



## Technical note

# The architectural acoustic design for a multipurpose auditorium: Le Serre hall in the Villa Erba Convention Center

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## ABSTRACT

Large spaces, circular in plan, can be preferred by architects to design large auditoria, even though they can cause acoustical singularities such as focusing and whispering gallery. In large auditoria for multipurpose functions are becoming a common request to use the space for different activities such as conferences, concerts of classical and amplified music, shows, etc. and the necessity to find architectural solutions in order to consider the variable acoustic demands according to different possible layouts, are growing. In this paper, as a case study, architectural acoustic design approaches and solutions for a circular auditorium are presented. The case study was made in “Le Serre” hall for 1000 people, in the Villa Erba Convention Center, located in Cernobbio (Italy), in which different combinations of movable architectural elements are developed to create a multipurpose space. A geometrical acoustic analyses are included, followed by the description of different methods to avoid focusing and whispering. Room acoustics procedures and implementations of computer simulation techniques are developed.

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## 1. Introduction

In this paper, the architectural acoustic design to turn the entrance hall “Le Serre” into a multipurpose auditorium is presented. The hall is a big circular space that connects together different pavilions of the Villa Erba Convention Center at lake Como (Italy).

The Center was designed by architect Mario Bellini in 1987 to host exhibitions of various kinds, especially those related to silk industry, a very important activity in Como at that time.

Le Serre hall had the function of an atrium, an entrance space that allowed access to all the exhibition areas. The circular structure, with glass and steel architecture, has approximately a diameter of 22 m and an height of 6.20 m

With the passing of time, the activities, that gave rise to the center, have diminished, and new needs have arisen for the use of the Villa Erba. In particular, the need to use the large entrance hall as a hall for conferences, banquets and concerts began to grow.

These needs hardly suited the acoustics of the room, which was very reverberating, with echoes and focuses due to its circular shape in plan.

Initially, the problem was solved through temporary installations, heavy curtains and furnishings that helped to reduce the reverberation time. The decision to convert the hall into a multipurpose auditorium with variable acoustics arose when, alongside the

various uses, the request to host a large classical music festival was accepted.

The places dedicated to the listening of music are usually prestigious places, whose acoustic response responds to certain peculiar characteristics.

The necessity to achieve an acoustic response in the room to host such events and to find an adequate sound quality for the conference activities, also optimizing the use of electro-acoustic equipment, led to the development of the project shown in the paper. Architectural acoustic design approaches and solutions are explained, and different combinations of movable architectural acoustic elements are applied to a case study for ca. 1000 people. Nowadays movable architectural acoustic elements represent, in fact, a big opportunity to control the variable acoustics in multipurpose auditoria [1].

The request proved to be anything but trivial, since it is a space whose shape does not contribute to creating a uniform distribution of the sound field, generating critical acoustic phenomena for listening to both speech and music.

Numerous configurations, with different combinations of the movable architectural element positions have been studied, depending on the number of seats in the room and activities to be undertaken. The Congress Center and a Concert Hall layout have been defined as the main configurations, characterized by the lowest and the highest Reverberation Time respectively, and they are

explained in detail in the paper. The process methodology is included.

First measurements in the empty hall have been performed to calibrate the virtual model used in the simulations with CATT Acoustic software: the initial input values of the diffuse field sound absorption coefficients and sound scattering were selected from literature data and the measured averaged values were compared with the corresponding values calculated with the software. An iterative procedure has been used to reduce the difference between the calculated and measured values. Next, the new architectural acoustic design has been introduced in the virtual model obtained by the calibration process, to confirm the targeted results.

## 2. Acoustic survey

Acoustic measurements were carried out in the Convention Center before developing the design to transform the space into a multipurpose auditorium.

The sound source used was a dodecahedron loudspeaker. Swept sine signals were generated. The sound pressure was recorded with a microphone connected with a preamplifier. The floor plan in Figs. 1–3 shows the three sound sources' and the nine receivers' position. The sound source was placed at the height of 1.5 m over the floor at three different points.

