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Acoustic characterization of the Municipal Museum Abade Pedrosa

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ABSTRACT

The 2016 rehabilitation of the Municipal Museum Abade Pedrosa (MMAP) in Santo Tirso, Portugal was analyzed to verify in what way acoustics interferes in the museum enjoyment. In situ measurements were done in the exhibition rooms: Reverberation Time, RASTI and Sound Level (LAeq). RT [500, 1k, 2k Hz] values were between 2.5 and 3.9 s. RASTI mean values varied between 0.44 and 0.55 s. LAeq values of background noise reached a top value of 43 dB in the 1 kHz frequency band and a global value of 57 dB(A). A multicriteria analysis was carried out to globally characterize the museum in a simple way, with an algorithm that ranks the rooms. A comparison of the measured values was done with similar studies in other museums: Soares dos Reis (Porto, Portugal), Serralves (Porto, Portugal) and other international museums, being possible to verify that the MMAP has worse acoustic values compared to those museums.

1. INTRODUCTION

The Municipal Museum Abade Pedrosa (MMAP), in Santo Tirso, Portugal, relocated to the premises of the former and old Santo Tirso Monastery, in 1985. However, it was not until 1989 that the museum was officially inaugurated, showcasing an exhibition focused on archaeology. The building possesses a rectangular floor plan, characterized by a central hall extending longitudinally. Granite is prominently featured in the primary structural elements. In 1997, additional exhibition spaces were integrated and in 2016, architects Siza Vieira and Souto Moura undertook the requalification and extension of the museum, culminating in the establishment of the Santo Tirso International Museum of Contemporary Sculpture (MIECST) (Figure 1).

2. METHOD

The acoustic characterization of MMAP was conducted through on-site tests: Reverberation Time (RT), RApid Speech Transmission Index (RASTI), and background noise sound level (LAeq). This study took place in May 2022 within the museum's exhibition rooms numbered 1 to 5, on a Monday, the day it is closed for visitors. The rooms are all connected between them, making it impossible to isolate them for the in-situ tests. Each exhibition room (Figures 3 to 7, Table 1) is equipped with openings leading to the corridor linking MMAP with MIECST (Figure 2). Given the presence of large display cabinets in every exhibition room, the sound source was positioned in room 1, one of the largest rooms, to facilitate the propagation of sound throughout the entirety of the exhibition space, extending to the furthest room (room 5).

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Figure 1: MMAP and MIECST.

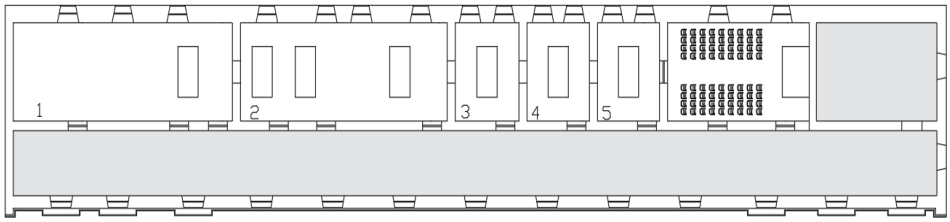

Figure 2: Floor Plan of MMAP [1].

Table 1: Dimensions of rooms 1 to 5 of MMAP [1].

Room	Length (m)	Width (m)	Max. Height (m)	Volume (m^3)
1	16.25	6.2	4.15	418.1
2	15.33	6.2	4.15	394.4
3	4.72	6.2	4.15	121.4
4	4.63	6.2	4.15	119.1
5	4.60	6.2	4.15	118.4

Figure 3: Room 1.

Figure 4: Room 2.

Figure 5: Room 3.

Figure 6: Room 4.

Figure 7: Room 5.

For the Reverberation Time (RT) measurements, the sound source B&K 4224 was placed in room 1 at a distance of 1.80 m from the rear wall. Using the B&K 2260 sound level meter, two points in each room were measured for 1/3 octave bands. For each point, two measurements were taken: one with the sound level meter rotated 45º to the right and another with the sound level meter rotated 45º to the left. (Figure 8).

