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THE ACOUSTIC FIELD UNDER THE DOME IN A CENTRAL PLAN CHURCH: MEASUREMENT AND SIMULATION

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Abstract

This paper is a further development of preceding studies [1, 2] on the acoustics of worship buildings. An experimental and computational investigation on a XXth Century Christian church, characterised by a central plan, a dome and a minor cupola above the altar is here presented. The experimental session has been carried out with the Impulse Response Analysis measurement system in 12 measurement points. A pyramid tracing software, validated with the experimental results, has been implemented in order to analyse the effect of the dome. A previous work [3] illustrated that the minimum Reverberation Time is reached at the centre of the dome, therefore the spatial distribution of RT is here more deeply considered. Further on, the effect of the presence/absence of the second cupola on the increasing/decreasing of RT in the church has been investigated. The potential behaviour of the dome and cupola as coupled volumes [4, 5, 6] has been evaluated, analysing also the variation of the absorbing coefficient of the surrounding surfaces (walls, pavements, dome and cupolas). A comparison with a more geometrically simple model has been carried out, aiming to define a possible general tendency of RT distribution in similar architectonic configuration.

INTRODUCTION

The subject of the investigation is the church of Santa Zita in Genoa, Italy, which construction started in 1874 by the donation of the Duchess Galliera, only in the 1899 was benedicted, but not completely finished. In 1926 the construction of the cupola, completely in concrete, was started and in 1929 it was completely finished. The church is characterised by a circular plan, with a diameter of 24 m, surrounded by 8 rectangular chapels with equilateral arches, 2 of them, one in front of the other, have also a semicircular apse, and one, where the altar is positioned (figure 1), has a dome with a circular base with a volume of 596 m^3, and a drum of 5 m of height. Above the circular plan is erected the big dome, (figure 2), of 7061 m^3 of volume, a drum of 7 m of height, with a lantern reaching the maximum height of 39.95 m. Both the domes are in armoured concrete, the entire pavement (surface=1107 m^3) is in marble. Due to the period of construction the interior is poorly decorated and it is entirely in plaster. On the pavement there are some wooden benches.

Figure 1- Interior view of the altar

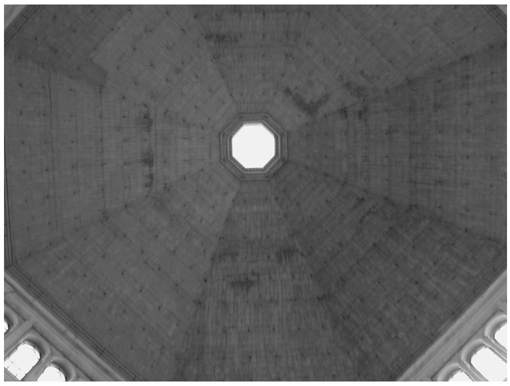

Figure 2- Interior view of the main dome

MEASUREMENTS

For the measurement campaign, the source of sound used, in accordance with I.S.O.3382-1975, for high values of RT, was a pistol-shot with blank cartridge. The room's response to the impulse given by the noise burst was sampled by a chain of instruments, consisting in a sound level meter with a ½" microphone and a filter set, connected to a computer for data registration. The method used to calculate the Reverberation Time (RT20, RT30) was based on the integrated impulse response method [7].
The source was placed in front of the altar and the measurements were executed in 12 points, uniformly distributed in the whole plan of the church (figure 3). The microphone at each location was placed at 1.20 m above the floor. The church was measured while unoccupied. For the selection of the measurement points, particular attention was given to the effect of cupolas. Therefore the central point and the four surrounding points were additionally chosen.
In order to analyse the effect of the dome experimental values of RT as a function of the source-receiver distance along the two diagonal and the transversal directions are shown in figure 3. To study the spatial distribution of the acoustical parameters 12

measured points were examined. From the measurement campaign results, it is evident that, at the centre of the dome, the minimum value of RT is reached.

