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A preliminary investigation on the acoustics of contemporary Algerian mosques inspired by the Ottoman style

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Abstract

The historical Ottoman mosques continue to exert a significant influence on mosque architecture in Algeria, even in the late 20th century. Within this framework, a novel interpretation of classic Ottoman mosques has contributed to the architectural landscape of Algerian cities. However, the primary question remains: do these models affect (and replicate) the acoustic conditions in the prayer hall, or is their influence limited to the shape? This study aims to address this question by conducting a comparative analysis of two contemporary mosques in Algeria inspired by the Ottoman style. The first is more conservative and located in the city of Boussaâda in southern Algeria. It was constructed by the initiative of the local population. The second is situated in northern Algeria, specifically in Oran. The government of Türkiye donated it and represents a new interpretation of Ottoman heritage. The study method is based on in situ measurements to assess primary acoustic parameters in compliance with current ISO standards. Results show that in both cases, very long reverberation times are measured, resulting in poor clarity and speech intelligibility. Comparison with historical Ottoman mosques of comparable volume shows that contemporary buildings are more reverberant, suggesting the need for improved acoustic control.

Keywords: *Worship acoustics, Ottoman mosques, acoustic measurements.*

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1. Introduction

The architectural style of mosques in Algeria has undergone continuous evolution since the country gained independence in 1962. The diversity of contemporary mosque architecture is evident throughout the country, with significant variations in design and style. The major stylistic influences can be attributed to two primary sources: the Ottoman and local pre-Ottoman styles. Indeed, the primary concerns appear to be the configuration and the embellishment of the edifices. However, there appears to be little interest in the acoustic aspects, likely due to limited research, despite several studies conducted in recent years. This study aims to deepen understanding of the acoustics of contemporary mosques in Algeria. To this end, two mosques were selected for closer examination. In situ measurements were taken in both mosques to assess the main acoustic parameters: reverberation time, early decay time, clarity, and center time (T20, EDT, C50, and Ts).

2. Ottoman architecture and Mosques

The influence of Ottoman architecture in Algeria has long interested scholars. The earliest manifestations of this influence can be traced back to the Regency of Algiers during the 16th century. However, it is during the reign of Hassan Pacha, marking the late Ottoman presence in Algeria from 1791 to 1798, that Ottoman architecture reached its peak of influence. The literature on the subject suggests that the architecture of Ottoman mosques in Algeria was influenced by the Ottoman model, albeit to a modest extent. These mosques typically feature a cubic volume covered by a central dome, often polygonal, and occasionally with smaller domes covering the galleries (e.g., Ketchaoua Mosque: Fig. 1) [1]. The interiors of Ottoman mosques in Algeria are generally characterized by a minimalist aesthetic, with ornamentation limited to the *mihrab*

and the dome. According to Devoulx [2], the most architecturally significant mosques in terms of beauty were either demolished (e.g., the "Essayida" mosque, demolished in 1837) or partially destroyed and rebuilt, such as the Ketchaoua Mosque, which has undergone several alterations that have completely transformed its exterior and interior architecture [2].

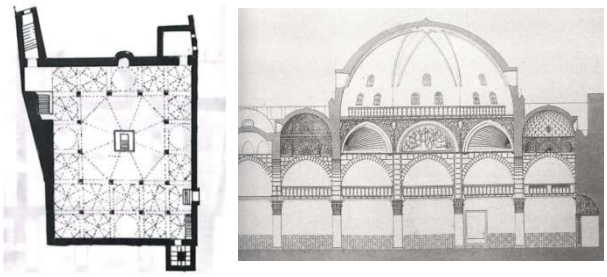

Figure 1. Initial Ketchaoua mosque, Algiers. (Plan : Bourouiba,R, 1986/ Section : Ravoisié A, 1846-1850)

