Acoustic Design Review for the Historical Aula Magna at the University of Parma. Measurement and Simulation Tools to Predict the Amount of Absorption to be in Place

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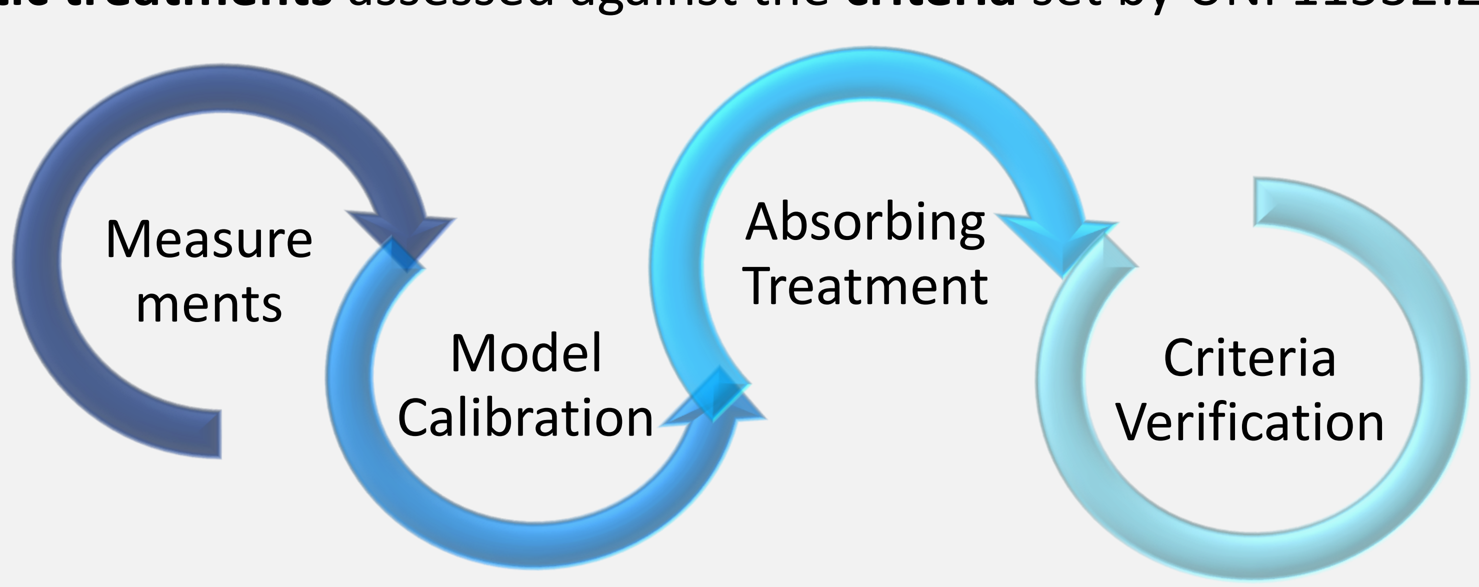
ABSTRACT

The Aula Magna at the University of Parma is part of a 16th-century palace located in the core of the city. The Aula Magna hosts periodically **celebrations**. The geometrical composition of the room, provided with a wagon vault, and the high level of reflections due to the hard finish materials lead to a poor quality of speech intelligibility. This paper deals with an acoustic design review of the current furniture inside the auditorium with the purpose of adjusting the acoustic parameters to be suitable for **ceremonies** and **conferences**. Acoustic measurements have been undertaken in accordance with the standard requirements outlined by ISO 3382-1 by picturing the existing conditions of the hall. A **digital model** has been realized to carrying out numerical simulations regarding the application of the acoustic treatments, assessed with a high level of accuracy. The quantity and quality of the proposed absorbing panels improve **the listening conditions** to a degree of comfort assessed against the criteria set by UNI 11532-2:2020

INTRODUCTION

The acoustic design project of rooms adapted to host meetings and conference events involves **historical buildings**. The acoustic corrections to be applied to cultural heritage constructions are sometimes **challenging** due to the constraints of the room geometry and finish materials. This paper suggests some mitigation measures applied to the Aula Magna at the University of Parma, by completing the following tips:

1. **Measurements** of the impulse responses (IRs).
2. Acoustic **simulations** carried out with Ramsete 3.02 to have control over the adaptation design process
3. Calibrated vs Simulated Results of the **3D model**
4. **Acoustic treatments** assessed against the **criteria** set by UNI 11532:2004



AULA MAGNA AT UNIVERSITY OF PARMA – BACKGROUND

HISTORY

The order of **Jesuits** arrived in Parma in 1539 and was established in the St Rocco's church. Three residential properties have been assigned to the Jesuits, who collaborated with the University of Parma by **teaching** specific subjects. The Jesuits collected donations from the kindness of the aristocrats, to include the **patrimony** consisting of a historical palace. The Jesuits got an own space for teaching but unfortunately, they have been ejected from Parma in 1768 and for this reason the palace fell into the property of the University of Parma.

Nowadays, the palace hosts offices, lecture rooms of the Department of Law and the Aula Magna, used primarily for degree celebrations, as shown in Figure 1.

Figure 1.
Aula Magna at the University of Parma during a degree celebration.

