ACOUSTIC DESIGN FOR LA ROMIEU CHURCH CHAMBER MUSIC

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1 INTRODUCTION

Theatre Projects Consultants (TPC) have been commissioned to assess the existing room acoustic conditions of La Romieu's Collegiale Church, with the view to propose an acoustic solution to transform it into a chamber music concert hall.

The hall is part of the Collégiale Saint Pierre, which also comprises a cloister, two towers and some ancillary rooms, all built with traditional stone masonry. This building dates from the early fourteenth century and is a Unesco World Heritage listed building. It is located in the Gers in the south west region of France on the way to Santiago de Compostela. The church is still used for Catholic rite, with one mass per month and circumstantial ceremonies. Masses at the church are amplified with an in-house sound system for speech. In this context, the natural acoustic of the space is very well appreciated by users who experience the impressive room response whilst singing. The church also welcomes tourists who appreciate its acoustics, contrasting with the ones of the cloister and of other rooms, creating a soundscape journey promoted by the Church.

The room acoustics problem was exposed when the space was used for professional music. Our work was requested by a vocal ensemble called "La Main Harmonique" who performs in this space. It first became apparent when rehearsals proved difficult because they could not hear each other on the stage, with an excess of reverberation feedback from the room creating a masking sound effect. Furthermore, an important sound saturation is occurring, particularly at high frequencies, and is perceived as aggressive for the musicians during rehearsals and concerts, particularly affecting the high registers of soprano and tenor. Finally, the acoustic difference between the occupied and unoccupied conditions is high and difficult to manage.

Over the years, musicians have approached the church with various solutions to perform in this space, but were unsuccessful as none of them considered varying the room acoustics conditions of the church. For example, they tried to change the stage position i.e. on the altar, in the middle of the church with public seating on each side, or at the rear of the church. Finally, they adapted their music by working on phrasing and tempo, as well as the power of singing voices to find a better balance.

In this context, the role and aim of TPC's study was to provide an internal potential acoustic treatment respectful of the historic building and considering both the music style of concerts and musicians requirements. Consequently, it was proposed to build removable acoustic elements suspended from the church ceiling. As it is a world heritage listed building, it was not possible to hang items directly from the vaults. We had to create a structure hanging from the church roof that was raised and lowered with cables, thanks to already existing apertures in the vaults that were originally used to raise and lower chandelier suspensions.

2 ANALYSIS OF EXISTING ROOM ACOUSTIC CONDITIONS

The goal of the study was to characterize the existing room acoustics, analysing the geometry and the impulse response measurement. Based on this information we produced an acoustic 3D model in order to propose the acoustic design. TPC considered the various musical genres played in the Church and had a long conversation with La Main Harmonique. The space is mostly hosting chamber music concerts, with a special focus on Renaissance music (secular music) consisting of singers accompanied by original historical instruments, but also early Baroque repertoire. The number of seats could change; in general some chairs are added behind the benches, with maximal capacity of 250 on benches and 300 with additional chairs.

The space is a single nave with four bays with quadripartite vaulting, ending to the South by a polygonal apse. Towards the rear of the Church, a mezzanine covers the entire width of the church with 4m height, which is the only element constructed by wood. Main dimensions are; Volume: 4450m^3; Height (max): 14,90m; Width: 9.06m; Length: 36.4m; V/N: 17.8m

2.1 In-situ Measurements

An in-situ measurement campaign was conducted to obtain the room impulse response which was in turn analyzed to obtain the reverberation time RT, the Early Decay Time EDT, and identify possible echoes and resonances. Measurements were performed according to the ISO 3382-1 *Acoustics — Measurement of room acoustic parameters* (*2004*) standard. The measurement chain comprised mainly of: an omnidirectional dodecahedral loudspeaker, a sound level meter integrator 1rst class (B & K 2250) incorporating an omni-directional 1/2 inch microphone (free field with correction for diffuse field) and the Dirac software.

An impulsive noise source (blank pistol shot) was also used, but the dynamics of this sound source saturated the system too much due to the empty room condition. Therefore our analysis took into account only the measurements with MLS signal generated by the Dirac software. Measurement conditions were unoccupied, temperature 17 ° C and humidity 62%. Five different sound source positions and a total of 17 sound receiving positions were used. Height of receivers and sources were respectively of 1.2m and 1.5m.

