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RESEARCH OF THE SOUND OF ORCHESTRAS IN THE CONCERT HALL OF THE SOLOMIYA KRUSHELNYTSKA LVIV NATIONAL ACADEMIC OPERA AND BALLET THEATRE

Oleksandr Voitovych
PhD in Art Studies, Senior Lecturer,
ORCID: 0000-0001-9885-7173,
e-mail: acoconcert_lviv@ukr.net,
Mykola Lysenko Lviv National Music Academy,
5, O. Nyzhankivskoho St., Lviv, Ukraine, 79000

The purpose of the article is to offer a method of aesthetic evaluation of the acoustic properties of concert halls based on the subjective perception of the sound of musical material. The research methodology is based on the following methods: analytical is used to study the scientific literature; theoretical – to define special terminology, describe the phenomena that occur during research and parameters used for the subjective assessment; empirical – while listening to orchestras in a concert hall with subsequent expert evaluation of the results; comparative – to compare the results of research; methods of analysis and synthesis – to process the results of research, and also the interviewing method – to get information from musicians and active listeners. The scientific novelty of the article is an attempt to give an aesthetic assessment of the sound of the orchestras in the concert hall of the Solomiya Krushelnytska Lviv National Academic Opera and Ballet Theatre by studying the phenomenon of subjective perception of musical material. Conclusions. The study has demonstrated that the subjective assessment of the acoustics of concert halls requires the selection of evaluation criteria and the establishment of their relations with objective acoustic parameters. Subjective evaluation and objective parameters are correlated with each other and give a complete description of the sound of the orchestra in the concert hall. Subjective assessment of the acoustic quality of concert halls is fully confirmed by objective acoustic parameters. Its application can be considered justified. It has received a clear confirmation from the professional musicians. The verbal questioning among ordinary concert-goers has shown the one-sidedness of their assessments. They vary between "good" and "excellent" and thus, are less accurate.

Keywords: objective parameters; subjective assessment; evaluation criteria; concert hall's acoustics; correlation; concert hall; orchestra

Introduction

Objective acoustic parameters characterize acoustics of the enclosed space. In our study, this is the acoustics of the concert hall. These acoustic properties depend directly on size, shape, type of chairs, audience absorption, material of walls, ceiling and stage. It also depends on columns, niches, irregular boxes, statues on the upper side walls and fine-scale ornamentation of the lower sidewalls. Objective acoustic parameters include RT, EDT, C_{80}, G, IACC, BR, LF (Beranek, 2004, p. 20).

Many years of research has shown that the acoustic properties of concert halls cannot be characterized only by objective parameters. To get the full assessment of the hall acoustics, a subjective evaluation based on the criteria of the established sample is used. In particular, it is examined in the articles by L. Beranek (1995), M. Barron (1988), T. Hidaka (Hidaka & Beranek, 2000).

Recent research and publications analysis

• works in the field of musical acoustics I.A. Aldoshin, Sh. Ya. Vakhitov, A.P. Yefimov, A. Benade, A. Gade, A.C. Gade, L. Kinsler, W. Kuhl, R. Lindsay, J. Pierce, etc.;

• works in the field of acoustics of musical instruments and instrument science V.I. Kozhukhar, L.A. Kuznetsov, T. Rossing, etc.;

• works on psychoacoustics J. A. Altman, J. S. Vakhitov, X. R. Schiffman, J. Angus, J. Blauert, D. Howard, D. Roederer, E. Zwicker and others;

• objective methods of studying the acoustics of enclosed spaces M. Barron, T. Kamisiński, R. I. Kinash, A. Kulowski, L. Marshall, M. Morimoto, W. Ahnert, W. Schmidt, L. Beranek, W. Sabine, and others;

• research in the field of communication of subjective criteria for assessing the sound quality of music and the objective properties of closed environments M. Barron, L. Beranek, J. Belank, J. Blankenship, J. A. Hidaka, A. Fischetti, M. Schroeder, and others).

