

## Acoustic field in two Medieval Abbeys: relationships between acoustical parameters and architecture in Morimondo and Chiaravalle Abbeys

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The results of the acoustic investigations carried out in two worship buildings, with the same architectural structure, belonging to the same historical period, but restructured in a different way, are presented. Morimondo and Chiaravalle Abbeys are characterized by the same longitudinal plan, with one nave and two aisles. They were built in the respect of the principles of the Benedictine monastic order. Their indoor surfaces present a similar distribution of stone and bricks. However some differences due to the internal volume distribution (presence of walls partially obstructing the connections between aisles and nave, chorus wooden walls located in a different position in the nave, etc) and their influence on the acoustic field in the two Churches can be highlighted.

The reverberation time values in the two Churches have a similar slope as function of the frequency, while the absolute values for each octave band differ quite for half a second reverberation time. In Morimondo and Chiaravalle Abbeys the acoustic field results less reverberant than in other Churches of the same monastic order, previously studied: this effect can be added to the higher absorption coefficient of the walls that were built of bricks instead of stones as the other ones.

### 1 Introduction

In a wide investigation on Church acoustics, developed in the last twelve years by the authors (first papers [1,2], others [3,4,5]), more extended studies have been carried out in the last four years concerning the Cistercian Architecture [6,7,8].

The first steps of the research started in the South of France, where measures were developed in three famous Abbeys, called “the three Provençal Sisters”, located at short distance from one another [6]. Silvacane (1144 A.D.), Senanque (1148 A.D.) and Le Thoronet (1160 A.D.) Abbey present a building structure quite similar for plant, elevation, transept, vaults, nave, aisles, etc.. The presence of only smooth-faced stone let the sound reflect mainly at low frequency.

From an acoustical point of view, such environment is characterized by a strong resonance, which gives higher values of reverberation time than in other Churches of almost the same volume.

Besides, the measurements pointed out that - in a few cases - the Reverberation Time increases in the range of frequency of Gregorian chorus, the only kind of music played by Cistercian Monks.

The reform carried out by the Cistercian monks since the XII century, in the Benedictine Order, with the purpose to return to the strict Rule of St. Benedictus “ora et labora” had great influence on the lifestyle, the

liturgy, and even the architecture and the indoor decoration of the Abbeys.

The internal environments of the Cistercian Churches, according to the rule of an extreme simplicity of life, are poor of inside decoration. The building usually was erected using the materials available in the surroundings (stones or bricks).

At present, lack of documentation does not allow to realize which knowledge of fundamental principles of Acoustics the Cistercian architects had. The highlighted effects may come from a precise design or were only a “natural” support to the liturgical songs, as some authors suppose [9, 10, 11].

Quite in the same years of the Three Sisters construction, in Italy more Cistercian Abbeys were built, with the same attention to the “poor architecture” and simple features, but with a considerable presence of brick on the surfaces facing the indoor environment.

The Abbey of Saint Maria (Tiglieto Abbey, 1120 A.D.), was the first Cistercian community outside the French territory, developing in Italy the typical role of cultural and economic growth involved in the activities of the monastic order. It was subjected to continuous adjustments in the centuries and its last restoration was finished in 2000. The present layout is rotated of 180°: the altar is now in correspondence to the entrance of the original plan.

Two other Italian Abbeys of the same period are Morimondo, founded in 1136 and begun only in 1182, and Chiaravalle, one of the first and most important

Cistercian buildings, initiated in 1135 by St. Bernardo, the main representative of the Cistercian Order.

While Tiglieto Abbey was subdued to major restoration, the last two Abbeys have strong similarities as regards the plan and the reduced simplicity (than the French ones) of the interiors. Their inner surfaces are made of bricks, painted mortar and stones in a different proportion. Moreover, in Morimondo Abbey, at the end of the nave, a massive wooden chorus covers a wide surface, beside and around the altar. A wooden stage under the altar was made in recent times. In Chiaravalle Abbey the wooden chorus is located in the central part of the nave and its walls close two arches connecting the nave to the aisles at each side.

The presence of more absorbent materials on the inner surfaces of these two Abbeys (wood, bricks, frescoes) make their resonance lower than in the other Cistercian Abbeys, even if their volume is bigger.

