

Virtual acoustics in heritage buildings: accuracy degree of acoustic parameters in the simulation of the Basilica “Santa María d'Elx”

Ana PLANELLS¹; Rosa CIBRIÁN¹; Salvador CERDÁ¹, Jaume SEGURA¹, Francesc DAUMAL²,
Alicia GIMÉNEZ¹

¹ Grupo de Investigación en Acústica Virtual Universitat Politècnica de València-Universitat de València

² Universitat Politècnica de Catalunya

ABSTRACT

Simulation techniques are widely used in different fields and with diverse objectives. Digital recreation of worship heritage sites is notably interesting for both the architectural value represented and the convenience of preserving the representations or different acts of cultural interest performed in them.

In this study a simulation of the Basilica of Santa Maria has been made in the two configurations of use: for the cult and for the representation of the "Misteri d'Elx", a medieval play declared a National Monument in 1931 and included in the first Proclamation of Masterpieces of the Oral and Intangible Heritage of Humanity by UNESCO in 2001.

Acoustic parameters measured in situ following ISO3382 and those obtained from the simulated model are analyzed. This comparison shows that temporal parameters are perfectly simulated and discrepancies between measured and simulated parameters are lower than 1%, while energy parameters present discrepancies around 20%.

The study proves that to achieve more acoustic similarity between the real and the simulated enclosure, new simulation algorithms should be developed, in order to improve accuracy in parameters that are more influenced by variables such as the location of the source. Also, "in situ" determination of the absorption coefficient of materials would allow to have simulations more adjusted to reality.

Keywords: Virtual Acoustics, Heritage, Simulation

1. INTRODUCTION

Old churches are important as the highest architectural representation of Christianity and for the historical and social values they reveal. The powerful influence of religion on society has created an important architectural legacy that includes some of the finest buildings made. Among religious buildings, churches were the focus of the greatest devotion and were endowed with the richest and most complex interior spaces. Also, churches are acoustically complex spaces from the geometric point of view because their dimensions, shapes, curved walls, side chapels, vaults, and domes often act as partially coupled spaces. The celebration of a service within these churches makes them places where the range of possible sound messages is varied: the same service may include the spoken word, organ music, and the singing of hymns –with each event achieving an optimal sound using reverberant acoustics.

The Basilica of Santa Maria d'Elx is a type of church which has a Latin cross plan of a single nave covered with a barrel vault with lunettes and four chapels at each side of the nave. Buttresses between chapels are drilled making possible to walk from one chapel to another and into the transept and the deambulatory. The apse is closed by a half dome and the crossing is topped with a large dome which rests on an octagonal drum and pendentives. The perimeter promenade is repeated in the first floor. A gallery located over the chapels and the deambulatory opens to the central space throughout balconies.

For the “Misteri” representation, several changes take place in the interior space. The dome is

¹ acusvirt@upv.es

² gf@aaa.com

covered with a painted canvas depicting the sky, furniture distribution is altered and wooden structures known as grandstands and “cadafal” are introduced. All of these create a new space in the Basilica that has been studied separately.

2. METHODS

2.1 In situ measurements

To determine the acoustic behavior in the Basilica, two measurement campaigns were carried out. These measurements corresponded to the configurations of the common use for worship and for the “Misteri” performance. The procedure followed has been the same in both cases, only varying the number of registered positions (FIG1)

For worship configuration we measured 37 receiver positions, all of them located in the ground floor as the upper floor is not used in this case. For the “Misteri” configuration the number of receiver positions registered has been increased to 84 receiver positions including the wooden grandstands, the ambulatory, the apse and the balconies of the upper floor because the audience occupies these spaces during the representation.

The acoustical measurement protocol carried out is established by the norm ISO3382-1, which describes the measurement procedure including measurement conditions, the minimum number of locations needed and the specification of the equipment (1)

Acoustic data has been gathered using two dodecahedral sources DO12 (Rated power 600W Sound Power > 120 dB, Frequency range: 80 Hz-6.3 kHz, directivity: almost spherical) that have been placed near the altar and in the center of the dome respectively.

We used three types of microphones. Monaural parameters have been measured with microphones G.R.A.S. Type 40 AK (Sensitivity to 250Hz 50 mV / Pa Frequency range: 3.15 Hz-20 kHz, upper limit of dynamic range (3% distortion): 164 dBre. 20μPa, lower limit of dynamic range: 14 dB, re. 20μ Pa).

