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ON THE SIMULATION OF OCCUPIED ACOUSTIC CONDITIONS OF DJEDID MOSQUE IN ALGIERS

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ABSTRACT

The old religious buildings are a considerable legacy of ancient knowledge. Their acoustics is part of this heritage, as demonstrated by the ottoman mosques built from the16th to the19th century in Algeria. However, given the many configurations in terms of source placement and worshippers position, one key issue is represented by the difficulty of assessing the acoustics under occupied conditions, which may be evaluated by means of acoustic simulations. Some calculation methods have been proposed in the literature, but they only allow prediction of reverberation time. Conversely, this paper is related to the simulation of the acoustics in the prayer room under occupied situation by means of geometrical acoustic simulations, allowing to obtain the full set of acoustic parameters, if needed. The selected case study is Jedid mosque (Djama'a el Djedid), which was built in Algeria in 1660, in a typical Ottoman style, and later restored in 1855. The mosque was chosen because is large and reverberant to allow a better appreciation of the variations due to occupancy. However, results showed that due to the strong concentration of absorbing elements on the floor, where carpets already contributed to absorb sound, the effect of the occupancy was limited, and acoustic conditions remained poor for speech intelligibility.
Keywords: *acoustic simulation; cultural heritage; Algerian mosques*.

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1. INTRODUCTION

The acoustics of mosques has been receiving a proper attention only in the last two decades, when a number of works have been published in order to better understand the specific features of such buildings, and whether any acoustic concept was used during the construction of such buildings. In fact, through an exploration of the acoustics of ancient mosques [1-5], particularly ottoman ones, some features have been finally revealed, but several things still need to be better understood. The effect of occupancy is a key element that characterizes the acoustics of every worship place, because people introduce significantly different absorption that may induce large variations compared to unoccupied situation. In this paper, a brief architectural description of the Jedid Mosque (Djama'a el Djedid) is given, with a focus on the acoustical data (dimensions, volume and building materials). Following this, an overview of the method used to account for the presence of the occupants, is presented. The results obtained in different occupancy situations are then presented. Finally, a brief discussion will be offered.

2. METHODS

2.1 Description of the mosque under study

The Jedid Mosque or also called *Djama'a el Djedid*, was built in 1660. The building was built during the reign of the Aghas, who wanted to express their supremacy through a distinguished architectural style [6-8], as the funding for the construction work came from an association (state-affiliated institution) called *Subul al khayrat*. It is worth recalling that at this time the Ottomans may have been seeking to establish a style that reflected their dominance, hence the use of Christian rather than Muslim craftsmen and masons.

The Jedid mosque represents one of the first achievements of an extrinsic style in the Maghreb.
The interior of the mosque reflects an Ottoman inspiration, as it is very similar to the mosques of Brousse, especially Ulu Cami of Brousse, built in 1400 [8]. The prayer hall is rectangular in shape and measures 39.5 x 24 m, covering an area of 1371 m² [6,8]. A large ovoid dome dominates the building. It is located at the intersection of the two barrel vaults, placed above the two naves. Four small squares, covered by small octagonal domes, supported by pendentives at a lower level, result from this crossing.
The building's exterior is decorated with merlons, reflecting the traditional Maghrebi architecture. The prayer hall has a rather sober decoration, characterized mainly by a white and blue tiled base along the walls of the prayer hall. However, the mihrab, the minbar and the central dome are richly decorated. This dome is decorated with openwork plaster and ceramic tiles of different designs, covering the pendentives [7]. The minbar is in white marble, very rich in sculpted decoration.

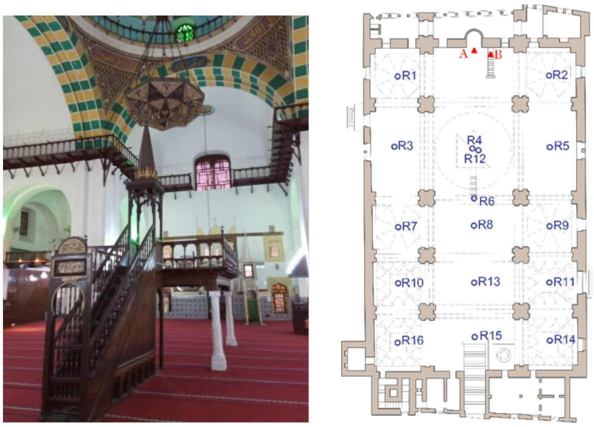

Figure 1. Inside view and floor plan of the Jedid mosque, Algiers, with position of sources (A,B) and receivers (R1-R16). Receiver 12 is located on the Mahfil, right above receiver 4.