2.1 Classical Ottoman mosques in Türkiye

Ottoman mosques developed over the centuries, particularly thanks to the work of Sinan [3], and acoustics followed the architectural solutions that resulted from the spatial configuration, material choices, and construction details. The latter include geometric features that facilitate the diffusion and absorption of sound, such as niches, muqarnas, mahfils, 'kündekari' woodwork, Khorasan plaster, and clay pots, which were thought to function as cavity resonators. In Ottoman architecture, this pottery is found mainly in domed structures [4-5]. In terms of spatial organization, the Selimiye Mosque represents the culmination of Sinan's architectural development, where the prayer hall is unified into a single monumental volume of approximately 79,300 m^3 (Fig. 2d) [1]. Süleymaniye Mosque (Fig. 2 b) is particularly notable for its sophisticated integration of architectural and acoustical design. Rather than relying solely on its overall geometry, the mosque combines carefully proportioned volumes, galleries, architectural detailing, material selection, and construction techniques.

2.2 Ottoman mosques during the Regency of Algeria

Based on the models produced by Sinan, Algerian mosques tried to replicate the same typological scheme. According to the size of the buildings, three main schemes of architectural features used in Algeria can be identified [1], they all share a layout centered around a large central dome, of orthogonal shape, surrounded on three sides by a single row of galleries (Safir Mosque), or by one or two rows on all four sides (Ketchaoua, Ali Bitchine, Moubaîa Mosque in Mascara), or even by four small domes at the four corners of the building (Sidi Mohamed Charef in Mazouna). The most widely adopted model in Algeria was the Selimiye Mosque, but in a more modest form, with limited ornamentation. The main materials used in the historical prayer halls were bricks and stone (for walls and domes), plaster for finishes, and marble and/or ceramics to decorate the *mihrab*, the dome, and the base of the walls [1]. One particularity in Algeria is the use of wood for the mezzanine. There are tile coverings at the dome of the Jedid (pêcherie) mosque, in addition to stucco and decorated plaster. Usually, the Ottoman mosques in Algeria during the Ottoman regency were sober [6],[7]. In addition, in most cases, the *minbar* was made of wood, except for some significant buildings like the Jedid Mosque, which is made of marble.

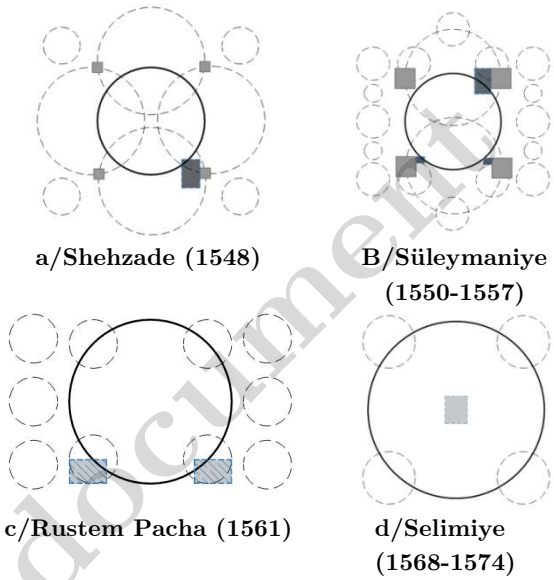

Figure 2. A chronological development of architectural features designed to enhance the acoustics of prayer halls in Ottoman mosques [1].

3. Contemporary mosques

3.1 Omar Ben Khatab Mosque (Ain-Hjel)

The Khateb mosque was built in 2006. It is the work of a mason well-known in Bousâada (Algeria). He built several mosques (1980-2006); all his works are inspired by the great Ottoman mosques in Istanbul, such as Süleymaniye (Figure 2-a). This example of a mosque features a prayer hall situated on the first floor. The plan is rectangular in shape, measuring (26.90 × 34.15 m^2), with annexes on three sides that are raised (2 to 3 meters) and open onto the main hall. The roof of the main hall consists of a central dome of small diameter, supported by four half-domes, which in turn rest on further lower half-domes (eight half-domes in total), the whole structure forming a pyramid. The height ranges from 7 to 23.80 meters, giving the prayer hall a total covered area of about 38.50 x 38.65 m^2, or approximately 12,638 m^2. The main materials used are concrete for pillars and domes, brick with cement finishing, and tiles for the wall-basement at a height of 1.35 m. The *mihrab* and the *minbar* are integrated into a single niche in the qibla wall (a new trend in contemporary mosques in Algeria), and they are made of grey marble. As usual, the floor is covered by a carpet. Despite its resemblance to Ottoman mosques (from the outside), the building is very sober on the

inside, due to the small size of the central dome, the low roof height, and the use of materials.