Microphones were placed at the height of 1.5 m over the floor too. Measurements were executed in empty conditions. The recorded impulse responses were elaborated and several acoustic parameters were defined following the ISO 3382-1 [2], such as the Early Decay Time (EDT), the Reverberation Time ( $T_{30}$ ), the Clarity ( $C_{80}$ ), and the Definition ( $D_{50}$ ). Table 1 reports the measured averaged values for the Reverberation Time ( $T_{30}$ ). They suggest the empty Hall is characterized by a very high Reverberation Time and the acoustic quality has to be improved.

## 3. Acoustic simulation: Calibration of the model

A virtual model was built (Figs. 4 and 5), and computer simulations were carried out using the software CATT Acoustic.

CATT Acoustic adopts the principles of the geometrical acoustics and uses a hybrid calculation combining the image source



Fig. 2. Villa Erba Convention Center: Le Serre interior space.

method with the ray-tracing method: the image source method is used for the early-scattered rays of the first reflections, while a ray-tracing technique, that considers the surface scattering according to a Lambert's cosine law, is used for the more statistically computed late part of the impulse response [3–5]. The software is used to evaluate the architectural acoustic design development. At first a comparison between measured and simulated parameters was executed to achieve a calibration of the acoustic model, in which the difference between measured and simulated acoustical parameters was minimized, at least to a value below the just noticeable difference (JND) for the Reverberation Time  $T_{30}$ . Next, the new architectural acoustic design was introduced in the virtual model [6,7].

The initial values of the diffuse field sound absorption coefficients ( $\alpha$ ) and sound scattering were selected from literature data [7–12] and the measured averaged values were compared with the corresponding values calculated with the software. An iterative procedure was used to reduce the difference between the calculated and measured values. This implied little adjustments to the sound absorption and scattering coefficients [8]. Table 2 shows the results of the calibration of the virtual model. Table 3 displays the absorption coefficients used in the final simulation.



Fig. 1. Villa Erba Convention Center: aerial view.



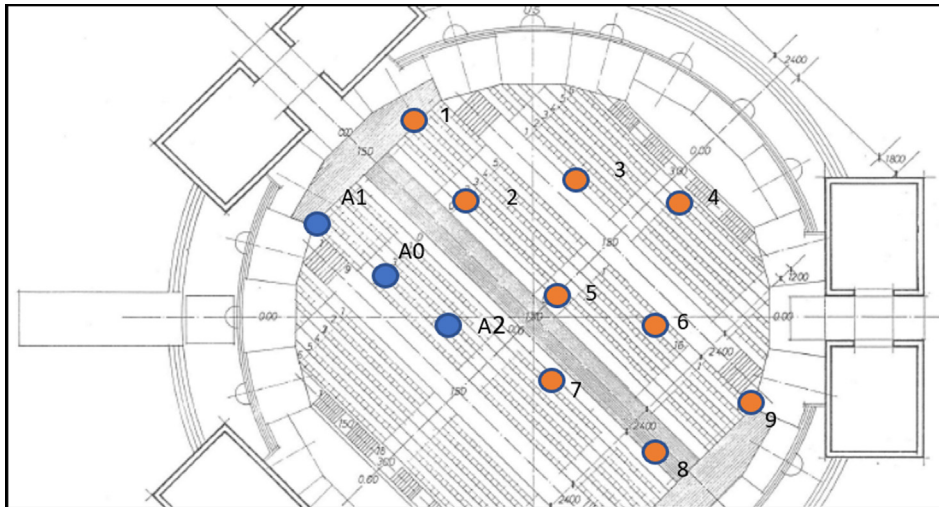


Fig. 3. The position of sources and receivers.

