was built. The results of the measurements of the main important acoustic parameters inside this model were compared with the computer simulations and were applied in the design process.

The new Opera House has five levels of balconies, that wrap around the sides of the room, creating an intimate space and visually linking the audience with the stage. The team created a room in which the ceiling was clearly identifiable as a homogeneous surface that closes off the top of the room, with a technical bridge behind a window inserted in the ceiling itself. This is an innovative approach in a classical theatre design as a timber lid on the room volume.
The surfaces around the proscenium are sculptured to direct the sound from the stage and orchestra pit towards the audience. In addition to this the proscenium roof is larger than its lateral walls, creating a sound reflector over the forestage and balancing the stage sound with the pit one.

Other geometrical features, such as the recessed side boxes and the rounded balcony fronts, provide useful sound diffusion and reflections to the stalls and back to the singers in a homogeneously fashion to enhance their feeling of acoustic support from the room.

The room plan is based upon a horseshoe shape for the balconies inscribed inside a box. The side walls optimize the lateral fraction energy and the rear wall counteracts the inherent focusing of a concave form. All seats have excellent sightlines to the stage, giving good direct sound paths as well. Sightlines into the orchestra pit start in the first balcony and extend to the rear of the 3rd tier, enabling a bright string sound throughout.

**COMPUTER SIMULATION ANALYSIS**

The purpose of room acoustic modeling was to predict and evaluate the acoustic behavior of the room before it was built.

Both techniques, scale modeling and computer modeling, are useful but possess different limitations and errors.

In computer modeling the simulation accuracy is limited by the theoretical simplifications in theories and algorithms used to describe the physical reality: not least those associated with diffraction and diffusion properties. In scale model measurements scaling of the signal frequency according to the model ratio causes problems with compensation for increased air absorption at high frequencies, and it is also difficult to find the right materials having absorption characteristics to be used to represent the real ones in the room.

The main acoustic virtues of simulations are: quick and automatic analysis of a large number of positions/parameters including a full record of transmission paths for individual reflections whereas the main advantage of scale models is its precise representation of diffusion and diffraction.

At first the reverberation time was checked with computer analysis, also in relation with the other main parameters, and the scale model (matching the same reverberation time) was used to better investigate the phenomena related to the reflection sequences generated in the room, i.e. the calculation of ISO 3382 parameters, visual inspection and not least the check for echoes.

The input and the geometry used in Catt and in Odeon simulations were the same.

The microphone and source positions were the same in the computer simulations and in the scale model. They were distributed in six audience areas: main floor (“gulv”) plus the five balconies with five on the main floor and three on each of the balconies, i.e. 20 positions in total. All positions were placed in the right side of the hall (as seen from the stage), because the hall is symmetrical along the long axis. The position No. 3 on the 3rd Balcony is in the president’s box. For each of the microphone positions three source positions were used. All source positions were placed near (1 m distance) the long axis of the hall:

1. in the orchestra pit about 20 cm from the rear wall under the stage
2. on the stage, “Downstage”, 10,7 cm from the stage front
3. on the stage “Upstage”, 33,5 cm from the stage front

Simulation model, microphone positions and results follow.

**FIGURE 2. geometric computer model**
The Reverberation Time, \( T_{30} \) was the first and still is the most important room acoustic parameter, as it influences the behavior of most of the newer parameters describing more specifically different aspects of the listening experience in an auditorium. The results of \( T_{30} \), Strength, \( G \) and Clarity, \( C_{60} \) from the two computer models are presented in Figures 4 to 6.

**Simulation results**

![FIGURE 3. microphone positions in the scale model](image)

**FIGURE 3.** microphone positions in the scale model

![FIGURE 4. \( T_{30} \) predicted reverberation time with computer simulation by Odeon and Catt Acoustics](image)

**FIGURE 4.** \( T_{30} \) predicted reverberation time with computer simulation by Odeon and Catt Acoustics

![FIGURE 5. Strength \( G \) per position predicted with computer simulations by Odeon and Catt Acoustics](image)

**FIGURE 5.** Strength \( G \) per position predicted with computer simulations by Odeon and Catt Acoustics
Sound strength $G$ is a measure of how much the hall contributes to the sound level as experienced by the audience. The results by both simulation programs we judged to be acceptable.

The Clarity parameter, $C_{80}$, is related to the possibility for the listener to detect the individual notes and voices in the running music. A high $C_{80}$ value means that the acoustics allows details in the score and orchestration to be clearly perceived by the listener, while a low value indicates a "muddy" sound where many details are blurred together. In general, positions with high $C_{80}$ values have also low EDT and vice versa.

The general trends indicate a clear sound with a high degree of uniformity throughout the auditorium.

**SCALE MODEL ANALYSIS**

The 1:20 scale model was built during the Spring 2011. The model was built from thin plywood and plaster. All surfaces have been painted several times in order to represent those surfaces in the real hall, which have only marginal sound absorption. Thus, the main sound absorbing surfaces in the model are the model audience sections (which had been tested for correct absorption relative to that of a full scale audience) and the drapes covering the back wall in the president’s box and the entrance doors just above the main floor level.