GEOMETRY

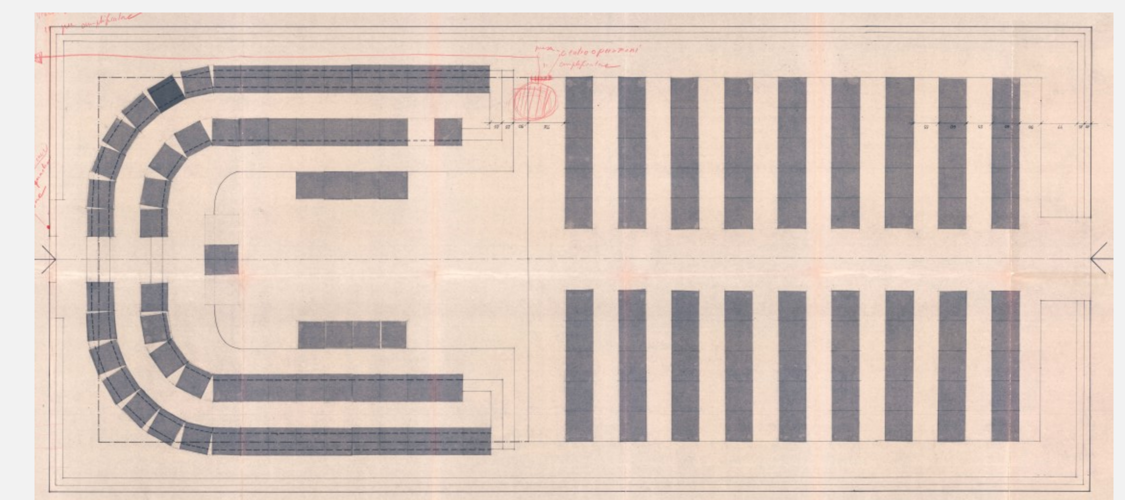


Figure 2.
Plan layout of the Aula Magna. Historical source.

The Aula Magna has a rectangular plan layout of 10.3×22.2 (W×L) m, as shown in Figure 2, with a max height of 12 m at the top of the vault. The **room volume** is 2400 m^3. The ceiling is composed of a **barrelled vault,** and it is perpendicularly crossed by pointed-arched vaults of smaller width. This geometry creates in the centre suitable space to allocate frescos, as they have been painted inside frames. The barrel-vaulted ceiling was constructed with a 5.15 m radius arc.

Figure 3.
Photo rendering of the Aula Magna.

ACOUSTIC MEASUREMENTS

Acoustic measurements have been undertaken by using the following equipment, and allocated as shown in Figure 4:

1. Equalized omnidirectional loudspeaker (Look Line);
2. Omnidirectional microphone (Bruel&Kjaer 4165).

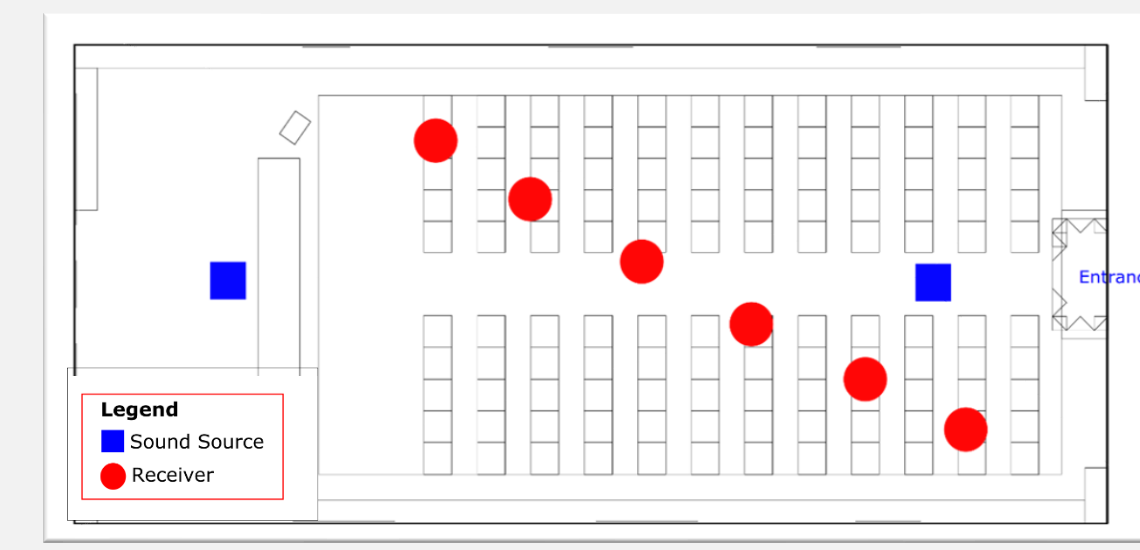


Figure 4.
Scheme of the equipment location during the acoustic measurements.

The excitation signal was an Exponential Sine Sweep (ESS) having a duration of 15 s. The measurements were undertaken in **unoccupied conditions**. Table 1 indicates the results of the acoustic parameters.

Acoustic parameter	Octave Bands – Frequency (Hz)					
	125	250	500	1k	2k	4k
EDT	1.9	3.1	3.8	3.6	3.1	2.3
T20	2.6	3.5	3.7	3.6	3.1	2.4
C50	-1.9	-9.7	-9.7	-8.4	-6.9	-5.8
C80	1.4	-4.6	-4.3	-4.9	-3.8	-2.4
D50	40	9.8	10	14	17	21
JLF	0.1	0.2	0.2	0.3	0.3	0.3

Table 1.
Averaged measured results of the acoustic parameters.

CRITERIA & REGULATIONS

In Italy the reference guidance for the acoustic criteria of educational buildings is UNI 11532-2:2020. By the categories' list, the Aula Magna falls into A3.2 group, that includes lecturer rooms, study group spaces and laboratories, where speech communication is considered the main room function.