3.2 Emir Abdelkader Mosque of Oran

Designed by a contemporary Turkish architectural firm, the building blends local (Arabo-Andalusian) style with Ottoman inspiration, embodying the tension between tradition and modernity, and between simplicity and sobriety [8]. The prayer hall is a vast cubic volume, with clear lines, distinguished volumes and articulations, reflecting the culmination of Sinan's late-design mosques, as well as the traditional Ottoman mosques of Algiers (Ali-Bitchine, Essayida, Ketchaoua). The dimensions of the main prayer hall are 35.25 x 31.60 m², with an additional volume serving as a transition between the interior and exterior, ensuring the mosque's orientation toward the qibla and housing the entrance. The total volume of the prayer hall is approximately 17,000 m³. The mosque's typological framework is traditional, as is the preservation of the *minbar* as permanent furniture. At the same time, a more modern design is evident in the *mihrab*, with a large surface area (4 x 7.4 m²). A large dome covers the main space, situated at 15.60 m from the ground floor to achieve a height of 25.40 m. The dome consists of two skins. The interior one is made of decorative plaster. The main materials used are concrete and wood (for the lateral walls, the gallery roof, and the wall forming the mezzanine). Columns are covered with marble (under the dome). Two large plaster panels decorate the qibla wall on both sides of the Mihrab. Finally, the floor is covered by a thick carpet.

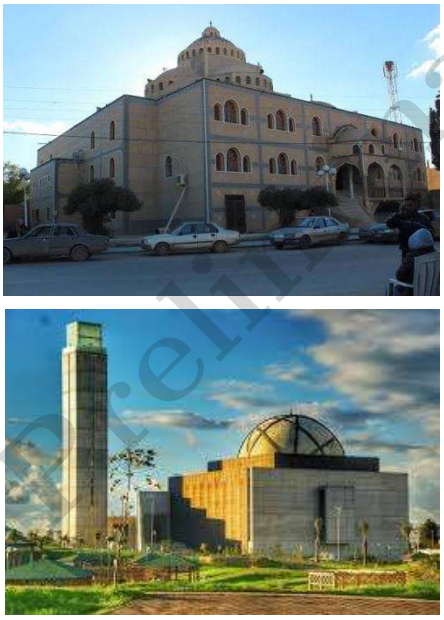

Figure 3. Sample mosques: a) Omar Ben Khatab Mosque of Ain-Hjel (above) b) Emir Abdelkader Mosque of Oran (below) (photo courtesy of the Author).

4. Acoustic survey

4.1 Instruments

The methodology adopted is based on the ISO 3382 standard [9]. In situ measurements were taken using an omnidirectional sound source (Dodecahedron Ntek-OMNI 5), connected to an omnidirectional microphone (Behringer ECM800, 13 mm) via a sound card (Onyx Artist 1.2). Impulse response acquisition was carried out using Audacity software in combination with the Aurora suite plugin [10]. The sine sweep covers frequencies from 20 to 10,000 Hz and lasts 20 s, providing a sufficiently high signal-to-noise ratio.

a)