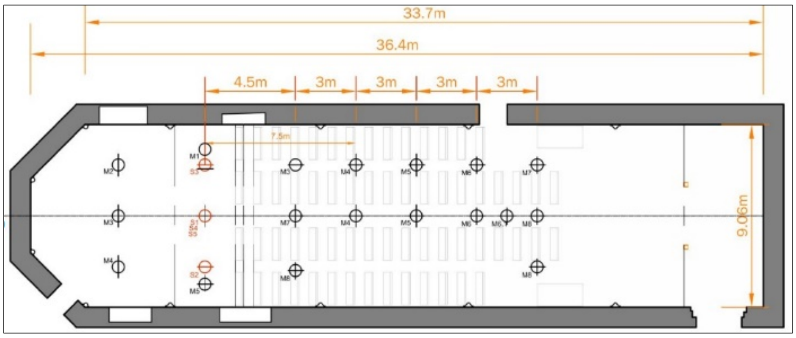


Figure 1, Plan showing sources and receivers settled for in-situ measurements

2.1.1 Reverberation Time (RT)

The Measured RT was homogenous for every receiver point, and source position shown on Figure 2.

	63	125	250	500	1000	2000	4000	8000
S1	4.66	4.62	4.96	5.18	4.74	3.94	2.80	1.77
S2	4.56	4.54	4.96	5.13	4.85	4.00	2.81	1.80
S3	4.54	4.60	4.90	5.13	4.78	3.95	2.89	1.81
S4	4.69	4.46	4.98	5.10	4.79	4.03	2.91	1.88
S5	4.74	4.51	4.88	5.12	4.82	4.01	2.90	1.88
AVG	4.64	**4.55**	**4.94**	**5.13**	**4.80**	**3.99**	**2.86**	1.83

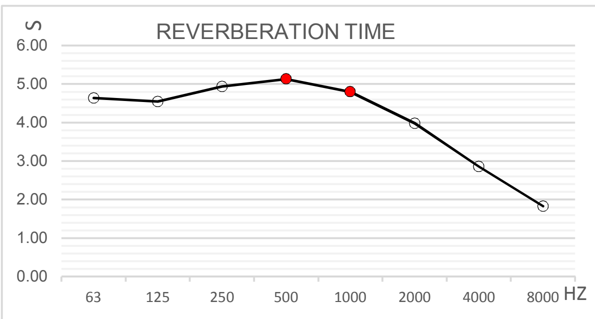


Figure 2, Reverberation Time measured; per octave band (octave bands 63Hz not accurate)

2.1.2 Reverberation Time and EDT

The measured Early Decay Time (EDT) was also homogenous for every receiver position. The average spectrum of EDT and RT are similar, which is explained by the unoccupied condition[6].

Different situations were observed depending on the dodecahedral loudspeaker position. For positions on the Church axis, the measured EDT for each receiver was quite low compared to the RT. For receiver positions located near lateral walls (~2.8m), an EDT similar to the RT was observed.

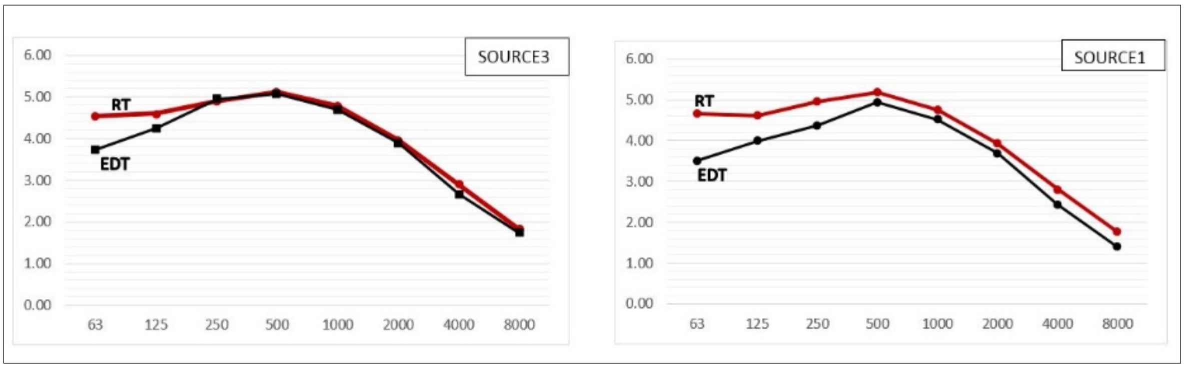


Figure 3, EDT/ RT comparison. Source located near lateral walls (source 3 – left) and Source location on axis (source 1 - right)