**Table 1**  
measured averaged values.

Convention Center – Empty hall	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Reverberation Time $T_{30}$	2,78	2,77	3,10	3,41	3,31	2,46
Early Decay Time	2,12	1,97	2,32	2,62	2,51	1,89
Definition $D_{50}$	<39%	<39%	<33%	<32%	<32%	<42%
Clarity $C_{80}$	<-2	<-2	<-2	<-2,5	<-2,5	<-1,8

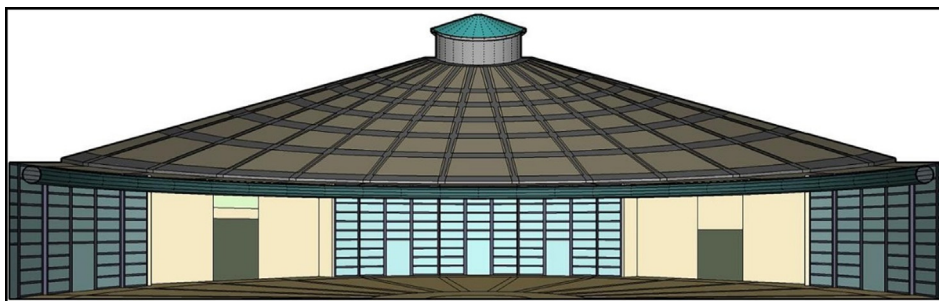


Fig. 4. Virtual model section.

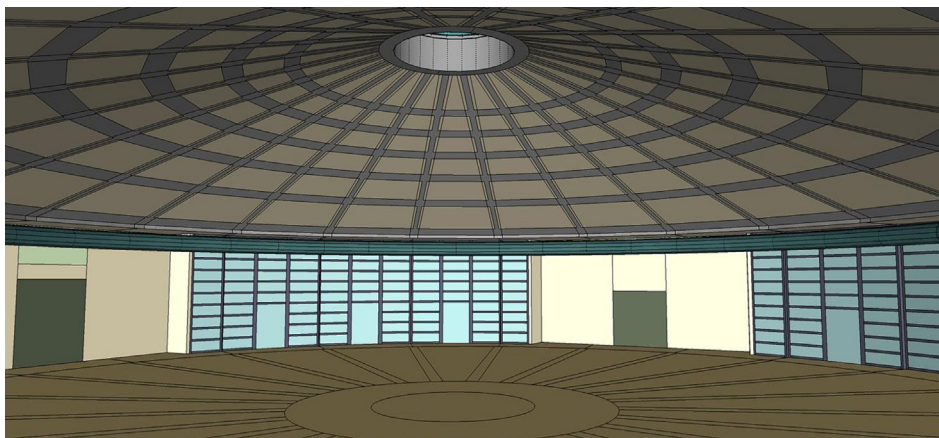


Fig. 5. Virtual model interior.

**Table 2**

Reverberation Time: calibration values.

Convention center	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Empty hall: calibration values	2,91	2.89	3.23	3.5	3.46	2.57

**Table 3**

absorption coefficients.

Material	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Aluminum sheet roof	0,15	0,12	0,09	0,07	0,07	0,05
Metal structure profiles	0,02	0,03	0,03	0,04	0,04	0,04
Marble floor and walls	0,02	0,03	0,04	0,04	0,04	0,05
Windows	0,12	0,1	0,08	0,06	0,05	0,05

#### 4. The architectural acoustic design process

The architectural acoustic design for Le Serre hall aims at first to obtain an equal sound energy distribution in the room even though most of the room boundary surfaces are concave, and then to achieve the suitable sound quality according to the hall's different uses and configurations. To control the acoustic phenomena depending on the concave surfaces, mainly focusing and whispering, some architectural acoustic design approaches and solutions are investigated.

A first approach [13] suggests covering the concave curved wall or ceiling with sound absorption material. The absorption is effective at high frequencies, while at lower frequencies requires treatment that involve multiple absorbing layers of great thickness that eliminate many reflections from the walls and ceiling.

A second approach is to break up a concave surface into smaller scattering surfaces and thus to change the geometrically focused reflection into a diffuse reflection [14]. The dimensions of these scattering elements must be comparable with the wavelengths of the sound field.

