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# ACOUSTICAL PARAMETERS DISTRIBUTION IN HISTORICAL BUILDINGS WITH A COMPLEX GEOMETRY

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## ABSTRACT
This paper presents an experimental investigation on acoustical parameters of several churches (XI-XVI sec.), mainly located in the historic centre of the city of Genova, all characterised by a longitudinal plan with two aisles and by a volume from 1500 to 20.000 m$^3$. Churches are often being used as auditorium without any technical knowledge about their acoustical response. Here comes the necessity of a wide investigation on the various acoustical parameters such as Clarity index, Definition index, Centre Time and various Reverberation Times (e.g. EDT, RT20, RT30), which can give more reliable information on the acoustic response of a close environment.

## 1 - INTRODUCTION
In recent times the development of more sophisticated measurement techniques allows for the evaluation of various acoustical parameters such as C50, C80 (clarity index), D50 (definition index), TS (Centre Time) and various Reverberation Times (e.g. EDT, RT20, RT30). These methods have been mainly applied for the design or acoustic correction of theatres and auditoriums. Literature regarding this type of environments is very wide, while only a few papers [1] have been published about the sound quality of other types of historical buildings.
A typical example where the acoustical characteristics have been disregarded is represented by the religious buildings. These structures have not been designed and constructed for acoustic purposes. The shape and the materials of the original projects and the following restorations were based on architectural criteria, taking into account not only space distribution necessities but also often harbour music performances. So comes the need of an investigation on the acoustic parameters of these constructions.
This work is a part of an experimental study and consists in the measurements in the more historically relevant churches located in the city of Genova in order to identify either the type of music could be played in each church or the eventual requirement of a space correction.

## 2 - SELECTED CHURCHES
The examined churches have various architectural styles and are all belonging to different periods, often very difficult to state, since their construction progressed over several centuries.
They were selected in accordance with same specifically interior geometric characteristics: longitudinal plan with two aisles. S. Maria di Castello has consistent lateral chapels on the left aisle only, the same chapels distribution is found in S.Agostino, but here half of them were closed by absorptive panels.
Smaller chapels are, instead, symmetrically positioned in N.S. Consolazione and SS. Annunziata. S. Lorenzo, the Cathedral of the city of Genova, and S. Matteo have few chapels on the left aisle only. All the others present no lateral chapels.

They all have various volumes so to be classified in two categories: small volume which varies from 2200 $m^3$ (SS. Cosma e Damiano) to 4600 $m^3$ (S. Donato) and big volume from 14500 $m^3$ (S. Agostino) to 26600 $m^3$ (SS. Annunziata). Moreover the Cathedral S. Lorenzo is characterised by a volume of 43500 $m^3$.

## 3 - MEASUREMENTS

Every church plan was preliminarily studied in order to define all the subspaces where to position the measurement points. The number of measurement points was varied with the church space distribution and the pavement area, from a minimum of 11 to a maximum of 27 points. The emission of an impulse source noise was recorded, with a digital recorder connected with the notebook board, for each measurement point.

This procedure was developed on site while the post-processing session was carried out in the laboratory by calculating the Impulse Response by means of an octaves real time analyser with Schoreder's backward integration [2]. The following acoustical parameters have been analysed:

*Intelligibility, distinctness parameters* [3]:**C50** and **C80** [dB], Clarity Index defined as ten times the logarithm of the sound energy arriving within 50 and 80 ms related to the energy coming in afterwards; **D50** [%], Definition defined as the ratio of the incoming sound energy within the first 50 ms to the total energy of the impulse.

*Reverberation parameters:* **EDT** [s], Early Decay Time; **RT** [s], Reverberation Time; **TS** [ms], Centre Time is the centre of gravity along the time axis of the squared impulse response.

## 4 - RESULTS AND DISCUSSION

This paper presents the results of the measurements in ten churches. A previous work [4] shows the acoustical parameters average over the different measurement points and the spectrum between 125 and 8000 Hz for each of the ten analysed churches. Little variations of the Reverberation Time among the different measurements points are observed in all the churches. This effect shows the lower influence of the direct than the reflected path of sound on the RT.