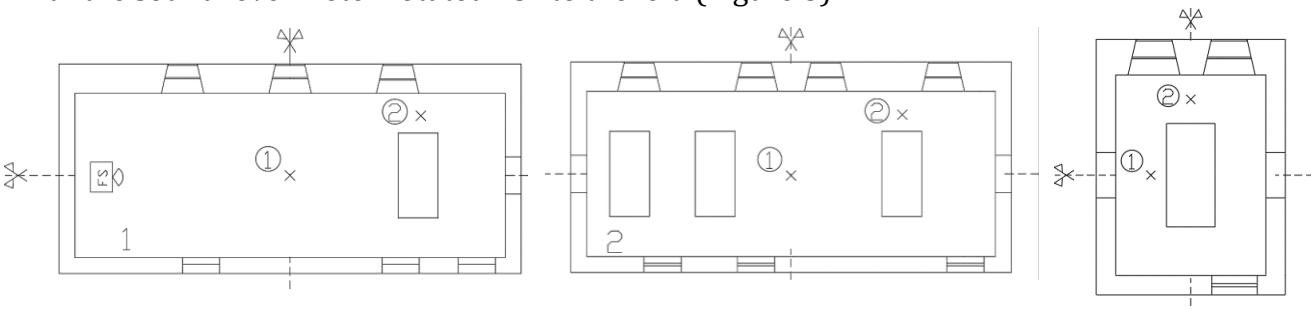

Figure 8: RT Measurement – Location of the sound source (FS) and position of points 1 and 2 measured in room 1 (left), room 2 (middle), and rooms 3, 4 and 5 (right) of MMAP [1].

For RASTI measurements, using the B&K 4419, the sound source (B&K 4224) was mounted on a tripod to simulate the typical speaker height and positioned along the central axis of each room. In larger rooms 1 and 2, six measurements were conducted, whereas in rooms 3, 4, and 5, which are smaller, two measurements were taken (Figure 9).

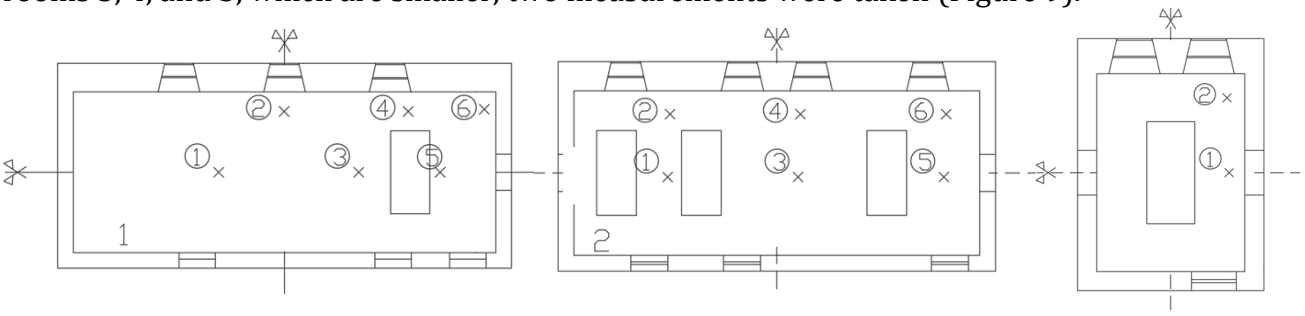

Figure 9: RASTI Measurements – Schematic depiction of the sound source positioning and the various points measured within room 1 (left), room 2 (middle) and rooms 3, 4 and 5 (left).

The visit of MMAP occurred on the day the museum was closed and without visitors, and as there are no HVAC devices present in any of the spaces, only the sound level test for background noise with no visitors was conducted. For this purpose, the sound level meter B&K 2260 on a tripod, was set for 1/3 octave band, positioned at the same locations as during the previous Reverberation Time (RT) measurements.

