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Optimization of the acoustic response both for orchestra and for a solo instrument, the exquisitely romantic piano of Chopin, in the case study "Chopin concert hall"

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ABSTRACT

The Chopin concert hall's shape takes account of classical forms: starting the design from a shoebox volume it tends to approach a vineyard, as a reinterpretation and synthesis of both ones.

The proposed method involves a predictive analysis. Acoustics performance evaluation have been carried out using the room acoustic modeling program, Catt Acoustic. This has been used with two source types with the same sound power: an omni-directional source and a source with realistically-directional characteristics based on measurements from a real grand piano instrument. Objective analyses have been carried out on three acoustic parameters: the Sound Pressure Level (SPL), the Reverberation Time (T_{30}) and the Clarity Index (C_{80}).

The proposed designed room shape, materials and the selected stratigraphy of the coatings are the ones for which the differences in SPL, T_{30} and C_{80} are negligible when comparing the two source types simulations, moreover the parameters values are optimized.

Keywords: Concert Hall, Room Acoustics, Source Directivity

1. INTRODUCTION

This case study was developed after the invitation by the architect Franco Tagliabue to participate to an architectural competition, in which particular attention to acoustic design was requested.

The purpose of the Architecture Competition was to find the best design for an International Music Centre, located in the vicinity of the Birthplace of Fryderyk Chopin and Park in Żelazowa Wola, Poland.

As the composer cannot be separated from the performers of his piece, also the concert hall was molded as a further instrument of support and participation in music listening.

The strong connotation of the geometry of the room was dictated by the need to capture the intimate, velvety, exquisitely romantic piano sound of Chopin, together with the best response for symphonic music.

For this reason, in the predictive analysis, two different types of sources were used: an omni-directional source and a source with realistically-directional characteristics based on measurements from the real instrument Gran Piano (1).

To find the optimized configuration and coating typologies many layouts were simulated.

The one in which the differences in SPL, T_{30} and C_{80} were negligible is then presented in this paper.

To find out this layout many analyses were carried out before, comparing differences in data output considering the just noticeable differences (JND).

1.1 The purpose of the Architecture Competition

The purpose of the Architecture Competition was to find a design for an International Music Centre and to select the best Investment located in the vicinity of the Birthplace of Fryderyk Chopin

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and Park in Żelazowa Wola.

The conceptual architectural design had to consider the spatial relationship with the Birthplace of Fryderyk Chopin, which is the focal point of the historic park surrounding it; in particular, the design had to harmonize the Music Centre with the commemorative function of the site. In fact, the Park-Memorial was created in the 20's and 30's of the 20th century primarily to commemorate the great artist. The building outline dimensions had to be organically harmonized with the landscape without dominating the surroundings.

1.2 The concert hall

The Birthplace of Fryderyk Chopin in Zelazowa Wola, a branch of the Fryderyk Chopin Museum, is visited each year by thousands of tourists and music lovers from around the world. Activities undertaken by the Fryderyk Chopin Institute have shown considerable and increasing potential for Zelazowa Wola, and consequently a growing demand for what it has to offer to both adults and children, from the local region, other parts of Poland and beyond, visiting the site individually, in families and also in organized groups.

The concert hall had to be used both for concerts with natural acoustic response and electroacoustic enhancement (pop music and jazz concerts), as well as conferences and film projections.

The investor didn't impose any particular shape to the hall, but anyhow they preferred a classical arrangement of auditorium and stage. The aim was to achieve the highest possible acoustic standards whilst making it possible to realize creative architectural ideas. There was no provision to design for the use of an organ, except a positive one. The stage, measuring up to approx. 200 m^2, had to be equipped with moveable steps or podia for the orchestra (up to 100 musicians). The width of the stage had to be approximately 19 m/20 m; the depth 10 m/12 m.

2. THE DESIGNED BUILDING

The designed building for the competition has a multi-functional character, and the infrastructure is devoted to artistic (concert), educational, workshop (including masterclasses), recording and conference activities. The realization of the complex investment is designed to make it possible to enhance the offer with an artistic program on the highest level of performance art, a program of musical artistic education addressed togifted pupils and students, a program of universal education for different groups (adults, families, children, pupils, students and teachers).