For spatial parameters we used a multipattern microphone AT4050 / CM5 (frequency range: 20-20000 Hz, sensitivity: 15.8 mV, polar patterns: cardioid, omni, figure-of-eight) and its corresponding phantom power supply. Finally, the measurement of the binaural parameters was performed with a head HMS III.0 (frequency range: 3 Hz-20 kHz, -3 dB / + 0.1 dB; dynamic range: typ > 118 dB, max SPL 145 dB). The acquisition and subsequent calculation of measures has been made with the WinMLS software.

2.2 Simulation

Two simplified models have been developed, one of the Basilica in its usual state, and another introducing the modifications that take place for the representation of the “Misteri”. The models have been done by combining the AutoCAD and SketchUp design programs. The first one has a greater degree of precision and has been used to construct a wire that has subsequently been exported to the second to form the surfaces, since the latter supports faces with greater number of sides reducing significantly the necessary planes and has a plugin that Allows the export of the model to acoustic simulation software. The planes that delimit the models have been grouped in different layers depending on the materials to facilitate the assignment of their acoustic characteristics. Each material has been given an absorption coefficient and a diffusion coefficient for the frequencies of 125, 250, 500, 1000, 2000 and 4000 Hz.

Regarding the scattering coefficients, three levels have been established according to the roughness of the surface as it has been done in similar works (2, 3). The values of these scattering levels are shown in Table 1.

The materials used and the absorption coefficients assigned to each one are collected in Table 2.

Table 1 - Diffusion levels and coefficients used

Diffusion	125	250	500	1K	2K	4K
Low (L)	0,12	0,13	0,14	0,15	0,16	0,17
Medium (M)	0,20	0,25	0,30	0,35	0,40	0,45

High (H)	0,30	0,40	0,50	0,60	0,70	0,70
----------	------	------	------	------	------	------

Table 2. Materials used in simulation.

Material	Area	Área	Absorption coefficients used						Disp.
	%	%	125	250	500	1K	2K	4K	
	Wor	Mis							
Stone walls ¹	62,5	63,9	0,04	0,03	0,025	0,025	0,02	0,02	B
Vaults ²	12,7	13,2	0,04	0,03	0,025	0,025	0,02	0,02	M
Marble floor ³	7,9	6,5	0,01	0,01	0,01	0,02	0,02	0,02	B
Dome ³	2,6	-	0,04	0,04	0,05	0,05	0,06	0,06	M
Pews ²	5,1	2,8	0,10	0,15	0,18	0,20	0,20	0,20	A
Stained-glass windows ³	1	0,3	0,13	0,12	0,08	0,07	0,06	0,04	B
Altarpieces ⁴	0,9	0,9	0,14	0,10	0,06	0,08	0,10	0,10	M
Pendentives ₁	0,8	0,8	0,04	0,03	0,025	0,025	0,02	0,02	A
Organ (estimated)	0,8	0,8	0,12	0,14	0,16	0,16	0,16	0,16	A
Red marble ²	0,7	0,7	0,01	0,01	0,01	0,02	0,02	0,02	B
Doors ²	0,6	0,6	0,14	0,10	0,06	0,08	0,10	0,10	B
Altar ²	0,1	0,1	0,03	0,04	0,11	0,17	0,24	0,35	B
Ceramic floor ²	4,3	4,3	0,01	0,01	0,01	0,02	0,02	0,02	B
Wooden structures ⁵	-	2,6	0,35	0,25	0,18	0,30	0,35	0,05	B
Carpet ⁶	-	1,1	0,02	0,03	0,05	0,10	0,30	0,50	B
Sky canvas ²	-	1,4	0,10	0,38	0,63	0,52	0,55	0,65	B

¹ Adjusted in the calibration process of the worship model

² (4)

³ (5)

⁴ (6)

⁵ Adjusted in the calibration process of the “Misteri” model

⁶ CATT-Acoustics (7) Material Library

3. RESULTS

Some parameters have been selected, linked to the main subjective qualities of the rooms, in order to acoustically characterise the Basilica of Santa Maria and evaluate the simulation quality (8).