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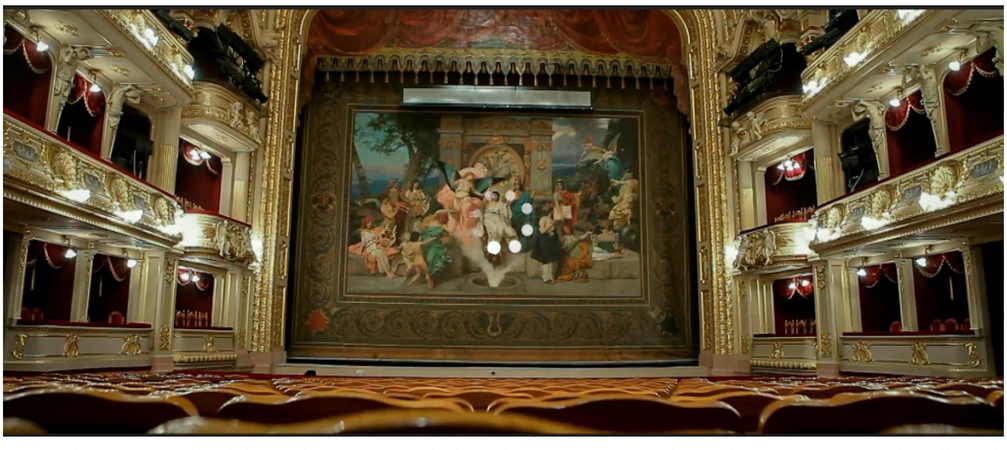
Purpose of the article

The purpose of this article is to offer a method of aesthetic evaluation of the acoustic properties of concert halls based on the subjective perception of the sound of musical material.

Main research material

The Solomiya Krushelnytska Lviv National Academic Opera and Ballet Theatre or Lviv Opera House (former name – the Grand City Theatre) was built in 1897–1900 under a project designed by Zygmunt Gorgolewski. (Pic. 1).



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

It was used for: opera, ballet, symphony music, chamber music, soloists, chorus.

The main structural elements of the building were made from local limestone (Polyansky quarry), the whole plinth – from solid Ternopil sandstone. *The walls* were plastered with lime mortar. Unlike other theatres of that time, from the exterior of the building it was impossible to draw a conclusion about the internal layout of the tiers. Its construction lasted three years and four months. The architectural style of the theatre is pseudo Renaissance, which is also called Viennese or Italian. In general, it is a mixture of different architectural styles. The hall had the horseshoe-shaped plan (lyre) (22.5 x 18.5m) and could host about 1 thousand people. *The stage* was raised to a height of about 1m regarding the first row and had two safety curtains, which weighed more than 12 tons and were purely decorative. *Decorations:* there were not only paintings and sculptures, but also luxurious fretwork, gilding, carving (sculptors P. Garasimovych, P. Viitovych, J. Giovanetti, E, Pidhirsky). *The ground floor boxes* were framed by columns. *The seating area:* seat backs and armrests were soft, upholstered in soft cloth. *The first balcony* was decorated with twenty unique paintings on gray marble. *The second balcony* was "supported" by Atlantes and Caryatids, *the third* – by Terminuses.

The concert hall of the Lviv Opera has been reconstructed several times. The last one took place in 2008. It included the replacement of the floor, upholstery elements and cosmetic repairs of the interior. Acoustic measurements of the interior, numerical modeling and laboratory tests of individual interior materials (boards, carpets, borders) were made to preserve the acoustic properties. It was observed that a good floor installation design provides the best sound absorption characteristics in the low frequency range (Kamisiński, 2010; 2012; Kinash et al., 2010). The architectural features of the studied hall are given in Table 1.

To improve the spectral characteristics and prevent the effect of the echo on the rear wall of the sub-balcony space, which has the shape of a semicircle, a sound-absorbing panel (Schröder-diffuser) was installed (Kamisiński, 2012).

Research of the sound of orchestras was done by attending live performances. Nearly 150 people participated in the survey. Among them were composers, conductors, musicians, musical critics, regular concert-goers. They filled in 80 (53%) questionnaire forms. In addition, a verbal questioning was conducted among ordinary concert-goers. The initial conditions for the sound evaluation were the following: the orchestras were professional and staffed with professional musicians, the instrumentation and performance were impeccable from the professional point of view. Therefore, such criteria as ensemble and arrangement (instrumentation) were not used in this case. The orchestra was placed in the orchestra pit.