In terms of criteria, the following are applied:

1. For room volume greater than 250 m3, the speech transmission index (**STI**) shall **be ≥ 0.5** or ≥ 0.6 if it is provided with an amplified audio system.
2. Speech clarity index (**C50**) has not **any criteria to be** applied for rooms having volume size more than 250 m3.
3. Regarding the reverberation time (**T20**), for rooms having volume size comprised between 30 m3 and 5000 m3, equation (1) shall be applied. T_{20} value at 500 Hz for the Aula Magna shall be **near 0.9 s**, as shown in Figure 5.

$$RT = 0.32\,Log(V) - 0.17 \qquad (1)$$

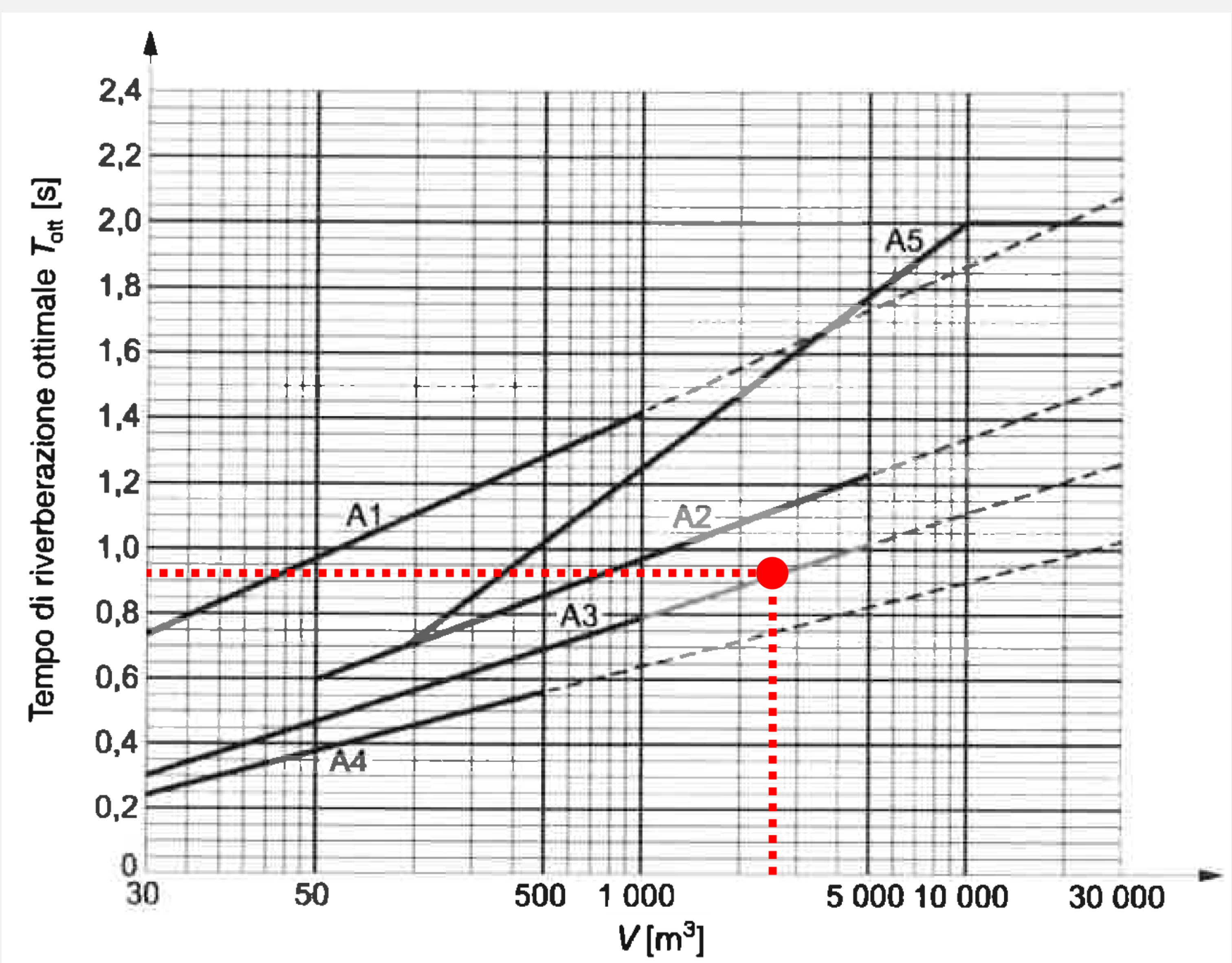


Figure 5.
Optimal values of reverberation time at 500 Hz.

3D MODEL

DIGITAL MODEL CONSTRUCTION

A digital model of the Aula Magna has been realized by using **AutoCAD** software. All the elements have been drawn as flat plans and then exported in dxf format. The AutoCAD layers have been grouped based on the existing finish materials, as shown in Figure 6.

