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THE ACOUSTICAL IMPROVEMENT OF HISTORIC MONUMENTS SAINT JOSEPH CHAPEL - A CASE-STUDY

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ABSTRACT
The Saint Joseph chapel in the city of Caluire et Cuire, France is an historic monument built in 1885 by the architect Sainte Marie Perrin. CSTB has been asked to study the acoustics of the chapel. The aim is to create an acoustic environment that permits non-amplified performances such as chamber music with the goal of a reverberation time of 1.5s.

Characterizing acoustic measurements have been done in the chapel. The measurement results are presented. They show a reverberant acoustic which is too high for classical music.

After analysis of the acoustic measurements, CSTB was asked to propose modifications to improve the acoustics. These proposed modifications have to take into account the constraints due to the historical shape and architecture of the chapel.

Two different solutions are proposed. The first solution is based on greatly increasing the absorbing surfaces and comes close to the ideal acoustic for classical music. The second solution allows the improvement of the actual acoustic with less absorbing material. Some diffuse and mode breaking surfaces are added. This second solution also includes a proposal for adapted music in this architectural and acoustical framework.

INTRODUCTION
The Caluire et Cuire municipality would like to renovate the St Joseph Chapel, which was constructed in 1885, so that non-amplified performances can be given. The chapel is no longer used for worship services. The main objective of this renovation is to transform the volume of the chapel into a space that is adapted for musical concerts and, more specifically, for chamber music or instrumental recitals. To achieve this goal, it will be necessary to reduce the excessive reverberant acoustics to a reverberation time of 1.5 s at mid-range frequencies (see Table I) and at the same time to respect the architectural constraints of the historic building.

Table I.- Reverberation time objective for the seated chapel

Frequency	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
RT	2.7 s	1.9 s	1.5 s	1.2 s	0.8 s	0.5 s

SAINT JOSEPH CHAPEL BEFORE RENOVATION
Characterizing measurements have been done before the start of the renovation.

Description
The chapel has a surface about 500 m² with an estimated volume of 8100 m^3. Its roof has an average height of 15 m. The nave is 30.50 m long and 16.50 m wide including an aisle on each side. The choir is 5 m long and 9 m wide. The roof is covered with painted plaster and has several arches above the aisles. The chapel is ornately decorated with painted and sculptured motifs. Woodwork has been installed on the lower part of the side walls. The Stations of the Cross are composed of painted fabric which has been mounted on the walls (see Fig. 1 and 2).

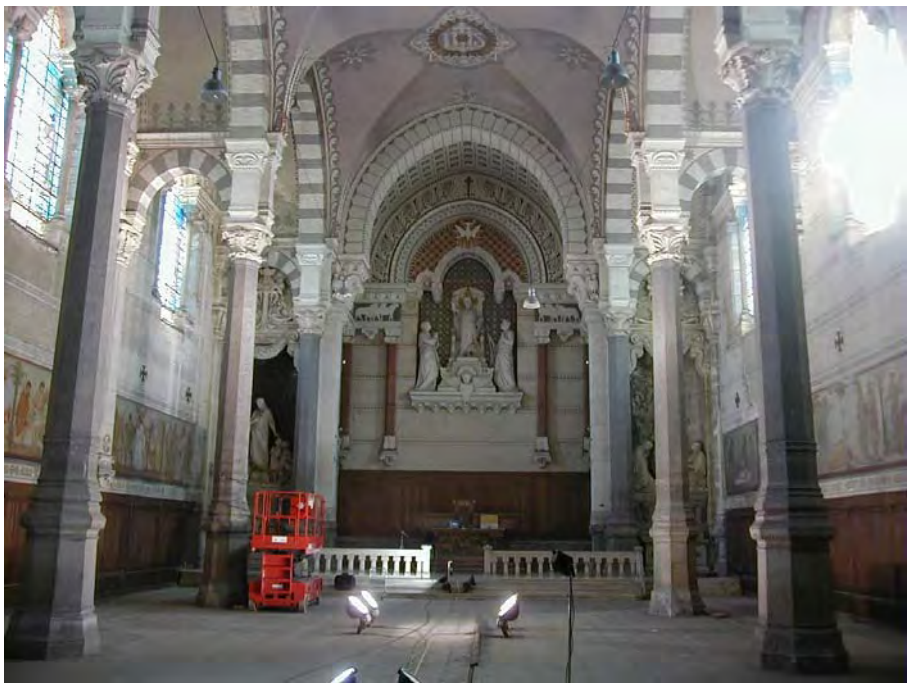

Figure 1.- Front view of the chapel

Figure 2.- Rear view of the chapel

Measurement Results

The measurements have been done with a standard MLS-technique with the chapel being empty and without seats for 3 loudspeaker and 6 receiver positions. The measurement results are given in Table II. Some typical measured echograms are shown in Fig. 3.