Table 1

Architectural features of the studied hall

L (м)	B (м)	H (м)	S ($м^2$)	S ($м^2$)	S ($м^2$)	S ($м^2$)	S ($м^2$)	V ($м^3$)	V ($м^3$)	V ($м^3$)	V ($м^3$)	V ($м^3$)	N
Floor	Floor	Floor	Full	Floor	Boxes	Stage	Orches-tra pit	Full	Floor	Stage	Orches-tra pit	Per person	Seats
22	18	15	590	190	400	420	65	16200	5500	10700	125	4,69	1012

Subjective assessment was carried out according to such criteria as: spatial impression, spatial perspective (liveness); width, binaural spatiality; timbre; clarity, transparency, intelligibility; loudness, dynamic range; intimacy; texture; sound balance; room support (musicians of orchestra); freedom from noise and distortions (Voitovych, 2018; Hoeg et al., 1997). Table 2 shows the questionnaire used for the evaluation of live performances.

Table 2

Questionnaire for the evaluation of live performances

	Hall	**Orchestra/ensemble**	**Title**	
	Member	**Positions**	**Seat**	**Date**
№	Subjective criteria	What characterizes	Comments	Ranking
1	Spatial impression, spatial perspective (Liveness)	Spatial impression, sound perspective, depth, vitality, homogeneity of spatial sound, apparent room size		1-5
2	Width, binaural spatiality	Width, display width of the sound source, the horizontal width of feeling, localization of sound sources		1-5
3	Timbre	The richness of sound. Richness of spectrum down range (envelopment, warmth). Richness of spectrum upper range (grace, brightness), especially in a fast, full of music.		1-5
4	Clarity, transparency, intelligibility	Legibility melodic and harmonic lines, musical instruments certainty		1-5
5	Loudness, dynamic range	Sound level Difference between «p» and «f».		1-5
6	Intimacy	Closeness to the sound source. Smoothness or pied.		1-5
7	Texture	Uniformity of spatial sound		1-5
8	Sound balance	The soloist / orchestra. Between groups of instruments		1-5
9	Room Support (Musicians of orchestra)	Musicians' capacity to hear themselves and the rest of the orchestra.		1-5
10	Freedom from noise and distortions	External noise, ventilation noise, the noise of the public		1-5
11	Main impression			1-5

Participants were asked to rate the acoustic qualities of the hall on a scale of 1 to 5 (Table 3).

Table 3

Ranking scale

Bad	**Poor**	**Mediocre**	**Good**	**Very good/Excellent**
1	2	3	4	5

Common descriptive terms are shown in Table 4.

Table 4

Common descriptive terms

№	Subjective criteria	Examples of common descriptive terms
1	Spatial impression, spatial perspective (Liveness)	Volume / narrow. Long / short
2	Width, binaural width	Wide / narrow. Big / Small
3	Timbre	Rich / poor. Warm / cold. Brilliant / dim
4	Clarity, transparency, intelligibility	Clean / muddy. Legibly / illegible
5	Loudness, dynamic range	Loud / quiet. Wide / narrow
6	Intimacy	Near / far
7	Texture	Smoothness / Pied
8	Sound balance.	Good balance / not balanced
9	Room Support (Musicians of orchestra)	Good / bad
10	Freedom from noise and distortions	Perceptible / imperceptible disturbances

The Figure 1 shows the general acoustic impression of composers, conductors, musicians, music critics, regular concert-goers from live performances. The verbal questioning, which was conducted among ordinary concert-goers, is shown in Figure 2.

