COMPARING THE ACOUSTICS OF MOSQUES AND BYZANTINE CHURCHES

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ABSTRACT:

This work is based on the activities of the Department of Engineering of the University of Ferrara (Italy) within the CAHRISMA Project (*EU Contract ICA3-CT-1999-00007, Conservation of the Acoustical Heritage and Revival of Sinan`s Mosques Acoustics - CAHRISMA, 2000 – 2003*). The project deals with the means of qualifying and enhancing the acoustical heritage of mosques and byzantine churches. The group carried out the acoustical measurements inside a selected group of spaces of worship and systematically collected their primary acoustical data. By successive processing, the main features of the two types of enclosures can be described and compared. The transition from the acoustics of a byzantine church to that of a mosque is also analyzed thanks to the architectural similarity between the former St. Segius and St. Bacchus church in Istanbul (now Kucuk Ayasofia mosque) and the Basilica of St. Vitale and St. Agricola in Ravenna, Italy.

1. INTRODUCTION

Within the CAHRISMA project (Karabiber 2000) six spaces were selected and acoustically measured, namely: mosques - Suleymanie, Selyimie, Sokullu and the byzantine churches - St. Irene, St.Sofia (now museum), St. Sergius and St.Bacchus. The measurements in Istanbul took place in two separate sessions. The first at the end of May 2000 (Sokullu and SS. Sergius and Bacchus) and the second in October 2000 (Suleymanie, Selyimie, St. Irene and St.Sofia).

The measured mosques show heights comparable with the plan dimensions and are composed of a wide central volume, surrounded by partly uncoupled galleries and balconies. These buildings have a huge slightly lowered dome, resting on pillars and on inferior orders of half domes. The materials covering the ceilings and walls are decorated plasters, marbles, stone and ceramics, all of them scarcely sound-absorbing. On the contrary the floor, though made of stone, is completely covered with carpets.

Regarding the byzantine churches, they have an octagonal plan (or greek cross plan in the case of St. Irene) and present a wide gallery on the sides surmounted by a high balcony. All of them are covered by a dome of variable height. The interior finishing materials differ from mosques and also from one church to the other. In fact, while in the church of St. Sofia many surfaces were covered by mosaics or marble, in the church of S. Irene the walls and ceiling are made of stone and bricks. Inside St. Sergius and St. Bacchus most of the lateral walls are finished with painted plaster. The volumes of selected environments range between the 5700m^3 of Sokullu and the astonishing figure of 180000m^3 for St. Sofia.

To the original group of measured spaces, also the byzantine church of S.Vitale was later added though not expressly scheduled in the project. This was done because of the architectural similarity between this byzantine church with the church of St. Sergius and St. Bacchus. The main difference between these two last worship spaces is that St. Vitale, having a volume of nearly 25800m^3, is still equipped with a reflective floor as it was in its origin. On the contrary the church of SS. Sergius and Bacchus is today used as a mosque with a sound absorbing floor. For this reason its acoustical characteristics are better explained and consistent if it is examined as a mosque, and this will be actually done below.

In the following the results of the acoustical measurements in the selected rooms will be resumed and commented in order to present the sound fields in mosques and byzantine churches.

2. THE ACOUSTICAL MEASUREMENTS

2.1 The positions of the sound sources and of the receivers

Inside each space of worship a grid of receivers was set with attention to the covering of the most significant areas occupied by the congregation and by the leaders. Typically inside mosques three positions for the sound source were examined, namely *Mimbar*, *Mihrap* and *Mahfel*. These correspond to the locations of the main singer during the services, and are far apart from each other. It is important to obtain this sampling of the source because the liturgy is strictly connected to the singers' position.