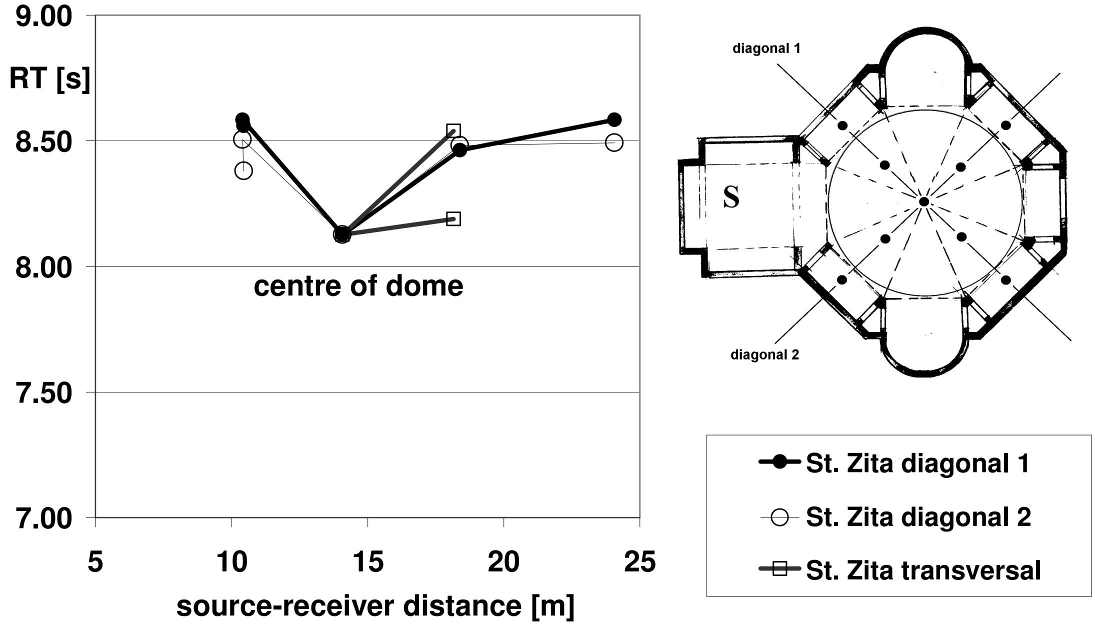

Figure 3 – Experimental values of RT (125 Hz – 4 kHz) as a function of the source-receiver distance along the two diagonal and the transversal directions

COMPUTATIONAL SYSTEM

For the computations, a pyramid - tracing model [8] has been applied, validated by means of the results of the measurement session [3]. Two digital version of the same church were applied: a simplified one, with only a cylinder and a dome having the same diameter of the real St. Zita, represented in figure 4, and a complex one, more similar to the real church, represented in figure 7. The aim of having built two digital models is to analyse the possibility of defining a potential general tendency of RT distribution in similar architectonic configuration, but less articulated than the real one.

The simulation's receiver positions correspond to the 12 measurement points at 1.7 m of height from the floor. The validation was carried out with an iterative method: the absorption coefficient values were assigned to the various surfaces in order to have the output parameters of the model to fit the experimental reverberation times. In details, for the analysed church, due to the big extension of plaster surfaces, their absorption coefficient resulted more difficult to detect and therefore were found out by a succession of simulations. The absorption coefficient of surfaces constituted of marble (pavement) and wood (benches) were provided by literature experimental

values and were taken as fixed values, while the ones referred to all the others plaster surfaces, were found out by the iterative method.
Both the models were implemented, and among the 12 points mean values of RT in the frequency range 125 Hz - 4 kHz, a difference between experimental and simulation results varying from –0.04 to 0.51 s for the simplified model and from –0.1 to -0.43 for the complex model. Simulation results are rather good for the whole range of measurement points. In both the models there is a minimum of RT at the centre of the dome, like in the campaign (figure 3), even thought in the simulation the behaviour is more flat than in the experimental measurements.

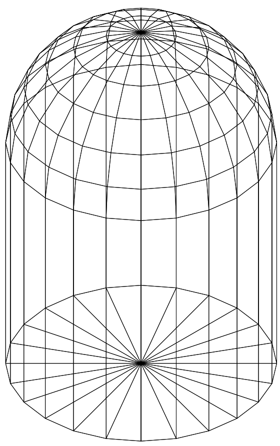

Figure 4 – Simplified model for simulation

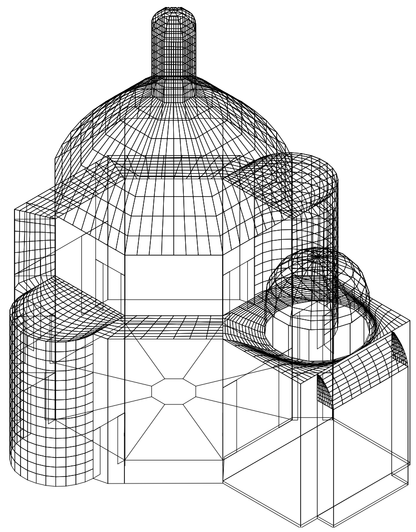

Figure 5 – Complex model for simulation

Values of the various absorption coefficients are reported in table 1. There is a slight difference of the absorption coefficient of the plaster since to fit the same experimental values the simple model, with a less articulated surfaces had to have higher values of absorption.