- Reverberation parameters: reverberation time (RT) and early decay time (EDT)
- Energy parameters: speech clarity (C50), music clarity (C80), central time (Ts) and sound strength (G),
- Spaciousness parameters: interaural correlation coefficient (IACC) and lateral fraction index (JLF)

3.1 Reverberation parameters

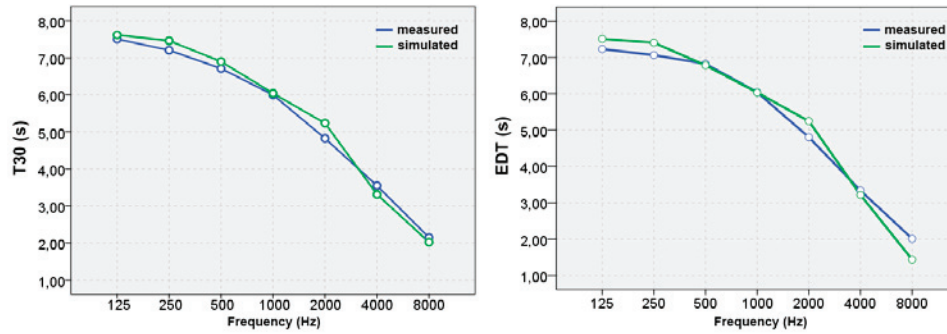


Figure 2 – Reverberation parameters for worship configuration.

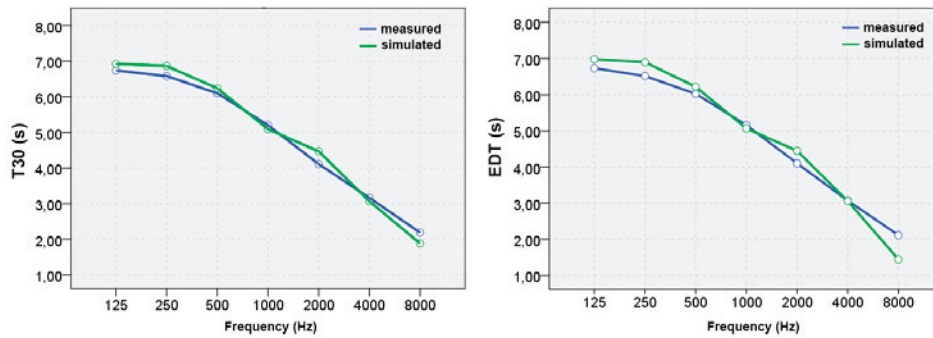


Figure 3 – Reverberation parameters for “Misteri” configuration.

Figures 2 and 3 show the mean values of the room by frequencies, measured and simulated in the Basilica, for reverberation parameters in both configurations.

In both cases the results obtained by comparing the mean values of the RT parameter are good for all source and receiver positions studied and all frequencies. There are more statistically significant differences but at the perception level the results show that they exceed 2 JND only for the frequency of 2000 Hz in the transept zone and in a minimum amount that could be neglected.

In the case of EDT, the differences obtained in terms of the real value are generally acceptable. In 84% of cases the differences between the measured and simulated values are below 2 JND.

It can be concluded that RT and EDT allow a good simulation since they do not show hardly differences between the measured and simulated values.

3.2 Energetic parameters

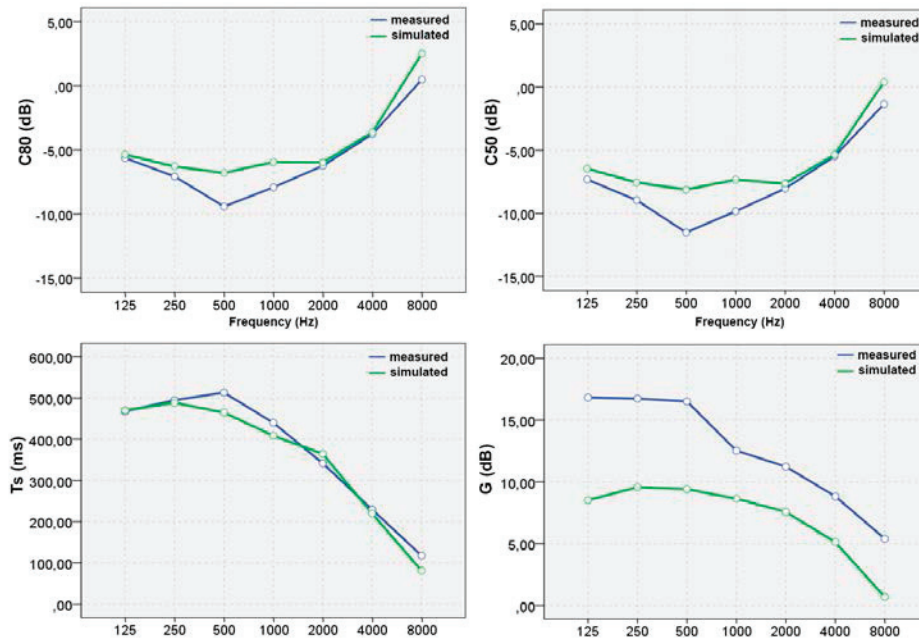


Figure 4 – Energetic parameters for worship configuration.