2.2 Focalisation and Shape

It was observed that reflected sound energy is much greater at the church geometric central axis. Analysis of the impulse response has shown that for sound receivers located on the Church axis close and powerful reflections arriving at around 100ms were observed. The cross-section geometric analysis of the hall indicates that sound is focalising for those locations. The sound energy created by the focalisation effect and late reflections, implies sound energy of about 3dB higher than other receiver points.

Figure 4 shows the focalisation points in cross section. Distinctive sound reflections from the concave arc vaults were also observed on the altar.

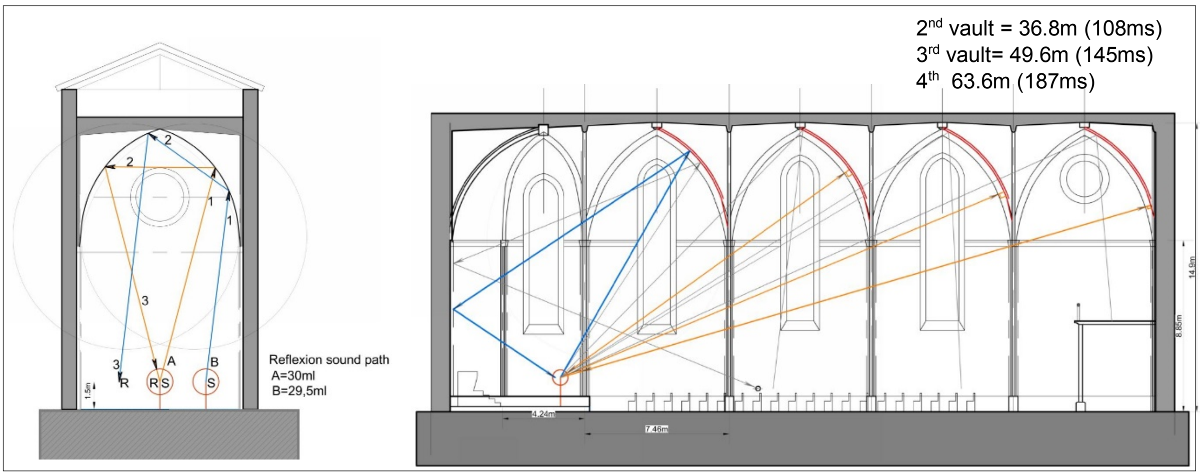


Figure 4, focalisation at ribbed vaults

2.3 Acoustic Modelling

To produce comparative results between the current situation and the proposed solution, we made a simulation of the room with the goal to obtain the same broadband RT [measured] unoccupied.

This simulation allowed us to set the appropriate sound absorption area, and visualize on the sound cards the problems related to the energy distribution. As should be predicted, criteria related to Intelligibility and clarity is very poor.

Note: between a simulated situation and reality there are still uncertainties. Some cases we documented them with the existing literature[1], but some points still to go thoroughly into: the absorption of church benches and large stained glass windows at low frequencies.

