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IMPROVEMENT OF CLASSICAL MUSIC SOUND CONDITIONS BY SIMULATING CHANGES IN CONCERT HALL ACOUSTICS

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Abstract

The purpose of the research is to propose a method of acoustic research of concert halls to improve the classical music sound conditions with the help of innovative computer technologies. **The research methodology** is as follows: to improve the sound conditions of classical music, a computer simulation method is proposed, which involves the use of specialized software. The method of subjective evaluation through the criteria of the established sample is used to systematize the results of the study. The comparative method was used to analyze the sound of audio materials of the created spatial sound images of the orchestral music sample. **The scientific novelty of the research** is that it presents a methodology of acoustic research for the environment, in particular concert halls, which arose as a result of changes in the acoustic conditions of classical music. **Conclusions.** As a result of the experiment, the main goal was achieved – to improve the sound conditions of classical music. The result was achieved by modeling changes in the acoustics of the concert hall. The use of this methodology can be recommended during the research of existing and projected concert halls. In further studies, the use of diffusers with low absorption coefficients in the lower frequency band can be recommended. It should also be noted that interference with the interior of a historic building should be discreet, as this may cause dissatisfaction among the authorities controlling heritage preservation.

Keywords: concert hall acoustics; objective acoustic parameters; computer modeling; subjective estimation; diffuser

Introduction

The acoustic environment of the concert hall is formed due to direct and reflected sound waves coming from a source that sounds on the stage or in the orchestra pit. Size, shape, ceiling, stage, type of chairs, audience absorption, and material of walls have a direct influence on its acoustic properties. The homogeneity of spatial sound is also affected by columns, niches, irregular boxes, statues on the upper side walls, and fine-scale ornamentation of the lower side walls. Acoustical conditions of a concert hall characterize objective acoustic parameters. It is RT, EDT, C_{50}, C_{80}, L_{80}, G, IACC, BR,

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Br, LF, ITDG. Of these, the most important can be considered RT (reverberation time), EDT (early decay time), C_{50} (language intelligibility), C_{80} (musical intelligibility), L_{80} (volume), G (power of sound) (Beranek, 2004, p. 20).

Empirical studies published in 1996 found that the optimal reverberation time depends on the type of musical performance and its style. So, for organ music the reverberation time is 3.0 ÷ 5.0 s., for symphony music – 2.0 ÷ 2.2 s. and for chamber music – 1.3 ÷ 1.6 s. (Beranek, 2004). Modern calculations of reverberation time that have been carried out in the world's most famous concert halls for symphonic music have defined a range of 1.8s <RT <2.0s. Other objective acoustic parameters also have recommended values (Arias, 2013).

The acoustic properties of a closed environment affect a person's perception of the nature of sound vibrations (speech, music, noise), which is determined by the psychoacoustic properties of human hearing. To assess the sound of classical music using the method of subjective evaluation according to the criteria of the established sample, such as spatial impression, spatial perspective (liveness); width, binaural spatiality; timbre; clarity, transparency, intelligibility; loudness, dynamic range; intimacy; texture; sound balance; room support (musicians of an orchestra); freedom from noise and distortions (Hidaka & Beranek, 2000; Voitovych, 2017).

To improve the sound conditions of classical music, need to change the acoustics of the concert hall in accordance with the recommended values.

Purpose of the article

The purpose of the research is to propose a method of acoustic research of concert halls to improve the sound conditions of classical music with the help of innovative computer technologies. To achieve the goal, one needs to perform the following tasks: to simulate the acoustic environment of the concert hall using specialized software; to influence the factors that shape its acoustics; to form a spatial sound image of the sound of selected samples; to conduct a subjective assessment of their sound before and after changes in the acoustic environment.

Recent research and publications analysis

The following works were analyzed: papers in the field of musical acoustics A. Benade, L. Beranek, A. Gade, A. C. Gade, L. Kinsler, W. Kuhl, R. Lindsay, J. Pierce, etc.; objective and subjective methods of studying the acoustics of enclosed spaces M. Barron, L. Beranek, T. Kamisiński, R. L. Marshall, M. Morimoto, W. Ahnert, W. Schmidt, J. A. Hidaka, and others; diffuse sound reflection and diffusers M. Schroeder, T. Cox, P. D'Antonio, etc.; software development for acoustics simulations Prof. Dr. Wolfgang Ahnert, Dr. Rainer Feistel.