Table 1- Absorption coefficient of the surfaces considered in the simulations.

	Frequency [Hz]					
Material	**125**	**250**	**500**	**1000**	**2000**	**4000**
Marble (simple model)	0.01	0.02	0.03	0.03	0.04	0.01
Wood (simple model)	0.11	0.12	0.12	0.12	0.1	0.1
Plaster (simple model)	0.075	0.075	0.081	0.1	0.152	0.075
Marble (complex model)	0.062	0.07	0.067	0.062	0.071	0.095
Wood (complex model)	0.11	0.12	0.12	0.12	0.1	0.1
Plaster (complex model)	0.062	0.07	0.067	0.062	0.071	0.095

Effect of the dome

In acoustically coupled rooms reverberation times are fairly different from independently measured reverberation times without mutual power flow interactions through coupling areas or separating walls. In general, the reverberation time is assumed to depend on the sum of the volumes and on the total absorption of the coupled rooms, unless the total absorption of the receiver room is much higher than the coupling area. In this case the aperture behaves like an open window, and the coupling is less effective.
In order to analyse the outcome of a possible coupling effect between the volume of the dome and the volume of the rest of the church, the simplified model was applied. Various simulations were carried out changing the absorption of only the dome surfaces and maintaining unaltered the absorption coefficient of the cylinder surfaces in the simplified model. In figure 6 the RT values at 1000 Hz in the different 12 measurement positions are shown. It can be noticed that the minimum of RT is reached at the centre (position 8) for values of absorption coefficient of the dome up to 0.3. For values of absorption within 0.4 and 0.7 there is no influence of the geometry in the spatial distribution of RT: the RT values are the same in all the measurement points. Then, for absorption higher than 0.8 there is a radical changing in the behaviour: the minimum is no more reached in the centre (position 8) but in a position lateral the source (position 7). The same minimum value is also reached in the position 1, which is also symmetrically lateral the source.

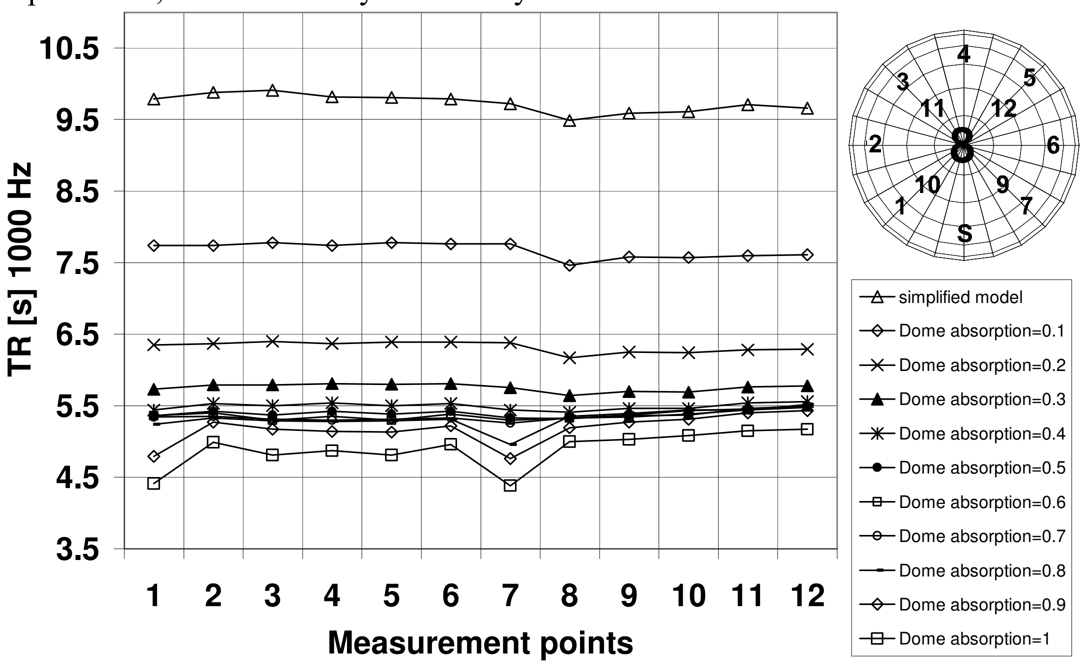

Figure 6 – Simulation values of RT (1000 Hz) with the simplified model, in the 12 measurement points in different conditions of absorption coefficient of the dome