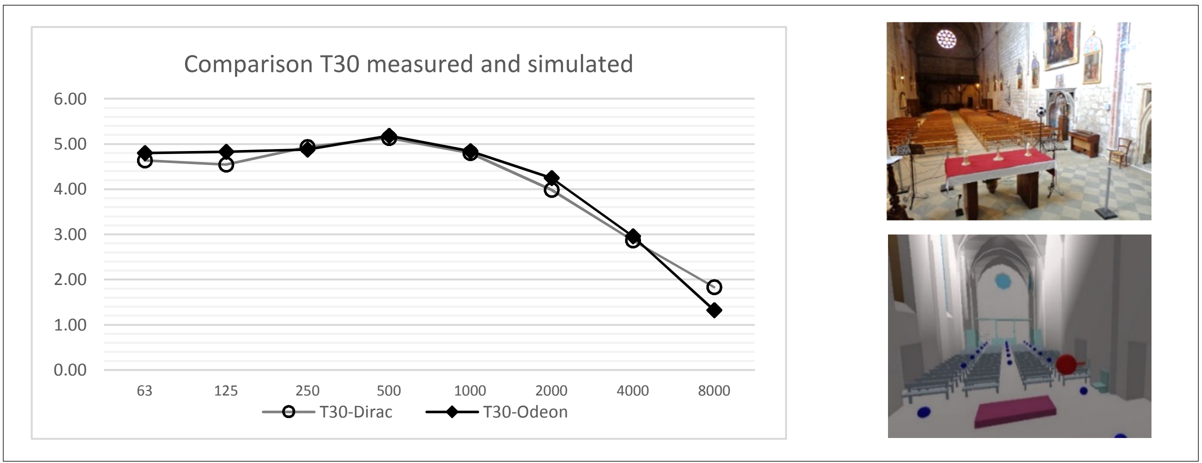


Figure 6, comparison of RT30 measured with Dirac and the 3D modelling produced with Odeon.

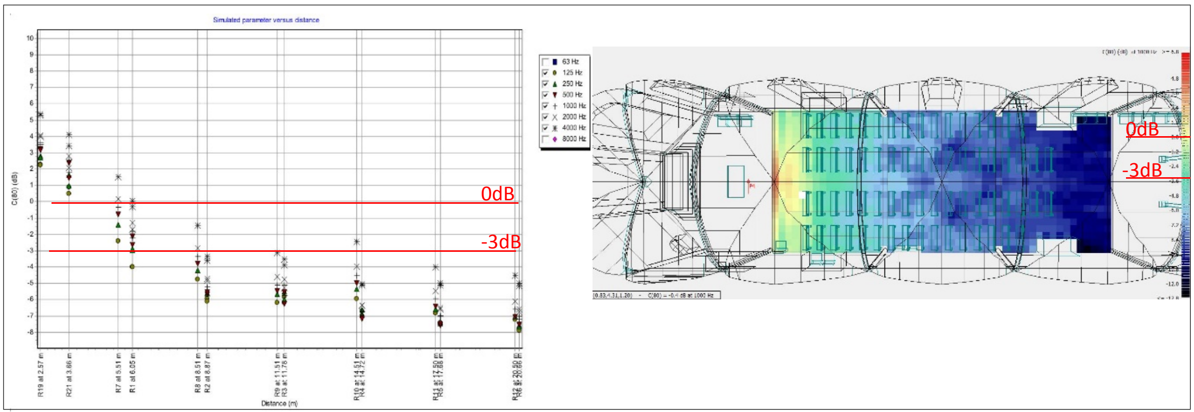


Figure 5, Poor results are obtained for concert criteria parameters. Graphics shows C_{80} versus distance. The mapping illustrates a poor C_{80} at 1000Hz for half of the audience. At first row -0,3dB and at -9.5dB last row

3 INTERNAL ACOUSTIC DESIGN

The acoustic proposition was developed with aim to provide good conditions for different chamber music concerts, particularly for vocal ensembles and small choral groups. Because human voice is very directive, and differs in singers register, there were two main problems to solve: very loud and late reflections, and selective high frequencies reflections (comb filter effect).

Therefore it was necessary to control the reverberation time as well as room acoustic parameters relative to clarity and voice intelligibility.

Otherwise, renaissance music (secular music) as explained musicians, needs to have an important late reverberant sound, even though being necessary clarity because of small vocal ensemble with solo moments. So, this requirement was traduced as a necessity to improve direct sound (actually lost through the ceiling) and control late reflections from surfaces producing focalisation. Any path coming after 100ms with important sound level might be controlled.

This determined an area of intervention at the ceiling with the height being as close as possible to public, but still permitting sound to travel around the nave.

Target was defined by following criteria at mid frequencies RT, EDT, G, & C_{80} for occupied condition:

RT_{mid}	EDT_{mid}	G_{tot}	C_{80}	STI**
2.3 (±0.1s)*	1.8 -2.2 s ($\Delta_{receiver\text{-}pos}$)	3 to 10 dB	-3 to 0	Expected 0.60-0.40

*** Reverberation Time- RT**: average at middle frequencies ~2.3 sec (+-0,1sec). This value was determined by the following abacus in function of volume.