Considering both these approaches, different solutions are discovered for the Convention Center "Le Serre", characterizing every configuration by a specific layout, indicating the distribution of the variable acoustic elements, the seat capacity, and the source position.

As the biggest absorbing surface in large auditoria is usually the seating area, in the following simulations in this study, it was

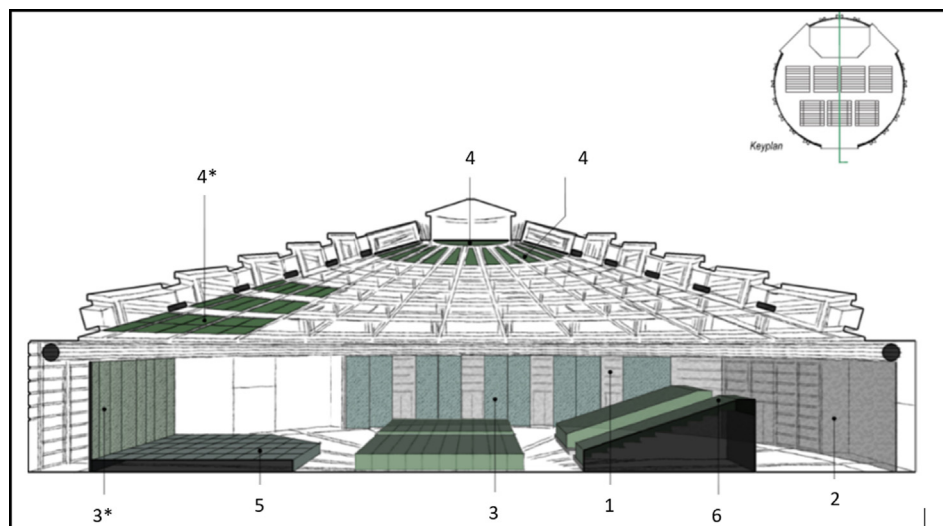
assumed the chairs with thick padding had an absorption characteristics closely resembling that of a seated occupant, to not introduce another process variable (as suggested by Beranek [15]).

Approximately the 50% of the seats are placed on movable telescopic tribunles, the other 50% are single movable chairs, that can be fixed each other when placed, according to the standard for the safety conditions.

Variable acoustic elements are placed mainly around the vertical walls to avoid focusing, whispering as well as to control the reverberation time and the other significant acoustic parameters, while fixed plates are hung from the ceiling to create a new shape of the active reflecting ceiling, removing the possible focusing effects.

Two different curtain typologies, made of heavy absorbing materials and light absorbing materials ( $\alpha_w = 0.75$  and  $\alpha_w = 0.20$  according to UNI EN ISO 11654 [18]), are located in front of the glazed vertical walls with the possibility to draw them around the entire perimeter (elements n°1 and n°2 in Fig. 6).

Rotating wood panels, motorized vertical pivoting elements, are hung from the ceiling structure and can be moved around the hall perimeter, overlapping the curtains, if necessary (elements n°3 in Fig. 6). They can pivot and stop at any position to provide different lateral reflections for intensity and direction. Some of them are used to create the back wall of the acoustic chamber in the Concert Hall configuration (elements n°3\* Fig. 6). The panels are made of curved wood, 5.8 m high and 1 m wide, being 40 in total.



**Fig. 6.** The designed architectural acoustic elements in Concert Hall configuration: light curtains (1) heavy curtains (2), pivoting panels (3), wood plates (4), stage (5), telescopic seats (6), acoustic chamber elements (\*).

**Table 4**Reverberation Time  $T_{30}$ : optimal range.

Configuration	500 Hz–1 kHz
Congress center	$0.9 < T_{30} < 1.2$
Concert hall	$1.5 < T_{30} < 2.1$

**Table 5**

Main acoustic parameters: optimal range.