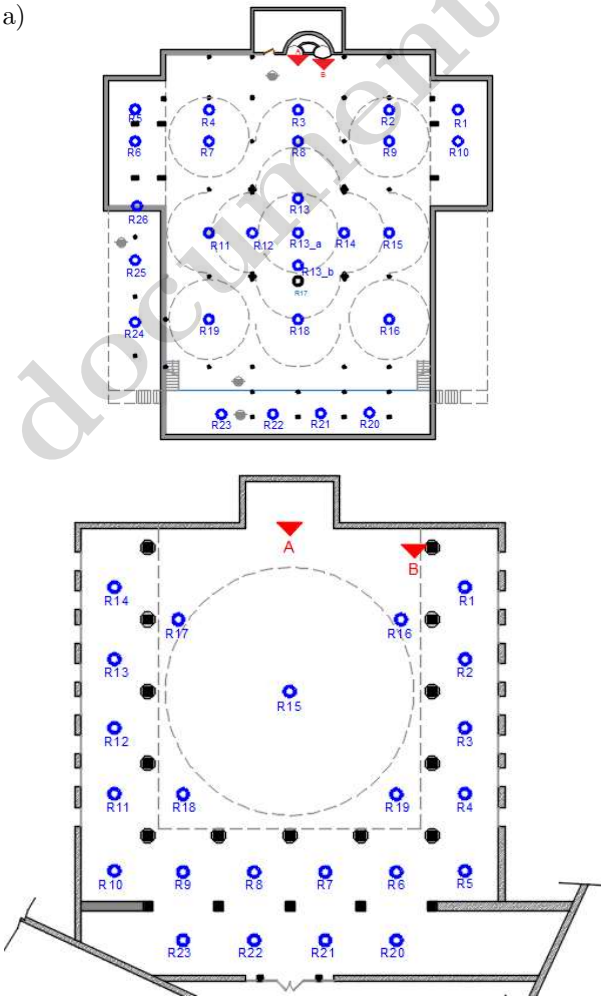

Figure 4. Position of Sources and Receivers: a) Omar Ben Khatab Mosque of Ain-Hjel, b) Emir Abdelkader Mosque of Oran.

4.2 Source and receiver positions

According to the literature about the prayer tradition, the mosque is characterized by two main sources: the first one is located 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)[11-14]. In both cases, the

source was at mouth-neck height, 1.55 m above the surface where the speaker is standing.
In mosques, worshippers are standing, organized in rows during the prayer (Source A), occupying the entire prayer hall (according to their number), or they may stay randomly during the preaching (Source B) until the prayer hall gets full [11]. So, the receiver positions are defined according to the spatial configuration. 28 receivers (R1-R28) are used in the Omar Ben Khatab Mosque and more than 41 receivers (R1-R23_F2) in the Emir Abdelkader Mosque.

5. Results

5.1 Reverberation Time and Early Decay Time

Results of T20 values over octave bands show a long T_{20} at 250 Hz at Ain-Hjel's Mosque, and at mid frequencies (500 Hz–1 kHz average), the average value is about 6.23 s (±0.40s). Oran's Mosque T20 at mid frequencies is just 3.22 s (±0.10s) (Figure 5). If we consider a point-by-point assessment, at mid-frequencies the T20 values show some exceptions at Ain-Hjel's Mosques, notably A-R1 (4.13 s), which reaches 8.03 s at B-R27 (situated on the second floor); the longest value is obtained at A-R11 (10.07 s). Otherwise, at the Emir Abdelkader Mosque (Oran), all receivers (regardless of position) exhibit shorter reverberation times for both sources, despite the mosque's larger volume compared to the Omar Ben Khatab Mosque (Ain-Hjel). No significant difference was observed between the mean values of T20 and EDT at mid-frequencies for the Oran Mosque; however, a slight difference was noticeable between the T20 and EDT values for the Ain-Hjel Mosque. Therefore, all listeners at the Oran Mosque receive both direct and reverberant sound, whereas at the Ain-Hjel Mosque, worshippers receive mostly reverberant rather than direct sound.

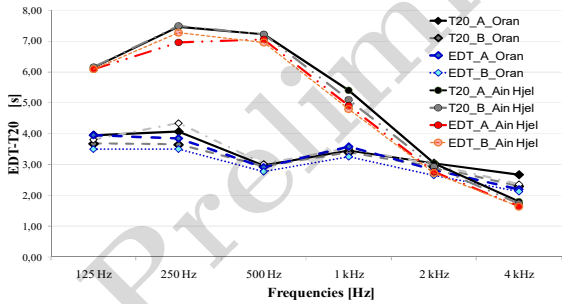

Figure 5. Average values of (T20), (EDT) over octave bands.