In particular a main concert hall, practice and rehearsal rooms, a control room, a Recording studio, educational rooms and a conference room are included in the designed building (figure 1).

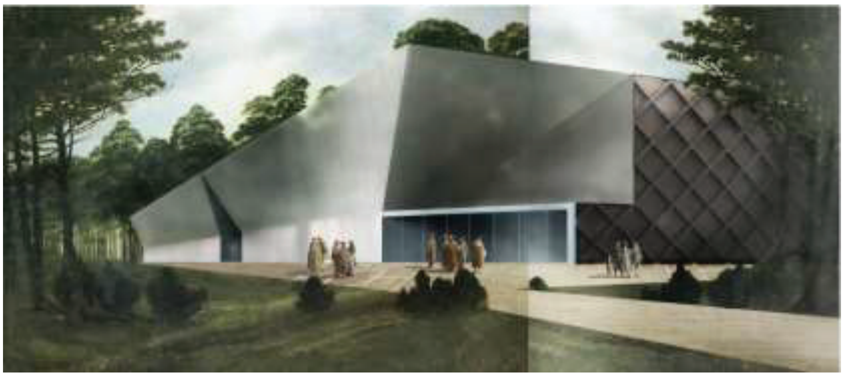


Figure 1 – the building form outside

2.1 The main Concert Hall

The hall's shape and the layout of boundary walls (ceilings, audience and stage walls) are of fundamental importance for the acoustic quality (2). The layout and the position of the walls are crucial with regard to proper sound reflections, as they ensure even distribution and diffusion of reflected sound and proper directional distribution of early sound reflections.

Side walls are non-parallel and their progressive widening toward the back of the hall is at least about 10 degrees. The ceiling over the stage, the stage side walls and the back wall provide the audibility of sound between musicians (3).

The audience area layout is designed such as to ensure sufficient proximity of the stage to the audience and create an impression of intimacy between the audience and musicians (4). The stage is perfectly visible from each piece in the audience area (figure 2).

The hall volume per seat is about 10 m^3, including the performers (650 listeners + 100 performers).

The hall's internal ceiling are made of massive material (> 150 kg/m^2) to provide early reflections across the entire frequency range. The sound reflecting surfaces are often irregular to scatter the reflected sound at high frequencies.

The walls include diffusing elements of about 5 cm in depth, to disperse the sound at higher frequencies to reduce the directivity effects of the piano source after the first reflection.

The Stage floor is deigned of massive material (concrete) with wooden finishing (parquet).

The stage floor is resonant, laid on wooden beams (50 mm thick wood).

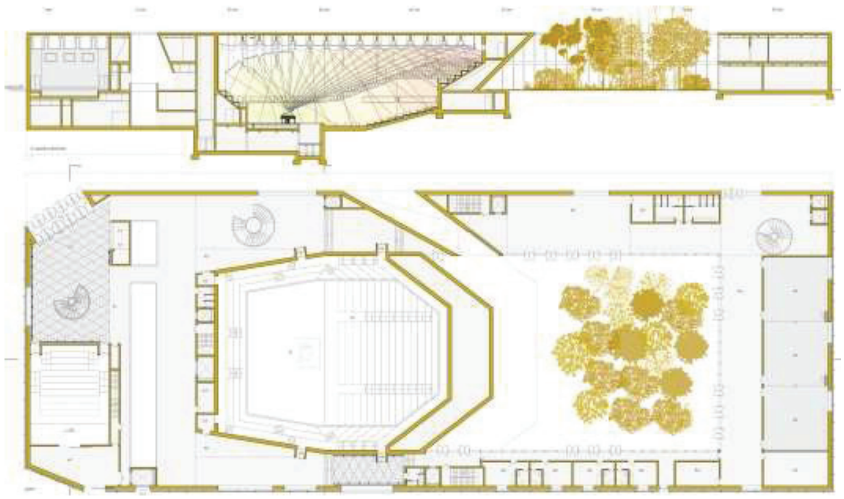


Figure 2 – building's section and plan including the main concert hall

3. ROOM ACOUSTIC MODELING

SketchUp 3D modelling software was used to create a virtual acoustic model of the Concert Hall, based on plans and sections which describe the geometry of its interior space.