Congress Center Configuration	500 Hz	1 kHz	2 kHz
Clarity $C_{80}$ [dB]	$-3 < C_{80} < 3$		
Strength G	$> -5$		
Lateral Fraction LF [%]	$> 20$		
Concert Hall Configuration	500 Hz	1 kHz	2 kHz
Definition $D_{50}$ [%]	$40 < D_{50} < 95$		
Speech Transmission Index STI [%]	$> 50$		

The fixed wood plates, hung from the ceiling, are in the middle of the hall (elements n°4 in Fig. 6) and over a perimetral area to create the acoustic roof for the acoustic chamber (elements n°4\* in Fig. 6). They occupy approximately the 27% of the ceiling surface and they create a new shape of this active reflecting surface. The central plate hides the metal structure. It is a circular element with double curvature that increases the reflections from the ceiling in all directions, helping to achieve a uniform sound pressure distribution over the audience, independently from the specific layout.

In the Concert Hall configuration, to reach the warmth of its sound, necessary to musicians, a wood platform for the stage is also implemented (elements n°5 in Fig. 6). Its wood floor provides both beneficial support as a sounding board in the low registers, as well as low frequency absorption for airborne sound. The flooring is sufficiently light that it responds to vibrations generated by the cellos and double basses, providing tactile feedback to the musicians, but not so light that it absorbs significant energy [15].

The pivoting panels are stored in the Congress Hall configuration and the heavy curtains are put behind the stage and behind the seats, light curtains cover the perimetral windows.

The optimal Reverberation Time range [16,17] at the middle frequencies to achieve in the two main configurations is displayed in the following table (Table 4):

To ensure an adequate acoustic quality, other acoustic parameters are evaluated according to the uses of the hall [15]. First, a uniform distribution of the Sound Pressure Level SPL is checked.

In the Concert Hall configuration, the Clarity Index  $C_{80}$ , the Strength G and the Lateral Fraction LF are considered, while in the Congress Center configuration the Sound Transmission Index STI is checked. The values to achieve are shown in the Table 5.

## 5. Simulation results and discussion

SketchUp 3D modeling software is used to create a virtual acoustic model for the multipurpose Center “Le Serre”. Two different configurations are presented in the paper: the Concert Hall (Fig. 7) and the Congress Center (Fig. 8). They represent the configuration with the highest and lowest Reverberation Time, considering 1000 seats respectively Table 6.

Many other configurations are possible as results of different combinations among the variable architectural acoustic elements such as when reducing the pivoting panels the drama theatre configuration or chamber concerts configurations are realized.

The SketchUp 3D modeling is exported to CATT Acoustic to carry out the acoustic assessment.

To study the acoustic answer for the different configurations, source and receivers maintain the position of the acoustic survey.

Curved surfaces discretization for the pivoting panels and their scattering coefficient are evaluated according to Vorlaender [10], i.e. relevant scattering appears for frequencies referred to a wave-

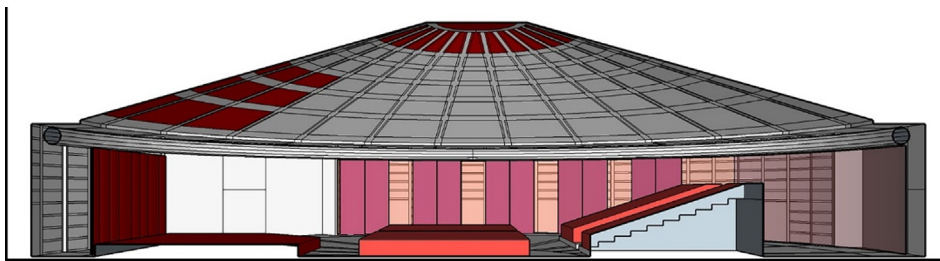


Fig. 7. SketchUp 3D model: “concert Hall” configuration.