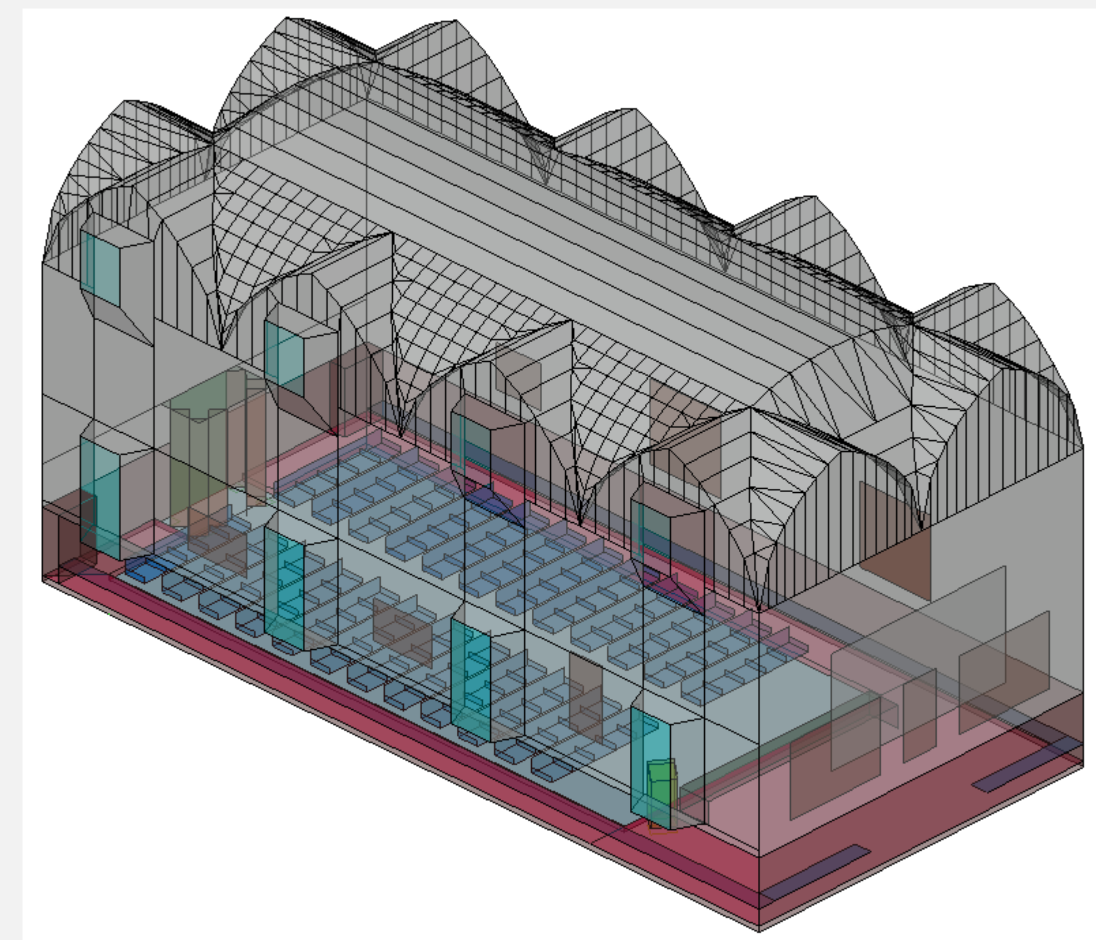


Figure 6.
Axonometric view of the 3D model.

A photogrammetric acquisition of the digital model has been realized by using a DJI Mavic **Mini drone**, a Qoocam 8K 360° camera along with some wide-angle photos taken from a smartphone. After reprojecting the 360° images, a selection of 250 pictures has been carried out to be elaborated with the **Polycam Web**.

MODEL CALIBRATION

The calibration process of a digital model consists of a loop procedure of room acoustic modelling to increase the accuracy of the simulated results. A total of **13 calibrations** have been undertaken before matching the required values. The difference between measured and calculated values of T20 have been minimized across all the octaves, as shown in Figure 7.

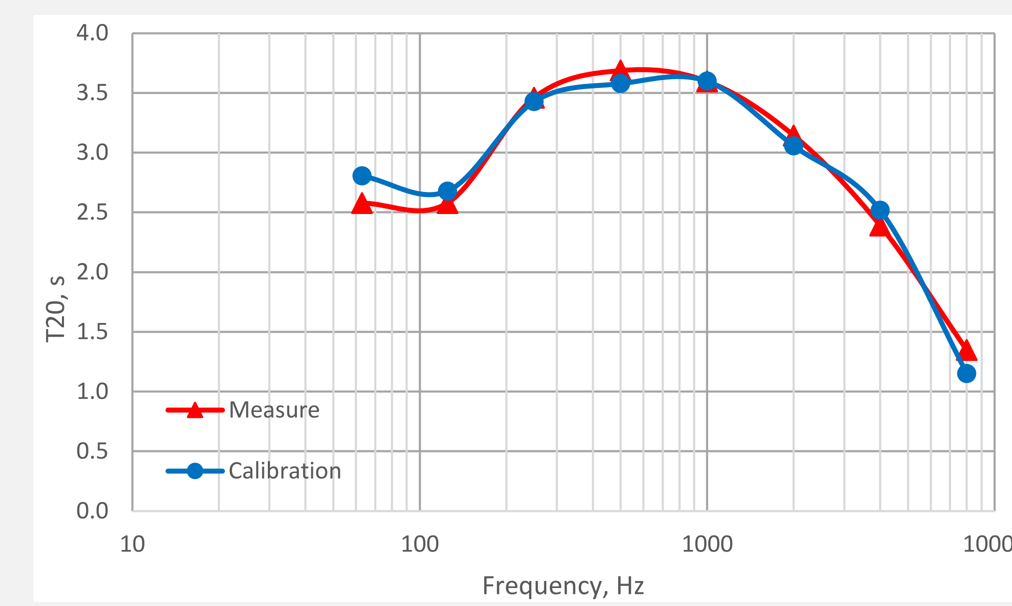


Figure 7.
Calibration of reverberation time (T_{20}) values.

The values shown in Figure 7 are not beneficial for a good speech understanding, also due to a diffuse nature of the room. This detrimental condition is also expressed in terms of C_{50}, found to be between -10 dB at 250 Hz.

The calibration of speech clarity index shows a discrepancy out of the allowance given to the just noticeable difference (JND), that is equal to 1dB.