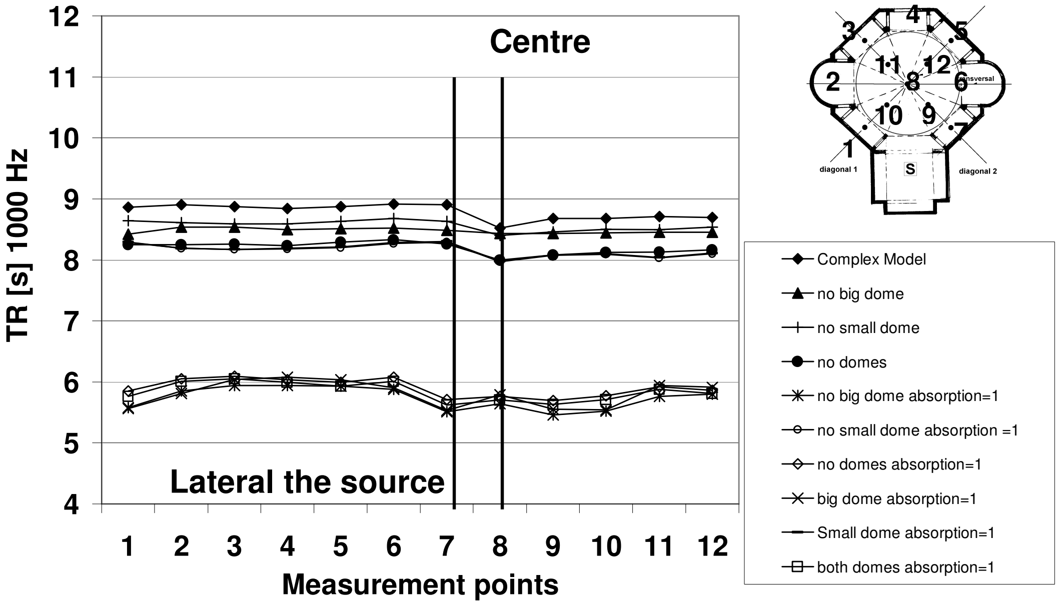

Figure 7 – Simulation values of RT (1000 Hz) with the complex model, in the 12 measurement points in different conditions of absorption coefficient of domes and screens

The same scientific approach was applied to the complex model, where two domes are present: the big one (figure 2) of 7061 m^3 of volume, and the small one, above the altar, with a volume of 596 m^3. Three type of absorbing material were employed for three geometrical configurations. Figure 7 shows the RT values at 1000 Hz in the 12 measurement positions for different simulations. A screen, having the same absorption coefficient of the plaster (table 1), was placed, first, under the big dome (simulation "no big dome"), second, under the small dome (simulation "no small dome"), and finally under both the domes (simulation "no domes"). Then the same screen, but having an absorption coefficient of 1 was again placed, under the big dome (simulation "no big dome absorption =1"), under the small dome (simulation "no small dome absorption =1"), and under both the domes (simulation "no domes absorption =1"). The third and last configuration was realised by increasing the absorption coefficient of the surfaces of the big dome (simulation "big dome absorption=1"), the small dome (simulation "small dome absorption=1") and both the domes (simulation "both domes absorption=1").

It can be noticed, that also in the complex model, the minimum of RT is reached at the centre (position 8) for low values of absorption coefficient. This confirms the effect of the dome when the surfaces absorption coefficients are lower than 0.3, result that was found for the simple model. However, it also proves the effect of a central plan, since with simulation with the screen, and therefore in absence of domes, the minimum is reached at the centre anyway. In addition there is a validation of the behavior in comparison to the simple model, with high values of absorption: the minimum is no more reached in the centre but in positions lateral and closest to the source (position 7 and 1). This effect is probably due to the presence of the source: with high values of absorption, the RT is lower in the points next to source. Changing the position of the source and replacing the 12 microphones, with the same symmetry in the simple models (figures 8 and 9), validated this behavior. Results of RT (1000 Hz) simulated by means of the simple model, as function of the various measurement points in high conditions of absorption coefficient of the dome (0.7, 0.8, 0.9, and 1) is shown in figure 10 with two position of source (source A and source B). It is evident that in both source configurations there is a minimum in the distribution of RT in the points 1 and 7 which are always the points with a minor source receiver distance.