In the model, the stage house was provided with sound absorbing textiles (300g Molton) along all walls and ceiling surfaces.

**Measurement Technique**

The measurements were carried out using a portable PC with the “Dirac V5.0” software installed. The source was an electrical spark source (developed at the Technical University of Denmark), the signal was picked up by a GRAS $1/4''$ microphone type 40BE attached to a GRAS preamplifier type 26CB. The signal was then filtered through a high pass Filter Rockland Model 852 before being sampled at 192 kHz in a sound card Creative E-MU 0202.
connected to the PC by a USB-2 port. The high pass filter was introduced to eliminate the influence of eventual low frequency noise in the measurement environment.

All together, the measurement system was adjusted to cover the frequency range 1.000 – 80.000 Hz equivalent to 50 – 4000 Hz in full scale.

At the high frequencies used in the model, the sound absorption in the air is much higher than at the normal frequencies. Besides the frequency, the air absorption depends on temperature and relative humidity. Therefore, these parameters were measured in the model before the measurements in each position, with a Fluke model 791 temperature and humidity meter.

With the spark source having almost omnidirectional radiation characteristics and emitting very short sound impulses with high intensity, the microphone recorded broad band impulse responses from the model room.

In each measurement position, up to 15 impulse responses were recorded and ensemble averaged in order to improve the signal to noise ratio.

All signal processing including ensemble averaging, frequency transformation of the signal from the model to the full scale frequency range, compensation for excess air absorption at high frequencies in the model and calculation of the acoustic parameters (Reverberation Time, Early Decay Time, Sound Strength and Clarity) in octave bands from 125 Hz to 2.000 (4.000) Hz were carried out by the Dirac software.

**Measurement results**

The values versus frequency averaged over all 20 microphone positions are shown in the following graphs for each of the three source positions.

**FIGURE 8.** reverberation time results from the scale model

**FIGURE 9.** clarity results from the scale model
FIGURE 10. Strength results from the scale model

In general Figures 9 and 10 show a slight decrease in $C_{30}$ and $G$ from left to right which is likely to be related to the source-receiver distance increasing from left towards right in the graphs.

The reasons for the fairly low values in positions mf 3-5 and 1b 2-3 with the source in the pit is probably that the source is not visible from these seats, whereby the direct sound which normally carries a lot of the clarity information, is strongly attenuated.

When the source is placed on stage – in the upstage position in particular - there is a general tendency towards high values in the side balconies close to the stage. (The only exception is position 3b1.)

Apart from the deviations from the general trends the results indicate a clear sound with a high degree of uniformity throughout the auditorium.

DISCUSSION AND CONCLUSIONS

The values, trends and relations between the acoustic parameters are similar in the computer and scale models; but in some cases the absolute values are different, especially for $C_{30}$ and $G$. These differences could be related to the diffusion coefficient of the rounded surfaces. The diffusion in the scale model is likely to be higher than the value applied in the computer simulations, and the directivity of the scattering from various surfaces will be different.

In general, both the scale model and the computer simulations produce $T_{30}$ values which were practically independent of the source position. The only exception occurs at high frequencies when the source is placed far back in the sound absorbing stage house.

Overall, the RT value from the scale model is around 1.4 Sec. at mid frequencies. This corresponds well with the expectations according to the simulation results using Catt and Odeon.

For $C_{30}$ and G the scale model shows a natural tendency towards lower values when the source-receiver distances become larger. The values with the source in the pit are generally lower (less clear) than when the source is placed on stage - both in computer simulations and in the scale model. This is a typical – and desirable - finding in opera theatres, since the singing should possess higher clarity than the accompaniment. In general, the G values with the source in the pit are higher than those with the source on stage. This is a consequence of the physical law of the level decreasing with distance and of the high sound absorption of the stage surroundings.

With the source in the pit, the values in mf1 and mf2 are significantly higher than further back mf3-5. This is due to the source being invisible from the latter positions. (Low values would also have been found in mf1 and mf2 if a closed pit rail had been installed in the model.)

As for $C_{30}$, also G shows high values in the balcony seats closest to the stage. This tendency is seen for all three source positions used.

For each of the source position the fairly small differences between the seat positions indicate a high degree of uniformity for the sound level distribution in the hall.

After the comparison between scale model and computer simulations results, an improved stage-to-pit balance was studied resulting in the prosenium arch being increased.

In general, we recommend to increase the floor rake in the side balconies in order to improve the sight and sound lines from seats close to the side walls in these areas.
Both scale model and computer simulations of the Astana theatre predicted highly satisfactory acoustic conditions in this new theatre with favorable values for the most important room acoustic parameters, $T_{30}$, EDT, $C_{80}$ and $G$. In general, the variation in conditions with seat position is small, and no serious risks of unfavorable echoes in the auditorium were found.

REFERENCES