The model was exported to CATT Acoustic (5) to carry out the acoustic assessment, a calculation engine known to be effective in the prediction of the acoustic parameters. The length of the room impulse response was set manually. It was not possible to use measured data to calibrate the model because the concert hall was just designed and not built (6).

A complete calculation of all the acoustic parameters was carried out to verify the acceptability of the obtained results. The absorption coefficients were known accurately.

The acoustic evaluation method and the predicted acoustic parameters are those presented in ISO 3382-1 (7). Based on this approach, most acoustic parameters were considered in 27 receivers positions (figure 3) and their average values calculated to describe the acoustic quality of the space (8).

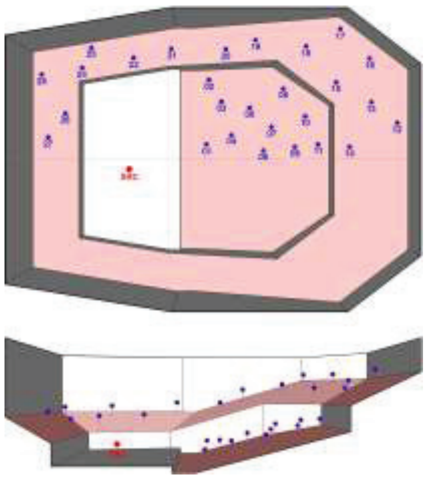


Figure 3 –main concert hall SketchUp model. Source (SRC) and receivers positons indicated

The parameters considered in the objective analysis are as follows:

• The analysis focuses primarily on the musical quality. The study is based on the values provided by parameters such as Sound Pressure Level (SPL), Clarity (C_{80}), the Sound Strength (G), Lateral Fraction Coefficient (JLF) and the Centre Time (Ts), associated with the balance between early and late energy reaching the receiver.

• The quantification of the reverberation is presented through the analysis of the time parameters, i.e. the reverberation time (T_{30}) and Early Decay Time (EDT).

The source position was on the stage.

The receiver locations were distributed throughout the audience seating area, and are shown as solid dots in the figure above.

As mentioned already, two different types of sources were used in the study: an omni-directional source and a source with realistically-directional characteristics based on measurements from the real instrument Gran Piano.

For the omni-directional source, which radiates sound equally in all directions, the same spherical directivity pattern was used in all octave bands. Catt Acoustics is also able to create realistically-directional sources based on measurements, thus directivity data for the piano measured by Meyer (9) have been used.

To find the optimized configuration and coating typologies many layout were simulated.

The one in which the differences in SPL, T_{30} and C_{80} are negligible, is reported in this paper.

To find out this layout many analyses were carried out before, comparing differences in data output considering the just noticeable difference (JND) (10).

For this study the subjective limen used for SPL was 3 dB, differences below 1 dB for Clarity and approximately below 5% for T_{30}.

3.1 The calculated results

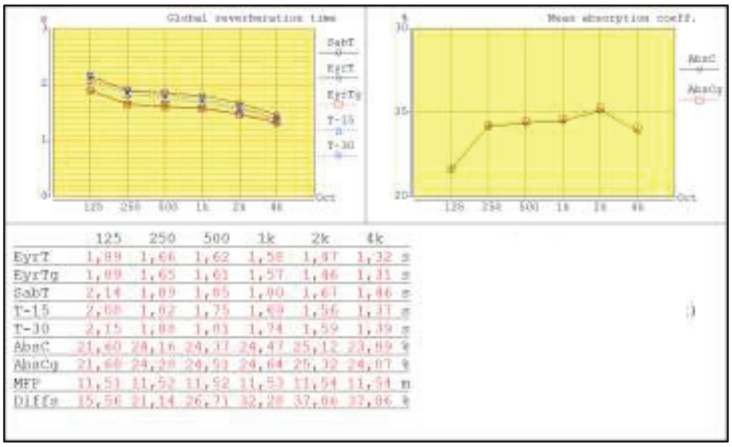
In a symphonic concert hall, the T_{30} should range between 1.7-2.0 s (500-1000 Hz) in a fully occupied hall. The range is confirmed by the simulations for this case study where the T_{30} range is between 1.7-1.8 s (500-1000 Hz). The reverberation time behavior trough the frequencies is flat, with a small boost at low frequencies and the ratio of average in 125-Hz and 250-Hz octave bands to the average of T in the 500-Hz and 1000-Hz octave bands (bass ratio) is between 1.1 and 1.3, to impart warmth to the music (figure 4).

