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# The Acoustics of the Mekor Haim Synagogue, Portugal

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**ABSTRACT**

This paper focuses on synagogues and in the acoustic characterization to the main worship area of the 1938 Mekor Haim synagogue (Oporto, Portugal), the largest in volume in the Iberian Peninsula. Reverberation Time (RT), Rapid Speech Transmission Index (RASTI) and the equivalent noise level of background traffic noise, were measured on the floor where the Torah is read (and where men have their seats), and on the top floor where women have their seats. The analyses of the results are done as a comparison with values found in other studies regarding Catholic churches and mosques with similar volume. The main results found are: average RT (500–1k Hz) of 4.6 s, average RASTI of 0.37 and 0.31 on the men's and women's floors respectively, average sound pressure level of background noise of 54/59 dB on men/women's floors (36/37 dBA) and NC-31/32 or NR-32/33 at the men/women's floors. Suggestions for improving the acoustics of this synagogue are presented that can make the RT values to decrease to about 2 s with the corrections taking place only at its dome.

Keywords: Synagogues, Acoustics, Reverberation time

## 1. INTRODUCTION

Being Judaism the oldest of the major monotheistic religions, it is natural that the synagogue architecture predates the church and mosque architectures. After the destruction of the Temple of Salomon, the use of musical instruments in Judaic worship places was forbidden. Besides voice, only the *Shofar* (wind instrument made by the horn of any animal, except bovine) was allowed to be used between the *Rosh Hashanah* and the *Yom Kippur*. In many synagogues musical instruments or electrical sound reinforcement are still not allowed [1].

Perhaps the most important at a Judaic worship moment is to be able to hear and understand the reading of the Torah. The traditional solution to make this possible was to place the *Bimah* (place from where the Torah is read) at the center of the ground floor, raised up to eight steps above the floor [1].

## 2. THE MEKOR HAIM SYNAGOGUE

### 2.1 Characterization

The *Mekor Haim* Synagogue (Street Guerra Junqueiro, Oporto, Portugal) built in 1938, is the largest in the Iberian Peninsula (Figures 1 and 2). The worship place for men is on ground floor, and the one for women is on the 1st floor (mezzanine).

The men's worship place has an area of 222 m$^2$ and a ceiling that reaches 14.06 m at the highest point of the room's dome. At the mezzanine the ceiling height is 4.35 m. The women's worship place has an area of 112 m$^2$ (ceiling height of 5.68 m). The volume of the worship space is 2399 m$^3$.

The floor is made of wood and there are some carpet walkways on the ground floor. On this floor the walls are covered with wall-tiles, and the pillars with marble up to 1.73 m above the floor. Above this height, the walls and the pillars are made of painted plastered concrete. On the women's floor, the

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walls are covered with wall-tiles up to 2.80 m above the floor. The pillars and the other parts of the walls are of painted plastered concrete. On the side walls there are five large windows that fill the entire ceiling height of the women's floor, and a small part of the men's floor (Figure 2). The ceiling and the dome are also of painted plastered concrete. The Torah Ark is made of stone and plaster, with wooden doors (Figure 2). In each floor there are two doors for connection to the lobby, made of glass with wooden frames, and a central partition made of the same materials (Figure 1).

The chairs and the *Bimah* are made of wood. On the ground floor, the chairs are under the balconies in a total of 72 seats with 14 seats of chairs placed near the corners. On the balconies there are 110 seats.

There is no HVAC equipment or a sound reinforcement system.


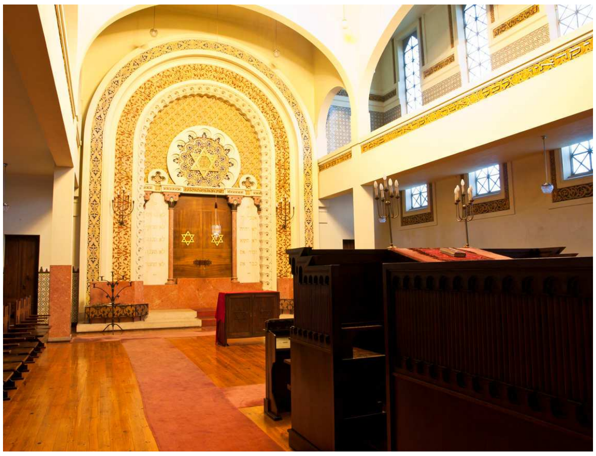

Figure 1 and 2 – Mekor Haim Synagogue, Oporto, Portugal [2]

## 2.2 Acoustic Characterization

### 2.2.1 Reverberation Time

All the RT measurements were made with the access doors to the lobby and to the street, closed. The Ark's doors were also closed (Figure 2).