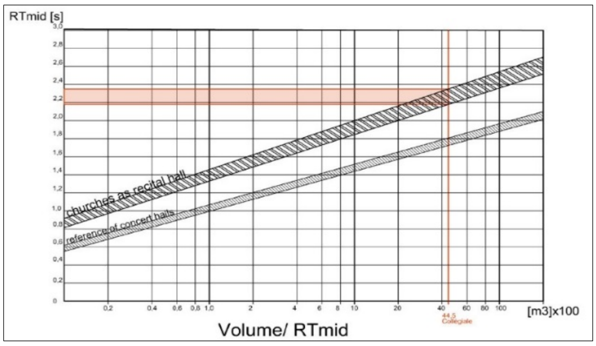
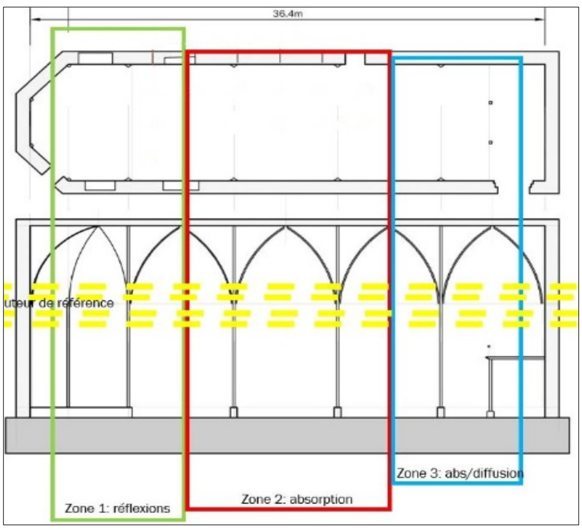


Figure 7, Reverberation Time middle frequencies average (500Hz-000Hz) related to space volume

**** Sound Transmission index - STI**
STI target for concert hall must be carefully considered as it is an acoustic criterion best adapted for speech intelligibility. We are using it in this context because of the direct relation between RT reduction and consequent speech intelligibility improvement. In this case, STI values ranging between 0.40 – 0.60 will be acceptable, without reducing the RT excessively.

3.2 Intervention Areas



Three areas were defined as follows:

1st Area: Stage area where the sound energy sources (musicians). The goal is to prevent the sound to travelling to the choir vault. Instead reflections will be controlled to return the sound to the audience. This will also improve musicians' mutual listening.

2nd Area: Central area, suspended absorptive elements to avoid important reflection over stage, and important resonances originated by ribbed vaults.

3rd Area: Bottom area combining absorptive and diffusive elements

Figure 8, areas of intervention, 2nd and 3rd areas with absorption elements to control RT.

Areas highlighted in yellow represents the appropriate limits to place different elements. They will be suspended from the ceiling between 7 to 11m from the floor. 1st Area will have suspended canopies made on thick 3cm Plexiglass; 2nd Area will have absorbent velums made with Acoustic50 (Mermet), and 3rd Area with velum and spheres made of MDF and acoustic foam, and covered by transparent fabric Aeria (Texaa).

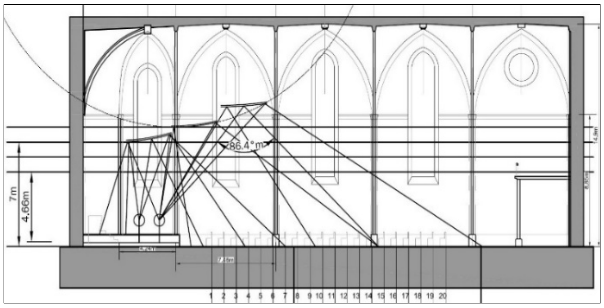
3.2.1 Area 1 – Canopies

Reflector surfaces were designed to produce early reflections towards the audience, and reduce late reflections from the vault. This also helps by reducing the apparent distance related to Dir/rev, which is important for seats after the 6th row (distance to source up to ~8m)

Geometry and dimensions of canopies were designed following Rindel(1986)[5]. First limiting frequency f_1 is 125Hz, and second limiting frequency f_2 is 66Hz (ΔL_{wrc} -3dB). Each canopy are 7.5m^2 (ie. 2.5mx2.4m with a total surface of 67.5m^2).