As regards the byzantine churches generally three positions for the sound source were chosen, all of them located in the area close to the altar. In fact this is by far the most important area for the celebrating priest. The distribution of receivers covered in each space the main floor, the gallery and the balcony which are found both in mosques and byzantine churches. In Fig. 1 a typical plan with reference to positions of sound sources and receivers is shown. The measurements were taken with only a small group of researchers inside the rooms or with some reduced group of tourists inside the mosques. The conditions of occupancy were in any case to be regarded as "unoccupied".

2.2 The measurement chain

The measurement chain was the same in all of the spaces for worship. The parts of the chain are recalled in Table 1, where each task has the indication of the respective instrumentation.

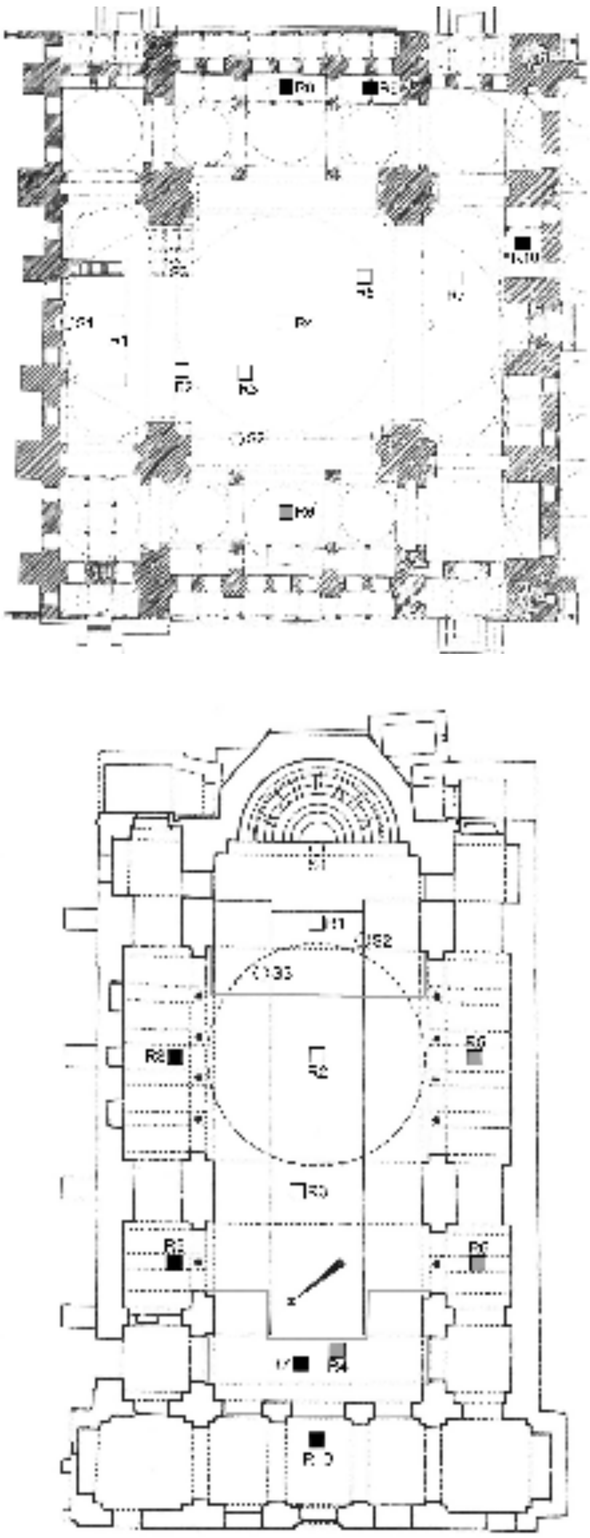

Figure 1. Top: plan of Suleymanie mosque. Bottom: plan of S.Irene. The sources are indicated by white circles and receivers by squares. Filled black squares are on the balcony and grey ones are in the gallery. The drawings are not in scale.

