ACOUSTIC REHABILITATION OF A LITTLE CHURCH IN VINAROS (SPAIN)

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ABSTRACT

Some old churches in Spain are presently used for concerts and other musical or leisure performances. The acoustical conditions of theses buildings are not optimal for these new uses. For this reason, it is necessary to modify its original structure in order to achieve better acoustical features. This paper describes the work done in order to improve the acoustics of a church in Vinaròs, it is presented the refurbishment of this space as a multiple-use room, also to keep the old aesthetics it is proposed a reversible actuation. The proposal is virtually analyzed by using a ray tracing tool.

1. INTRODUCTION

Acoustic rehabilitation of churches for a non-liturgical use is an open field in acoustics. Many resources and efforts have been invested to obtain the adequate public environment where anyone can listen to a specific kind of musical signal. In order to develop this sort of rehabilitation projects several techniques can be used. Among them the most well-known techniques are: the method of the scale model for the acoustical modelling and acoustic simulation techniques by means of several numerical methods. Here, it is interesting to point out that the acoustic simulation is quite cheaper than other methods, for this reason nowadays they are widely spread.

Old Churches are presently used as concert rooms, however the structure of these buildings is not optimal. The modification of these churches for non-liturgical uses have made grown interest for rehabilitation of these ecclesiastical spaces, in order to adapt them as poly-functional rooms devoted to cultural or leisure activities.

In the Iberian Peninsula, most of the towns and cities have one or more churches, chapels, cathedrals, monasteries or convents, which have had modifications inside through the centuries and, therefore, have varied their acoustic conditions. Thus, when they are refitted for other uses, as for example musical auditoria, it would be interesting to take into account this factors, in order to have similar final results as in the original case, since the acoustical conditions of the churches are deficient for new uses in most of the cases, due to architectural alterations, changes in the furniture, or decoration, it has also influence the different position of musicians, performers and audience.

In this rehabilitation proposal, the original structure of the church as a whole has been respected. Also, the aesthetic and artistic identity has been preserved, acting in a reversal way and making adaptations for each one of the needs and uses of the room. From the point of view of conservation and refurbishment of patrimonial goods, we have respected the original space, but with minimum changes. From the point of view of the current use, we have proposed a set of reversible alterations in the environment which allow optimum acoustical conditions in this room for the uses planned. In this paper, a simulation with CATT Acoustics simulation package has been made, in order to predict the response of the acoustic refurbishment proposals.

2. HISTORY AND CHARACTERISTICS

Saint Augustine Church is part of the remains of the old Augustinian Fathers Monastery which dates from the 16th century. It is a baroque building that has a Latin cross shape with three side chapels at each band among the buttresses connected themselves. The stone cross has a dome upon the tambour and scallops and a presbytery roofed with groin vault, as well the side chapels of the nave, which are nowadays totally empty. The façade stands out by its symmetric composition. At both sides of the entrance two bell towers are risen with their own door, which frames the central wall crowned by a molding cross section and its façade of lintel access (Fig 1).

Figure 1. Saint Augustine Church façade.

The church was used as a stable for the Napoleon cavalry in 1808 and also it was deteriorated during the Spanish Civil War. The church was used temporarily to worship and it was definitively closed to the audience in 1975. In the 80's (eighties), the old church was fitted out and restored functionally as an auditorium, being nowadays the Wenceslao Aiguals de Izco Local Auditorium

Saint Augustine church consists of a 400m^2 surface, which has attached the chapel of Saint Victoria in which the Local Museum rooms are located. The plan church is 29.3 meter long from the entrance door to the apse; it is around 16 meter wide counting the width of the side chapels, 13.2 meter high from the floor to the vault and 23.1 meter high to the central part and the highest from the dome. Therefore the church volume is around 4900m^3. The stalls have a surface of 72m^2 and consist of 14 rows of 13 seats each one of them (Fig 2).

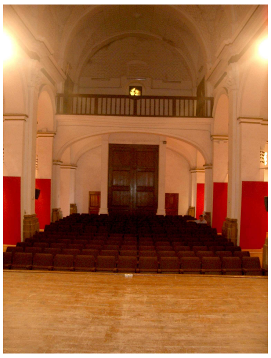

Figure 2. Stalls and choir of the church.