$$f_1 = \frac{c}{(1/s+1/r)*B^2 \cos^2 \partial}$$

$$f_2 = \frac{c}{(1/s+1/r)*A^2}$$



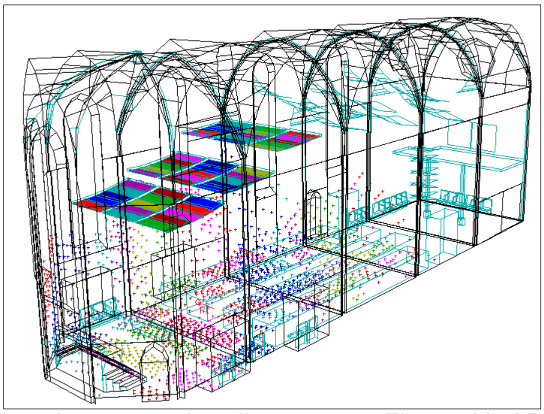


Figure 9, geometric analysis of longitudinal section of canopies covered audience area. Figure 10, 3D model Odeon showing canopy's efficacy.

3.2.2 Area 2- suspended velums

Velum shape were taken from vaults, but suspended, in number of 12 unities

Hz/α	125	250	500	1000	2000	4000
Acoustic50* velum	*0.10*	*0.30*	*0.40*	*0.60*	*0.80*	*0.80*

* Values are taken from Laboratory Emitech-Cetram, made on 21/11/2015- FR.

3.2.3 Area 3 - suspended velums & spheres

Velum shape 4 unities and 4 spheres of Basotec 80mm with absorption coefficient as follows

Hz/α	125	250	500	1000	2000	4000
Basotec spheres	*0.15*	*0.50*	*0.70*	*0.75*	*0.80*	*0.75*

3.3 Simulation Results:

Actual occupied							
Criteria	Band (Hz)	125	250	500	1000	2000	4000
RT (T30)	minimum	3.28	3.14	3.18	2.95	2.72	2.06
	maximum	3.44	3.35	3.4	3.17	2.97	2.22
	average	**3.37**	**3.25**	**3.26**	**3.03**	**2.8**	**2.15**
EDT	minimum	2.88	2.62	2.47	2.27	2.04	1.46
	maximum	3.67	3.58	3.63	3.39	3.15	2.5
	average	**3.37**	**3.22**	**3.19**	**2.95**	**2.7**	**2.08**
C80	minimum	-7.9	-7.6	-7.6	-7.2	-6.7	-5.2
	maximum	2.3	2.8	3.2	3.6	4.1	5.4
	average	**-4.7**	**-4.3**	**-4.1**	**-3.7**	**-3.2**	**-1.9**
G	minimum	3.4	2.7	2.2	1.5	0.9	-0.7
	maximum	8.5	8.3	8	7.8	7.5	7
	average	**5.2**	**4.8**	**4.8**	**4.2**	**3.7**	**2.4**
STI	minimum	0.18					
	maximum	0.61					
	average	0.29					

Proposal occupied							
Criteria	Band (Hz)	125	250	500	1000	2000	4000
RT (T30)	minimum	2.71	2.34	2.31	2.12	1.93	1.61
	maximum	2.91	2.47	2.48	2.34	2.24	1.81
	average	**2.78**	**2.4**	**2.39**	**2.2**	**2.02**	**1.68**
EDT	minimum	2.03	1.75	1.62	1.44	1.24	0.97
	maximum	3.05	2.72	2.72	2.5	2.29	1.92
	average	**2.71**	**2.37**	**2.32**	**2.12**	**1.91**	**1.57**
C80	minimum	-5.3	-4.7	-4.8	-4.3	-3.8	-2.7
	maximum	4.6	5	5.4	5.8	6.2	7.2
	average	**-2.1**	**-1.2**	**-0.9**	**-0.4**	**0.1**	**1.2**
G	minimum	2.2	1.1	0.6	-0.1	-0.8	-2
	maximum	8.1	8	7.8	7.6	7.4	7.1
	average	**4.2**	**3.6**	**3.6**	**3**	**2.5**	**1.6**
STI	minimum	0.24					
	maximum	0.66					
	average	0.35					

Figure 11, tables showing Existing situation (left) versus Proposal situation (right), for RT(T30), EDT, C_{80}, G and STI.