Table II.- Measurement results for the empty chapel without seats

Frequency	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
RT	5,6 s	5,2 s	5,5 s	5,4 s	3,7 s	2,3 s
EDT	5.0 s	4.9 s	5.3 s	5.1 s	3.5 s	2.1 s
C80	- 4.4	- 5.4	- 7.3	- 6.4	- 1.8	0.3
D50	21.2	16.1	9.2	13.2	31.8	40.8

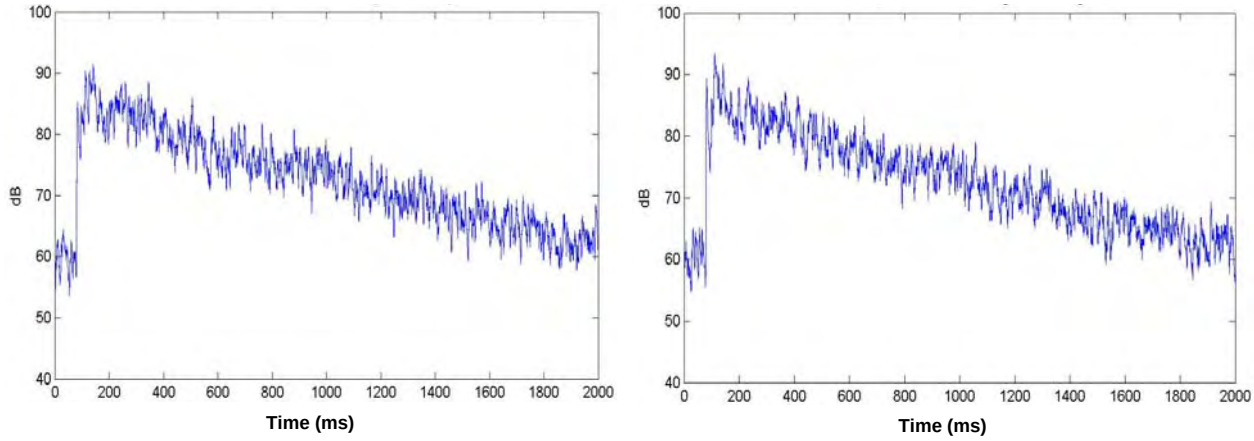

Figure 3.- Typical measured echogram (integrated 2.5ms) for the octave band 500 Hz and 1000 Hz

The reverberation time in the empty chapel is around 5.5 s at 500 Hz and, as originally suspected, much too high. This does not allow the performance of musical concerts in good acoustic conditions. The other criteria such as clarity and definition have typical values for acoustics with too much reverberation.

On the other hand, the echograms show smooth decay-curves which leads us to presume that the chapel has good acoustic qualities due to its architecture which is harmoniously composed of reflecting surfaces and diffuse elements including columns, capital, low-relief, high composed arches, and banisters. These qualities are hidden by the excess reverberation.

The seating capacity has been estimated to be 320 seats. Table III gives the estimated reverberation time for the chapel with 320 listeners. These values are still too high for classical music concerts and some architectural adjustments need to be made.

Table III.- Estimated reverberation time for the chapel with 320 listeners

Frequency	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
RT	4.4 s	3.8 s	3.6 s	3.3 s	2.6 s	1.8 s

PROPOSED MODIFICATIONS

The main objective is to add absorbing surfaces to reduce the reverberation time in coherence with the architectural constraints of a historical building. First a list of possible absorbing surfaces has been established.

List of possible acoustic treated surfaces

The surfaces which could be possibly used for an absorbing acoustic treatment are the following:

- Floor (total surface of 432 m^2): It is possible to add a textile covering (fixed or detachable) on all or a part of the floor. The seating section would be about 160 m^2.
- Walls: approximately 350 m^2 could be treated with absorbing material like absorbing plaster or curtains (not counting the parts of the walls used by the frescoes or the woodwork).
- Arches: in the same manner as the walls, 180 m^2 could be treated with absorbing plaster and additionally 9 m^2 could be treated with mineral wool placed behind the rosettes.
- Doors: 70 m^2 of movable curtain could be placed before the sacristy and below the gallery.

To decrease the reverberation time to 1.5 s at mid-frequencies (with listeners), it would be necessary to increase the absorption over 500 m² of equivalent absorbing surfaces. To decrease the reverberation time to 2 s at mid-frequencies (with listeners), it would be necessary to increase the absorption over 300 m² of equivalent absorbing surfaces. Two solutions have been studied:

1st solution: A maximum of absorptive surfaces
The following proposed solution has in total about 270 m² of equivalent sound absorbing surfaces:

- Floor : carpeting below the seats and the side aisles
- Walls (woodwork): Mineral wool behind the grooved woodwork
- Walls (Stations of the Cross): mineral wool behind the painted fabric
- Walls (below the stained-glass windows): curtains or moving absorbing panels
- Walls (around the stained-glass windows): absorbing plaster or absorbing foam
- Doors (before the sacristy and behind the husting): curtains
- Arches: absorbing plaster or absorbing foam
- Ceiling: Mineral wool behind rosettes

With this proposed solution and a fully seated chapel, a reverberation time of 2.0 s at 500 Hz could be achieved (see. Table IV and Fig. 4). Despite the large effort of adding sound absorbing material (even in technically difficult places) the goal of 1.5 s at 500 Hz cannot be reached. The acoutics obtained would be acceptable for some choral concerts, but not for chamber music.