2.2 Measurement method

Acoustic measurements carried out in the mosque were made in compliance with current standards [9] and were described in detail in [10]. Monaural parameters were used in the subsequent analyses.
The sound source was located in two positions: at the Mihrab (A), where the Imam guides prayers toward the direction of Qibla, at a distance of 1.5 m from the back wall and at the Minbar (B). In both the cases the source was at mouth-neck height, 1.55 m above the surface where the speaker is standing (resulting in 3.5 m for source B).

Receivers were distributed over all the areas that can be occupied by worshippers. According to common practices during the religious services, for source A (Mihrab), for which worshipers stay standing, receivers were located at ears height, at 1.65 m from the floor, while for source B (Minbar), worshippers must be seating on their knees, so height was set to 0.85 m as proposed by other authors [1], despite it is below the minimum value recommended by standards [9].

2.3 Acoustic simulation of occupancy

In order to take into account the effect of occupancy a common research approach is that of measuring the space under unoccupied conditions and then use acoustical modelling (usually based on geometrical acoustics (GA)), to simulate the effect of the occupants [11]. When measurements of unoccupied conditions are available, it is customary to “calibrate” the acoustic model, so that optimal agreement between measured and simulated conditions is found, so that any other subsequent modification in the space may lead to reliable predictions.
To account for the acoustic absorption due to the worshippers, several sources of data are available [12,13] but, in the present case the values given by Elkatheeb [13] were used as being specific for the different postures used in the mosques. As these values are given in terms of absorbing area per occupant, if directly applied to floor surface they may result in absorption coefficients higher than one. Even if this may be acceptable when using such coefficient in Sabine’s formula, this becomes a problem when using GA predictions as surfaces may only accept coefficients lower than one. Consequently, even if this is not the conventional approach when modelling an audience, a series of vertical double-sided surfaces were added on the floor to simulate the audience. In this way, a larger surface was available and absorption coefficients lower than one could be used. This also leaves the floor open to contribute with some extra absorption (as demonstrated in [13]), while actually considering the mutual masking effect of the different rows. Once the actual audience surface was determined, assuming two different heights to represent the standing and the seated positions (respectively 1.2 and 0.5 m to consider only the body without head and neck), absorption coefficients were calculated accordingly.
CATT-Acoustic software (v. 9.1g) [14], with the calculation engine, TUCT v.2, was used for acoustic simulations and the “Algorithm 1” was considered as the room volume is closed and sufficiently mixing. A number of rays sufficiently higher than the minimum number recommended by the software was used, equal to $3{\cdot}10^6$.

Impulse response length was set equal to the longest expected T_{30} (i.e. 4 s and 3 ms for empty and full case).
The resulting geometrical model was made of about one thousand planes, with an overall surface area of 5300 m^2 and a volume of 10500 m^3. Windows and other secondary elements were modeled as sub-planes, so to minimize the overall number of surfaces and speed up calculations. Small pillars and open balustrades were not modelled (e.g. for the Mahfil, only the horizontal plane was included). Scattering coefficients were set to 0.1 for all surfaces, but auto-edge (a special option that allows to increase scattering coefficients along the borders of surfaces) was set to "on" for all those elements having large exposed edges. For the audience, scattering coefficients spanning from 0.3 to 0.8 (respectively from 125 Hz to 4 kHz) were assigned to take into account the complex geometry. After the calibration of the model, the effect of occupancy was estimated under fully occupied conditions, with the worshippers evenly distributed in spaced rows, also on the mezzanine.