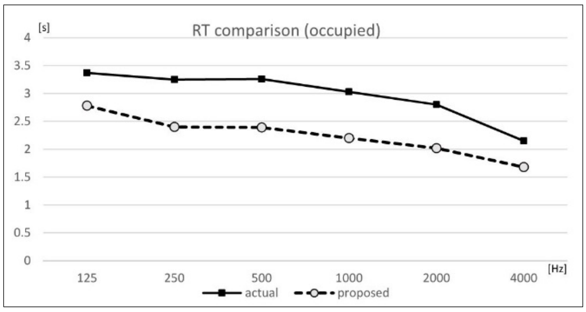


Figure 12, graphic RT –T30 (125-4000Hz) where Existing situation continuous line, and Proposed on dashed line.

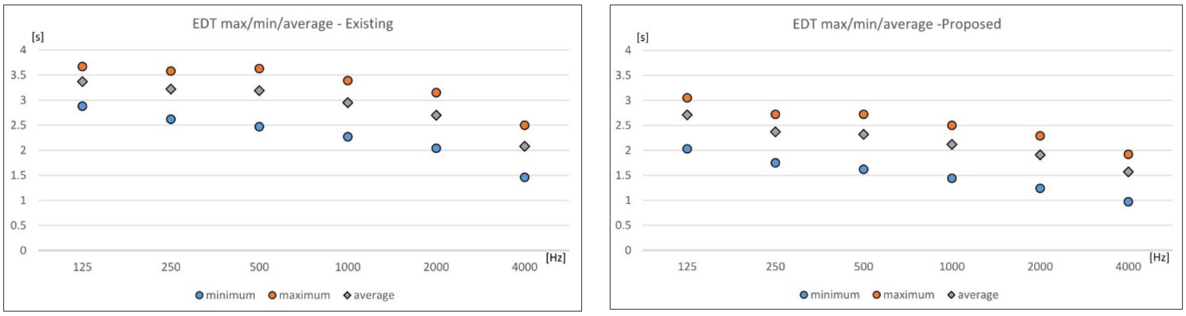


Figure 13, EDT global values comparing Existing situation (left) and proposal (right), for minimum, maximum and average 125-4000Hz.

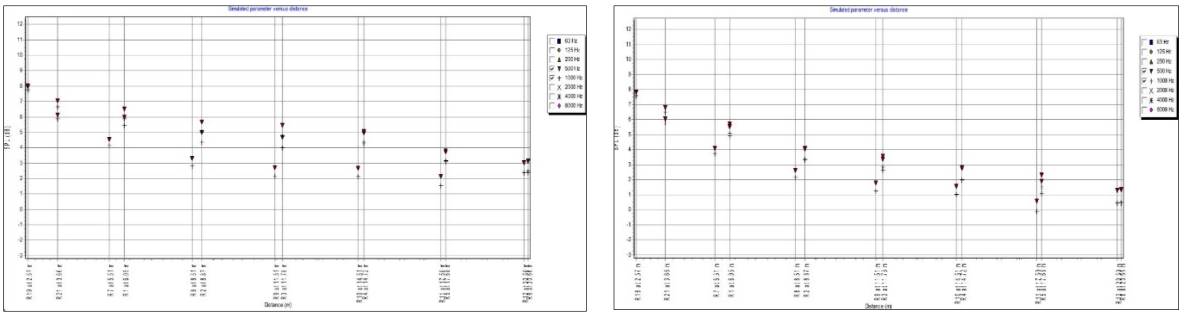


Figure 14, G 500Hz & 1000Hz evolution related to distance: Existing (left) and Proposal (right)

4 CONCLUSION

Working in collaboration with the vocal ensemble resident in the church, we could analyze the existing acoustic characteristics. To do so, it was used the in-situ measurements and the observation during rehearsals and concerts. With this information and supported by the existing literature room acoustic targets were determined.

Despite a difficult geometry to manage acoustics, it's been possible to establish an acoustic design to enhance the listening experience for chamber music concerts, achieving RT and C_{80} targets. Placed at the ceiling, this design also permits to control sound focalisation and resonances produced by the ribbed vaults. The proposed acoustic design will permit to perform concerts with the stage placed on the apse in good conditions.

Other subjects, not concerned by this study might be examined later. Discussion about diffuser panels for side walls and audience layout are necessary. Improvement of benches layout at the center plan, and audience attenuation (grazing incidence effect) on the longitudinal direction must also be analyzed.

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