The RT was measured at 11 points (8 on the ground floor) with the presence of only two persons (Figures 3 and 4) for octave band frequencies (125 to 4k Hz) with a B&K 2260 sound-level meter and a B&K 4224sound source.

As seen in Tables 1 and 2, the average RT is similar on both floors (3 to 5 s) but higher when compared with the recommended values for rooms where speech intelligibility is important (1.0 to 1.5 s). The average RT measured or predicted (for 2/3 occupancy) in this synagogue, is much higher than the ideal recommended values for synagogues (Table 2).

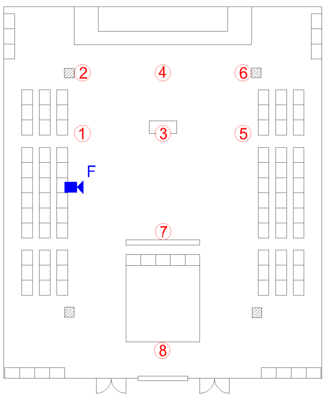


Figure 3 – Location of the sound source (F) and of the 8 measured RT points on the men's floor

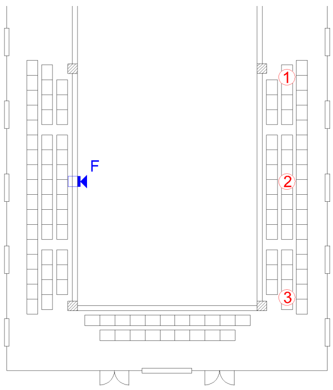


Figure 4 – Location of the sound source on the ground floor (F) and of the 3 measured RT points on the women's floor (mezzanine)

Table 1 – Measured RT average values on the ground floor (M - men) and on the mezzanine (W - women)

| RT (s) | Frequency (Hz) | | | | | |
|---|---|---|---|---|---|---|
| | 125 | 250 | 500 | 1k | 2k | 4k |
| $RT_{average}$ (M / W) | 3.4 / 3.3 | 4.4 / 4.3 | 4.6 / 4.6 | 4.6 / 4.5 | 3.7 / 3.8 | 2.8 / 2.9 |

Table 2 – Comparison of the ideal average RT (500-1k Hz) with the measured and predicted RT

| Situation | RT measured (s) | RT ideal (s) |
|---|---|---|
| Empty room (measured) | 4.6 | 1.3 - 1.7 [5] |
| Room with 2/3 occupation (predicted) | 2.9 | 1.4 [6] |

### 2.2.2 RASTI

On the RASTI measurements, the receiver was 1.25 m above the floor (position of seated people) and the sound source was on the *Bimah* (where the Torah is read). There were 12 measuring positions (9 on the ground floor) (Figures 5 and 6) with three readings at each point with a B&K 4225 and 4419.

On the ground floor the average RASTI is 0.37 (*poor* speech intelligibility, almost *bad*). The points that get better speech intelligibility are those situated in the center of the synagogue and in line with the source (Figure 5 and 7), and as one moves away from the center, the value decreases. There is one exception, the RASTI value at position 9 that is higher that the value at position 8 (mainly due that this point is close to a corner and there are reflections that slightly enhance the value).

On the mezzanine, despite its very bad RASTI average value, it is possible to verify that position 2 (central mezzanine) has a RASTI value above the average. The value at this point is equal or greater than at some of the points on the ground floor (Figure 7).