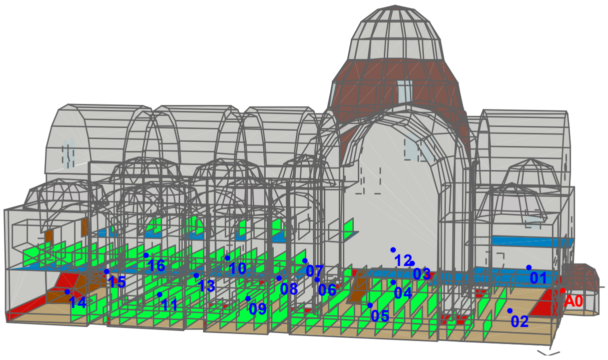

Figure 2. 3D model of the mosque

3. RESULTS

After the calibration of the empty model was completed, a good agreement was obtained both in terms of spatially averaged T_{30} values (Fig. 3a), with a relative error that never exceeded 2.5% (corresponding to half the just noticeable difference (JND) set by the standard [9]), and point-by point values represented by a more position sensitive parameter like mid-frequency center time (Ts) (Fig. 3b). In this case, slightly larger errors were observed (within 2 JNDs), but the general trend was very well respected and the largest variations appeared in points where obstacles affected direct sound. The absorption coefficients that were needed to obtain such agreement are given in Table 1 and were obtained starting from literature values and making small adjustments that could be compatible with the nature of the material. It is important to point out that carpet proved to be very absorbing in the high frequencies, in agreement with values measured in Ref. 13.
At this point, as anticipated, the occupancy was added to the model. The overall surface area of the added elements was about 1400 m^2 (both sides) for the standing audience and 590 m^2 for the seated one. Thus, based on the absorbing areas given in [13] and an estimated occupancy of 915 persons [10], the relevant absorption coefficients were given in Table 1, with seated audience having higher values because of the reduced surface area.

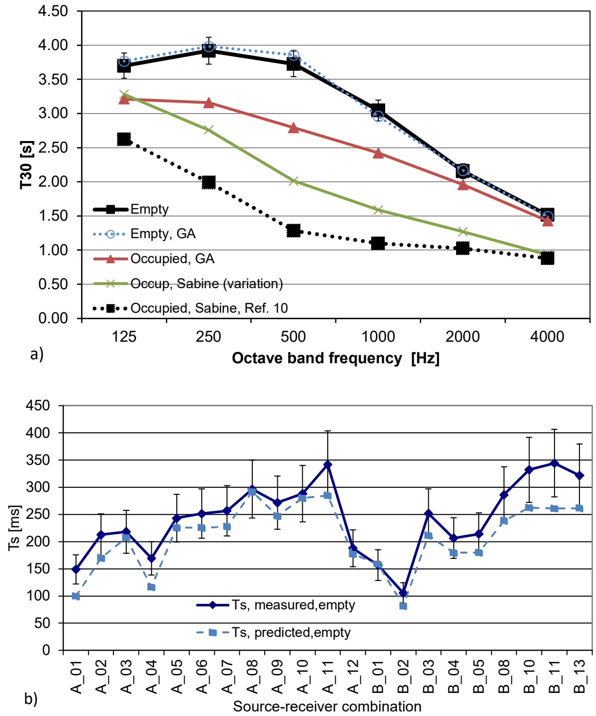

Figure 3. Comparison between measured and predicted: a) T_{30} spatially averaged vs. frequency, also including predicted values under full occupancy; b) point-by-point mid-frequency (500-1000 Hz) Ts values (error bars correspond to 2 JNDs). Some combinations are not available because of lacking measurements.

Table 1. absorption coefficients used in the calibrated model.

	125	*250*	*500*	*1k*	*2k*	*4k*
Plaster	0.03	0.03	0.03	0.03	0.06	0.06
Glass	0.35	0.25	0.18	0.12	0.07	0.04
Wood mezzanine	0.45	0.35	0.20	0.17	0.15	0.10
Carpet*	0.04	0.04	0.19	0.40	0.75	0.87
Standing aud.*	0.05	0.12	0.23	0.41	0.56	0.67
Seated aud.*	0.12	0.34	0.51	0.79	0.91	0.99

* After Ref. 13

The resulting average of predicted T_{30} values (Fig. 3a), showed expectedly longer values if compared to those predicted using Sabine's formula in [10]. In fact, in that case, as the characteristics of the carpet were not known, the absorption due to the audience was entirely added to the existing one, also assuming perfectly diffuse sound field (which is not at all obvious considering that the audience is basically distributed on the floor and, partly, on the mezzanine). Anyway, as anticipated, the actual absorption coefficient of the carpet was quite high, which meant that only the incremental contribution of the audience had to be taken into account. In fact, in [14], it was shown that the absorption due to a single person on carpet was higher than that of the person on bare floor, but much smaller than the simple sum of the absorption due to carpet and person taken individually. This suggests some "masking" effects that will be useful to the subsequent discussion. To the purpose of understanding the results, by assuming a substantial agreement with the absorption coefficients of the carpet [13], and adding only the incremental contribution of the audience, resulted in values that are halfway between the previous two predictions.