ACOUSTIC DESIGN PROJECT

The measures adopted consist of the substitution of the existing metal decorations on walls with paintings on **canvas**, also the addition of **absorbing panels** having dimensions of 1.49 × 1.19 m (L, H), and a **carpet** along the corridor has been added. The absorption coefficients of the proposed new materials are indicated in Table 2.

Material	Abs. Coeff. @ Octave Frequency (Hz)					
	125	250	500	1k	2k	4k
Abs. Panels	0.22	0.60	1.00	1.00	1.00	1.10
Canvas	0.35	0.38	0.40	0.40	0.46	0.50
Carpet	0.01	0.05	0.10	0.20	0.45	0.65

Table 2.
Absorption coefficients of the new materials .

The application of the acoustic solutions proposed to mitigate the impact for the excess of reverberation are shown in Figure 8.

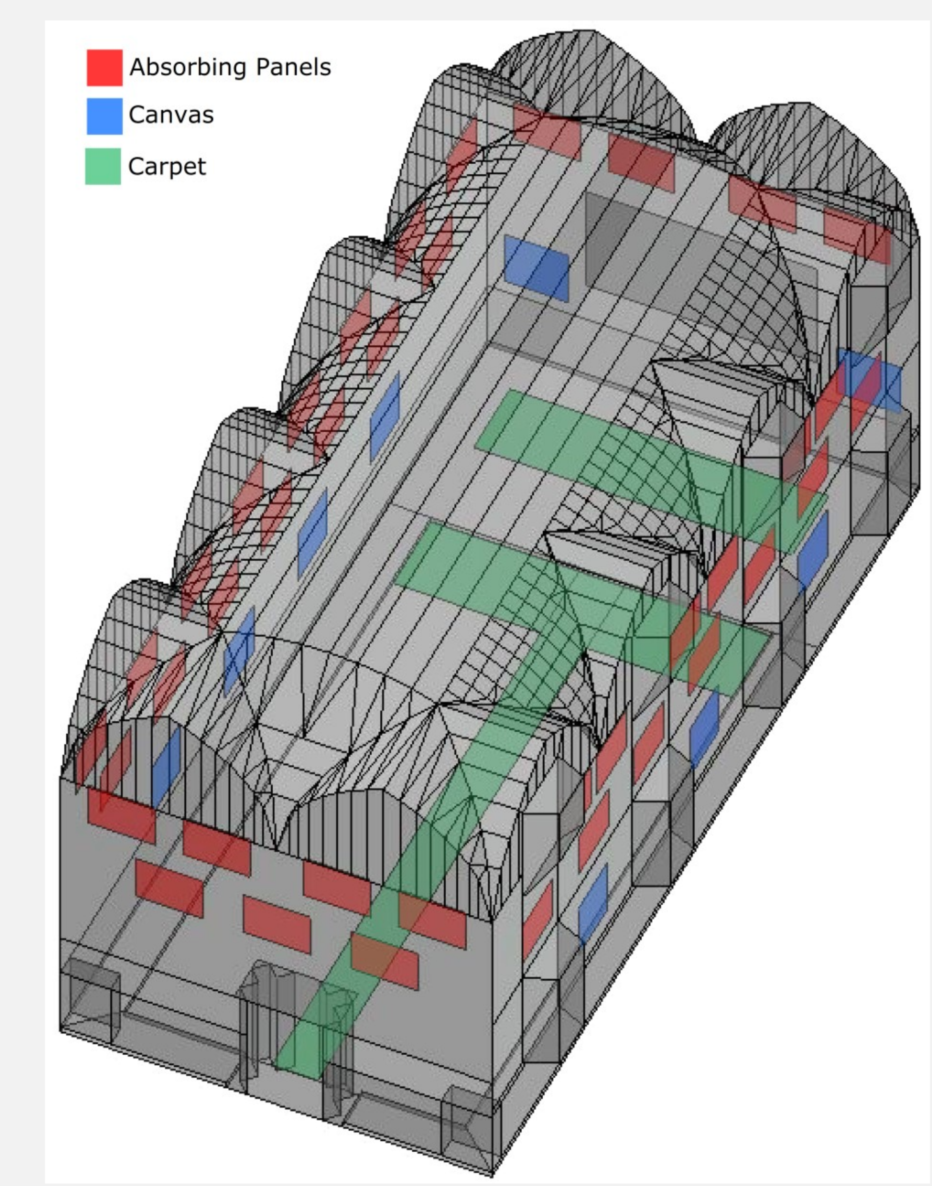


Figure 8.
Application of acoustic measures.

OUTCOMES OF ACOUSTIC SIMULATIONS & DISCUSSIONS

REVERBERATION TIME – T20

An omnidirectional sound source has been installed at the location of the desk while 32 virtual microphones have been installed inside the model, homogenously distributed across the audience area. The acoustic simulations have been carried out without and with the audience at 100% occupancy.

Figures 9 shows the comparison between measured and simulated values of T_{20}, considered the averaged of all receivers' positions.