Main research material

One of the factors, which has the greatest impact on the acoustic properties of an enclosed environment, is the building materials. The acoustics of concert halls

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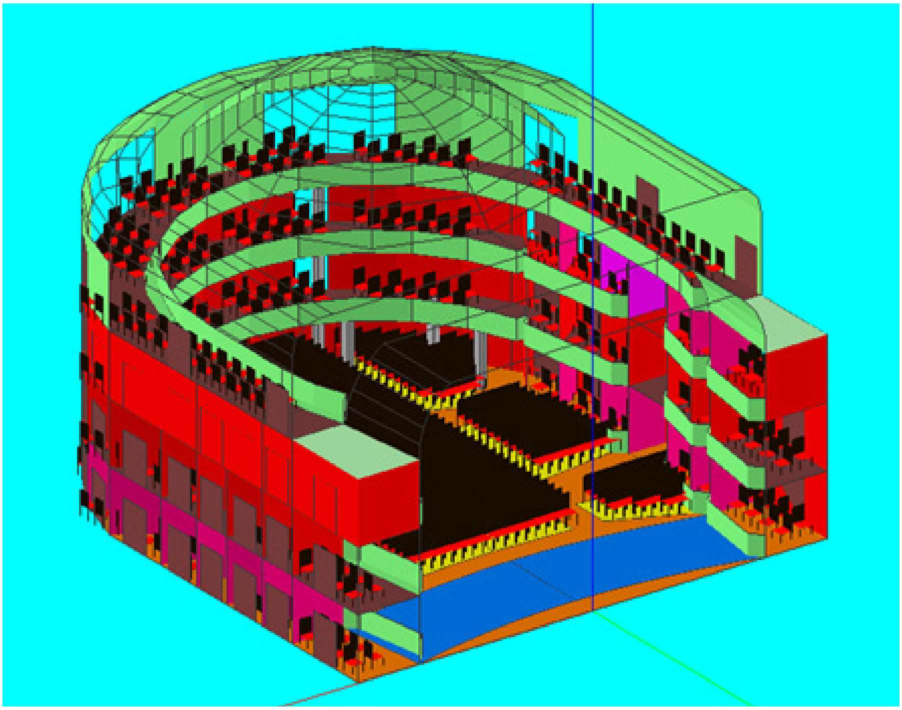
directly depend on the building materials of the ceiling, walls, floor, auditorium chairs, materials of the stage, the orchestra pit, and their decoration. By changing them, you can affect the acoustic properties of the concert hall.

The method of computer simulation of physical processes of the environment is widely used to perform tasks. The created model according to its acoustic characteristics should be as close as possible to the original.

To create the concert hall model has been used specialized software EASE 4.3. The program consists of sections. Of these, the section for the construction of architectural models of various buildings, including concert halls, and the acoustic research section of the created models, which can "auralize" the sound of audio material (processing of audio material by a spatial processor that simulates its acoustic environment). To create an architectural model, this software has a wide selection of samples of building materials and interiors.

The Solomiya Krushelnytska L'viv National Academic Opera and Ballet Theatre was chosen for research. His concert hall has already taken part in our previous research (Voitovych, 2020). After the last reconstruction (2008), the floor, upholstery elements, and cosmetic repair of the interior were replaced. Acoustic properties were preserved.

A model of the concert hall was created based on data on architectural features and finishing materials.



Picture 1. *A model of Concert Hall of the Solomiya Krushelnytska Lviv National Academic Opera and Ballet Theatre*

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As a result of numerical simulation, the objective acoustic parameters of the model and the original are as close as possible to each other.

