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OLD CHURCHES AS CONCERT HALLS: A NON-SABINIAN APPROACH TO OPTIMUM DESIGN OF ACOUSTIC CORRECTION

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INTRODUCTION

In Europe many cities are rich of ancient, beautiful churches and cathedrals; some of them are no longer used for their original purpose, and are converted to large general purpose halls. Moreover, also in still consacrated churches, some musical performances held, sometimes of non-religious kind.

In all these cases acoustics becomes a large problem: speech intellegibility is very poor, and can be improved only by massive, highly distributed sound reinforcement systems. Musical performances are generally bad, due to the lack of early lateral reflections, and to the presence of echoes and strong reverberation.

These three problems are mutually related: the side walls of the churches contain many openings, communicating with lateral naves or chapels; these spaces add volume to that of the main nave, increasing reverberation. The ceiling is very high, and usually curved or with domes; sound reflections coming from it are very late and not uniformly distributed. The back wall (usually corresponding to the facade of the church) is flat and reflecting, and causes echoes in a large part of the seating area.

The classic acoustic correction based on sound absorption of such spaces is not appropriated, due to the cost of treating large surfaces and volumes, and to the limitations imposed by the authorities to safeguard the historical buildings.

In the following, an alternative approach is presented, in which no absorbing material is added to the room; instead, reflecting panels are used to redirect the sound energy to the only absorbing surface still available: the seating area. This makes the sound field strongly non-Sabinian, and requires a more sophisticated approach, involving both scale models and computerized ray tracing techniques.

THE CHURCH OF S.LUCIA IN BOLOGNA

When in 1988 the University of Bologna celebrated the 9th Centenary of its creation, the academic authorities wanted a large "Aula Magna" to hold commemorative celebrations, and a lot of collateral performances like concerts, ballets and conferences.

The Church of S.Lucia has been unused and neglected for many years; in this occurence it was rescued for the enjoyment of the community, restoring its imponent architectonical environment; but, in the restoring process, no acoustical care was taken. A highly reflecting finishing of the wall and ceiling surfaces, an hard floor, and the choice to put as few new objects in the hall as possible, caused the reverberation time to grow beyond any acceptable limit.

A sound reinforcement system was installed, providing many small sound sources, located near the audience. This made possible to understand speech, but the source localization was lost. Indeed, the system can now only be used for conferences, not for live performances, due to its limited frequency passband.

After a number of classical concerts, subjective judgements were collected, both from skilled listeners and from the performers. They all judged the acoustics of the hall very bad, complaining about reverberation and echoes. Also if no one complained about the lack of lateral sound, this fact can be supposed by the general impression of *detachment* from the sound source. Furthermore, the performers were not happy to be placed in the middle of a large space, having no surface near them, that could give them more *intimacy* and the capacity to hear each other [1].

Obviously, after these initial problems, a sound absorbing treatment was suggested: but it was firmly opposed by the Authority for the Protection of Historical Buildings. Meanwhile, a lot of objective measurements were made. The analysis of the echograms digitally recorded in the hall pointed out the uneven temporal ditributions of sound reflections, with a large gap between the direct wave and the first reflections, and some strong echoes emerging from the long reverberating queue **(fig. 1)**.

PROPOSED TREATMENT

At the present in the main nave there exists a large steel structure, suspendend about 6m over the audience, sustaining both the lighting and the sound reinforcement devices. Such a structure is the only *modern* intrusion in the architecture of the hall. The structure is made of reticular beams, and is modular.

The design of the acoustic panels requires the reticular structure to be extended to cover almost all the floor area: under it, transparent methacrilate panels will be placed. These panels should be horizontal over the audience, and properly tilted over the sound source, in such a way to redirect the reflected sound over the audience.

Other panels will be placed along the side walls, to provide useful lateral reflections, by a proper inclination. The communication with the lateral naves will be prevented by transparent panels inserted in the openings. The echoes from the back wall will also be avoided, placing along it other panels with the same inclination as the lateral ones. **Figg. 2 and 3** show the two sections of the church, with the proposed layout of reflecting panels. The transparency of all the new surfaces does not degradate the architectonic appearance of the hall.