TS values between 50 and 250 ms, normally connected with a good suggested assessment, are measured on the whole ground area in the small volumes churches. Otherwise TS values referred to big volume churches get up to 450 ms.

The Clarity index, C80, appears to be one of the acoustical parameters more sensitive to the space geometry. Figure 1 shows C80 related to the source distance, respectively in the left aisles, the centre naves and the right aisles, of all the ten measured churches. In Churches with a big volume (the legend presents churches with a decrescendo volume order) increasing values of distance correspond to decreasing values of C80, which becomes progressively more distant from the optimum values for music ($-4 \leq C80 \leq +2$) [3]. In S. Agostino some acoustical treatments have been recently realised and therefore C80 values show a better steep.

Figure 2 illustrates the plot of C80 distribution related to the source distance of two churches with similar volumes but different space distribution: S. Maria di Castello, described above and S. Maria delle Vigne, without chapels.

The first (1130 a.C.) is simply decorated (Romanesque style) while the second presents a rich use of stucco and adornments (Baroque style). It can be observed that C80 of S. Maria di Castello decreases with the source distance more rapidly.

## 5 - CONCLUSIONS

This experimental study represents a preliminary investigation on a type of buildings, not commonly analysed in the acoustic field. Measurements on ten selected churches are presented, all characterised by a two aisles longitudinal plan, belonging to various historical periods and mainly located in the historic centre of the city of Genova.

Little variations of the Reverberation Time among the different measurements points are observed in all the churches. Small volume churches are characterised by TS values from 50 to 250 ms while in big volume churches TS reaches values up to 450 ms.

Measurements of C80 related to the source distance, respectively in the left aisles, the centre naves and the right aisles, of all the ten measured churches are presented. C80 values decrease with distance from the source and, more precisely, above 15 m they result to be out of the optimum range values for music. This is more evident in big volume churches, where the maximum length is around 55 m. In S. Agostino C80 values show a better steep, probably due to the recent acoustical treatments. A comparison between two churches with similar volumes but different space distribution, (with and without lateral chapels) illustrates a more rapid decrease of C80 in the one with a more complex geometry.

A further development on other types of religious building has already been scheduled.

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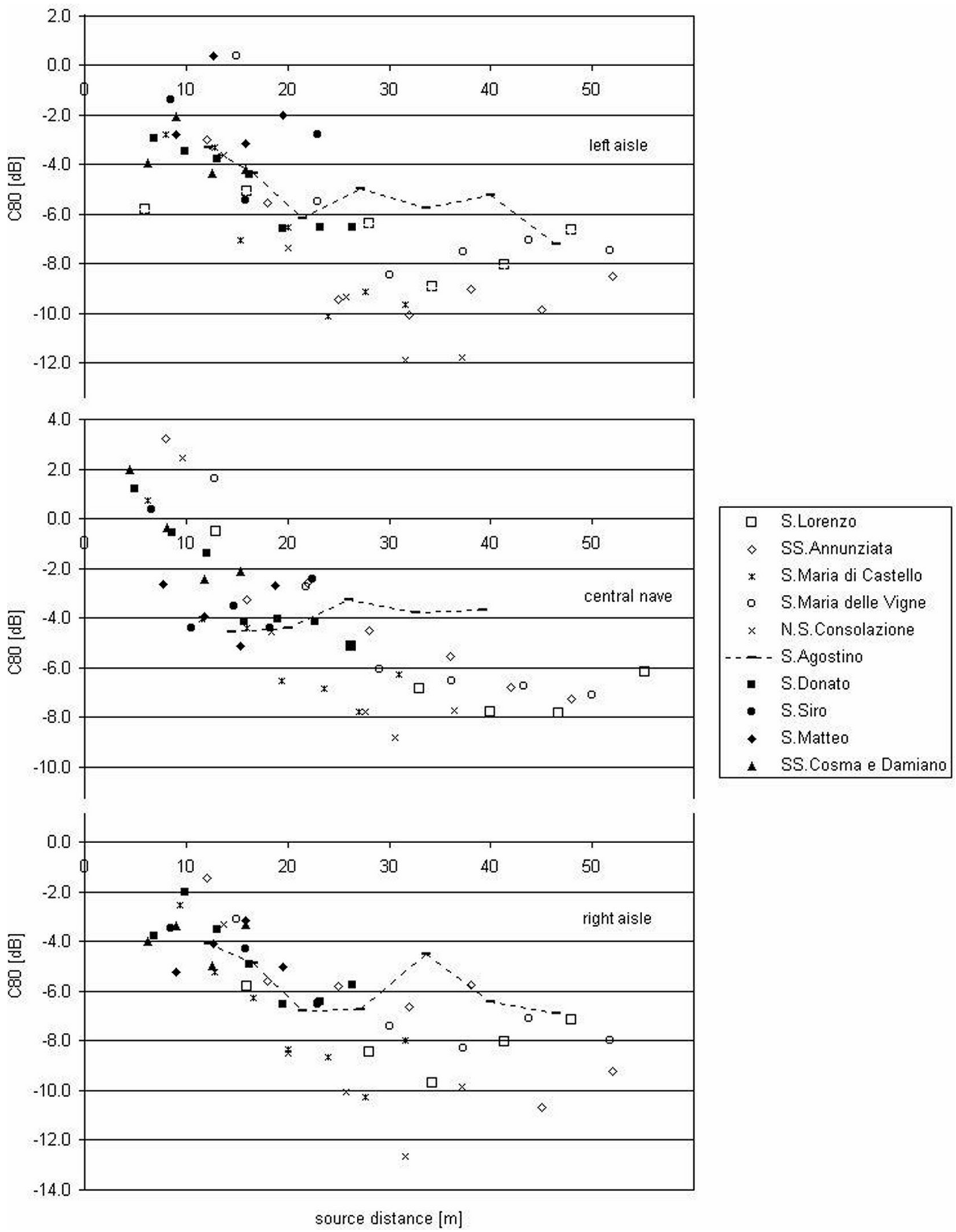