3. MODEL AND SIMULATION: A PREVIOUS STAGE

3.1 Geometric model

In order to model Saint Augustine Church in Vinaròs, a variation of the ray-tracing method has been used. This was a hybrid cone-tracing combined with an image-source approach called randomized tail-corrected cone-tracing algorithm (RTC-II). The geometric model was developed by using CATT Acoustics [3], in order to predict the acoustic behavior and to carry out a valid global proposal to its restoration and acoustic fitting-out.

Ray tracing algorithms take into account that a wave generated by a source can be linked to a ray, cone or pyramid by means of the eikonal equation. The source statistically emits a series of rays with a specific energy which, on inciding with the surfaces of the walls which delimit the geometric model, lose energy with each reflection. In our case, both calculation programs used take into account specular and diffuse reflections. In the case of CATT, the diffuse reflections are calculated from the explicit parametrization of the absorption and scattering parameters of each surface.

The modeling process of one court consisted in defining all surfaces in the same court, whatever its shape and dimensions, specifying the coordinates of its respective vertexes [4]. In the case of Saint Agustine Church of Vinaròs (as has already explained above), the coordinates have been calculated from the ground plan provided by the Culture Department of the Town Council of Vinaròs and from the measurements made with an ultrasound sensor of the elevation levels necessary to develop the model in three dimensions that allows simulating of the acoustic behavior of the court and, in this way, can put in to carry out the proposal of adequate materials to the restoration and acoustic fitting-out of the church to can be used as an auditorium (Fig 3).

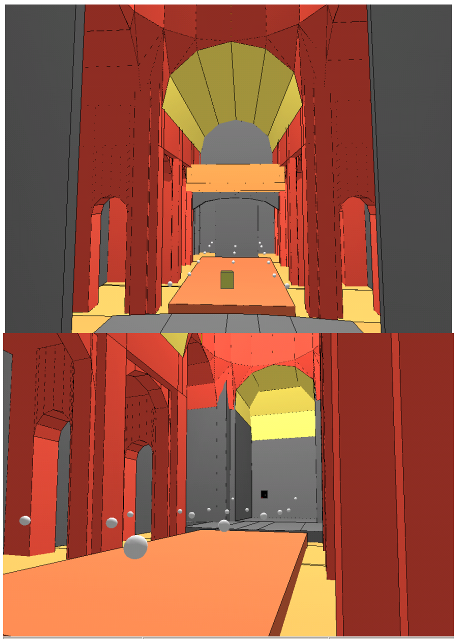

Figure 3. Different views of the modeled church in CATT. *(a) front view, (b)back view*

As each one of the surfaces the church consist of a certain material, it is necessary to provide the respective values of absorption coefficients of each one of them. As surfaces are smooth enough, their scattering coefficients are low, (about 10%) according to the Lambert law. Finally, to complete the model, it is necessary to specify the position and characteristics of the sound sources in the building and the positions of the respective receivers.

3.2 Calibration of the model

In order to make a proper calibration of both models, measurements were made by using a MLSSA card, which uses the MLS technique to perform the acoustic assessment of parameters in any room according to ISO 3382-1:2007. Measurements were done in 16 positions.

The MLS technique uses a pseudo-random binary sequence as excitation, whose self-correlation function corresponds to a Dirac delta ($R_{xx}(t) \approx \delta(t)$). The cross-correlation of any signal with $\delta(t)$ is the signal itself, which means that:

$$R_{xy}(t) \approx \delta(t) * h(t) = \int h(\tau)\delta(t+\tau)\, d\tau = h(t) \quad (1)$$

Therefore, in a linear system, if we calculate the cross-correlation between the MLS signal applied to the input and the signal recorded at the output, we can determine the impulse response of this system and thus calculate its transfer function by means of applying the FFT.

The values obtained for RT30 in octave frequency bands were used to calibrate both acoustical simulation models. In this case, an error up to 10% in this reverberation parameter has been allowed, in order to keep the 'just noticeable differences' (jnd's) values in an adequate range for all the parameters. Figure 4 shows the spatial average values per frequency bands of RT30 for the tonal curve of the room. The error bars show the difference between measurement and simulation.