3. RESULTS

3.1. Reverberation Time

As depicted in Figure 10, room 1 exhibits the least variability among the RT measurements, displaying a minor decline up to 160 Hz and reaching a peak value at the 800 Hz band. Despite the substantial differences in volume, rooms 2 and 5 demonstrate comparable RT values across all frequency bands, exhibiting similar variability. Rooms 3 and 4 record the highest RT values, with room 4 notably featuring two prominent peaks: one at the 125 Hz frequency band and another at 1 kHz frequency band. Towards higher frequencies, convergence is observed across all rooms, with values ranging between 1.6 and 2.7 seconds. The most significant disparity occurs between rooms 1 and 4 at 1 kHz, with an RT of 2.2 seconds.

The measurements were arranged for 1/1 octave frequency band ranging from 125 to 4k Hz. Table 2 presents the average RT values for each room.

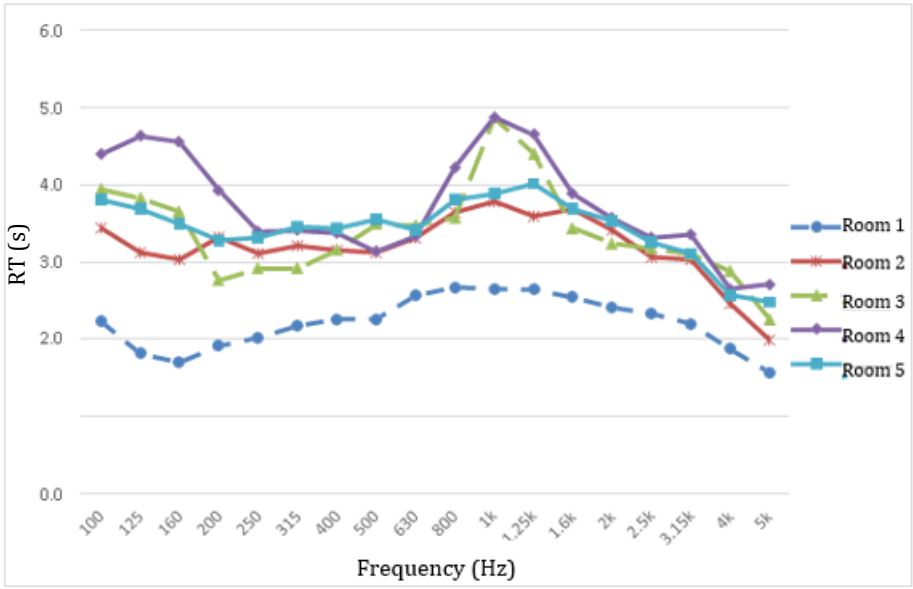

Figure 10: Average RT values in each of the exhibition rooms at MMAP for the 1/3 octave frequency bands [1].

Table 2: RT values in rooms 1 to 5 in 1/1 octave bands, along with average RT for each room at frequencies of 500, 1k and 2k Hz.

Frequency (Hz)	**Room 1**		**Room 2**		**Room 3**		**Room 4**		**Room 5**	
125	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
250	1.88	1.95	3.18	3.21	3.45	4.15	4.29	4.74	3.41	3.90
500	1.91	2.15	3.07	3.02	2.86	2.86	3.20	3.94	3.17	3.51
1000	2.34	2.38	3.11	3.28	3.34	3.39	3.34	3.21	3.41	3.51
2000	2.64	2.67	3.82	3.51	4.28	4.26	4.59	4.55	4.12	3.67
4000	2.44	2.41	3.39	3.37	3.32	3.25	3.61	3.55	3.51	3.46
Avg RT [500, 1k, 2k Hz]	2.47	2.49	3.44	3.39	3.65	3.63	3.85	3.77	3.68	3.55

Room 1 exhibits the lowest values, followed by room 2, corresponding to the largest volumes within the museum. Room 4 had the least favorable values at both points 1 and 2.