In the present work the study on the acoustic field inside these two Churches is presented.

## 2 The Abbeys

Chiaravalle Abbey (Figures 1, 2) was constructed under the supervision of St. Bernardo, and, maybe, with a more accurate attention to the original architectural features required by the Benedictine rule. Its surfaces show only partially bricks on view: they are mostly covered with mortar. Most part of the columns is covered with mortar and is painted, even though in the deteriorated parts, bricks merge under the mortar. The transept is totally painted and also the surfaces over and behind the altar.



Figure 1: Chiaravalle – Interiors

Morimondo Abbey (Figures 3, 4), has a more sober aspect: its surfaces are mostly in bricks, and the large chorus is located behind the altar. It was designed in the same years as Chiaravalle, but its construction begun only 50 years after.



Figure 2: Chiaravalle – External view



Figure 3: Morimondo – Interiors



Figure 4: Morimondo – External view

Chiaravalle has a plan quite super-imposable on Morimondo (Figures 5 to 8) but the interiors are quite different. In fact it presents a higher vault under the steeple and the connections between the central nave and the aisles are partially closed in correspondence with the chorus, located in front of the altar, between the transept and the rest of the nave.

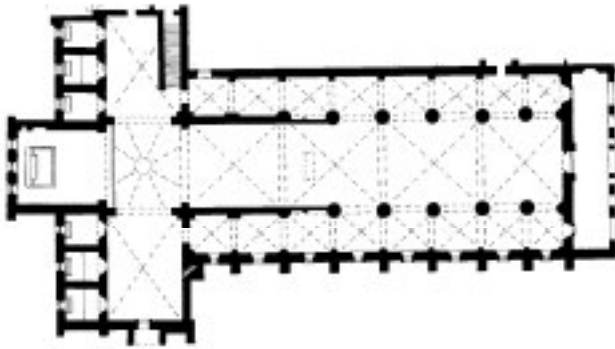


Figure 5: Chiaravalle - Plan

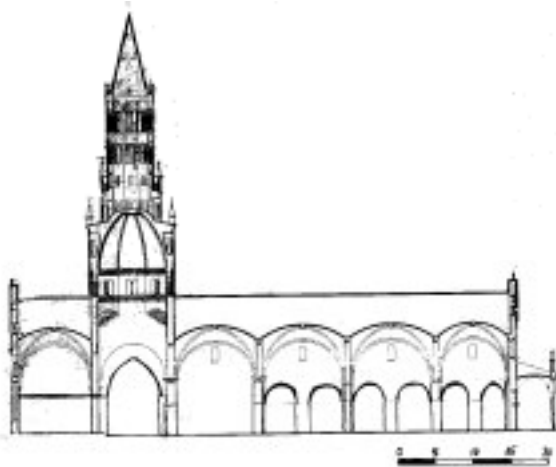


Figure 6: Chiaravalle - Longitudinal section

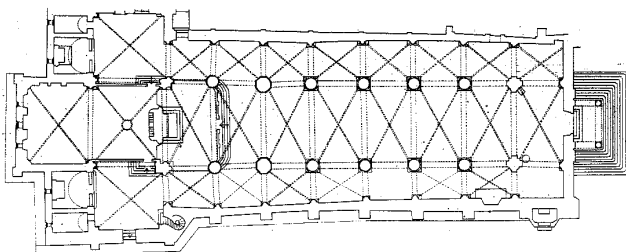


Figure 7: Morimondo - Plan

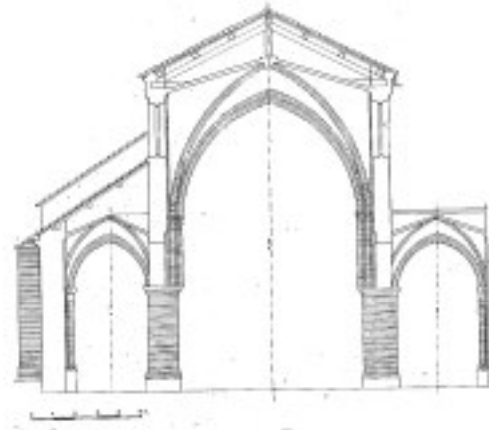


Figure 8: Morimondo - Transversal section

An approximate evaluation of the extension of the various surface materials is indicated in Figure 9.