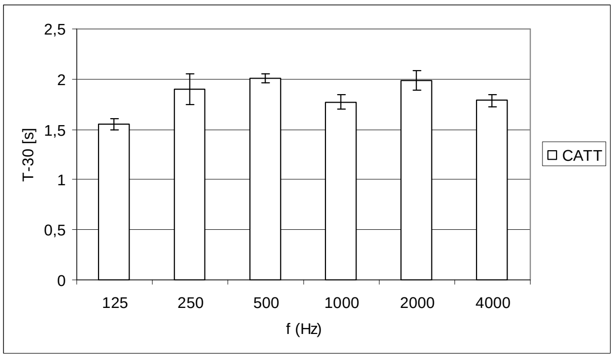

Figure 4. *Average tonal curve for T30 measurements, CATT for 16 positions*

Once the models are developed and calibrated, they are available for throwing a certain number of rays (with a number high enough to get valid results according to the volume of the room). These rays come from the sources modeled in the process.

In our case, 20,000 rays were thrown, considering for CATT 2 seconds of truncation time. This choice presented a compromise formula obtaining the satisfactory results for a reasonable calculus time. After tracing the whole amount of rays and processing the information of the simulation, it is possible to obtain the impulse response in a specific receiver [5], [6].

The original church is modeled, before intervening (sticking absorbent panels in the vault, apse, etc). The surfaces are defined and are organized in groups, attributing the type of material they are made up of to each surface or group. Five materials have been considered mainly in the original church. The configuration of materials to model the original church has parquet floor for the stalls floor, which show a slight slope in order to get higher height. In the side chapels, the central round, the sides of the church and the front and back walls of the room, the material used is plaster and vermiculite. In the vaults and dome, the chorus, the entrance door and the stage floor, common wood was used. For side corridors and for the ones which are between the stage and the first row of stalls carpet was used. The values of the respective absorption coefficients (α) have been taken from the bibliography [7] for frequencies between 125 and 4000Hz in octave bands.

3.3 Sound source

The characteristics of the source have been defined as well as its position and orientation that could belong to a person's mouth located in the centre of the stage, in the position (X;Y;Z) (19.2, 7.9, 2.3) with a certain power. To these effects and subsequent ones, it could be noticed that the origin of coordinates (0, 0, 0) chosen to model the court have been located at floor level at the left side of the entrance of the church seen from the stage. The acoustic characteristics of the source are:

Position: X = 19.23 Y = 7.90 Z = 2.30
Orientation: Azimuth = 0.00º
Rise = 0.00º
Rotation = 0.00º
Limit angles: Azimuth: between 0.00º and 360.00º
Rise: between -90.00º and 90.00º
Delay in the emission: 150 ms
Acoustic parameters (to the six octave bands between 125 and 4000 Hz)

Frequency	125	250	500	1000	2000	4000 Hz
Resonant level to 1m	70.0	73.0	76.0	79.0	82.0	85.0 dB
Power	73.1	76.1	79.1	82.1	85.1	88.1 dB

Horizontal -3dB : 35.00º (to all octave bands)
Vertical -3 dB: 45.00º (to all octave bands)

Table 1. Sound source characteristics.

Regarding to the number of receivers, 16 were considered regularly distributed in the stalls, three receivers in the first seat stall (a), in the seventh and thirteenth of the first row, in the fifth, ninth and fourteenth. Two detectors were positioned symmetrically on the stage at both sides of the source (Ed and Ei, right and left stage) and two detectors more in the choir, to both sides (Cd and Ci, right and left choir). Figure 5 shows the positions of each one of the 16 receivers considered, as well as the source position.

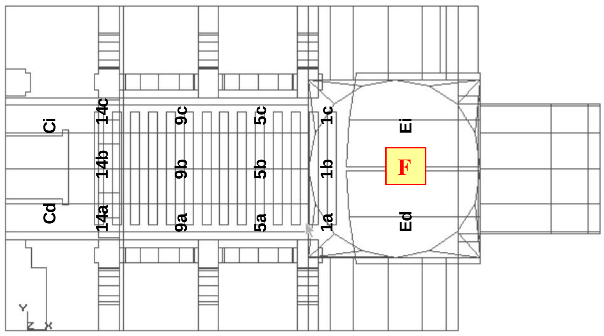

Figure 5. *Average tonal curve for T30 measurements, ATT for 16 positions*

The number of the receivers used is big enough to characterize the acoustic response of the church in detail and has been selected according to the ISO 3382-1:2007. It is also necessary to introduce data to the software (CATT), because of the propagation properties in the environment such as: relative humidity (50 %), room temperature (20 °C) and air absorption (dB/100m). Finally, it is interesting to emphasize that to build the model of the Saint Agustine Chuch, 530 different surfaces were considered.