Task	Instrumentation
Generation of test signal	– PC with MOTU2048 soundcard – Amplifier – Lookline dodecaedric sound source
Micing of sound field	– Binaural probe Neumann KU100 – B-format probe Soundfield ST250
Recording of the signal	– Line preamplifier Tascam MA/AD8 – Digital recorder Tascam DA38
Post elaboration	– PC with MOTU2048 soundcard / Laptop with Roland UA100 USB Sound Card – Cooledit with Aurora package

Table 1. Chart of the measurement chain employed for the acosutical measurements inside the rooms.

The measurement chain allowed the parallel spatial sampling of binaural and B-format data of the sound field created by the dodecaedric sound source within the empty rooms and the successive off-line post-elaboration. The test signal consisted in an exponential sine sweep from 80 to 18000Hz of 20 sec duration. The raw data were then digitally stored on magnetic tapes via a 20bit digital recorder and later processed for calculation of acoustical parameters according to a specific technical standard (ISO3382, 1997). The sound sources were placed 1.25m above the floor whereas the receivers were at 1.1m. The two sound probes were put side by side at nearly 0.7m to minimize mutual influence. The calculation of acoustical parameters was based on the omnidirectional signal enclosed in the B-format coding (called W). The calibration of the measurement chain was done by means of a reference measurement at the end of each session. In this case the sound probes and the source were put on the stage at a fixed distance (2m) from each other and height above the floor (2m). This measure was used to establish the level of the direct sound with respect to the other source-receiver couples.

3. RESULTS

3.1 The reverberation time

Fig. 2 and 3 report the relationship between the measured reverberation times in mosques and byzantine churches and the volume of the respective enclosures. This is shown for the “all pass” and the “mid frequencies” values respectively.

As expected, the reverberation times in mosques and churches show a marked correlation with the increase in volume of the enclosure. Nevertheless the mosques and the byzantine churches behave differently especially when the volume is bigger. In particular the “mid frequencies” in Fig. 3 tell us that an higher reverberation time can be expected in churches when the volume is larger than 20000m^3. In the same plot also a set of two curves is introduced referring respectively to unoccupied and occupied concert halls. It is interesting to see that the reverberation time at mid frequencies in mosques is in line with that of unoccupied concert halls of comparable volume whereas the byzantine churches are generally more reverberant.

The above plots can also be used to set the predicted reverberation time according to volume for a newly built mosque.

Then Figs. 4 and 5 report the dependence of the measured reverberation times with frequency for the byzantine churches and the mosques. It is seen that the shape of the curves is quite different in the two cases.

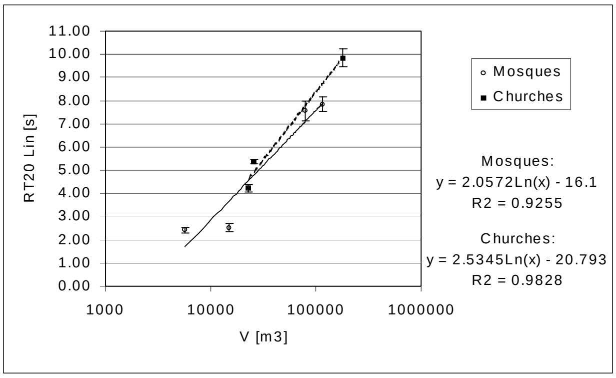

Figure 2. The relationship between the measured reverberation times and the volumes of mosques and churches:all pass values.

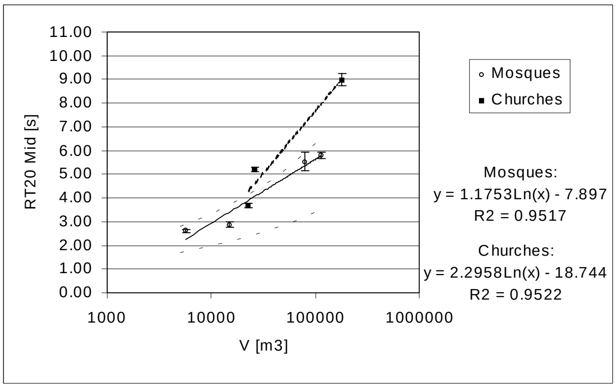

Figure 3. The relationship between the measured reverberation times and the volumes of mosques and churches: averaged values of 500Hz, 1kHz and 2kHz octave bands. Dashed lines indicate the occupied and unoccupied concert halls.