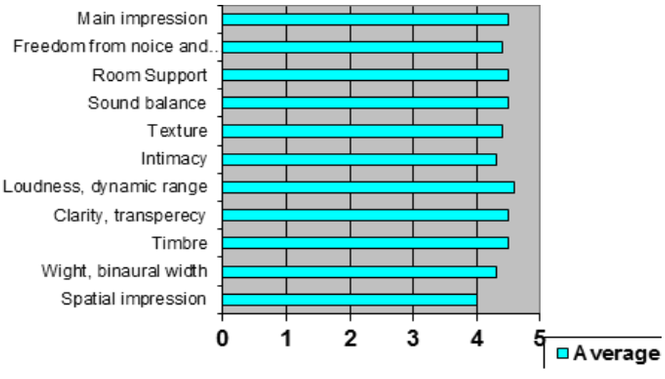


Figure 1. Average values of acoustical impression from live performances

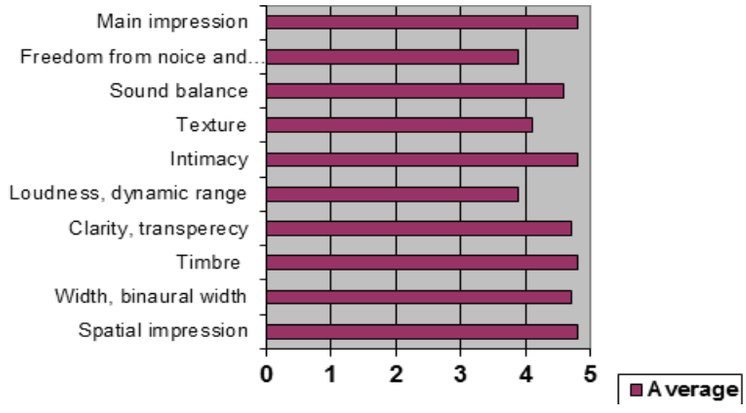


Figure 2. Average values of verbal questioning

Acoustical objective parameters were obtained from the Impulse Response in each measurement position and answer the recommendations and requirements specified in the Standard ISO 3382-2009[1]. The objective parameters were: reverberation time RT_{30}, early decay time EDT, bass ratio BR, brightness Br, musical clarity C_{80}, definition D, strength factor G, centre time Ts, early lateral energy fraction LF_{E4}, and interaural cross-correlation coefficients $IACC_{E3}$. The draft of hall can be seen in Figure 3.

In our case, the source was sine sweep signal placed on stage on the center line of the hall. The hall was empty. A receiver position was placed to the left from the central line. The sources were located 2m above the stage and the

[1] ISO-3382-1: "Acoustics – Measurement of room acoustic parameters – Part 1: Performance spaces (ITD)". 2009.

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microphones 1.5m above the ground. Impulse response has been studied by CATT-acoustic and EASERA software. Experts from the Department of Vibroacoustics of the Mining and Metallurgical Academy named after Stanislaw Staszyc in Krakow and Department of Architecture of Lviv Polytechnic participated in the acoustic measurements (Kamisiński, 2010; 2012; Kinash et al., 2010). Average objective acoustical parameters can be seen in Table 5.

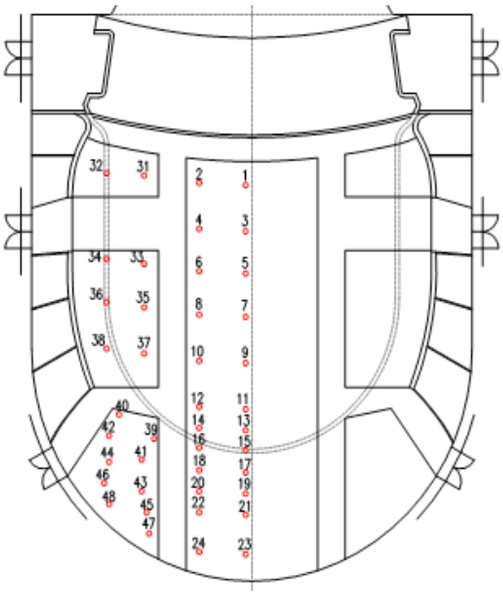

Figure 3. Concert hall plan and measuring points

Table 5

Average objective acoustical parameters

RT_{mid}	EDT_{mid}	BR	Br	C_{50}/C_{80}	D_{50}	G_{mid}	LFC_{E4}	ITDG	$IACC_{E3}$	$ST_{(sp)mid}$
1,23с	1,07с	1,12	0,81	1,7/5,01 дБ	60%	2,32дБ	0,6	24мс	0,25	-10дБ

Years of research into the acoustics of concert halls, with contributions of Beranek, Barron and other experts, have yielded the values of acoustic parameters that are best suited for listening to classical music. Most of them come from large theatres and concert halls around the world under the guise of acoustic comfort (Beranek, 2004, p. 491; Barron, 1988). They are listed in Table 6.