3.4 First calculations

After the analysis of the results obtained from the predictive running of the model of Saint Agustine Church in its original state, it should be pointed out that the church offers poor acoustic conditions for talking and for musical and multi-functional use.

On one hand, the reverberation time ranges obtained are between 1.35 and 1.95 for CATT. The optimum reverberation time for a court whose volume is 4900m^3 should range between 0.9 and 1.3s [4], [8], [9], [10], [11]. This reverberation time is produced by a high reflectivity and low diffusion on the walls and the plastered ceiling (and *vermiculite*). We also have to keep in mind possible fo-

calizations, which can appear due to the dome, the vaults and the apse. All these focalizations result in a non-constant distribution in the room, as in case of the pressure levels and the definition and clarity indexes (D50 and C80).
In this way, the pressure levels off in the room after a typical distribution of decreasing in the receivers each time further away from the source. This is due to the decrease of intensity with the distance, in free field conditions. For this reason, reflections should be reinforced in the last rows, creating a diffuse field, more uniform in the whole audience zone and the stage. It is observed that the pressure levels decrease up to 10 dB between the receivers located in the stage and located in the last rows.
The values for the definition D50 index are included between 30% and 72% for CATT. These values adequate, but ideal values should be taken between 50% and 75% to assure good intelligibility. In this way, speech does not loose definition or clarity and it can be listened in a proper way in every place of the church [4]. Therefore, the values obtained at the stage receivers oscillate between 65% and 78% for CATT. These high values for D50 parameter are reasonable due to the proximity to the source. In the same way, analyzing the values of the clarity index C80, we can conclude that the results are not the optimum ones. Although the values for the front rows can be considered as acceptable, the results for the back rows are totally unacceptable [4].
For Speech Transmission Index values (STI) and Rapid Speech Transmission Index (RASTI), the results obtained qualify the church acoustically in its original state as a weak or regular room. The values of the STI index were between 0.5 and 0.66 for CATT. These indexes are measured in normalized units between 0 and 1 and show the intelligibility in the church [8], [4], [9]. The results obtained show regular intelligibility to use the church as a room for speech.

4. RECOMMENDATIONS FOR REHABILITATION

The main aim exposed in the study of Saint Agustine Church in Vinaròs is to improve the acoustics of the room, although respecting the structure and aesthetics of the church as much as possible. Here it is important to point out that the church in its current state has already undergone a process of fitting-out. This is the main reason for the existing slight slope in the stalls, as well as the use of parquet flooring, the carpet and the absorbent material in the vault, the dome and the apse. The absorbent material was damaged in its function, as well as aesthetically, due to humidity. In this work, this absorbent material has not been considered in the modeling, but instead the church has been taken in its original state, without this absorbent material. The slope of the stalls, the parquet and the carpet of the floor have also been taken into account. Non-considering the absorbent material is due to aesthetic reasons, as the absorbent material panels break the aesthetics of the building. Therefore, in the global proposal of rehabilitation and acoustics fitting the preservation of the original structure has been contemplated first working on it in a reversible way. This was made by implementing several objects which can be removed after the performances, if desired, giving a wide range of possibilities.
After the study of the several proposals made in several churches [8], [12], [13], [14], [15], [16], [5], [6], [17] and the analysis of the different possibilities for Saint Agustine Church, our proposal consist of the following corrections in its model:

- The sloping floor of the stalls is kept, but the floor material is changed into an ordinary/poor-quality wood floor; the lateral corridors and the front corridor of the stalls are made of carpet; the floor of the chapels and the stage corridors are parquet; the walls of the chapels, apse, domes, vaults, walls and friezes are still made of plaster and vermiculite as in the original modeling; the balustrade of the choir and the access door to the church are made of wood.
- The setting of mobile curtains of gathered velvet is modeled, in front of the arches of the side chapels and covering the base of the dome, in such a way that it is not only used as an absorbent material but also it provokes a higher number of reflections on the audience zone, avoiding the fitting connection to the chapels. The focalization coming from the rays reflected in the dome and the delays or focalizations not desired, which increase the reverberation time punctually.
- At the end of the stage four common wood panels are set out, making up an acoustic shell that is located in front of the apse. These panels can be provided with wheels in order to carry them. The panels (Figure 6) are around 7 meter high and around 1.74 meter wide, which remain in the centre (a) and 1.86 meter wide, which are outward oriented (b). With this measurement, the reflections coming from the apse and its possible focalizations are mitigated. It also allows for the early reflections for the audience, as well as for the performers who can be listened to themselves better.
- On the stage three sheets/plates of stained-glass are hang up with several slopes, making up another acoustic shell (Figure 6), so they do not hamper the vision, but the sound arrives before to the audience as the reflections are produced in full time and are directed to the audience in a more direct way.
- Moreover, in the modeling a fourth stained-glass sheet/plate is setup at the feet of the choir, under the balustrade at the access door. This plane has a slope which produces reflections of the sound rays on the stalls, fostering the first reflections in the last rows. The sheets have different dimensions: the three settled on the stage are about 7 meter wide and 1.91 meter (c), 3.10 meter (d) and 2.00 meter (e) deep; and the choir sheet/plate has the dimensions of 1.20 x 6.40 meter (f).