2nd solution: A reasonable amount of absorbing surfaces
The following proposed solution has in total about 180 m² of equivalent sound absorbing surfaces:

- Floor : carpeting below the seats and the side aisles
- Walls (around the stained-glass windows): absorbing plaster or absorbing foam
- Doors (before the sacristy and behind the husting): curtains
- Arches: absorbing plaster or absorbing foam
- Ceiling: Mineral wool behind rosettes
- Diffuser: Add a maximum of large light fixtures or other diffusing elements

With this proposed solution and a fully seated chapel, a reverberation time of 2.4 s at 500 Hz could be achieved (see. Table IV and Fig. 4). Even if the decrease of reverberation will be clearly audible, again the goal of 1.5 s at 500 Hz cannot be reached.

Table IV.- Estimated reverberation time for the two proposed solutions

Frequency	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
RT (1st solution)	3.3	2.4	2.0	1.8	1.4	1.1
RT (2nd solution)	3.6	2.8	2.4	2.2	1.7	1.3

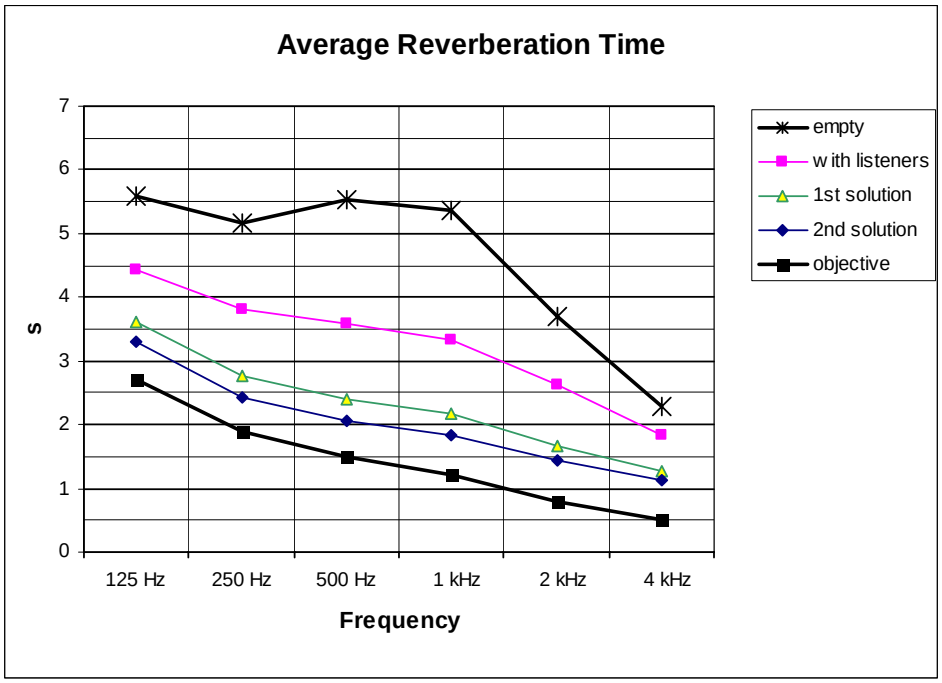

Figure 4.- Reverberation time of different proposed solutions for the chapel

What next? Discussion
The first proposed solution takes into account all acoustically treatable surfaces (884 m²). Even if it does not achieve the ideal objective it corresponds to a clear improvement. Choral music would have excellent acoustic conditions. To apply this solution, some heavy construction work would be needed including the especially delicate work for the installation of mineral wool behind the painted fabric of the Stations of the Cross and the application of the mineral wool behind the woodwork. It does not seem reasonable in terms of cost-effectiveness, especially since the desired chamber music performances will still not have good conditions.

By applying the second proposed solution the most easily treatable surfaces (walls, floor and arches) are treated. This solution achieves a large decrease of the reverberation and, although not optimal, the improvement would be easily audible. The valuable historic architecture of the chapel would be preserved. This solution should be accompanied by a study of which musical repertoire would be most adequate for this acoustic (see Fig. 5).

Some other solutions may be possible but for all these solutions the 320 seats will need to be as absorptive as possible and the arches should always be treated with absorptive material, diffusers or mode breaking surfaces such as transparent small reflectors because of their focalizing shape.

Figure 5.- Chorus recital in the chapel

CONCLUSIONS
The acoustics of the Saint Joseph Chapel in Caluire et Cuire has been studied. The measurement results show an excessive reverberant acoustic in the chapel. Its acoustics can easily be improved by adding some absorptive surfaces. Despite the maximum proposed acoustically treated surfaces, the goal of an adequate acoustic for chamber music performances cannot be achieved. A research of adapted repertoire such as choral recitals has been suggested.

Acknowledgement
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