An examination focused solely on the average RT, shows that room 4 exhibits the highest values compared to the other rooms, followed by rooms 3 and 5. These three rooms share similar display cabinets and volumes, thus resulting in elevated values. Conversely, room 1 records the lowest values, but they still fall significantly short of the considered maximum ideal values, which typically range between 0.8s and 1.4s.

3.2. RASTI

In Table 3, RASTI measurements are presented for each room. The B&K 4224 receptor conducted three measurements at each point, which was followed by the calculation of the arithmetic average for each point and subsequently, the average for each room.

It is evident that as the distance from the sound source increases, RASTI values decrease. This indicates a decrease in speech intelligibility with greater distance from the sound source, as sound waves experience significant attenuation, particularly in high frequencies, due to air

sound absorption. Furthermore, it is apparent that points measured behind the display cabinets yielded lower values compared to points measured along the sides of each room. This observation suggests that the presence of display cabinets has a detrimental effect on speech intelligibility.

Table 3: Average RASTI values and standard deviations for each room [1].

	Room average	**Standard deviation**
Room 1	0.44	0.05
Room 2	0.47	0.05
Room 3	0.55	0.02
Room 4	0.55	0.02
Room 5	0.53	0.02

In rooms such as Room 1, where display cabinets do not occupy most of the space, it is evident that until point 4, the values along the central axis of the room, directly facing the sound source, are notably higher compared to those along the sides. This phenomenon occurs because the waves reaching the receptor primarily originate from the direct field in the central axis, while on the sides, they predominantly stem from the reverberated field. Point 5, being measured behind a display cabinet, experiences the adverse effects of the cabinet, resulting in lower measured values. The peaks observed in Room 2, as depicted in Figure 11, correspond to the points measured at the sides of the room. Notably, Room 2 is equipped with three display cabinets, and points 1, 3, and 5 were measured behind these cabinets, experiencing a reduction in spech intelligibility in those areas. Without the influence of the display cabinets and despite the presence of the reverberated field, measurements at the other points tend to be higher.

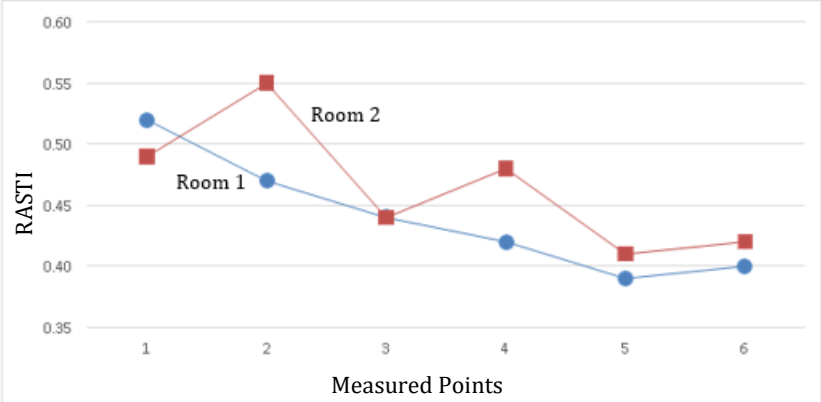

Figure 11: Average RASTI values for exhibition rooms 1 and 2.

In rooms 3, 4, and 5, the values were consistently similar, attributable to the identical dimensions and presence of identical display cabinets within these rooms. When comparing rooms 3 and 4, the average values are indistinguishable, resulting in overlapping graph lines as depicted in Figure 12. Conversely, rooms 1 and 2, with larger dimensions, exhibit higher RASTI values overall. Consequently, the speech intelligibility is superior in rooms 3, 4 and 5.

Globally, none of the rooms exhibit a RASTI value equal to or greater than 0.60, which is considered a recommended minimum threshold for museums. This value could ensure good speech intelligibility conditions contributing to visitor comfort. Therefore, none of the rooms meets the minimum requirements expected for museum exhibition spaces.