5.2 Clarity (C_{50})

Clarity (C_{50}) decreases with distance in the mosque of Ain-Hjel. C_{50} values range from -0.20 dB to -13.61 dB, with average values of -10.66 dB (500Hz) and -7.04 dB (1kHz), indicating poor speech clarity. The prayer hall is characterized by a predominance of late reflections over direct sound energy, despite receivers having a direct line of sight to the sound source. The shape of the prayer hall's roof (domes/half-domes) in relation to its height, combined with the material used (concrete), contributes to generating late reflections and less absorption by air and materials. According to Fig. 6, some receivers are at the same distance from the source but have different clarity values; however, the spatial configuration around those receivers is often not the same – some are located beneath the half-domes, whilst others are situated beneath the balconies (different height, different roof shape). The differences between A and B are negligible due to the short distance between the *mihrab* (A) and the *minbar* (B), which are integrated into the same niche.
In the case of the Oran Mosque, a significant decrease could be observed in clarity values (C_{50}), comprised between -0.71 dB (A-R14) and -11.60 dB (A-R23_F2) for source A, with average values of C_{50} of -6.53 dB (500Hz), and for source B, values of C_{50} are comprised between 2.40dB (B-R1) and -13.19 dB (B-R12_F2).
For both mosques, receivers situated on the ground floor present better clarity than those on the second floor (Fig. 6). The position of source B (*minbar*) relative to source A (*mihrab*), as well as its height above the ground, taking into account the height (and volume) of the prayer hall, is important for the propagation of sound inside the mosque.

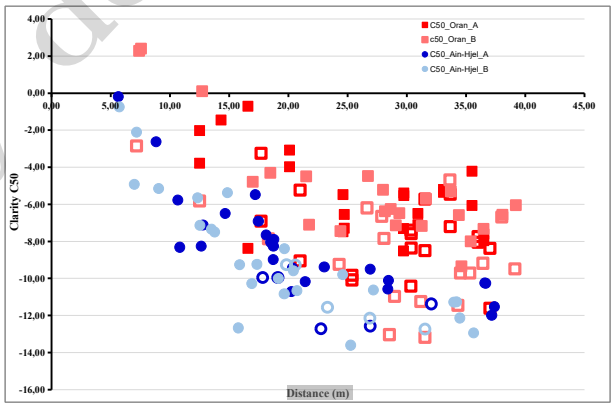

Figure 6. Clarity C_{50} average values according to source-receiver distance.

5.3 Central Time (Ts)

Very long Ts characterize the Ain-Hjel Mosque; the average values for both sources are about 450 ms (A and B, respectively). The shortest Ts is about 246 ms (A-R1), and the longest Ts is 534 ms (A-R19). The Ts values for the main prayer hall show little difference from values measured for the subspaces (balconies), which are the most distant receivers. On the other hand, the average Ts values at the Oran Mosque are about 269 ms for source A and 256 ms for source B, with the longest Ts at about 313 ms and the shortest at about 109 ms. Usually, there is a good agreement between distance and Ts, with Ts values increasing with distance. Values are better under the central dome than in the aisles. No symmetrical Ts values are observed inside the prayer

hall, but there is a tendency for them to vary as a function of the source-receiver distance, that is, for receivers close to the source. Beyond 30 meters, the Ts values become symmetrical on either side of the prayer hall. In addition, values of Ts for source B are better than source A in almost all cases, except for some receivers situated on the left side of the prayer hall; R-13, R_14 (for both levels). The mosque may be better suited for preaching than for prayer.

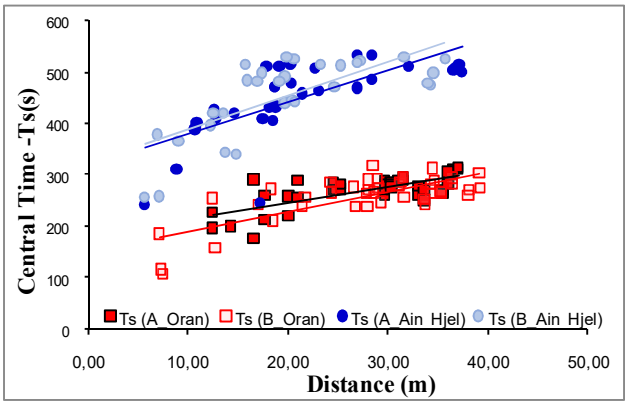

Figure 7. Central Time Ts.