In fact while the mosques show the maximum of reverberation in the lower frequency range the byzantine churches have generally the maximum in the medium frequrency range. This finding has an immediate link with the impression of a listener. The acosutic field in byzantine churches is extremely reverberant and the sounds overlap in time with little possibility of being separated. This applies also to spoken of sung phrases, whose intelligibility is greatly affected by the excess of reverberation. Such conditions of reverbeartion are also at the upper linit of acceptability for typical lyturgical music played with an organ. As regards the mosques the reverberation curves are easily grouped into two sub-groups of "large" spaces like Suleymanie and Selymie and the "small" ones like Sokullu and St. Sergius and St. Bacchus. For the former group the reverbeation time halves when passing from 500 Hz to 2 kHz causing a peculiar timbric effect in the spaces: the same phenomenon is observed also in the latter group but it is not so marked. In particular the frequency range of the singing formants (2 - 3 kHz) has a shorter reverberation time than the lower frequencies. This fact contributes in improving the oral unaided communication in the mosques since the masking due to the reverberation is controlled by the sound absorption in the higher frequency range.

3.2 The sound level

The sound level is investigated by means of the parameter called strentgth (G) reported in Fig. 6. The plot includes the overall values measured inside each space after averaging of all source and receiver positions.

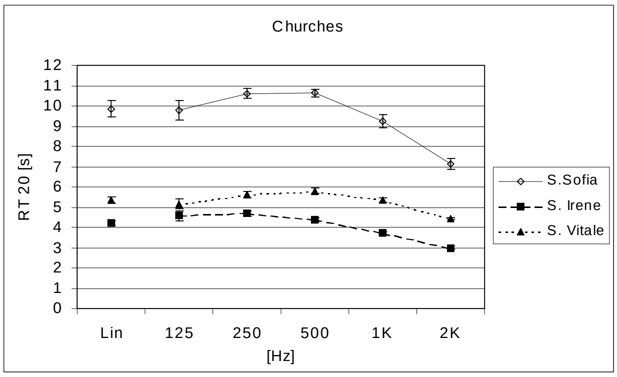

Figure 4. The dependence of reverberation time with frequency for the byzantine churches.

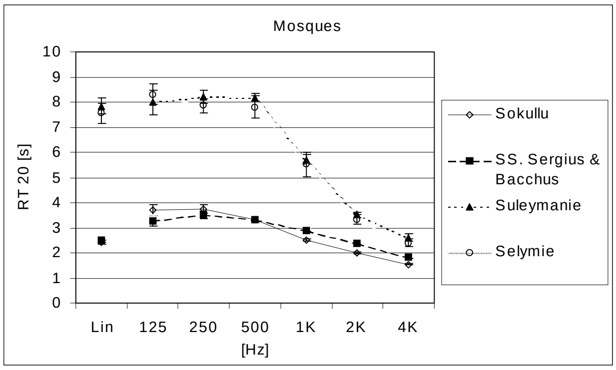

Figure 5. The dependence of reverberation time with frequency for the mosques.