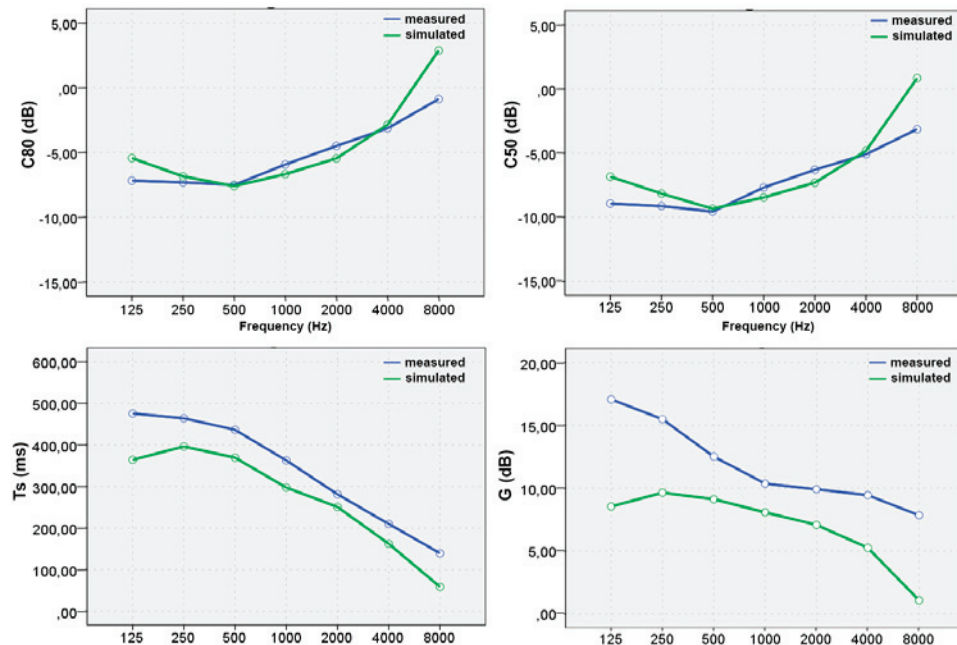


Figure 5 – Energetic parameters for “Misteri” configuration.

Figures 4 and 5 show the average values of room by frequencies, measured in the Basilica and the ones obtained in the simulation, for the four energetic parameters studied in both configurations. Contrary to what happened with the reverberation parameters, greater differences are observed. In the case of the parameters C50 and C80 the greatest differences are given at mid-frequencies for worship configuration, while at low and high frequencies the lines are closer. Results for “Misteri” configuration are better. The differences obtained in terms of the real value (measured) are generally acceptable. In 86% of the cases differences are below 2 JND.

In the case of the Tc parameter, worship simulation is better adjusted and the differences obtained in terms of the real value are small. The highest values are found in the chapels at 125 Hz with a

maximum value of 133 ms for worship and 143 ms for “Misteri”. When transferring the results to perceptual terms, the results are good since they do not exceed the 2 JND of difference in any case, reason why can be considered that the model is well calibrated with respect to the parameter T_c for all the zones and frequency bands.

In the G parameter, the differences obtained in terms of the real value are considerable in all cases, obtaining simulated values similar to those measured only in the transept at medium and high frequencies bands. In perceptual terms, there are also large differences, far surpassing the 2 JNDs in all the areas at low frequencies, and in the chapels and nave in mid and high frequencies, reaching values of 23 dB. It shows very poor fit in the simulation. Only in 30% of cases, the difference between the measured and the simulated value is less than 2 JND.