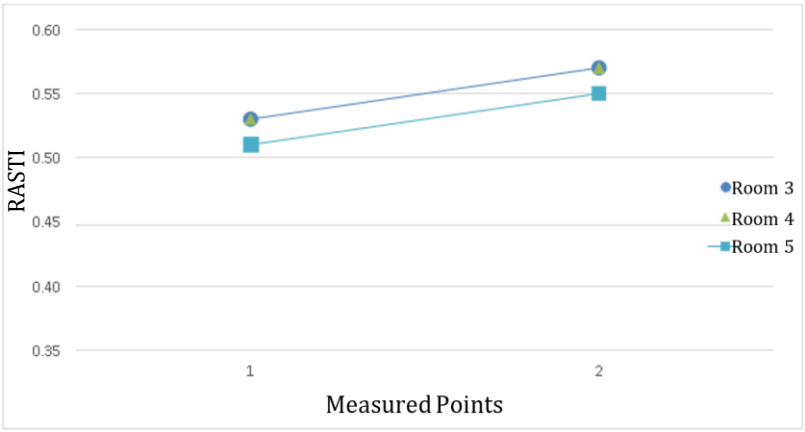

Figure 12: Average RASTI values for exhibition rooms 3, 4 and 5.

3.3. Background Noise

The MMAP lacks an HVAC system and the measurements were conducted on a day when the museum was closed to the public. The recorded values were measured in 1/3 octave frequency bands and adjusted to Filter A (Table 4). The highest values in low frequencies were the ones that became less expressive, as the human ear has more difficulty perceiving these frequencies.

Additionally, rooms 3, 4, and 5 were particularly affected by traffic noise emanating from U. Godoniz Avenue, one of the main streets near the historic center. Notably, the highest value is observed in room 1 for the 1 kHz frequency band.

In Figure 13, the sound level values exhibit subtle variations in the highest frequencies. Notably, despite possessing a similar volume to rooms 4 and 5, room 3 displays higher values. Additionally, it was in room 3 where the traffic noise from the exterior was particularly prominent. As for rooms 1 and 2, both exhibit a peak in the 250 Hz frequency band, while all rooms demonstrate higher values in the 1 kHz frequency band.

Considering the maximum limit value proposed in this study, set at 40 dB(A), it becomes evident that there is non-compliance in rooms 1 and 2 within the 250 Hz frequency band. Moreover, in every room, this threshold is surpassed in the 1 kHz frequency band. Therefore, the observed background noise levels are deemed inappropriate.