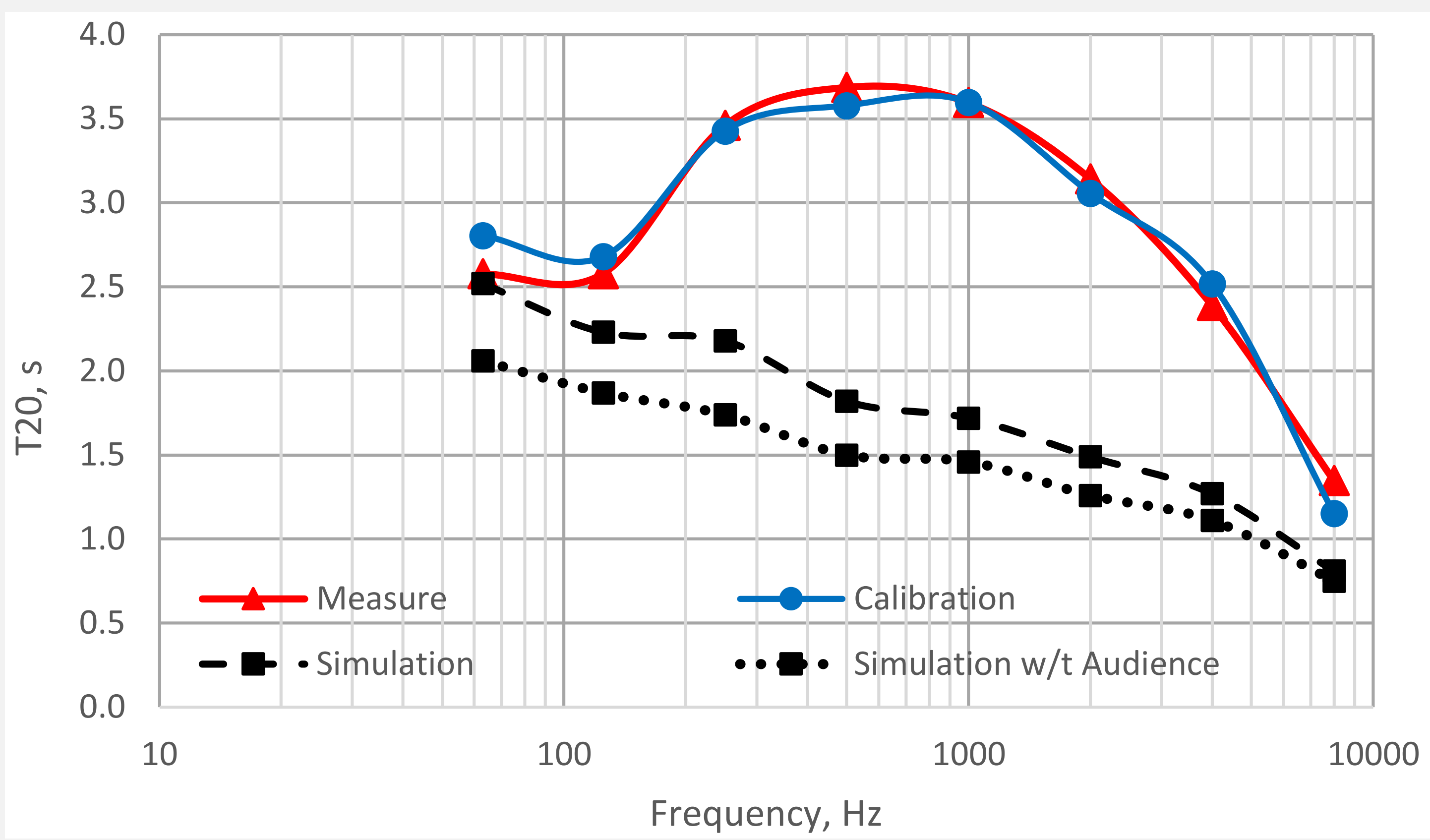


Figure 9.
Measured and simulated values of T_{20}.

The simulated outcomes at mid frequency bands result more suitable for a conference hall, having the values fluctuating around 1.8 s and 1.5 s, related to the conditions without and with audience, respectively. the simulated value at 500 Hz is **meeting the target** expressed by regulation, to be around 0.9 s.

The **spatial distribution** of T_{20} indicates a concentration of sound energy at the quarter back of the room, as shown in Figure 10.