3.3 Spatial parameters

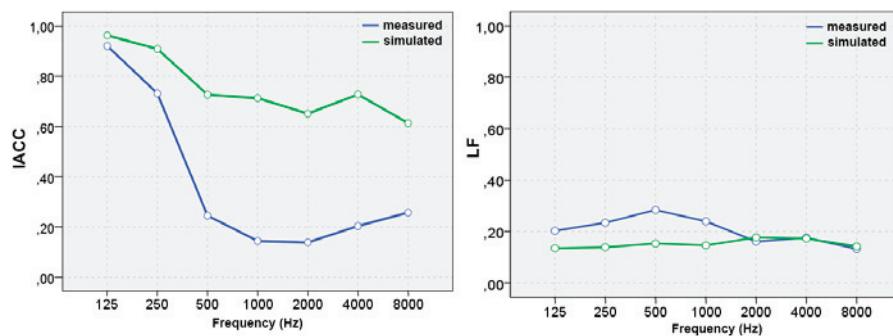


Figure 6 – Spatial parameters for worship configuration.

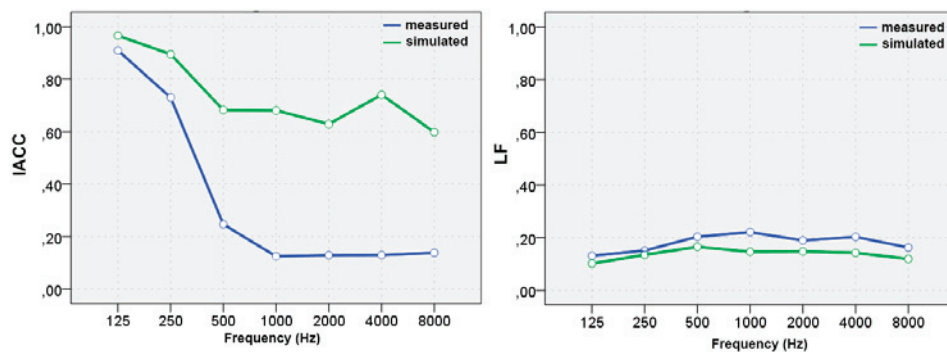


Figure 7 – Spatial parameters for “Misteri” configuration.

Figures 6 and 7 show the average values of room by frequencies, measured in the Basilica and the ones obtained in the simulation, for the two spatial parameters studied in both configurations. In the case of the IACC parameter, the results are generally poor, only are close at 125 Hz. For all other frequencies, the simulated values are much higher than those measured. As with G , the IACC parameter is not adjusted in the simulation, since in only 30% of cases the differences between measured and simulated values are below 2 JND.