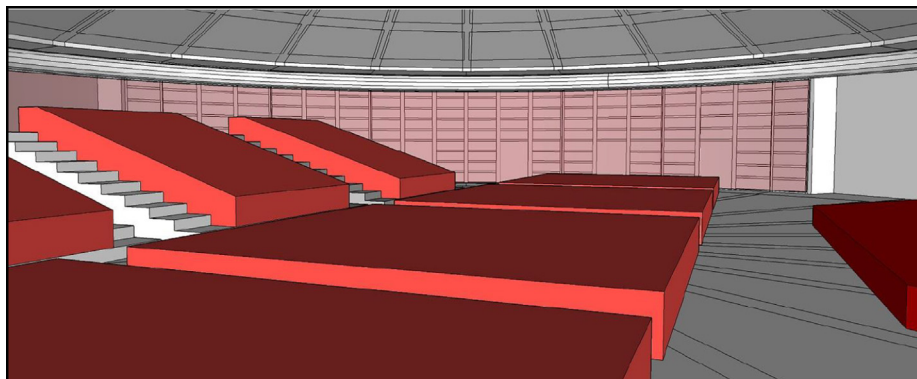


Fig. 8. SketchUp 3D model: “Congress Center” configuration.



**Table 6**  
Absorption coefficients.

Absorption coefficients	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Pivoting panels	0.15	0.12	0.10	0.08	0.06	0.06
Wood plates	0.16	0.13	0.11	0.09	0.07	0.06
Audience	0.51	0.64	0.75	0.8	0.82	0.83
Light curtains	0.18	0.23	0.35	0.45	0.5	0.5
Heavy curtains	0.21	0.28	0.42	0.65	0.84	0.85
Stage	0.15	0.12	0.10	0.08	0.06	0.06

length that is around twice the discretization segment length (corrugation profile).

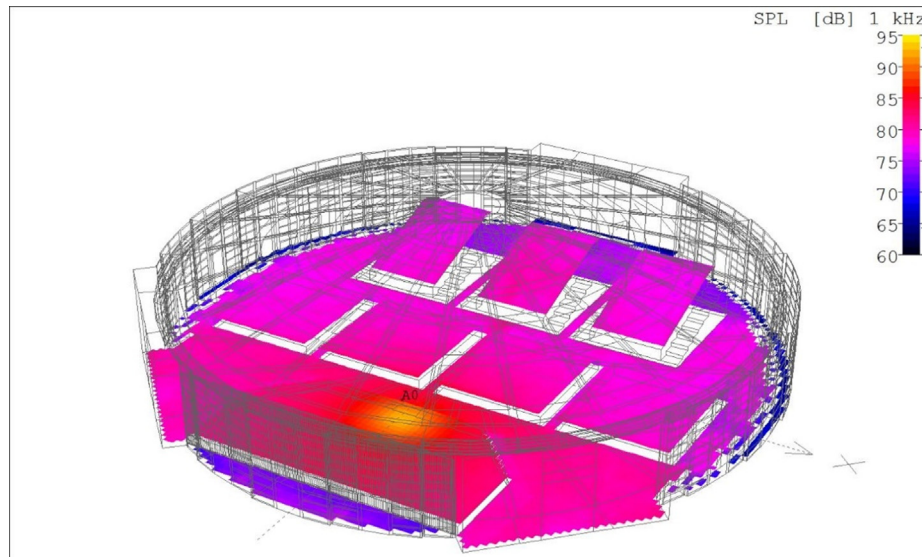
The sound absorption values ( $\alpha$ ) are selected from literature.

Next to the Reverberation Time, other room acoustic parameters are investigated, some of them are displayed (Figs. 9–12). The average simulated values for the main acoustic parameters are summarized in Tables 7 and 8.