Each point has the bars related to one standard deviation of the mean values. The first and clearest observation is that the sound level both in byzantine churches and in mosques has a decreasing trend with increasing of the volume. The logarithmic fit lines have quite a good regression coefficient.
The values are good just for the smaller mosques and allow in general only a fair degree of communication over a small distance without the aid of electroacoustic devices. Then the sound level inside the byzantine churches is higher than that in the mosques with a comparable volume. This is true on average but the values in the different positions are not constant, and in both cases they decrease when moving away from the sound source. This means that there is a sort of overlap between the data as also shown in Fig. 6. Typically the lower levels for a smaller mosque (or church) can be compared with the higher levels measured inside a large one. In other words what happens is that, given a mosque and a byzantine church of comparable volume, the sound level measured at the same distance from the sound source will differ by a fairly constant amount depending on the volume. The churches show a higher sound level for most of the volumes tested. For larger volumes the difference tend to vanish since in both types of enclosures the shielding effects of architectural elements and also the air absorption become quite relevant.

3.3 The clarity

The attributes of the sound field concerning clarity and the definition of the message delivered in the spaces for worship have been measured according to suitable parameters like clarity (C50 and C80) and definition (D).

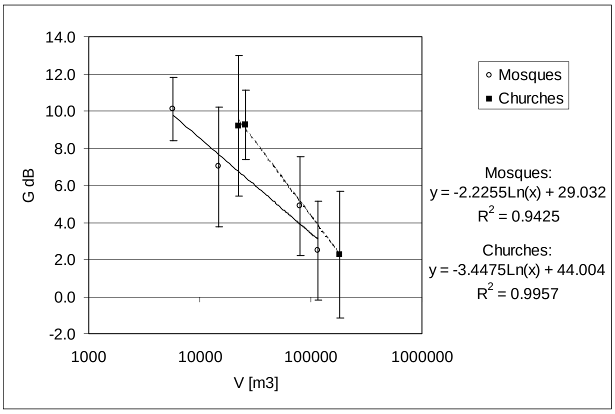

Figure 6. The measured values of the parameter strength G. The deviation bars of one standard deviation are included.

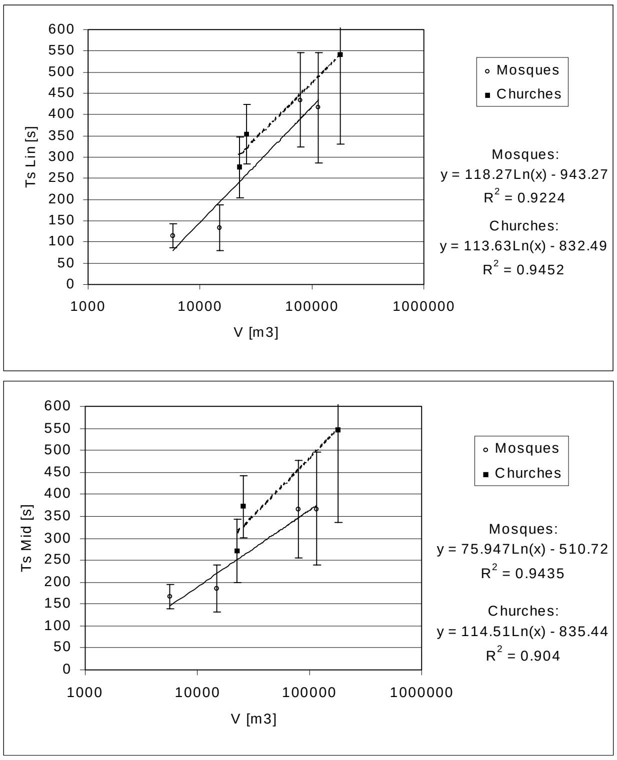

Figure 7. The centre of gravity of energy. Top: all pass values; Bottom: averaged values of 500Hz, 1kHz and 2kHz octave bands.

Also the so-called center of gravity of energy was measured (Ts) and this parameter is selected for being reported in this section. Actually Ts is highly correlated with the former indexes C or D but it is not as scattered from position to position as C and D are.