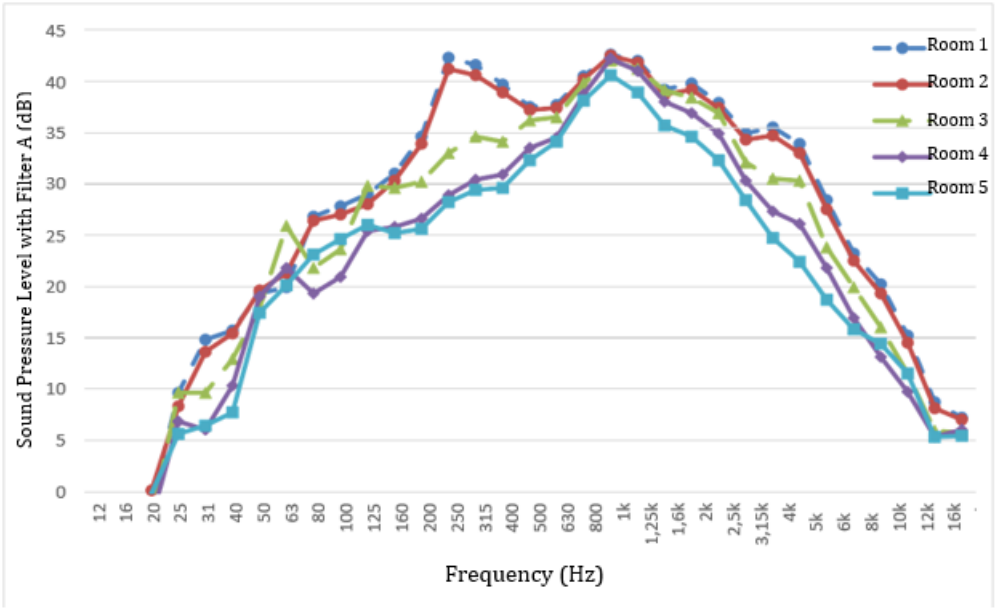

Figure 13: Sound level values of background noise with the application of Filter A in every exhibition room of MMAP for 1/3 octave bands.

Table 4: Background noise sound pressure levels (dB) in the five exhibition rooms of MMAP for 1/3 octave frequency bands [1].

Frequency (Hz)		Room 1	Room 2	Room 3	Room 4	Room 5
	31	14.9	13.7	9.7	6.1	6.5
	40	15.8	15.5	13.0	10.4	7.8
	50	19.4	19.7	18.0	19.1	17.5
	63	20.0	21.4	26.0	21.9	20.2
	80	26.9	26.5	21.9	19.4	23.2
	100	27.9	27.1	23.7	21.0	24.7
	125	29.1	28.1	29.9	25.5	26.1
	160	31.1	30.4	29.7	25.9	25.3
	200	34.7	34.0	30.3	26.7	25.7
	250	42.4	41.3	33.1	29.0	28.3
	315	41.7	40.7	34.7	30.5	29.5
	400	39.8	39.0	34.2	31.0	29.7
	500	37.6	37.3	36.3	33.6	32.4
	630	37.8	37.5	36.6	34.6	34.2
	800	40.6	40.3	39.9	38.8	38.2
	1k	42.7	42.6	42.1	42.3	40.7
	1.25k	42.1	41.9	41.3	41.1	39.0
	1.6k	39.3	38.8	39.2	38.1	35.8
	2k	39.9	39.3	38.5	37.0	34.7
	2.5k	38.0	37.5	37.0	35.0	32.4
	3.15k	35.0	34.4	32.2	30.4	28.5
	4k	35.6	34.8	30.6	27.4	24.8
	5k	34.0	33.1	30.4	26.2	22.5
	6k	28.5	27.6	23.9	21.9	18.8
	8k	23.3	22.6	20.0	17.0	15.9
	10k	20.3	19.4	16.1	13.2	14.5
	12k	15.3	14.6	11.6	9.8	11.6
LAeq (dB)		51.7	51.1	49.3	48.1	46.5

4. MULTICRITERIA ANALYSIS

For this study, a simple additive method will be employed, which is a linear formula incorporating weighted values aggregated according to the significance attributed by the decision maker. This can be represented by Equation 1.

$$v\ (zi) = \sum_{j=1}^{na} wj * ci,j \quad (1)$$

In this equation, v represents the final result, w denotes the relative importance or weight assigned to each criterion, a signifies each attribute under study, and c represents the score assigned to each of the evaluated parameters. Simply put, weights are assigned to the acoustic parameters based on their importance in satisfying the evaluation criteria (c) with which they are associated. Therefore, the acoustic parameters that will be considered for the evaluation of the global acoustic quality of the museum (PQAM) are Reverberation Time (RT); speech intelligibility from RASTI or STI; background noise sound level (LAeq); and background noise sound level with HVAC (LAeq (HVAC)).

A scale of 0 to 10 was considered, where 0 (zero) corresponds to the worst value and 10 to the best value. After defining the criteria and assigning scores to each parameter, weights were allocated to each criterion, considering their influence on the acoustics of the museum. (Table 5, Equation 2).

Table 5: Weight of each criterion considered in the algorithm.