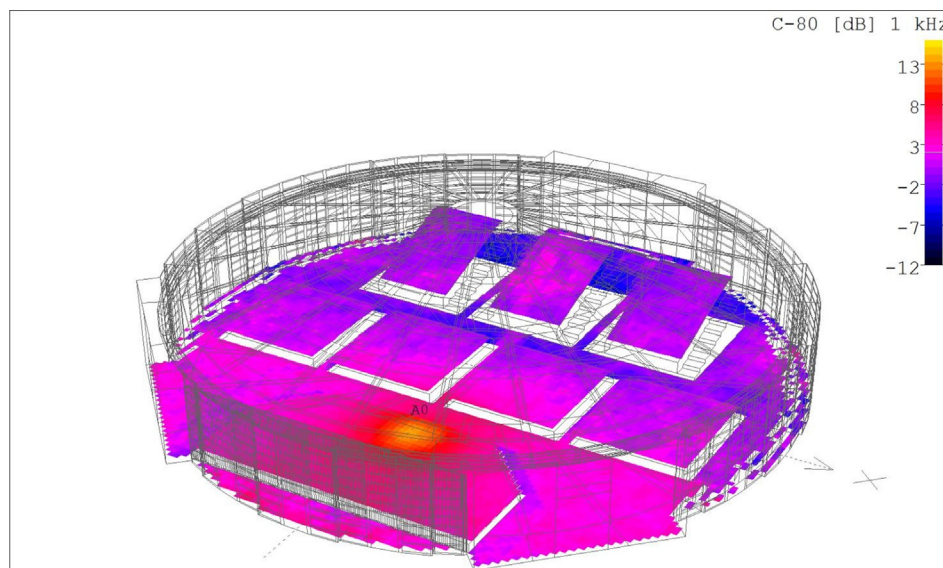
The simulation results achieve the optimal acoustic range for the wished acoustic quality.

The fixed plates hung from the ceiling are useful to reinforce the early reflections, useful in the configurations for both speech and music.

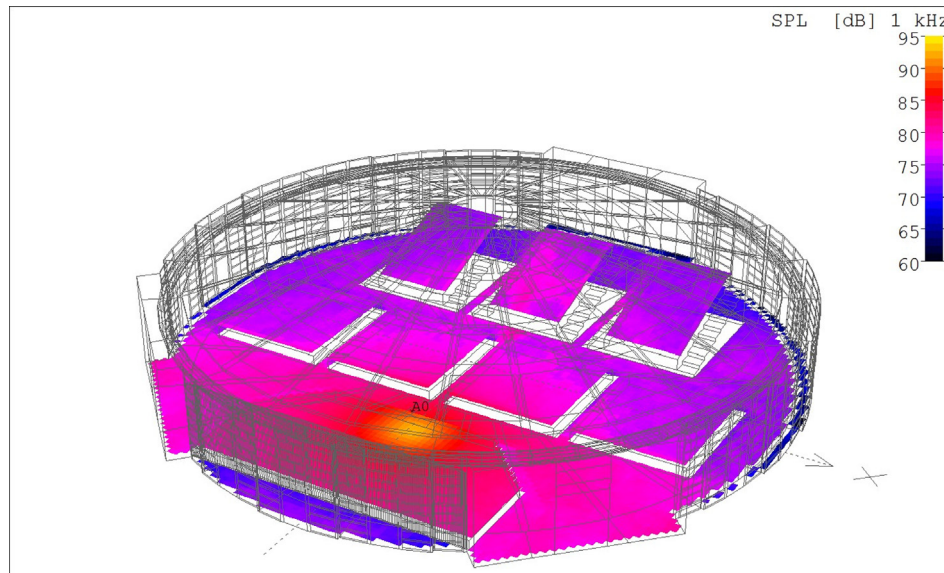
The absorbing curtains avoid the focusing and whispering effects, the pivoting panels influence the late reverberations, controlling the later energy fraction.