The position and inclination of all the panels have been accurately defined finding the image sources (for 3 source positions) and evaluating the area covered from the reflected sound and its delay after the direct wave. This evaluation is not sufficient to predict the acoustic benefits obtainable, and statistical acoustics (based on Sabine's theory) is not applicable, because it does not take into account the redirection of sound paths. Thus it was necessary to test the effects of this design through more advanced techniques: scale model and computerized ray tracing

SCALE MODEL EXPERIMENTS

A 1:100 scale model of the church was already available: it was built before the restoring of the building, to evaluate the aesthetic and visual effects of various seating layouts. Altough this model was not originally intended to provide a good acoustic simulation of the true hall, it was constructed of painted wood sheets, and the average absorption coefficient of such a material was not very different from that of the hard walls of the church (taking into account the frequency shift due to the Savart's Theorem).

The problem in testing the scale model was due to its high scale ratio, which required ultrasonic measurements: a spark plug was employed as the sound source, and an hydrophone was used as receiver. The impulses were digitized with an FFT analyzer (sampling rate 256 kHz), and the squared impulse responses obtained were directly compared in the two room arrangements: with and without the sound reflecting panels.

The results of this experimental verification were encouraging, showing the reduction of the gap between direct wave and reflections, and the disappearing of late echoes. Nevertheless, the insufficient frequency range of the instrumentation, and the air absorption, caused the estimation of reverberation times and other acoustical quantities related to the temporal distribution of the sound energy to be erroneeous in comparison with the experimental results collected in the true hall.

COMPUTERIZED RAY TRACING

The ray tracing technique has been used for many years, and is particularly useful due to its capacity to model also complex geometries with non-uniform sound propagation [2]. The computational time grows only linearly both with the number of surfaces and with the required lenght of the impulse response, so this technique becomes very efficient for very complex rooms with a long reverberating response.

The computer code employed was expressely developped for this study: it uses standard alghoritms for the isotropic generation of sound rays and for calculating the paths, but is innovative in the receiver alghoritm, that computes the sound energy density in the receiving volume (a sphere of radius 1m), taking into account the effective lenght of the path intersecating such a volume: this receiver is omnidirectional, is consistent both with a free field and a diffuse field analytic solution, and is not affected by numeric uncertainties caused by rays passing tangent to the sphere.

Fig. 4 shows the mathematical model of the room (96 surfaces). In it, 16 receivers are placed, corresponding to the same positions in which the experimental results were measured. A full simulation involves the tracing of 1 million rays, with a computation time of more than 100 h on a 33Mhz 386+387 computer. However, after the assignement of proper absorption coefficients to the surfaces, a good correspondance with the experimental data was obtained, both in terms of reverberation times and acoustic quantities (Clarity, Baricentric Time, Lateral Efficiency).**Fig. 5** shows one of these responses, calculated in the same point of fig. 1.

The comparison with the responses obtained with the reflecting panels added **(Fig. 6)** shows that they are effective both in reducing reverberation time (from 7s to 4s) and Baricentric Time (from ~300 ms to ~185 ms), and increasing Clarity (from -9 dB to -1 dB) and Lateral Efficiency (from 0.3 to 0.5).