**Figure 1:** C80 related to the source distance respectively in the left aisles, the centre naves and the right aisles, of the all ten measured churches.

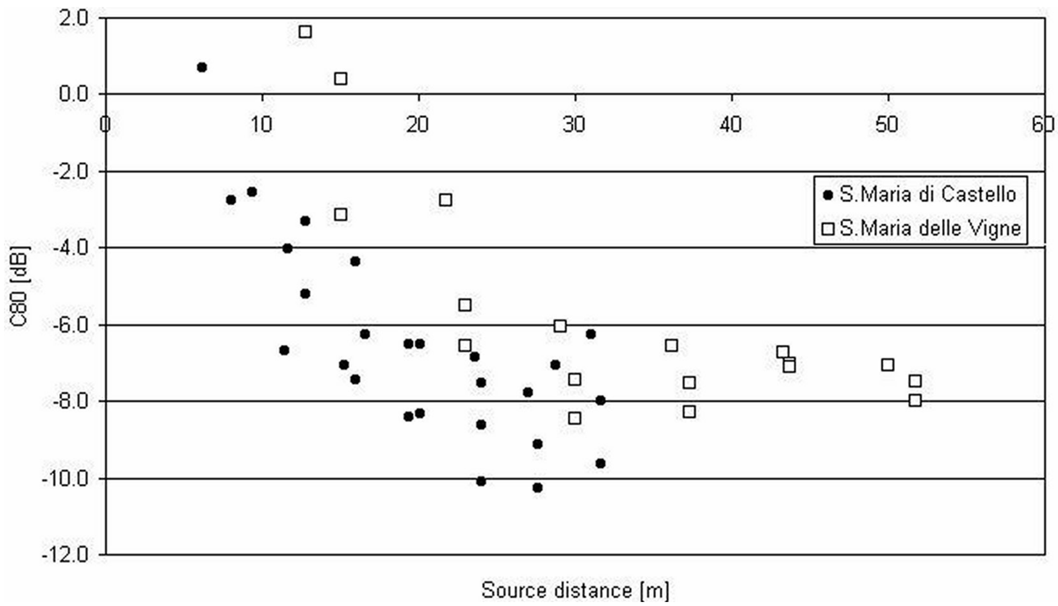


**Figure 2:** C80 distribution comparison of two churches.