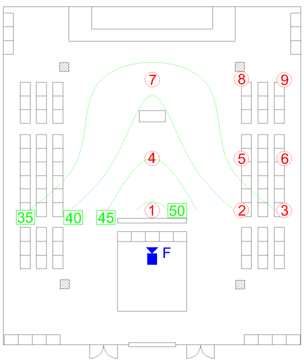


Figure 5 – Location of the sound source (F), and of the RASTI measuring positions and equal RASTI lines, on the ground floor

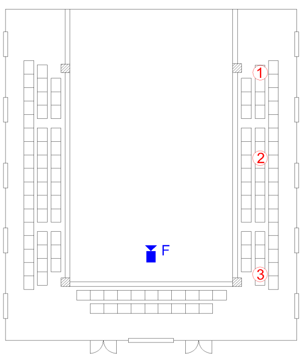


Figure 6 – Location of the sound source on the ground floor (F) and of the measured RASTI positions on the mezzannine

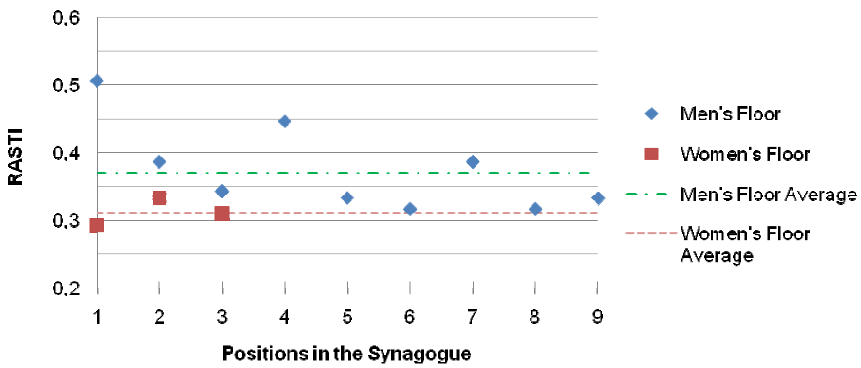


Figure 7 – Measured RASTI values at various positions and averages in the synagogue

### 2.2.3 Background noise

For the measurements of the background noise sound level, only the noise generated by road traffic was considered since the synagogue does not have HVAC systems.

The background noise measurement (63 to 8k Hz) was made at five positions (three on the ground floor) using a sound level meter B&K 2260.

The global sound pressure level on the room is 57 dB (54 dB on the men's floor and 59 dB on the mezzanine). The global sound level on the room is 37 dBA (36 dBA on the men's floor and 37 dBA on the mezzanine).

There is a 5 dB difference between the background noise sound pressure level values on the ground floor and on the mezzanine, due to the ten windows that cover almost all the walls on the women's floor.

To evaluate the level of annoyance caused by the background noise, analyses were made using the Noise Criteria (NC) and Noise Rating (NR). Although these methods are used to analyze noise from mechanical equipment or HVAC (which does not exist in this synagogue), this analysis is performed to assess how the background noise compares with the recommended values for rooms where speech intelligibility is important (Table 3). These values show a non problematic background traffic noise.

Table 3 – Comparison between NC and NR values in the Synagogue with ideal values [5, 6]

| Parameter | Mekor Haim synagogue (measured) | Ideal |
|---|---|---|
| Noise Criteria / Noise Rating | 31-32 / 32-33 | ≤ 30 |

## 3. COMPARISON WITH OTHER CHURCHES AND MOSQUES

### 3.1 Comparison with Catholic Churches with similar volume

The results in the synagogue were compared with others obtained in Catholic churches. For that, some Portuguese churches with volumes between 1310 and 3360 $m^3$ were selected as "similar" to the Mekor Haim synagogue (2399 $m^3$) [7, 8]. In Figure 8 the average RT values (500 - 1k Hz) for each church are presented in terms of their volume compared with the synagogue.

Unlike in the churches, in the Mekor Haim synagogue musical instruments are not allowed, so there is no need for hight RT values, that are more suitable for music, for organ music for example, or for religious chants. However, almost all the churches have average RT values less than the one in Mekor Haim synagogue, when it should be the opposite (Figure 8).

The average RASTI values measured in each church and in the Mekor Haim synagogue are in Figure 9. The all-church average RASTI value is 0.45, higher than the 0.34 in the synagogue.

All churches have an average RASTI value greater or equal to 0.40 (the synagogue value) except Mértola church with 0.34. In the churches, only one (Santa Clara) can be considered to have a *good* speech intelligibility. There are three churches (Misericórdia, S. Bento de Cástris and S. Pedro de Roriz) that have an *acceptable* speech intelligibility, while on the rest the speech intelligibility is *poor*.