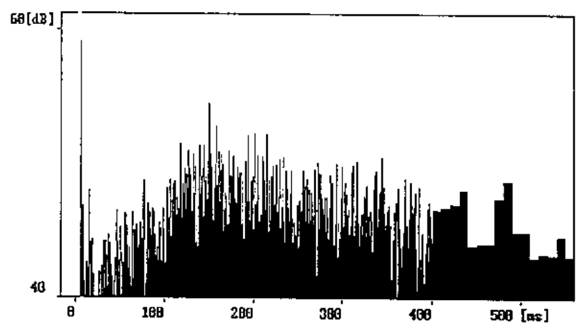

Fig. 1 Experimental Impulse Response - Church of S.Lucia

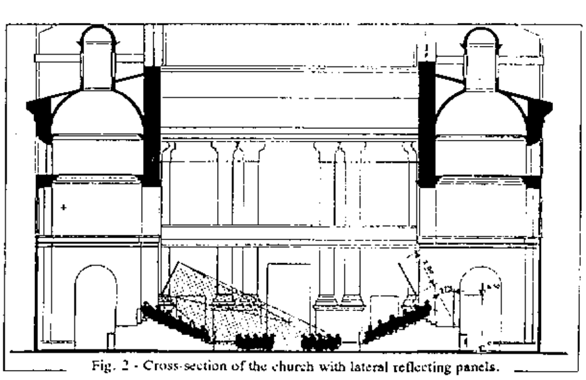

Fig. 2 - Cross-section of the church with lateral reflecting panels.

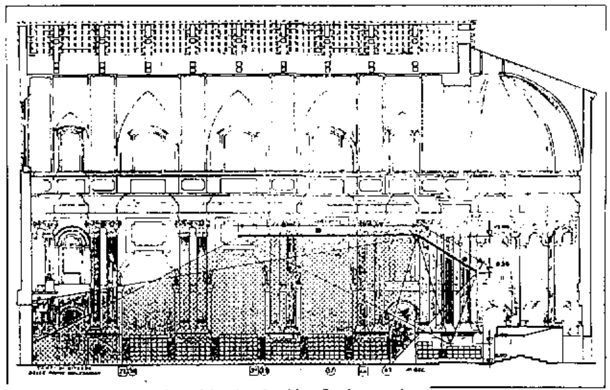

Fig. 3 - Longitudinal section of the church with reflecting panels

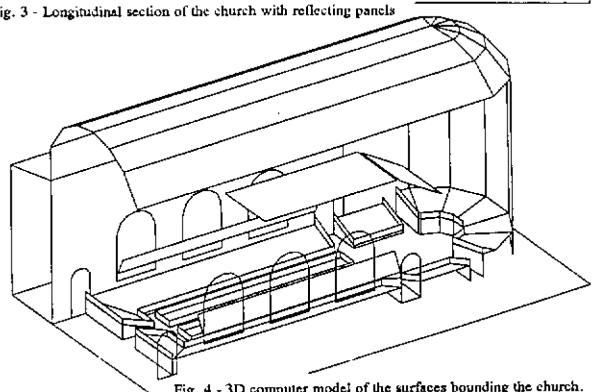

Fig. 4 - 3D computer model of the surfaces bounding the church.

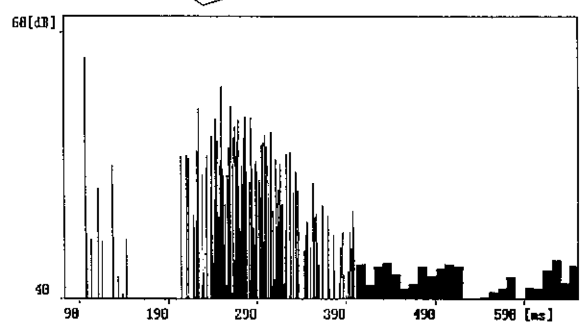

Fig.5 Numerical Impulse Response - Church of S.Lucia - before treatment

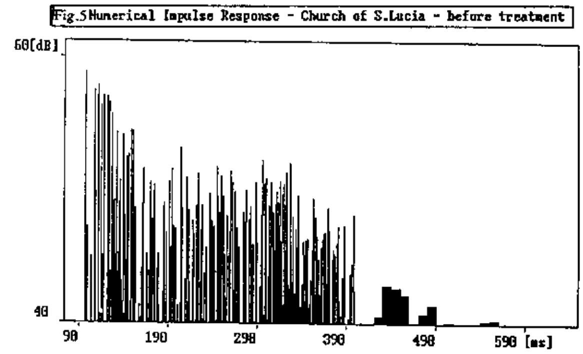

Fig.6 Numerical Impulse Response - Church of S.Lucia - after treatment

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