Anyway, results of GA simulation took into account the actual position of the absorbing surfaces that, being basically on the floor (although the audience was modelled by vertical flat surfaces), provided only a limited "extra" absorption because the new surfaces only intercepted those rays that would have been absorbed by the carpet (in fact at high frequencies differences are almost negligible). In a similar way, previous experimental studies where the density of the occupants was taken into account, [12] showed that in a denser audience the absorption per capita decreased. For the above reasons, no significant difference was found between a standing and a seated audience. Conversely, to disprove this hypothesis a simulation was carried out where the audience was raised 2 m over the floor, and in this case much bigger variations were found.

Consequently, with reference to the fully occupied conditions the mosque remained quite reverberant with relatively poor acoustic conditions. In fact, mid-frequency Ts and clarity for speech averaged over the three octave bands from 500 Hz to 2 kHz ($C_{50(3)}$) showed an average improvement by 50 ms and 1.5 dB (Fig. 4 a,b), but in most of the space the values remained not adequate for speech intelligibility. Similarly, STI values (simulated using proper signal spectra) changed from an average value of 0.47 to 0.50 after full occupancy (Fig. 4c), confirming that the variations were negligible because of the superposition of the audience on the already absorbing carpet, as well as because of the non-diffuse behavior of the space.

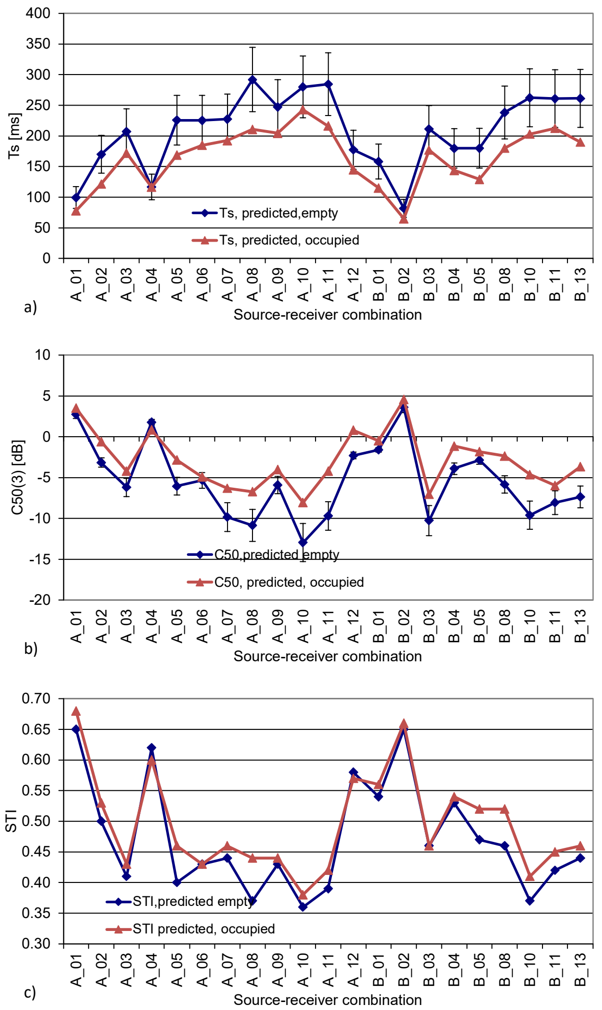

Figure 4. Comparison between predicted values in unoccupied and occupied conditions at individual source receiver combinations: a) C50(3); b) Ts; c) STI.

4. CONCLUSIONS

The present paper investigated the effect of occupancy on the acoustics of Jedid mosque in Algiers. GA modelling was used to simulate the effect of worshippers, using absorption values available in the literature. Due to strong non uniform distribution of the absorption, variations in acoustical parameters were smaller than predicted with classical diffuse-field formulas. Further investigations are under way to better explain the results shown here.

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