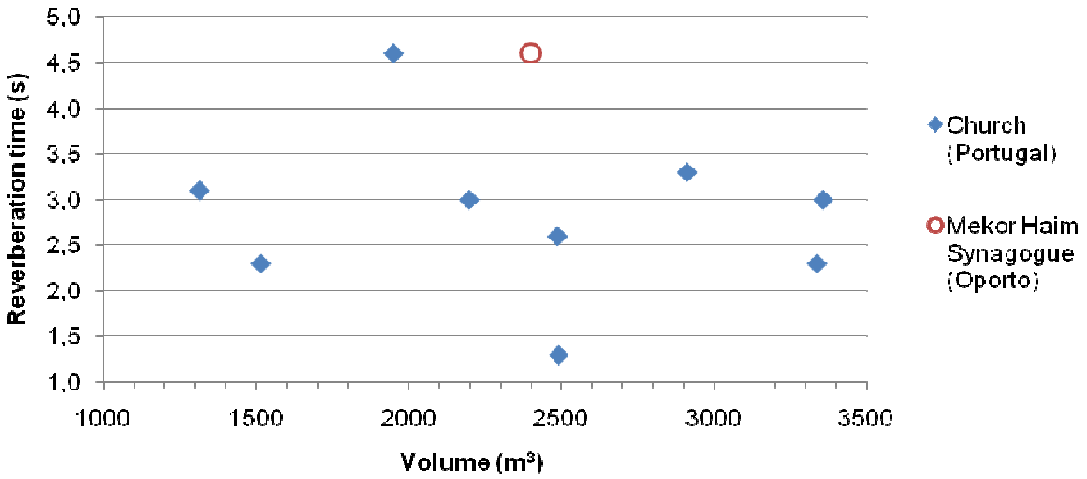


Figure 8 – RT average values (500-1k Hz) in the Catholic churches and in Mekor Haim synagogue

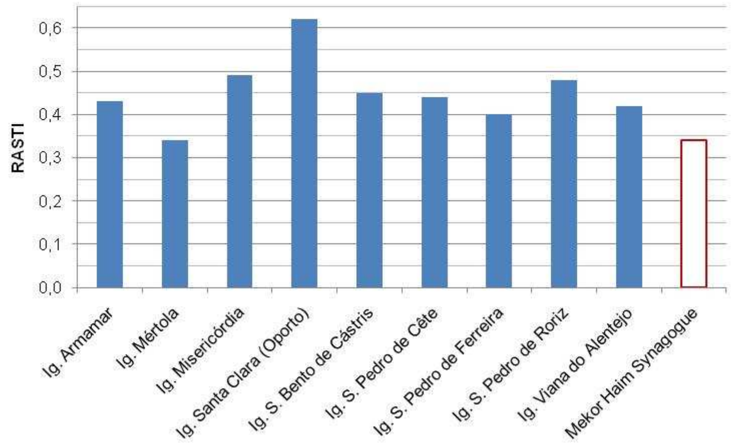


Figure 9 – Average RASTI values in the Catholic churches and in the Mekor Haim synagogue

### 3.2 Comparison with Mosques with similar volume

In mosques, as in the synagogues, there is no music, only speech. So, low RT values and high RASTI values are desirable [9]. In the mosques there is also a separation between men and women but it is possible to have some electrical sound reinforcement system (SRS), which may, in certain way, improve the speech intelligibility on the women's area. The presented values (mosques) were measured without the use of SRS.

Of the several mosques studied for comparison [9] only those with volumes between 1560 and 2500 $m^3$ were chosen because they are close to the synagogue's volume (2399 $m^3$).

Abdou divided his studied mosques in groups according to their volume, presenting the average RT values of each group [9]. In this paper only mosques from groups C and D (volumes: 1500-2000 and 2000-3000 $m^3$) were considered.

Figure 10 shows the differences among RT values in the mosques and in the Mekor Haim synagogue. In mosques, the higher RT value is obtained for the frequency band of 125 Hz, while at this synagogue the highest value belongs to the frequency bands 500-1k Hz. Despite the very similar volumes and construction materials, the RT values behavior along frequency bands is quite different, with the values in the mosques decreasing with frequency. In this synagogue there is a decrease on high frequencies mainly caused by the great volume of the room. The difference of the average RT values is due mainly to the mosques floor covered by thick carpets, and to the mosques and synagogue different ceiling heights.