In Fig. 7 one can see that there is a sort of bias in the parameter between mosques and byzantine churches. The slope of the two lines is quite similar so that the values of a church are reproduced by a mosque of larger volume. In general the Ts values are higher for greater volumes and inappropiate for the comprehension of speech. In any case the sound field inside mosques is more suited for speech showing lower values. The graph can also be interpreted in terms of useful listening areas. That is, both in mosques and churches the positions close to the sound source are remarkably better than the others, where also the parameter Ts is out of range for both speech and music. In the case of mosques the good listening area is usually wider that in a byzantine church of comparable volume.

4. THE ACOUSTICAL PERFORMANCE OF THE FLOOR

Many features of the sound field inside mosques are governed by the sound absorbing characteristics of the floor. This surface can be found in different arrangements from mosque to mosque. In particular it can be set by simply laying carpets on the floor or by building a wooden structure of some centimeters height, where the carpets are rested. Moreover this wooden structure defines an air-backing of a few centimeters with respect to the floor, which can be either left void or filled with material for thermal insulation.

In order to study the acoustical properties of mosque floor layouts a simple project was prepared. Then the mosque floor was built as a modular structure summing up to a sample of $12m^2$. The wooden structure consists of 25mm thick panels and, in order to model the air-gap underneath the structure, two heights were chosen: 40mm and 150mm.

The mosque floor model was then taken to a reverberation chamber and measurements of acoustical absorption were made (Prodi, Marsilio, Pompoli, 2001). Four configurations were tested, namely: carpet alone, structure (40mm) alone, structure (40mm) with carpet, structure (150mm) alone. The measurements consisted in the placing of the dodecaedric sound source in three positions in the chamber and sampling the sound field in six positions each time with omnidirectional microphones. Impulse responses were calculated and later parameters regarding reverberation time were extracted. The measurements followed the specific standard and the alfa absorption coefficients in the diffuse sound field were obtained.

From the results of these measurements reported in Fig. 8 it can be seen that the behaviour of the floor is a combination of the absorption of the carpet and of that of the wooden panel structure.

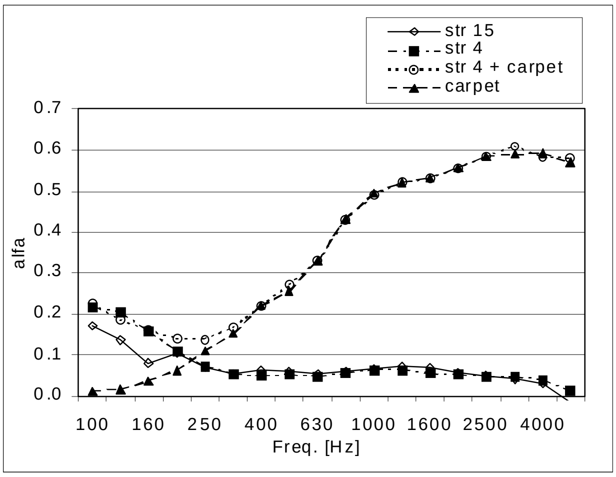

Figure 8. The absorption coefficient for each of the four tested configurations.

In particular the carpet works in the medium and higher frequency range whereas in the lower range one can see the typical absorption of a panel. As a confirmation of this, the effect of the air backing disappears when the carpet is placed alone. Moreover, the height of the structure sets the frequency showing the maximum sound absorption in the lower range so that for the higher structure the resonant frequency is shifted downwards.

It is also to be underlined that, even if the qualitative course of the measured curve could be estimated, a theoretical model of this system is still lacking.
Moreover, the measured data showed discrepancies with the data formerly available and this confirmed the need of such measurement campaigns in order to better understand the acoustics of mosques.

5. THE TRANSITION OF ACOUSTICS FROM THE BYZANTINE CHURCH TO THE MOSQUE

With the available data it was possible also to investigate the transition of the acoustical characteristics from byzantine churches to mosques. This happened for example when St. Sergius and St. Bacchus (SB) was converted into a mosque. The SB church is quite similar to the Basilica of S.Vitale in Ravenna, Italy (SV) since both churches are byzantine-style and date of the first half of the VI century. They have a central plan and are characterized by a principal volume covered by a dome and surrounded by an ambulacre, which is surmounted by a balcony. But, while SV is conserved in its original state with mostly a sound-reflecting floor, SB is today used as a mosque and includes typical sound-absorbing carpets covering the floor structure.