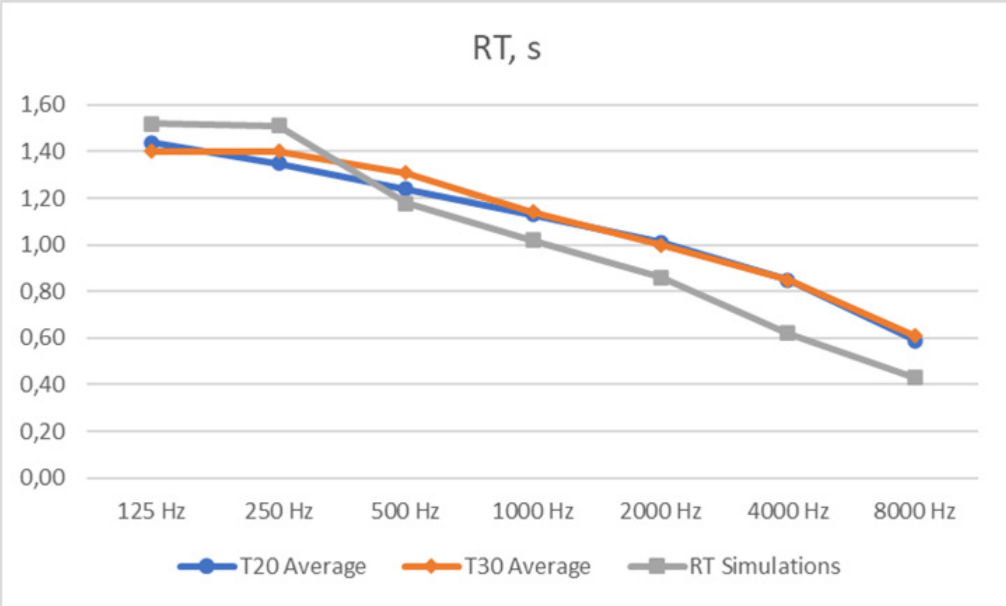

Figure 1. *Reverberation time of the current concert hall and its model*

Additional objective acoustic parameters have been selected for research. It is C50 (language intelligibility), C80 (musical intelligibility), and G (power of sound). Table 1 shows their average values.

Table 1

$C50_{mid}$ current/simulations	$C80_{mid}$ current/simulations	G_{mid} current/simulations
1.7/1.51	5.01/4.73	3.5/4.2

To improve the sound conditions of classical music in Lviv Opera House, it is desirable to increase the reverberation time to the recommended values. Moreover, other parameters must remain unchanged or have slight deviations.

One way to change the reverberation time is to change the treatment of the semicircular walls of the balconies in accordance with the semicircular wall under the balcony on the hall's stalls, where the Schroder-Diffuser panel is installed to improve acoustic characteristics and prevent echoes (Kamisiński, 2012). Also, must change the treatment of the irregular boxes on the hall's side wall.

The last century has seen a sharp increase in interest in the use of sound-diffusing surfaces in concert halls. The ideas and developments of Manfred Schröder, a professor of physics at the University of Göttingen (Germany), who published his fundamental work on diffuse reflections from surfaces constructed according to the

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principle of a mathematical sequence of maximum length (MSL) in 1975, served as a wide application of acoustic scatterers (Schröder, 1975).

Picture 1. *Schroeder diffuser: single plane 1D*

Picture 2. *Installation of diffusion panels of the semicircular back wall behind the under-balcony space in the hall's stalls*

As a result of the proposed changes in the interior of the concert hall model, the following results have been obtained.

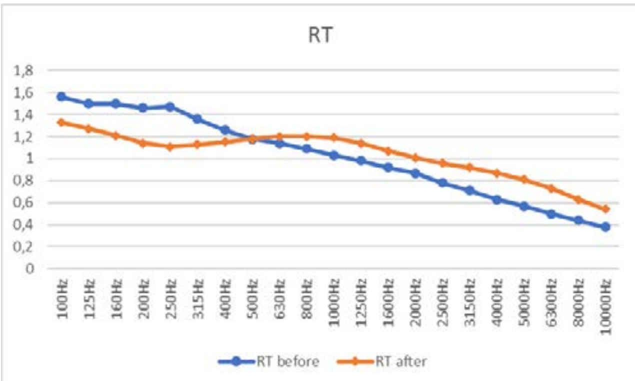

Figure 2. *Reverberation time before and after changing the treatment of the semicircular walls under the balcony and of the irregular boxes on the hall's side walls*

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The simulation results show an increase in reverberation time in the bands above 500 Hz and a decrease in the bands below 500 Hz.

Additional objective acoustic parameters before and after change show their average values in Table 2.

Table 2

$C50_{mid}$ before/after	$C80_{mid}$ before/after	G_{mid} before/after
1.51/0.83	4.73/3.83	4.2/3.9

For these data, a slight deviation of the values is noticeable. This can be explained by the interaction between objective acoustic parameters.

To fully evaluate the sound of classical music before and after changes concert hall's acoustics in Lviv's Opera, the method of subjective evaluation using the criteria of the established sample has been used (Beranek, 2004). This methodology has also been used repeatedly in our previous research to evaluate the live sound of orchestral music (Voitovych, 2020).

To conduct a subjective assessment of the sound of a musical work, it is necessary to create a spatial sound image of its sound in the environment before and after changes in the acoustic properties of the studied concert hall. This can be done by auralizing samples of audio material recorded in an environment in which there are no reflected waves. This environment is called – the "Free Field" (Hansen, 1951). This sound can be obtained in professional recording studios, where the proportion of reflected waves can be neglected, or in acoustically muffled chambers of research laboratories. The parameters of such objects are regulated according to international requirements (Voitovych, 2021a, p. 27).

To auralize the sound of audio material a piece of the Water Music collection (Suite II, Part 2: Alla Hornpipe) of German and English baroque composer George Frideric Handel is selected. The work has an orchestral performance. The orchestral texture is not burdened and saturated timbre. The harmonic vertical and melodic horizontal are clearly heard. Temporithmics – moderate. The sound dynamics are static. Such characteristics should maximally contribute to the auralizing of the selected musical material.