The Sound Clarity Index C_{80} in concerts halls should fall into a range from -2 to +3 dB across the audience. In this case study it falls into the same range (figure 5 and 6).

Also, other acoustic parameters were verified: the Sound strength G and the Lateral Fraction Coefficient JLF.

The Sound Strength, G, expressed in dB, that measures the energy gain in diffused field, relative to the sound energy produced by a source at a distance of 10 m in free field, is a recommended acoustic parameter for assessing concert halls performance: about 3 dB at medium frequencies, in 500-1000 Hz range is a recommended value. This recommended value is confirmed in the simulations and irregularities of the sound strength index don't exceed 3 dB across the audience.

The Lateral energy coefficient, that measures the impression of spaciousness related with the apparent width of the sound source, provide good impression of spaciousness because it falls into a 0.2-0.35 range, as requested by the literature.



	125	250	500	1k	2k	4k	
EyrT	1,89	1,66	1,62	1,58	1,47	1,32	s
EyrTg	1,89	1,65	1,61	1,57	1,46	1,31	s
SabT	2,14	1,89	1,85	1,80	1,67	1,46	s
T-15	2,08	1,82	1,75	1,69	1,56	1,31	s
T-30	2,15	1,88	1,83	1,74	1,59	1,39	s
AbsC	21,60	24,16	24,37	24,47	25,12	23,89	%
AbsCg	21,60	24,28	24,51	24,64	25,32	24,07	%
MFP	11,51	11,52	11,52	11,53	11,54	11,54	m
Diffs	15,56	21,14	26,71	32,28	37,86	37,86	%

Figure 4 – Reverberation Time distribution

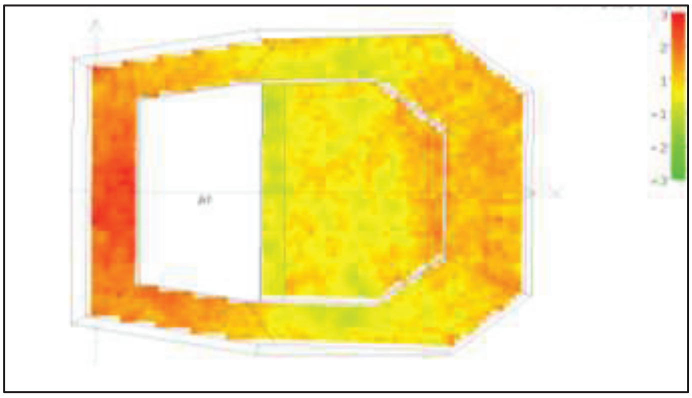


Figure 5 – Clarity C_{80} distribution 500 Hz, omnidirectional source

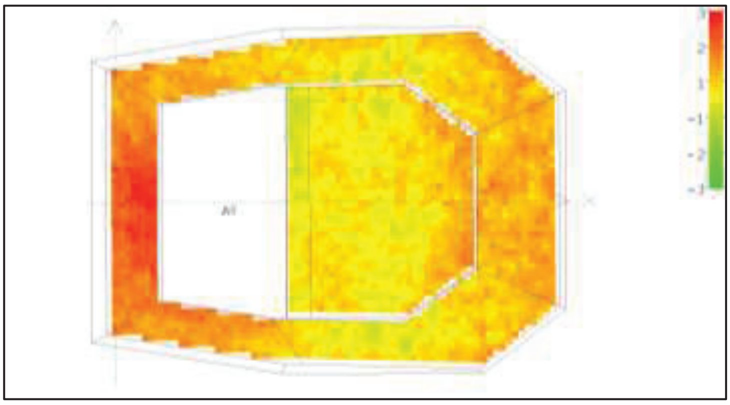


Figure 6 – Clarity C_{80} distribution 500 kHz, piano source

4. THE COATING

In the Concert Hall early reflections contribute to the sense of clarity, intimacy, loudness and to the sense of source broadening arriving from the side. All these characteristics are required for the best acoustics.