Figure 11 presents the average RASTI values in each group of mosques and in the synagogue. All the mosques have a RASTI value equal or greater than 0.40 with only 38% with a *poor* speech intelligibility (62% have an *acceptable* speech intelligibility). In total, the mosques have an average RASTI value of 0.46 while this synagogue has a lower value (0.34).

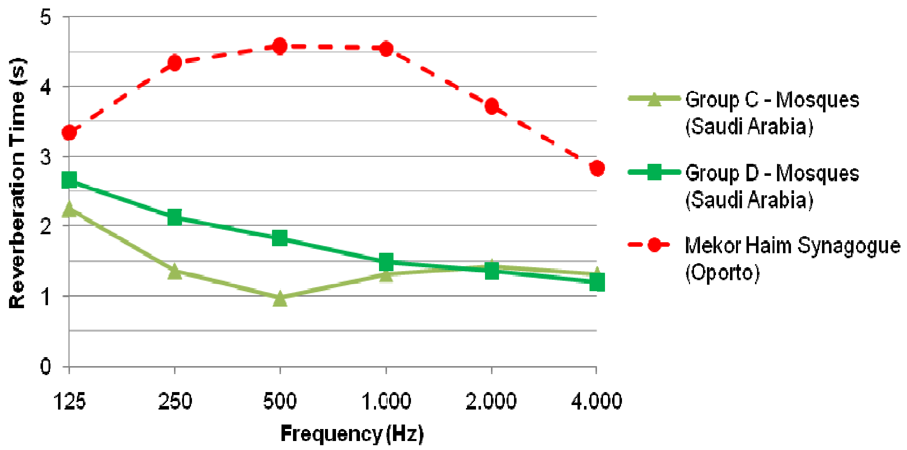


Figure 10 – Average RT values in the mosques and in the Mekor Haim synagogue [2,9]

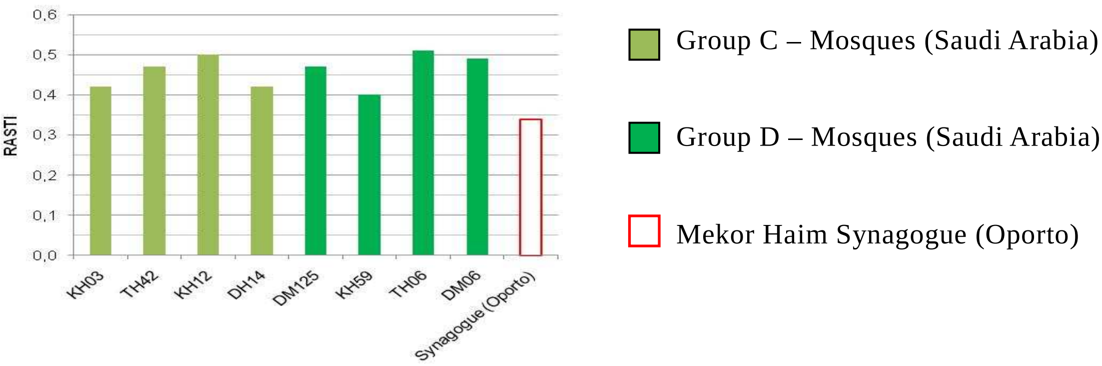


Figure 11 – Average RASTI values in the mosques and in Mekor Haim synagogue [2, 9]

## 4. ENHANCEMENT OF THE SYNAGOGUE ACOUSTIC BEHAVIOR

The background noise (road traffic) is noticeable inside the synagogue due to the low sound isolation of the large windows. However, as noted by the NC/NR values, it is not intrusive.
In the synagogue the main problem is the high RT values (and low RASTI values) and is here that corrections should work. In order to keep the architectural look of the interior, are excluded from the outset all the side walls that are covered with wall-tiles.

The dome is a very problematic element and, acting only on it by increasing its sound absorption, it would be possible to minimize the sound reflections and consequently reduce the RT.