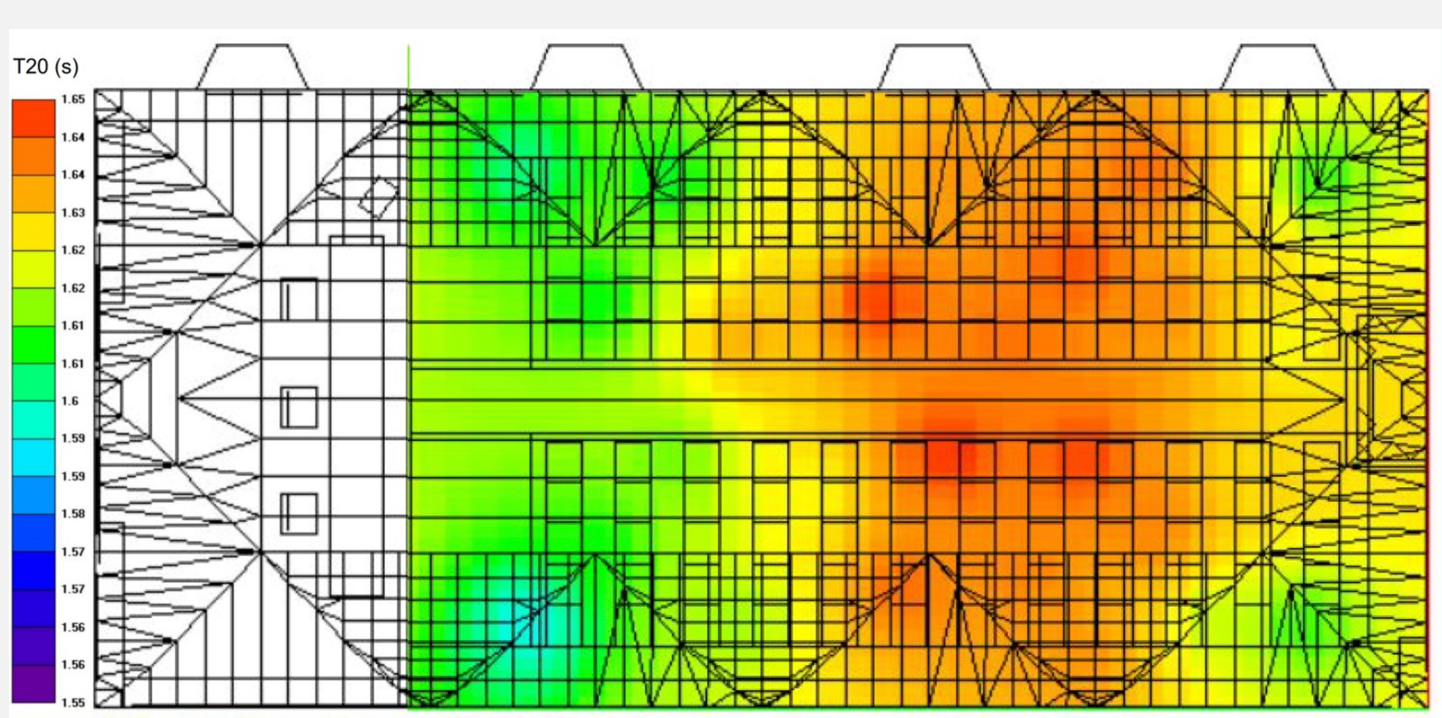


Figure 10.
Spatial distribution of T_{20} values at 500 Hz. Simulation without audience.

SPEECH CLARITY INDEX – C50

Figure 11 shows the improvement of the speech clarity index, found to be **more than 0 dB** at high frequencies only, with a shortfall of up to – 4 dB at low frequencies.

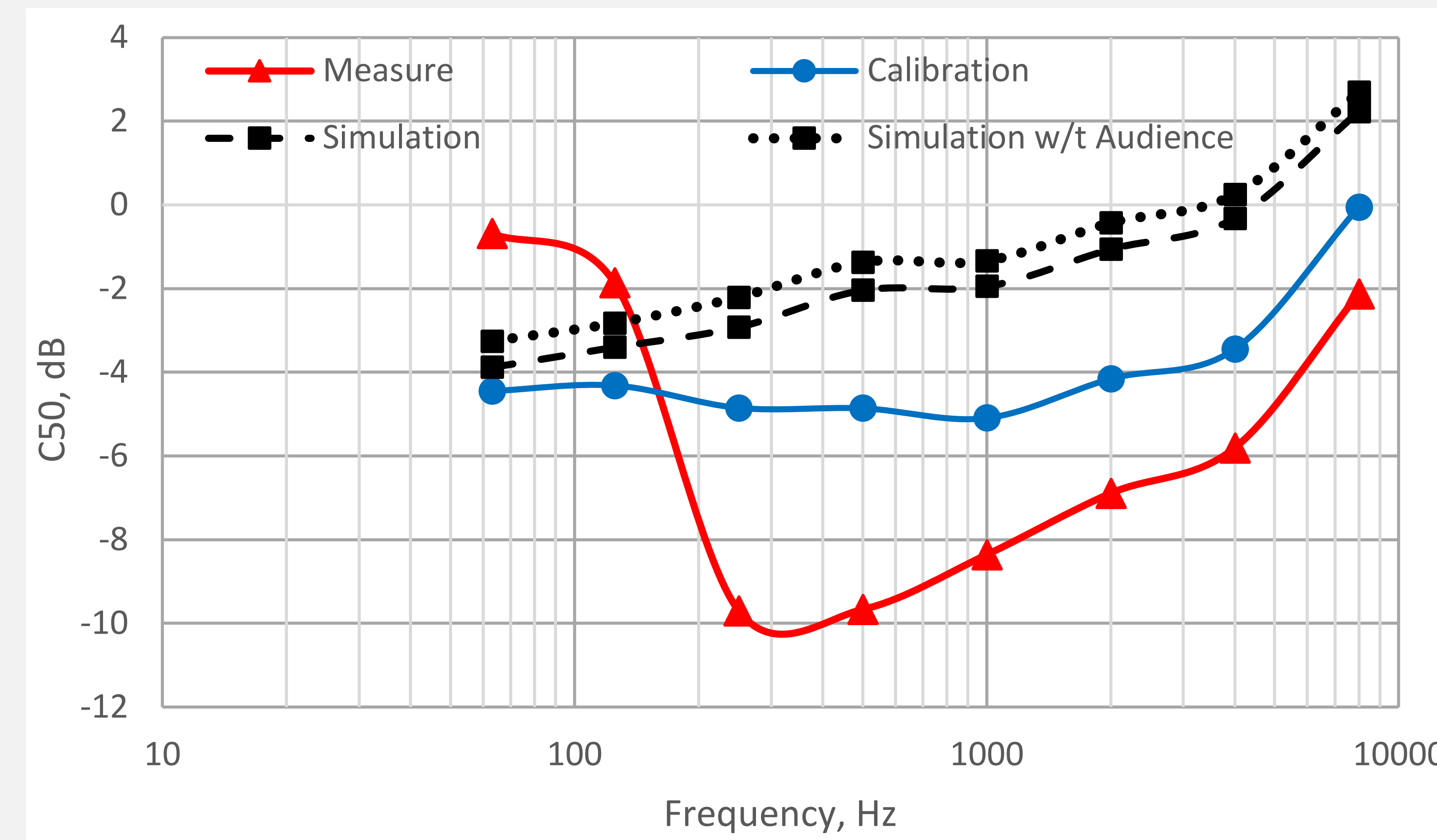


Figure 11.
Measured and simulated values of C_{50}.