Defined size, volume and form of the Hall, four typologies of reflectors are designed to influence different ranges of frequencies responses and to control both the early reflections and the later reflections.

These coatings spread and reduce the sound directivity of the piano source especially at higher frequencies (2- 4 kHz) to get negligible JND differences between outputs from omnidirectional and piano sources.

Starting from a unique system, made of regular texture (typology 1), rectangular wood elements of ca. 7 x 7 cm change their depth, in relation to their position to produce different acoustic behavior (typology 2); to control the lower frequency range also an absorbing material is introduced behind (typologies 3). As the concert hall can also be a conference center, a variable acoustic response coating typology is designed (typologies 4), (figure 7).

Strong reflections are required for the ceiling to direct reflections down onto the audience; big smooth panels achieve a sense of source broadening.

Reflecting surfaces near to listeners in the stall are introduced (typologies 1 and 2). There are two advantages of surfaces near the listeners: there is much greater control of reflection conditions throughout the audience seating areas and the side reflections arrive more laterally, creating greater source broadening (coloration effects are avoided). The typologies 3 and 4 are especially used much far away from the stage, on the lateral wall around the gallery. Typology 4 is used opposite to the stage.

To increase the spread of the reflection at the expense of reflection level on the original path, scattering treatment are added from typology 1 to typology 2.

Scattering panels contribute making a sound field more diffuse. Generous coating surfaces above all sections of audience are placed to promote diffusion and to have sound reflections arriving at listeners from different directions.

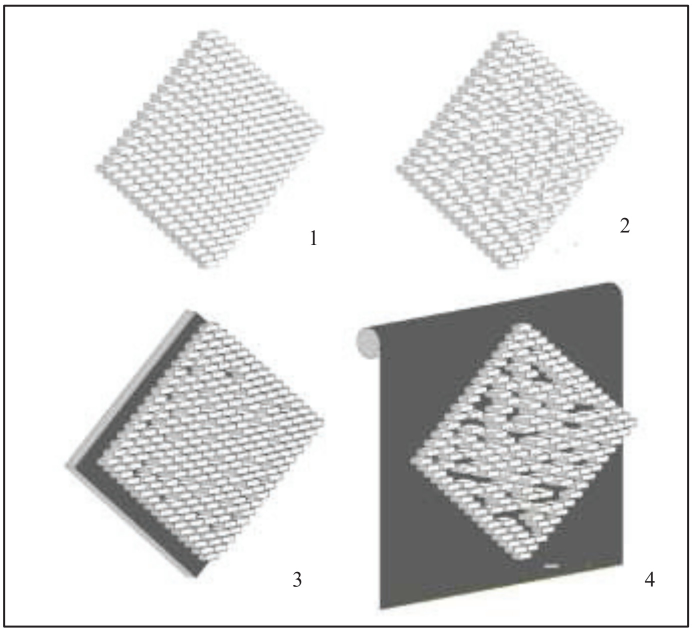


Figure 7 – the four different coating panel typologies

5. CONCLUSIONS

The concert hall has an original architectural and acoustic shape, in which the audience, that surrounds the stage, is never too far from it. The shape of the hall takes account of classical form: starting from shoebox-like shape it tends to approach a vineyard-like shape, as a reinterpretation and synthesis of both ones.

To provide sufficient early reflections for all seat locations, the design of the seating layout and reflecting surfaces around seating areas has been optimized.

The hall shape and the layout of boundary walls (ceilings, audience and stage walls) are of fundamental importance for the acoustic quality. Thus, the layout and the coating typologies of the walls have been designed to ensure even distribution and diffusion of reflected sound and proper directional distribution of early sound reflections both for symphonic music and a solo piano concert to capture the intimate, velvety, exquisitely romantic piano sound of Chopin. The ceiling over the stage, the stage side walls and the back wall result by simulation to provide very good audibility of sound between musicians positions.

The acoustic purposes of the Architecture Competition were totally satisfied in this case study, unfortunately there was no the chance to realize the project.

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