Table 6

Recommended objective acoustical parameters

ACOUSTICAL PARAMETER	RECOMMENDED VALUE
RTmid	1.8 <RTmid <2s
EDTmid	EDTmid ≈ RTmid
BR	1.10≤BR≤1,25 (If RTmid=2,2s) 1,10≤BR≤1,45 (If Tmid=1,8s)
Br	Br≥0,87
C_{80}	-4<C80<0dB
D	D>50%
Gmid	4<Gmid<5,5dB
Ts	60; 260ms
LF_{E4}	LFC_{E4}≥0,19
$IACC_{E3}$	(1-$IACC_{E3}$)≈0,70
ST(sup.)	-14≤ ST(sup.)mid ≤-12,5dB

Recommended objective acoustical parameters have some recommended values (Arias, 2013).

Subjective evaluation and objective acoustic parameters are used for the complete estimation of concert hall. Their correlations have been established after many years of research into room acoustics. Table 7 shows some correlations between them. ITDG (Initial Time Dilley Gap) is determined from the impulse response (bursting balloon) and represents a valid value in the range of 20–40 ms.

Table 7

Correlations between subjective evaluation and objective acoustic parameters

№	Subjective criteria	Acoustic parameters	Comments
1	Spatial impression, spatial perspective (Liveness)	RTmid, EDTmid	confirmed
2	Width, binaural width	$IACC_{E3}$, LF_{E4}	partially confirmed
3	Timbre: bass level	BR	confirmed
4	Timbre: grace, brightness	Br	confirmed
5	Clarity, transparency, intelligibility	$C_{80,}$ Ts	partially confirmed
6	Loudness, dynamic range	G	partially confirmed
7	Intimacy, texture	ITDG	confirmed
8	Room Support (Musicians of orchestra)	ST(sup.)	partially confirmed
9	Freedom from noise and distortions		confirmed

Conclusions

Basically, the sound of orchestral music in the Concert Hall of the Lviv Opera and Ballet Theatre received a good evaluation, as demonstrated by the subjective assessment and objective acoustic parameters. This sound is achieved by architectural decor in the form of small ornaments and columns with statues, niches, irregular boxes. It also depends on the size, shape, and type of chairs, audience absorption and material of walls, ceiling and stage. Slight deterioration of subjective perception can occur in the cavities of the sub-balcony space located near the rear walls, as a result of the focusing of sound waves. Evaluation of the acoustic quality of the halls as good indicates a more selective assessment of the musicians and is partly confirmed by the objective acoustic parameters. The verbal questioning conducted among ordinary concert-goers shows a slight difference in estimation from “good” to “excellent”. Therefore, the evaluation of the composers, conductors, musicians, musical critics and regular concert-goers better reflects the actual acoustic conditions.

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ДОСЛІДЖЕННЯ ЗВУЧАННЯ ОРКЕСТРІВ У КОНЦЕРТНОМУ ЗАЛІ ЛЬВІВСЬКОГО НАЦІОНАЛЬНОГО АКАДЕМІЧНОГО ТЕАТРУ ОПЕРИ ТА БАЛЕТУ ІМЕНІ СОЛОМІЇ КРУШЕЛЬНИЦЬКОЇ

Войтович Олександр Орестович
Кандидат мистецтвознавства, старший викладач,
Львівська національна музична академія
імені М. В. Лисенка,
Львів, Україна