SPEECH TRANSMISSION INDEX – STI

The STI indicates the degree of amplitude modulation in a speech signal, including any distortion caused by reverberation and/or background noise.

The measured STI values fall into the "fair" category, as defined by the intelligibility rating according to ISO 9921. With the insertion of the acoustic measures, the STI values are improved, to be within the "**good**" range and comprised **between 0.6 and 0.8**. The background noise level was found to be equal to L_{eq} 41 dB over 30 minutes measurement, without any mechanical ventilation in operation.

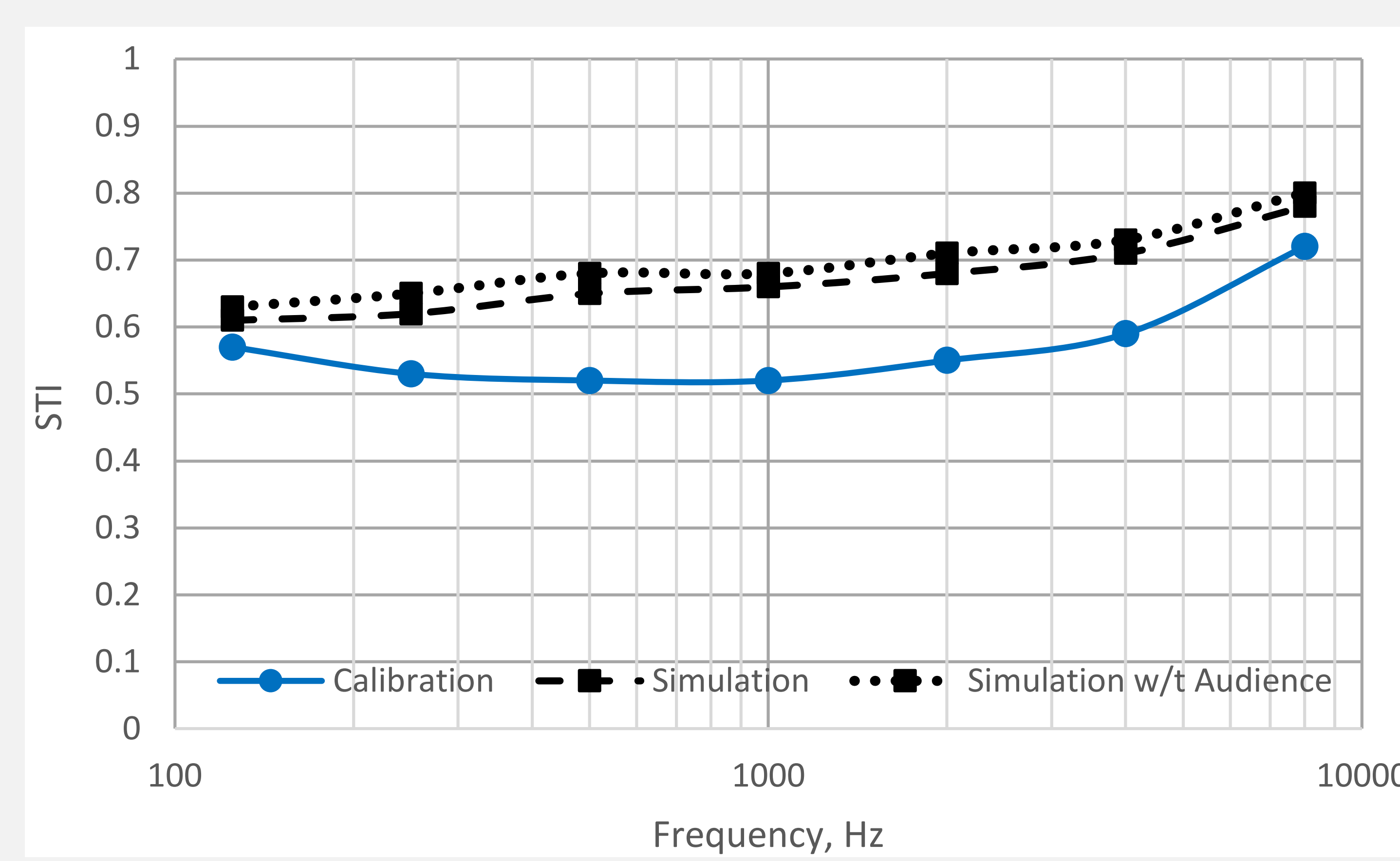


Figure 12.
Measured and simulated values of STI.

CONCLUSIONS

The analysis of the acoustic quality of the Aula Magna at the University of Parma reached considerable **improvements** in terms of speech understanding. The measurements have been used to calibrate a digital model that has been used for the acoustic simulations. The measures adopted in this design project involves the installation of acoustic **absorbing panels** and the placement of a **carpet** in the walking ways. The substitution of bronze sculptures with **canvas** has been undertaken at the level of the lower windows.

The overall result achieves the criteria set by **UNI 11532** in terms of reverberation time. Similarly, the speech clarity improved of about 8 dB at 500 Hz, to be closer more than 0 dB at high frequencies, only.

The application of the acoustic measures improved the **STI** parameter, by passing from a "fair" to a "**good**" condition, fluctuating between 0.6 and 0.8 as per the reference standard.

Further research studies will be focused on the acoustic **measurements** to be carried out **after** the **application** of the outlined design project, in order to assess the accuracy of the simulated results.

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