For the computer simulation, a recording of the selected piece's fragment was taken in a "Free Field" environment. After processing the program with a spatial processor, audio files were obtained, in which the sound of this piece of music is simulated on the hall's stalls of the auditorium when the source sounds on the proscenium. The curtain behind the source is closed.

In our case, the evaluation is performed by a phonogram. Unlike evaluating live performing assessments carried out using the criteria of the established sample for recorded audio. These are spatial impression, spatial perspective (liveness); stereo effect; timbre (grace, brightness, bass); clarity, transparency, intelligibility; loudness, dynamic range; intimacy, texture; sound balance; freedom from noise, and distortions; main impression (Voitovych, 2021b).

The audition was conducted by a group of experts from among sound engineers, composers, conductors, musicians, and music critics by the method of scoring

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through questionnaires, in conditions that meet international standards. These include geometric and acoustic listening conditions, requirements for technical characteristics and placement of control monitors, the number of experts, and their location for simultaneous listening (Hoeg et al., 1997).

After systematizing the results of the research, it was found that the sound of the selected musical work has been changed. Perception of spatial impression, and spatial perspective (liveness) has improved. Clarity, transparency, and intelligibility also improved to a small extent. Loudness, dynamic range, and the rest criteria of the established sample have not changed. To some extent, there was a dryness in the sound after simulating changes in the acoustics of the concert hall. This can be explained by a decrease in the amount of reverberation time in the lower frequency band. In general, the opinions of experts were somewhat divided in assessing the overall impression, which did not significantly affect the results of the experiment.

Conclusions

Analyzing the results of research on the Lviv Opera House, we can conclude that using the proposed method can achieve the desired results.

Computer modeling makes it possible to conduct acoustic research without interfering with the architecture of existing buildings, especially when they are historical monuments.

As a result of the experiment, it was found that the greatest results were achieved in the upper-frequency range where the reverberation time increased. Instead, in the lower frequency range, there is a slight decrease. This can be explained by the use of as a substitute in the treatment of side wall and irregular boxes Schroeder diffusers, which have a higher absorption coefficient in the low-frequency band than soft wall tapestry.

Changing one parameter affects other objective acoustic parameters. In our case, language intelligibility and the power of sound did not undergo significant changes, instead, musical intelligibility slightly improved its result.

After the auralization of the sample of audio material, a subjective assessment of the sound of the audio material was performed, which confirmed the achieved results in improving the sound conditions of classical music.

As a result of the experiment, the main goal was achieved – improving the conditions of sounding classical music. The result has been achieved by simulating changes in the acoustics of the concert hall. This methodology application can be recommended in studies of current and project concert halls.

In further studies, the use of diffusers with a low absorption coefficient in the lower frequency band can be recommended.

It should also be noted that interference in the interior of the historic building should be inconspicuous, as it may cause dissatisfaction with the authorities supervising the preservation of heritage.

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ПОКРАЩЕННЯ УМОВ ЗВУЧАННЯ КЛАСИЧНОЇ МУЗИКИ ШЛЯХОМ МОДЕЛЮВАННЯ ЗМІН АКУСТИКИ КОНЦЕРТНОЇ ЗАЛИ

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Анотація

Мета дослідження – запропонувати методику акустичних досліджень концертних зал для покращення умов звучання класичної музики за допомогою інноваційних комп'ютерних технологій. **Методологія дослідження.** Для покращення умов звучання класичної музики запропоновано метод комп'ютерної симуляції, що передбачає використання спеціалізованого програмного забезпечення. Методику суб'єктивної оцінки через критерії встановленого зразка застосовано для систематизації результатів дослідження. Порівняльний метод використано для аналізу звучання аудіоматеріалів створених просторових звукових образів зразка оркестрової музики. **Наукова новизна дослідження.** Представлено методологію акустичних досліджень для середовища, зокрема концертних зал, що виникла унаслідок зміни акустичних умов звучання класичної музики. **Висновки.** В результаті експерименту було досягнуто головної мети – покращення умов звучання класичної музики. Результат досягнутий через моделювання змін акустики концертної зали. Застосування зазначеної методики можна рекомендувати під час досліджень наявних і проєктних концертних зал. У подальших дослідженнях можна рекомендувати використання дифузорів з низьким коефіцієнтом поглинання в нижній смузі частот. Слід також зазначити, що втручання в інтер'єр історичної будівлі має бути непомітним, оскільки це може викликати невдоволення органів влади, які контролюють збереження спадщини.

Ключові слова: акустика концертної зали; об'єктивні акустичні параметри; комп'ютерне моделювання; суб'єктивна оцінка; дифузор