Мета дослідження полягає в тому, щоб запропонувати метод естетичної оцінки акустичних властивостей концертних залів, заснований на суб'єктивному сприйнятті звучання музичного матеріалу. Методологію дослідження складають методи: аналітичний – у вивченні наукової літератури; теоретичний – для визначення спеціальної термінології, опису явищ, що мають місце під час проведення досліджень, параметрів за якими здійснюється суб'єктивна оцінка; емпіричний – при прослуховуванні оркестрів у концертному залі з подальшою експертною оцінкою результатів; компаративний – у процесі порівняння результатів досліджень; методи аналізу і синтезу – для опрацювання результатів дослідження, а також метод інтерв'ювання – для отримання інформації від музикантів та активних слухачів. Наукова новизна дослідження полягає у спробі дати естетичну оцінку звучання оркестрів на живо у концертному залі Львівського національного академічного театру опери та балету імені Соломії Крушельницької шляхом дослідження явища суб'єктивного сприйняття музичного матеріалу. Висновки. З'ясовано, що суб'єктивна оцінка акустики концертних залів вимагає вибору критеріїв оцінки та встановлення їхнього зв'язку з об'єктивними акустичними параметрами. Суб'єктивна оцінка разом з об'єктивними параметрами корелюються між собою, – тому дають повну характеристику звучанню оркестру в концертному залі. Суб'єктивне оцінювання акустичної якості концертних залів повністю підтверджується об'єктивними акустичними параметрами. Застосування його можна вважати виправданим. Особливо точне підтвердження воно отримало серед музикантів фахівців. Усне опитування, проведене серед любителів-непрофесіоналів симфонічної музики, показало однобічність їх оцінок. Вони варіюються в межах «добре» і «відмінно», тому є менш точними.

Ключові слова: об'єктивні параметри; суб'єктивна оцінка; критерії оцінки; акустика концертного залу; кореляція; концертний зал; оркестр

ИССЛЕДОВАНИЕ ЗВУЧАНИЯ ОРКЕСТРОВ В КОНЦЕРТНОМ ЗАЛЕ ЛЬВОВСКОГО НАЦИОНАЛЬНОГО АКАДЕМИЧЕСКОГО ТЕАТРА ОПЕРЫ И БАЛЕТА ИМЕНИ СОЛОМИИ КРУШЕЛЬНИЦКОЙ

Войтович Александр Орестович
Кандидат искусствоведения, старший преподаватель,
Львовская национальная музыкальная академия
имени Н. В. Лысенко,
Львов, Украина

Цель исследования заключается в том, чтобы предложить метод эстетической оценки акустических свойств концертных залов, основанный на субъективном восприятии звучания музыкального материала. Методологию исследования составляют следующие методы: аналитический – в изучении научной литературы; теоретический – для определения специальной терминологии, описания явлений, имеющих место при проведении исследований, параметров по которым осуществляется субъективная оценка; эмпирический – при прослушивании оркестров в концертном зале с последующей экспертной оценкой результатов; компаративный – в процессе сравнения результатов исследований; методы анализа и синтеза – для обработки результатов исследования, а также метод

интервьюирования – для получения информации от музыкантов и активных слушателей. Научная новизна исследования заключается в попытке дать эстетическую оценку звучания оркестров вживую в концертном зале Львовского национального академического театра оперы и балета имени Соломии Крушельницкой путем исследования явления субъективного восприятия музыкального материала. Выводы. Выяснено, что субъективная оценка акустики концертных залов требует выбора критериев оценки и установления их связи с объективными акустическими параметрами. Субъективная оценка наряду с объективными параметрами коррелируются между собой, – поэтому дают полную характеристику звучанию оркестра в концертном зале. Субъективное оценивание акустического качества концертных залов подтверждается объективными акустическими параметрами. Применение его можно считать оправданным. Особенно точное подтверждение оно получило среди музыкантов специалистов. Устный опрос, проведенный среди любителей-непрофессионалов симфонической музыки, показал ограниченность их оценок. Они варьируются в пределах «хорошо» и «отлично», поэтому являются менее точными.

Ключевые слова: объективные параметры; субъективная оценка; критерии оценки; акустика концертного зала; корреляция; концертный зал; оркестр