6. Discussion and interpretation

Reverberation time (T_{20}) for Oran Mosque (3.22s) shows a better correlation with its volume (17.930 m³) compared with classical-contemporary mosques in the Ottoman style (Figure 8). Ain-Hjel Mosque has a very long reverberation time (6.23 s). There is a tendency for long reverberation times in contemporary mosques built in the classical Ottoman style, relative to the volume of the prayer hall; namely, Kocatepe Mosque (68.696 m³): 7.48 s, Şişli Mosque (4750 m³): 3.56 s. Üç Şerefeli Mosque, on the other hand, is a historical example (24000 m³): 5.72 s [15-17]. Clarity (C_{50}) is characterized by a dominating late energy over direct energy, which is the case for almost all Ottoman mosques in the literature.

In fact, the contemporary mosques in Algeria underscore the need for more reflection than for dry, direct sound. The unified configuration of the Oran Mosque (Emir Abd-el-Kader Mosque) positively affects Clarity (C50). In contrast, the mosque of Ain-Hjel, characterized by late reflections due to its roof configuration and the use of extra-reverberant materials, negatively affects speech intelligibility. From this analysis, it is clear that the minbar constitutes an important architectural furniture element when considered in terms of its dimensions, position, and material.

Previous publications suggest a Ts for mosques between 200 and 250 ms, which corresponds to the result obtained in the mosque of Oran, despite the use of very reverberant material such as brute concrete; in fact, mosques need longer Ts than speech rooms (120-200 ms). The mosque of Ain-Hjel is characterized by very long Ts, which confirms the poor speech intelligibility.

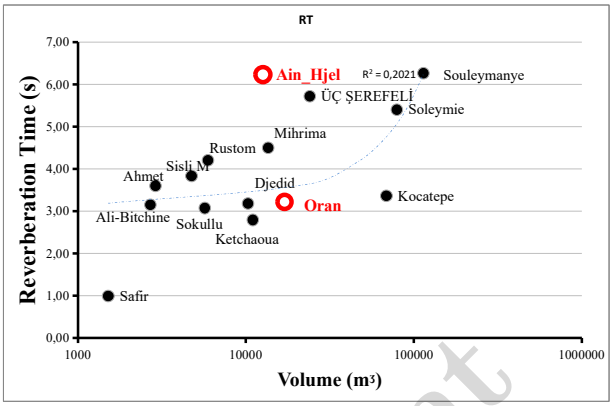

Figure 8. Comparison of reverberation time between classical Ottoman and contemporary mosques (with Ottoman influence).

7. Conclusion

The analysis of contemporary mosques in Algeria, inspired by classical Ottoman mosques, constitutes an interesting topic for research. From the results, it seems very important to choose the scheme (shape) according to the volume. The complex roof of the Omar Ben Khattab Mosque of Ain-Hjel, even within the small volume of the prayer hall (especially the size of the central dome), causes echoes, leading to problems with speech intelligibility. On the other hand, the appropriate choice of the scheme, combined with the right materials, despite the extensive use of wood, enhances the acoustic quality of the prayer hall of the mosque Emir Abdelkader of Oran. The position of the minbar (relative to the mihrab) and its height (relative to the roof height) are two important factors affecting the acoustics of the prayer hall in mosques. At the Ain-Hjel Mosque, we observe that the integration of the *minbar* into the same niche as the mihrab (which is a new trend in contemporary mosques in Algeria) has not contributed to improving the acoustics, particularly given the lack of proportion between the size and position of the minbar and the volume of the prayer hall. In this paper, only two mosques are investigated; future work could include additional cases to deepen understanding of contemporary mosques inspired by classic examples.

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