The columns show the percentage of surface ( $S_{mat}/S_{tot}$ ) of stone, brick, mortar and wood in the two Abbeys.

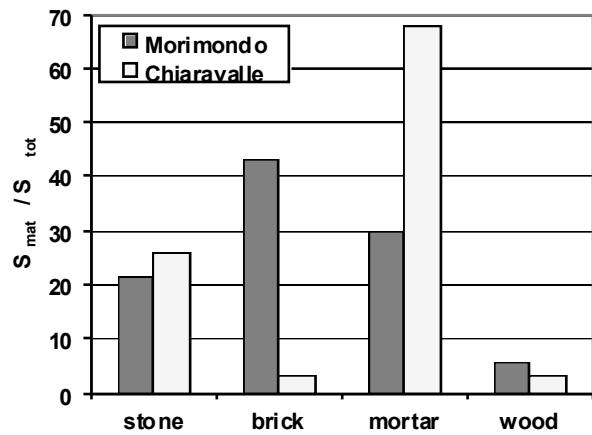


Figure 9: Surface materials

### 3 Measurements

For the measurements, a pistol-shot using blank cartridge was used as sound source (I.S.O.3382-1975). The room's response to the impulse given by the noise burst was sampled by a sound level meter with a 1/2" microphone and a filter set, connected to a computer for data registration.

The calculation of the Reverberation Time was based on the integrated impulse response method [12]. The measured parameters have been Early Decay Time (EDT), Reverberation Time (RT20, RT30), Clarity Index (C50, C80), Definition Index (D50) and Central Time (T).

The source was placed in front of the altar and the measurements were executed in 26 points for each

Church, uniformly distributed in the whole plan. The microphone at each location was placed at 1.20 m above the floor. The Churches were measured while unoccupied.

In the following Table 1 the main geometrical features and the mean values (125-4000 Hz) of the acoustical parameters are presented.

Table 1a: Geometrical features and mean RT values

Church	V [m <sup>3</sup> ]	S <sub>tot</sub> [m <sup>2</sup> ]	RT20 [s]
Morimondo	12110	1150	3.81
Chiaravalle	14970	1261	4.44

Table 1b: Mean acoustical parameters

Church	C50 [dB]	C80 [dB]	D50 [%]
Morimondo	-8.29	-5.26	15.34
Chiaravalle	-8.58	-6.50	13.74

In Figure 10 the mean RT values indicated in Table 1a are compared with the ones measured in longitudinal plan Churches (a nave with two aisles), A-dots [13,14], in central plan Churches, B-dots [15] and in the other Cistercian Abbeys [6,7,8], previously investigated by the authors. The other data (C-dots) were taken from the literature [16-21]. The X-axis indicates their inner Volume to plan Surface ratio.

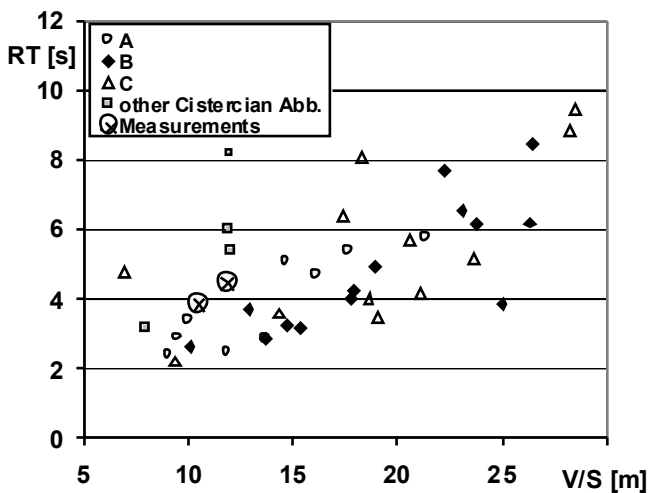


Figure 10: RT values versus V/S for Churches

All the Cistercian Abbeys are characterised by a longitudinal plan: Morimondo and Chiaravalle present RT values similar to the others (A-dots), while the three French Abbeys are more reverberant and show RT values higher than 5s, with a V/S ratio quite similar each other.