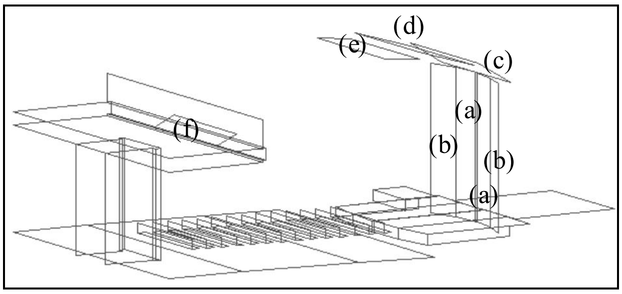

Figure 6. *Diagram with wood and stained-glass sheets.*

A change in the seats at the stalls is modeled that in the previous model for the acoustic fitting-out proposal was covered, including padding of half type, which is replaced with padding stall seats of bigger sound absorption. With this measurement, the acoustic absorption of the stalls is increased, where the reflections have been directed. This is the place where the audience is located. The number and rows of the stall seats remain as in the original state: 14 rows of 13 stall seats in each one of them.

In Table 1, the absorption values (α) for the octave of frequency between 125 and 4000Hz of the materials considered in the acoustical rehabilitation have been taken from the bibliography [7]. Also the surface used for each considered material is shown.

Material	**Surface (m^2)**	**Absorption Coefficient α**					
		125	**250**	**500**	**1000**	**2000**	**4000**
Plaster	*2898.04*	0.120	0.100	0.070	0.090	0.070	0.040
Ordinary wood	*592.65*	0.200	0.160	0.130	0.100	0.060	0.050
Parquet floor	*280.59*	0.200	0.150	0.120	0.100	0.100	0.070
Stained-glass sheets	*60.96*	0.180	0.060	0.040	0.030	0.020	0.020
Upholster stall seats	*73.43*	0.360	0.430	0.470	0.440	0.490	0.490
Carpet	*356.80*	0.130	0.060	0.130	0.200	0.460	0.700
Gathering velvet	*233.69*	0.070	0.310	0.490	0.810	0.660	0.540

Table 2. Absorption coefficient in frequency bands for each material.

The source and the receivers are previously considered, with their same names and characteristics. Once the church is modeled with the proposal of rehabilitation and the acoustic fitting-out proposal, we proceed to carry out the simulation of the room and to obtain the calculation of the acoustic parameters which characterizes the room. The simulation is made with a total amount of 20000 rays, taking into account in each case and setting a truncation time of 2 s in CATT.

5. RESULTS

The results obtained are shown below in a comparative way for the model simulated with CATT Acoustics [3] of Saint Agustine Church in Vinaròs in its original state and after applying the general proposal of restoration and acoustic fitting-out. Firstly, the calculated reverberation time is shown in three different ways (Sabine, Eyring and general or statistic), the level of the resonant pressure, the indexes of the D50 definition and C80 clarity, the STI and the RASTI parameters.

5.1 Reverberation time

The global reverberation time of the church is obtained in three different ways, taking into account the Sabine formula, the Eyring formula and the statistic way.