Church	V [m^3]	S_T [m^2]	S_F [m^2]	V/S_T	V/S_F
SV	25800	11400	980	2.26	26.33
SB	14900	6700	750	2.22	19.87
SV/SB ratio	1.73	1.70	1.31	1.02	1.33

Table 2. Basic geometrical data of the rooms.

Table 2 reports the main geometrical data regarding the two churches: volume (V), total surface (S_T), floor surface (S_F), and the ratios V/S_T and V/S_F. Finally, also the ratios between respective quantities in the two rooms are included (SV/SB). While V and S_T have the same ratios (with SV being the largest in absolute extensive terms), the floor surface is proportionally more extense in SB.
The effect of the floor was studied by calculating the theoretical curve for reverberation time and comparing it with the experimental results. The theoretical curve was obtained with the geometrical data of SB after introducing the modification according to the ratios in Tab. 1. A room equivalent to SV was obtained (called SB`) but, differently from SB, the floor in SB` was considered sound reflective. The consistency of the theoretical predictions with the data collected in SB and SV was tested.
Fig. 9 shows the reverberation time data measured in SB and SV and compares them with theoretical predictions for SB`. It can be noted that, for RT, the values of the prediction for SB` in the lower frequency ranges are overestimated. This evidence is in line with former findings (Marsilio, Prodi, Pompoli, 2001) where the difficulty in predicting RT correctly for mosques in the lower frequency range had been pointed out. This inconsistency is not due to the carpets but to other architectural details. In particular the articulation of the spaces into many niches, half domes and finally the presence of huge domes could have an impact on the reverberation time (Prodi, Marsilio 2003).

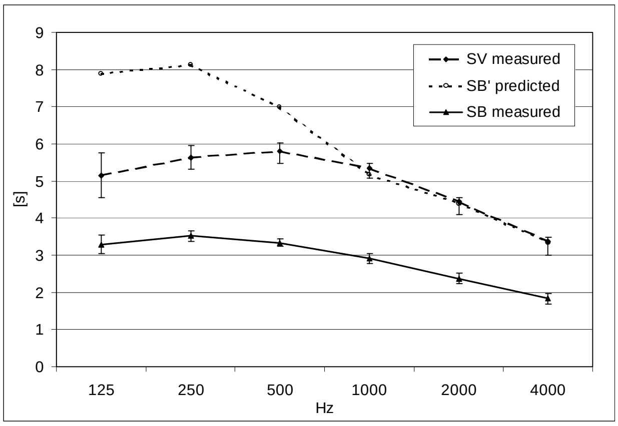

Figure 9. Experimental reverberation time curves for SV and SV and thearetical predictions for SB'.

On the other hand in the higher frequency range, where the effect of the carpets is paramount, the insertion of a sound absorbing floor completely alters the sound field and this can be predicted with good accuracy.

6. CONCLUDING REMARKS

The systematic collection of acoustical data of ancient byzantine churches and mosques gave the possibility of a scientific qualification and comparison of the acoustics of those two types of buildings for worship. The data, taken in the unoccupied rooms, show that the values of reverberation are very high, providing the room with a unique feeling of majesty. The rooms are generally poorly suited for musical performance and the delivering of speech messages suffers from the excess of reverberation, even though inside mosques the situation seems somehow mitigated by the sound absorbing effect of the floor surface. The result is that better speech communication can be established, at least in the short range. Finally, most of the spaces tested are inserted in a noisy city environment. Since no specific sound insulation was projected, they all suffer from noise intrusion which reduces even more the signal to noise ratio.

7. REFERENCES

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