Also the Clarity Index values C80 referred to the Volume/Surface ratio remain in the area of the other measurements, as shown in Figure 11.

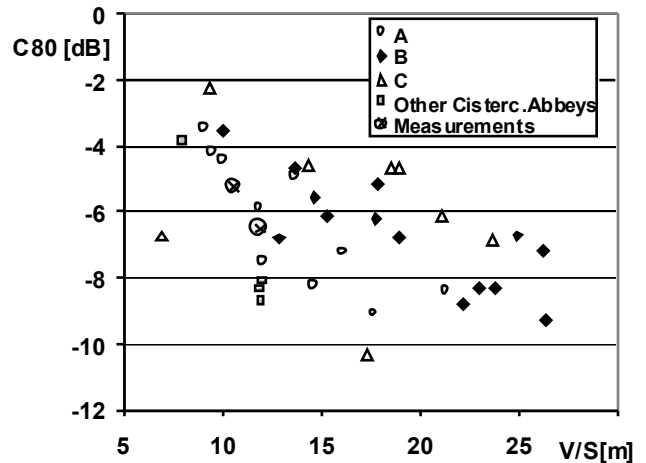


Figure 11: C80 values versus V/S for Churches

In Figure 12 the dependence of RT on frequency is highlighted for the two Churches. The RT assumes the same slope but the values measured in Chiaravalle Abbey are quite half a second higher than in Morimondo Abbey.

These values are significantly lower than the ones measured in the French Abbeys, mainly because of the different kind of surface materials, even if the volumes of these two Abbeys are larger (12-15000 m<sup>3</sup> to 7-1000 m<sup>3</sup>). Moreover, there is no sign of the RT increase in the frequency range of the Gregorian Chant ( $\cong$  250 Hz), as found in Le Thoronet Abbey [7].

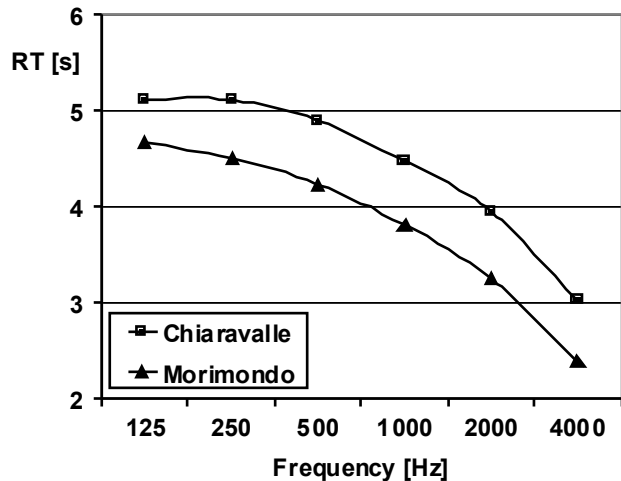


Figure 12: Mean RT as function of frequency

In order to investigate the influence of the materials and the different position of the wooden chorus in the two Abbeys, the RT values have been plotted as

function of the source-receiver distance for the nave and the two aisles separately (Figure 13).

In Chiaravalle Abbey, as previously said, part of arches connecting the central nave to the aisles is closed: in that area the sound cannot diffuse from the central body to the lateral spaces.

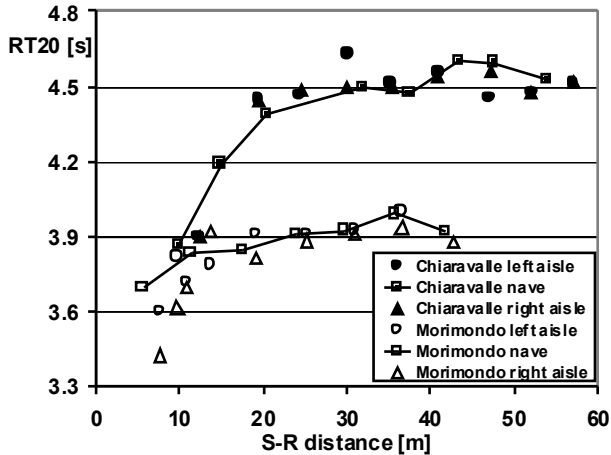


Figure 13: Mean RT as function of the Source-Receiver distance

This effect does not seem to make difference in the sound propagation along the nave or the aisles. A higher difference can be detected among the values near the source, in respect to the ones in the rear part of the Church. The presence of the chorus in the middle of the nave seems to absorb more the waves in this area. In the first 27-30 meters the RT varies between 3.9 s and 4.5 s. Over this limit, the RT remains quite constant towards the back.