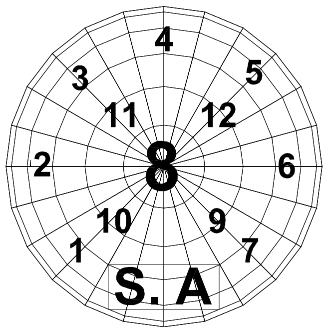

Figure 8 – Source position A

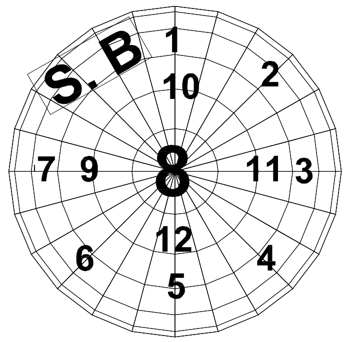

Figure 9 – Source position B

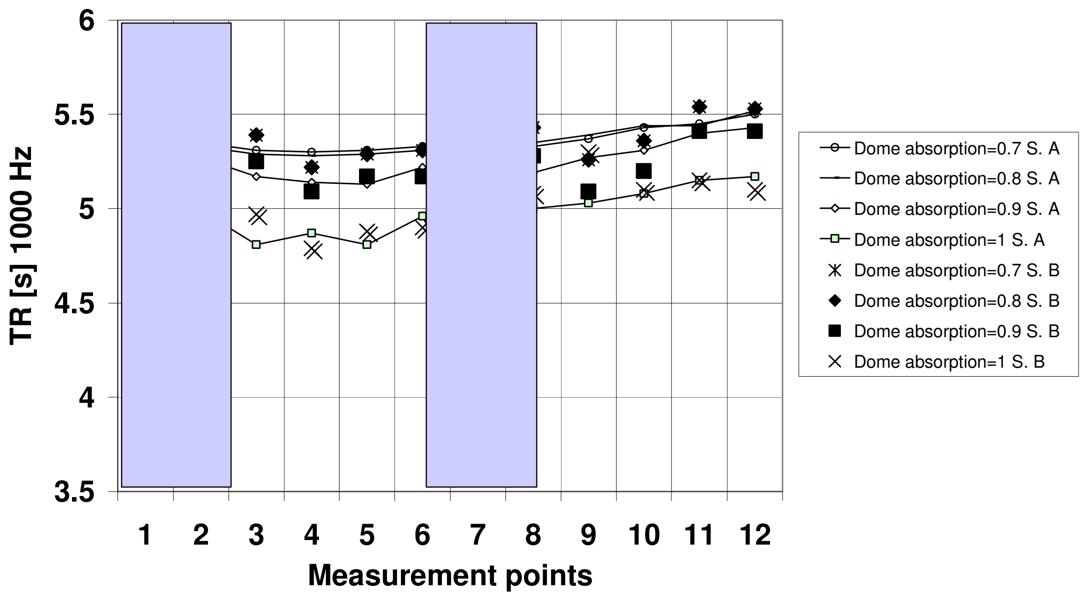

Figure 10 – Simulation values of RT (1000 Hz) with the simple model, in the 12 measurement points in high conditions of absorption coefficient with two source position

CONCLUSIONS

An experimental and computational investigation on a XXth Century Christian church, characterised by a central plan, a dome and a minor cupola above the altar, was carried out. In order to analyse possible effects of the domes as coupling volumes, two digital models were applied, a simple and a more complex ones. Either in measurement results and simulation, with both models, a minimum of RT is reached at the centre in plan under the dome. For values of absorption coefficient of the surfaces constituting the dome within 0.4 and 0.7, the RT values are the same in all the measurement points. There is no influence of the geometry and therefore of coupling effect in the spatial distribution of RT. In addition another effect was found for higher values of absorption coefficient (above 0.7) of the dome: the minimum of RT is no more reached at the centre but in the points closest to the source. This was found by implementing the simple model, the complex model and also by changing the source position in the simple model. Further experimental campaigns will be carried out on central plan churches characterised by surfaces having higher values of absorption coefficient, such as of the Baroque period.

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