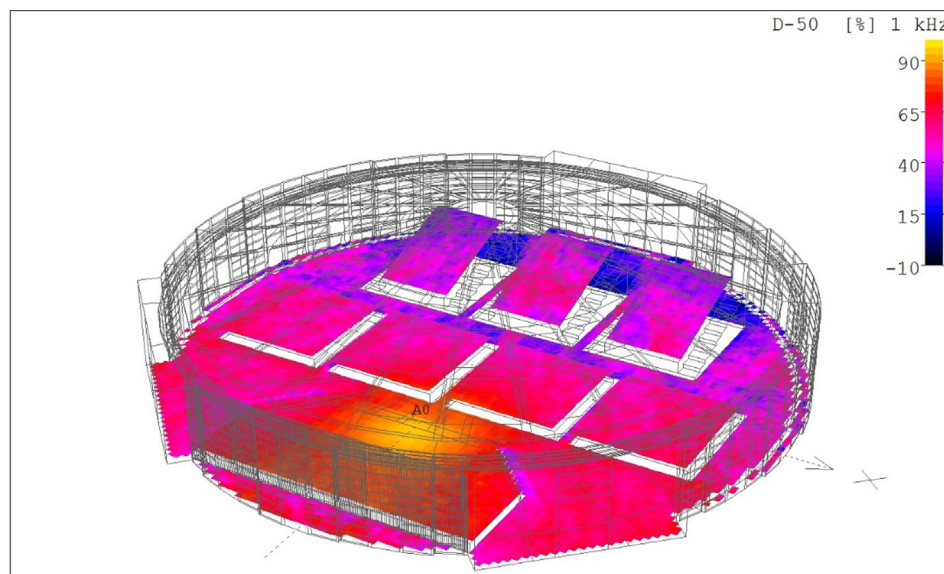
**Fig. 9.** Sound pressure level (SPL), 1 kHz – Concert Hall configuration.



**Fig. 10.** Clarity (C-80), 1 kHz – Concert Hall configuration.



**Fig. 11.** Sound pressure level (SPL), 1 kHz – Congress Center.



**Fig. 12.** Definition (D-50), 1 kHz – Congress Center.

**Table 7**  
average Simulated Reverberation Time  $T_{30}$ .

	Simulated reverberation time $T_{30}$					
	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Concert hall	2,13	1,99	1,72	1,59	1,48	1,25
Congress center	1,49	1,33	1,21	1,12	1,05	0,99

**Table 8**  
average acoustic parameters values.

Concert hall configuration	500 Hz–2 kHz
Clarity $C_{80}$ [dB]	$0 < C_{80} < 3$
Strength G	$> 0$
Lateral fraction LF [%]	$> 23$
Congress Center configuration	500 Hz–2 kHz
Definition $D_{50}$ [%]	$D_{50} > 50$
Speech transmission index STI [%]	$> 55$

In the Concert Hall configuration, the average Reverberation Time is near the lower limit of the suggested optimal range. This is considered the best result possible to achieve due to the boundary conditions. To further increase the acoustic quality in this configuration, it could be necessary to increase the volume, lowering the floor level in contrast with the committee's request to preserve the original space. A bigger volume would be also useful to decrease the Clarity Index and the Strength making the hall even "warmer".

## 6. Conclusions

The large space of Le Serre, the entrance hall of Villa Erba Convention Center, circular in plan, can become a big auditorium with multipurpose functions, thanks to the development of a specific architectural acoustic design.

Acoustical singularities such as concentrations of sound and “sliding” of sound along the walls, focusing and whispering, are avoided using absorbing materials on the walls and diffuser elements on the ceiling. These solutions also guarantee a uniform sound pressure level distribution.

Variable acoustic elements such as pivoting wood panels are introduced, and two different main configurations are identified, a Congress Center and a Concert Hall, together with other possible layouts.

The room acoustics procedures and implementations of computer simulations confirm the targeted results.

In the Congress Center configuration, the STI exceeds the 50%, the Reverberation Time  $T_{30}$  respects the range,  $0.9 < T_{30} < 1.2$ , as it happens for the Concert Hall configuration  $1.5 < T_{30} < 1.9$ . for this layout a bigger volume would be useful to decrease the Clarity Index and the Strength making the hall even “warmer”, but the simulation results confirm the sound field is adequate to achieve the wished acoustic quality according to that use of the space.

A bigger volume would be also useful to decrease the Clarity Index and the Strength making the hall even “warmer” in this specific case.

These conclusions and results are obtained by simulation by CATT software with calibrated model. Because of the coronavirus pandemic the realization process was interrupted.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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