Three solutions were considered for the acoustic correction of the synagogue. One solution is a cellulose system, like *K-13* [10], projected onto the surface of the dome and without any specific finishing. A second solution is a variant of the first one with a hand finishing and an appearance closer to the existing before the correction (like *SonaKrete* [10]). One last solution, and that allows a smooth finish, consists of mineral wool panels subsequently barred with a mineral mass in order to obtain a continuous surface (like *Baswaphon* [10]).

The application of the solutions *K-13* and *SonaKrete* in the entire dome would have an approximate cost of 6500 to 7500 €, while the solution type *Baswaphon* (40 mm thick) would be about 14000 €.
A prediction of the RT values after the intervention on the dome (empty room and 25% occupancy) was done considering those three types of solutions. Figure 12 shows the variations of the RT values for four options (two of *K-13*, one of *SonaKrete* and one of *Baswaphon*).

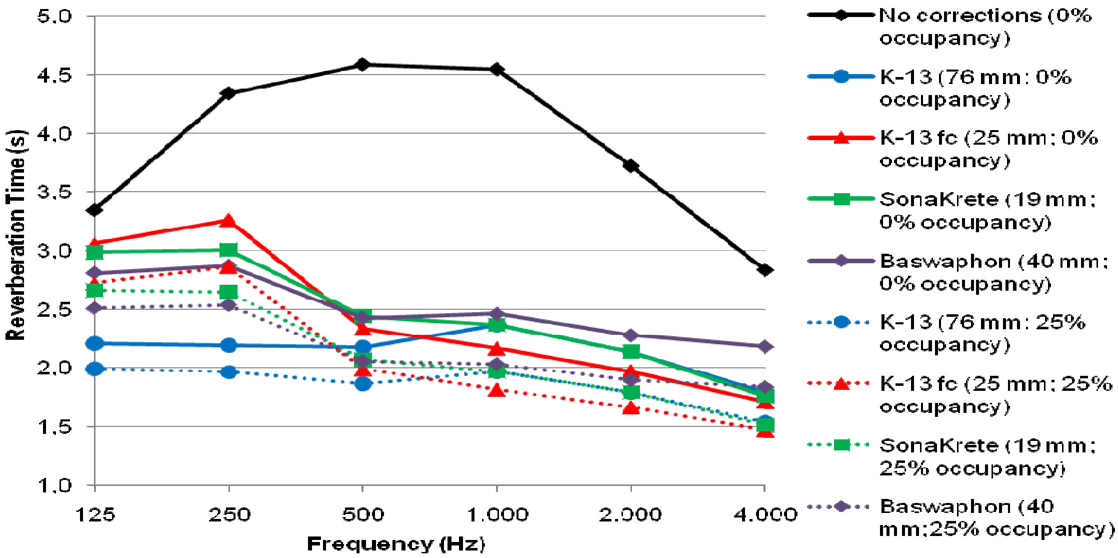


Figure 12 – Measured / predicted RT values according to applied solution the dome and occupancy rate

## 5. CONCLUSIONS

The average RT value in the Mekor Haim synagogue (4.6 s) is much higher than the ideal for rooms where speech intelligibility is important (1.0 to 1.5 s). This is due mainly to the volume, shape of the room as to the very sound reflective construction materials.

The RASTI on both floors is *poor* (0.37 and 0.31), being worse on the women's floor. The speech intelligibility is not so bad in the center of the synagogue.

The sound pressure level of background noise (road traffic) has a global value of 57 dB (37 dBA), and there is a difference of 5 dB between the men's and women's floors, which is worse in this last one due to its ten large windows.

The measured NC/NR values (NC-31/32 and NR-32/33 for men/women floors) are very close to the recommended maximum for this type of rooms.

Comparing its acoustic behavior with Catholic churches and mosques with similar volume, the outcome was similar in both cases. This synagogue presents much higher RT values than in churches and mosques, and a much lower RASTI value, this is, an acoustic behavior worse than these places of worship.

To correct the acoustic behavior of this synagogue suggestions were presented that can provide a 2 s improvement on the average RT value, treating only the dome. These improved RT values are still not at the ideal RT value of 1.0 to 1.5 s. It would be necessary to intervene in other elements of the room.


## ACKNOWLEDGEMENTS

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