The statistic reverberation time before the restoration and acoustic fitting-out proposal is between the values 1.49 and 1.88s. Therefore, the reverberation time of the original church is high for the uses that we want. Moreover, the reverberation time at low frequencies is lower than the medium ones. In this case, a higher RT at low frequencies is needed in order to improve the Bass Ratio (BR) in the room. Also the statistic reverberation time proposed takes values between 0.96 and 1.36s. Therefore, the reverberation time of the church once carried out the restoration and acoustic fitting-out proposal would be the adequate, as these values would be very near the intervals from 0.9 to 1.3s. The reverberation time in low frequencies is also higher than the medium one, around 20% therefore this good fact contributes to give more acoustic warmth to the room. In the following figures 7 reverberation times are shown:

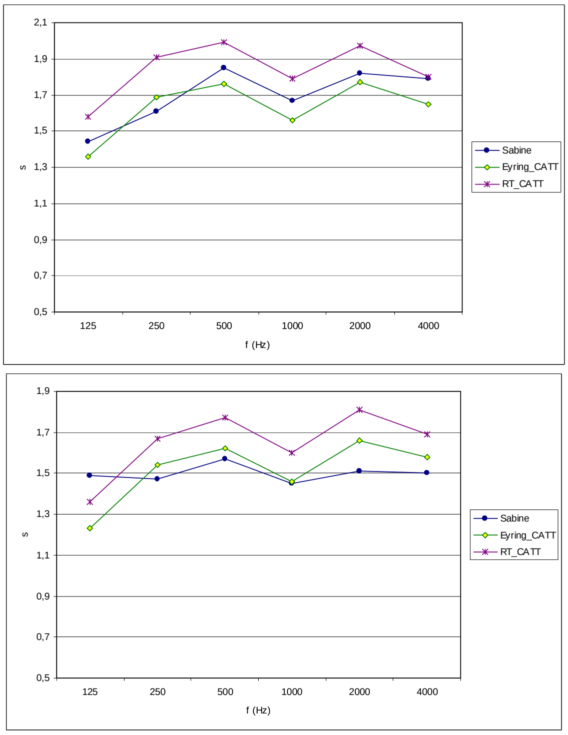

Figure 7. *Reverberation Times for "Sant Agusti" before (a) and after (b) the proposal.*

In the three cases, the reverberation time improves after the application of the proposal for rehabilitation and acoustic fitting-out. Reducing and adapting better to the optimum reverberation time of the church implies that it would be between 0.9 and 1.3s. So, in this way, the reverberation times before the proposal are between the values 1.31 and 1.88s and after it between 0.80 and 1.36s which confirms the improvement.

5.2 Pressure level (dB)

The pressure level L_p (dB) also experiments an important improvement after the acoustic fitting-out proposal, so it changes to adopt a more uniform distribution. In the former case, the pressure field has a similar behavior as in the free field. After the proposal, the field changes to be more homogenous in all the room. Therefore, pressure changes to adopt a diffuse field condition. This is shown in the values obtained for the 16 receivers, which ranges between 71.7 dB and 61.5 dB before the proposal and between 77.0 dB and 69.0 dB after carrying out the proposal, but also in the Sound Pressure Level distribution maps in Figure 9.

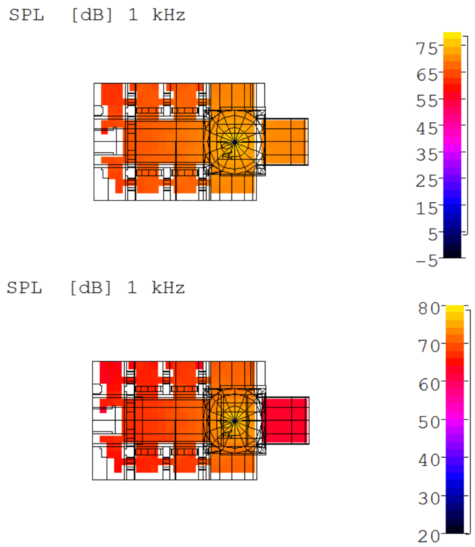

Figure 8. *General Pressure Level Distribution before (up) and after (down) the proposal*

5.3 Definition D50 (%)

Regarding the definition index, the changes in the results obtained before and after the restoration and acoustic fitting-out proposal are also noticeable. They do not take values between 12% and 43%, but instead between 39% and 79 %, which provide the church with better speech intelligibility. A room with these features can take, in the ideal case, values between 50% and 75%, what is achieved in most of the receivers, except from those in the middle part of the stalls. Figure 10 shows the maps of definition index D50 distribution for the 1000Hz band.