In Morimondo Abbey this effect seems to be less evident as it develops in the first 15 m. But in this case the source, positioned near the altar, was 15.8 m far from the apse, while in Chiaravalle the altar was placed in its centre.

In Figure 14 the comparison has been made referring to the centre of the Apse (Apse – Receiver distance). The break line indicates the position of the source in Morimondo Abbey.

For the two Abbeys in the first 27-30 m from the Apse the RT varies more than at a longer distance. In the rear part of the Churches, a more homogeneous distribution of RT can be identified, far from the position of the source and of the wooden chorus.

In Chiaravalle Abbey, the measurement points in the nave were not all correspondent to the centre of the vaults. A few of them were chosen under the centre of the arches. They are indicated with a sub-imposed circle in Figure 14. The different position and the shape of the ceiling does not seem to affect the measurements locally.

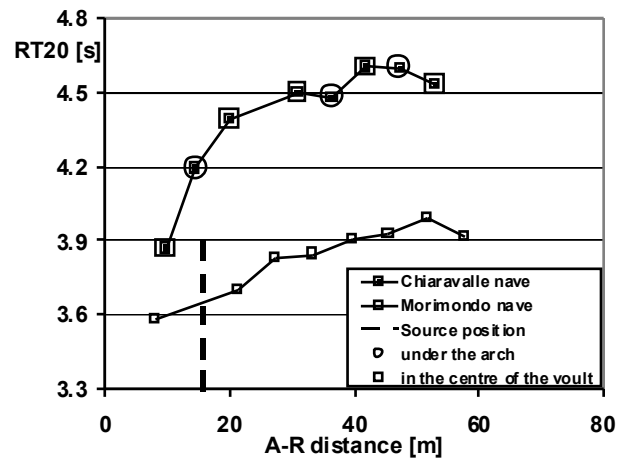


Figure 14: Mean RT as function of the Apse-Receiver distance

The C80 plot versus Source-Receiver distance (Figure 15) for the two Abbeys gives confirmation to the previous analyses regarding its distribution in longitudinal plan Churches [4, 14]. Also in this case no difference is shown among the measurements in the nave and in the aisles.

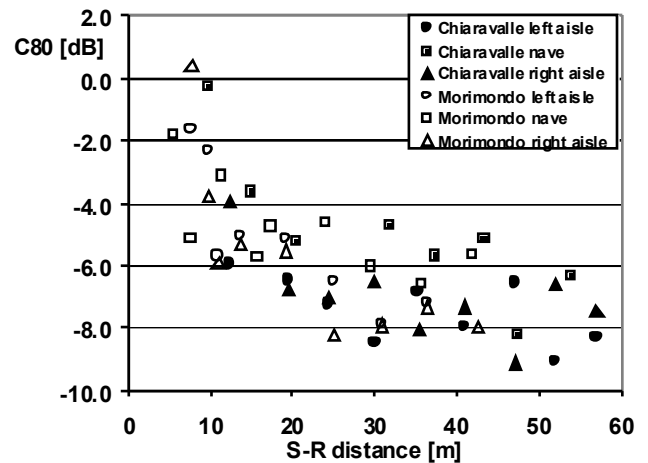


Figure 15: Mean C80 as function of the Source-Receiver distance

## 4 Conclusions

The analysis has highlighted some features of the acoustic field in two Italian Cistercian Abbeys: they present some aspects similar to the longitudinal plan Churches, but also some peculiarities that differentiate them from the others.

A first attempt to relate the architectural design to the acoustic knowledge of the Monks has not yet given significant results, due also by the poor documentation survived in the centuries.

## Acknowledgements

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