4. CONCLUSIONS

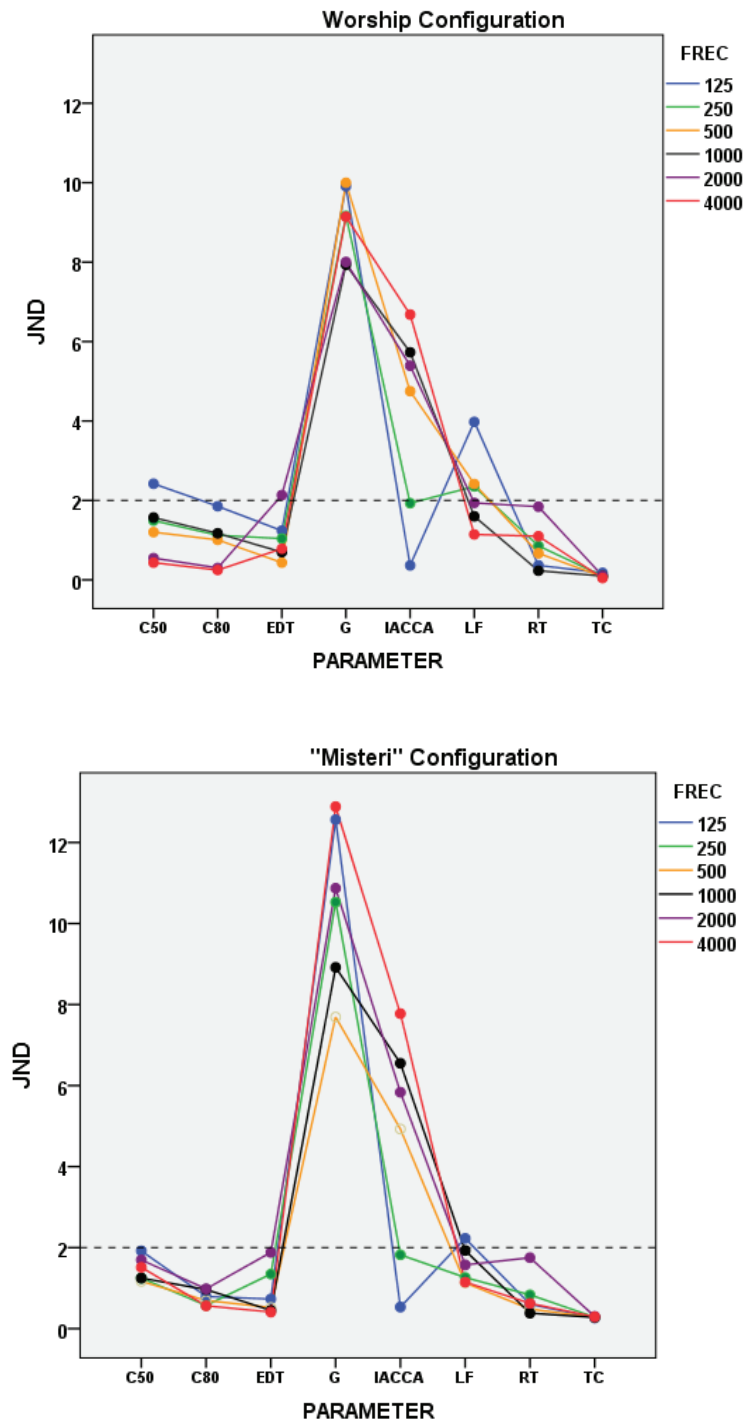


Figure 8 – Difference between measured and simulated mean values of room by frequencies in terms of JND.

Figure 8 shows the differences between measurements and simulations for the parameters studied by frequencies in terms of JND for both configurations. The EDT, RT, C80 and Tc parameters are kept below the 2 JND in all cases. The C50 and LF have problems at low frequencies while in the IACC it happens on the contrary with higher mismatches at high frequencies.

The reverberation parameters are very homogeneous, allow a global analysis at room level since they do not present important differences between some areas and the others, and fit well in the simulation.

The energy parameters are not homogeneous, a zonal analysis is necessary since the behavior varies from one to another and they adjust the simulation relatively well although they show differences in some points.

The spaciousness parameters are not homogeneous, require a zonal analysis and are poorly adjusted in the simulation so the values they provide cannot be considered as good. They allow a qualitative but not quantitative analysis of the acoustic behavior through the simulation.

ACKNOWLEDGEMENTS

This project has been funded by the Spanish Ministry of Economy and Innovation with the grant references BIA2008-05485, BIA2012-36896 and BIA2016-76957-C3-3-R. We would like to thank the “Patronato Nacional del Misteri d'Elx”, the singers and those people who are responsible of the Basilica of Santa Maria for their collaboration.

REFERENCES

1. ISO 3382-1:2009. Acoustics-measurement of room acoustic parameters, part 1: performance spaces. International Organization for Standardization, Geneva, Switzerland, 2009.
2. Alonso, A.; Sendra J. J.; Suárez R.; Zamarreño T. Acoustic evaluation of the cathedral of Seville as a concert hall and proposals for improving the acoustic quality perceived by listeners. *Journal of Building Performance Simulation*. Vol. 7, núm. 5, 2014. pp. 360-378.
3. Álvarez-Morales, L.; Zamarreño, T.; Girón, S.; Galindo, M. A methodology for the study of the acoustic environment of Catholic cathedrals: Application to the Cathedral of Malaga. *Building and Environment*. Vol. 72. 2014. pp. 102-115.
4. Vorländer, M. *Auralization, Fundamentals of Acoustics, Modelling, Simulation, Algorithms and Acoustic Virtual Reality*. Berlin: Springer-Verlag
5. Cox T. J.; D'antonio P. *Acoustic absorbers and diffusers. Theory, design and application*. Second edition, Taylor & Francis, Abingdon, Oxfordshire, UK.
6. Martellotta F. (2009). *Identifying acoustical coupling by measurements and prediction models for St. Peter's Basilica in Rome*. *Journal of the Acoustical Society of America*, 126. 2009. pp. 1175-1186.
7. Dalenbäck B. I. *CATT-Acoustic v9 powered by TUCT user manuals*. Computer Aided Theatre Technique. Gothenburg (Sweden), 2009.
8. Cerdá S., Giménez A., Romero J., Cibrián R., Miralles J. L. Room acoustical parameters: A factor analysis approach. *Applied Acoustics*, 70, 2009 pp. 97-109.