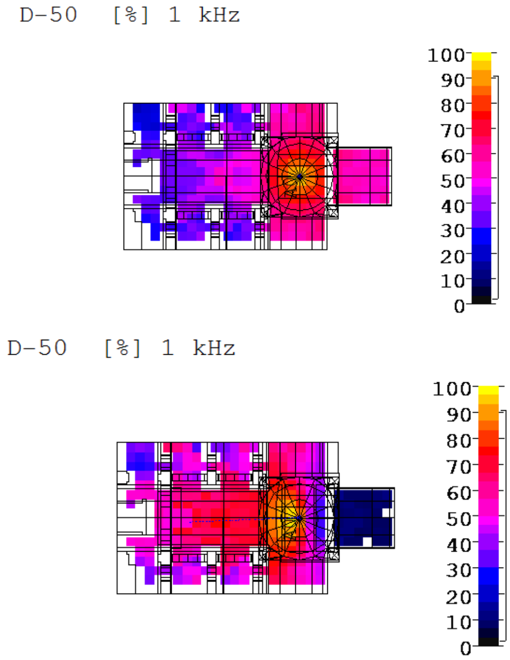

Figure 9. *Definition Index D50 distribution before (up) and after (down) the proposal at 1000 Hz.*

In Figure 9, a clear improvement in D50 values is observable. Generally, the best results for this index in the proposal of rehabilitation are shown in the receivers situated in the central part of the stalls. In the distribution, it is possible to observe that for the 1000Hz band, the largest part of the stalls present values that lower than 93%, while after the restoration and acoustic fitting-out proposal are not lower than 96%. Therefore, the sound of a musical performance (orchestra o chamber group) should be clearer and purer, so that each instrument is clearly distinguished. In this way, a listener could be able to distinguish separately all the notes in a quick musical passage played by the orchestra.

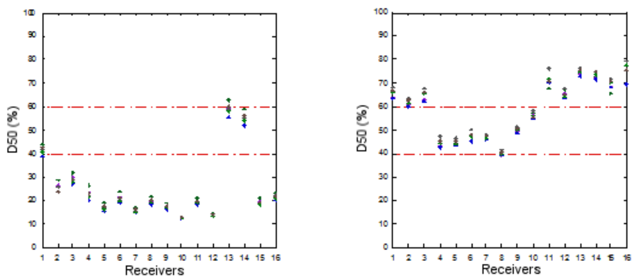

Figure 10. *Definition Index D50 distribution before and after the proposal.*

In Figure 10, the values of the definition index are shown for every receiver and for the frequencies in octave bands from 125 Hz to 4000Hz. It can be observed that before the proposal D50 values are lower than the recommended range (40% to 60 %) [4], for every receiver and every frequency. This is not the case for the receivers located on the stage, although in the case of the simulation after the proposal the D50 values are even higher in most cases.

5.4 Clarity C80 (dB)

The clarity index gives information about the improvement produced after the restoration and acoustic fitting-out in the general proposal. For a room like the Saint Agustine Church, the clarity parameter/limit would have ideal values from 3.1 and 9.1 dB. Before the proposal, the C80 index values in the 16 receivers are between -3 and +3 dB, whereas after the proposal the C80 values change to values between 0 and 9 dB, which produces an improvement in this parameter [4]. In Figure 12, the index C80 (dB) distribution is shown before and after the proposal for the 1000 Hz band.

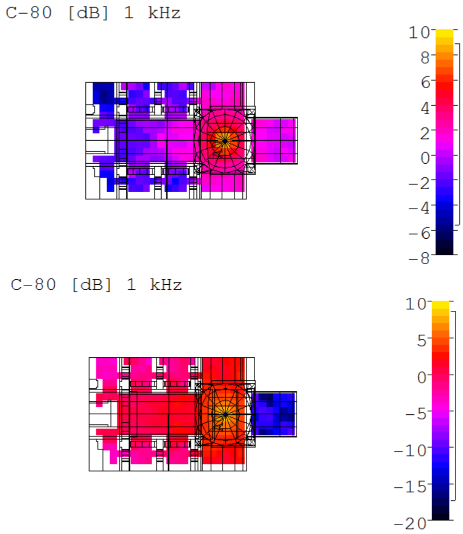

Figure 11. *Clarity index C80 Distribution before and after the proposal.*

Therefore, after applying the proposal in the church, melodies and harmonies (i.e. successive and simultaneous sounds) are perceived separately, allowing the separated audition of sounds produced by every musical instrument.

5.5 Speech Transmission Index (STI)

The STI index confirms a clear improvement in the values obtained after the restoration and acoustic fitting-out proposal. Before the proposal in the 16 receivers the values were between 0.45 and 0.61; then they take values between 0.57 and 0.76. That means that it goes from one poor acoustic qualification of the church to a good acoustic one. In Table II the values obtained for STI index in the 16 receivers can be seen, before and after the general proposal.

The STI index takes a half value of 0.52 before the proposal and after it is 0.65 which represents the clear improvement in the church intelligibility, increasing word clarity/definition, which is now a good acoustic room.

5.6 Rapid Speech Transmission Index (RASTI)

RASTI is devoted to explain the speech transmission for specific frequency bands. Figure 13 shows maps of the RASTI index distribution, before and after the restoration and acoustic fitting-out proposal.

The RASTI index before the restoration and acoustic fitting-out proposal does not exceed the 0.60 value in the stalls, while after the proposal the values range between 0.60 and 0.70. This index goes from sorting the room as a weak or regular to sort as a good one acoustically.

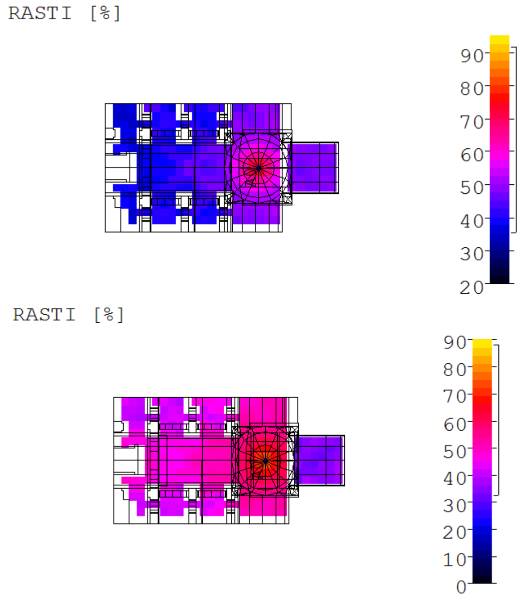

Figure 12. *Clarity index C80 Distribution before and after the proposal.*

6. CONCLUSIONS

The proposed corrective measures proposed to improve the acoustic quality of a room can be basically simplified in two: increasing the room absorption and diminishing the volume. In the global restoration and acoustic fitting-out proposal of Saint Agustine Church both solutions have been used.

On one hand, the church volume has been reduced, in order to diminish the reverberation time, using mobile curtains of velvet, which cover the dome and the arcades of the lateral chapels. Furthermore, establishing curved plates at the end of the stage, the apse area has also been eliminated. In this way, the room volume is diminished, but also shorter and early reflections are obtained in the audience. These reflections try to foster the reflections produced by the lateral walls and the set of sheets on the stage hanged from the dome or from its base. Also, reflections foster the acoustical quality of one room, producing a major sensation of intimacy.

Apart from this, the possible focalizations coming from the curved surfaces as the dome, the apse or the vaults of the chapels are avoided. They can be produced if the source is located near to r/2 (being r radius of the surfaces curvature).

Since in general terms, the part of a room occupied by the performers (usually the stage) should have more reflective areas around it than the part of the audience, the location of the wood plates and the stained-glass sheets which plan the sound towards the outside of the stage, but it also allows the performers to be listened to better. Therefore, a major intimacy sensation is provided to the church, in an acoustic and visual sense.

On the other hand, setting the velvet mobile curtains allows increasing the absorption in the church, by means of the padded stalls.

The proposal has been made in such a way that the actions performed in the church would not cause an irreversible impact on the original building. For this reason, it was always thought to respect the church structure and each solution has a reversible characteristic. This means that any element installed can be removed depending on the use.

The different combinations of elements can be used, depending on the musical style that is going to be performed. Combining the different elements which can vary the acoustic features, they can accomplish the desired conditions for each concert, audition or conference.

In this way, velvet curtains are movable, surfaces at the end of the stage can be supported by wheels and thus they can be moved comfortably and the stained-glass sheets can be removable. These sheets have been made of transparent stained-glass, because in this way it is possible to see the church through them and they are not an obstacle in the visual field. As the stalls seats were already covered, the only thing to change is the upholstery into another more absorbent. Finally, field measures should be taken to check the goodness of the proposal. Therefore this global restoration and acoustic fitting-out proposal could be verified with these measurements in order to validate the new model.

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