Criteria	**RT**	**RASTI or STI**	**LAeq**	**LAeq (HVAC)**
Weight (%)	40	35	10	15

$$PQAM = 0{,}40 \times C_{RT} + 0{,}35 \times C_{RASTI} + 0{,}10 \times C_{LAeq} + 0{,}15 \times C_{LAeq\ (HVAC)} \quad (2)$$

The conversion of PQAM results to a subjective evaluation scale was performed as demonstrated in Table 6, where results below 5.0 are categorized as "*Bad*" or "*Terrible*", while values above 5.0 represent the desired outcomes to achieve.

Table 6: Subjective scale applied to the Acoustic Quality Parameter in Museums when applying the algorithm.

Rating	***Terrible***	***Bad***	***Sufficient***	***Good***	***Excellent***
PQAM	[0; 2.5[	[2.5; 5.0[	[5.0; 6.0[	[6.0; 8.0[	[8.0; 10.0]

Room 1 stands out as the only one with positive results, albeit still classified only within the "*Sufficient*" category, with a PQAM score of 5.4. Following closely are room 3 and room 5, both scoring 4.6 and already categorized within the "*Bad*" category.

During the museum visit, the sensation was that each room exhibited a similar behavior, without subjectively distinguishing one from another in terms of acoustic quality.

In the case of rooms 2 and 4, the results are deemed "*Bad*" with global PQAM values of 3.7 and 4.3, respectively, representing the lowest scores observed. Rooms 3, 4, and 5 exhibit values quite closely aligned with each other, differing only marginally. However, room 2 emerges as the poorest performing room, primarily due to its high RT and LAeq values, which contribute to lower scores in those parameters (Table 7).

Table 7: Results of PQAM when applying the algorithm and corresponding converted results to the subjective scale of every exhibition room in MMAP. RT values are the average between P1 and P2 in the [500, 1k, 2k Hz] frequency bands.

Room	Avg RT (s)	C_{RT}	RASTI	C_{RASTI}	LAeq (dB)	C_{LAeq}	LAeq (HVAC) (dB)	C_{LAeq} (AVAC)	PQAM	Result
1	2.48	**6**	0.44	**6**	51.7	**1**	n.m.	**5**	5.4	*Sufficient*
2	3.42	**1**	0.47	**7**	51.1	**1**	n.m.	**5**	3.7	*Bad*
3	3.64	**1**	0.55	**9**	49.3	**3**	n.m.	**5**	4.6	*Bad*
4	3.81	**0**	0.55	**9**	48.1	**4**	n.m.	**5**	4.3	*Bad*
5	3.62	**1**	0.53	**8**	46.5	**6**	n.m.	**5**	4.6	*Bad*

n.m. – not measured

5. COMPARATIVE ANALYSIS BETWEEN MUSEUMS

Comparing results between museums is important to obtain a global perspective of how acoustic measures continue to be implemented in these spaces The approach taken in traditional museums, constructed decades ago without much consideration for acoustics, differs from the approach adopted in modern museums. Materials used vary, as do the geometries of the spaces, which dictate the necessity for materials capable of absorbing excessive noise that may be present. The primary objective acoustic parameters for comparison include RT, RASTI/STI, and background noise sound levels, which were the parameters evaluated in this study.

5.1. Reverberation Time

The museums selected for study, due to the similarity of tests conducted for comparison with MMAP, are as follows:

- Traditional typology: National Museum of Soares dos Reis (Porto); National Museum of Archaeology (Lisbon); Modern Art Museum of Kristinehamn (Sweden), Museum Rhmi M. Koç and Archaeology and Arts Erimtan Museum (Turkey), National Archaeology Museum (Italy);
- Modern tipology: Serralves (Porto), National Museum of Iceland and New Acropolis Museum (Greece).

Based on the average RT (500, 1k, 2k Hz) values, it can be concluded that the National Museum of Iceland exhibits the most favorable acoustic value (1.60 s), while the Modern Art Museum of Kristinehamn records the highest value (4.50 s), followed by Serralves' Museum with an average RT of 3.90 s. MMAP ranks as the fourth museum with the highest average RT (Figure 14).

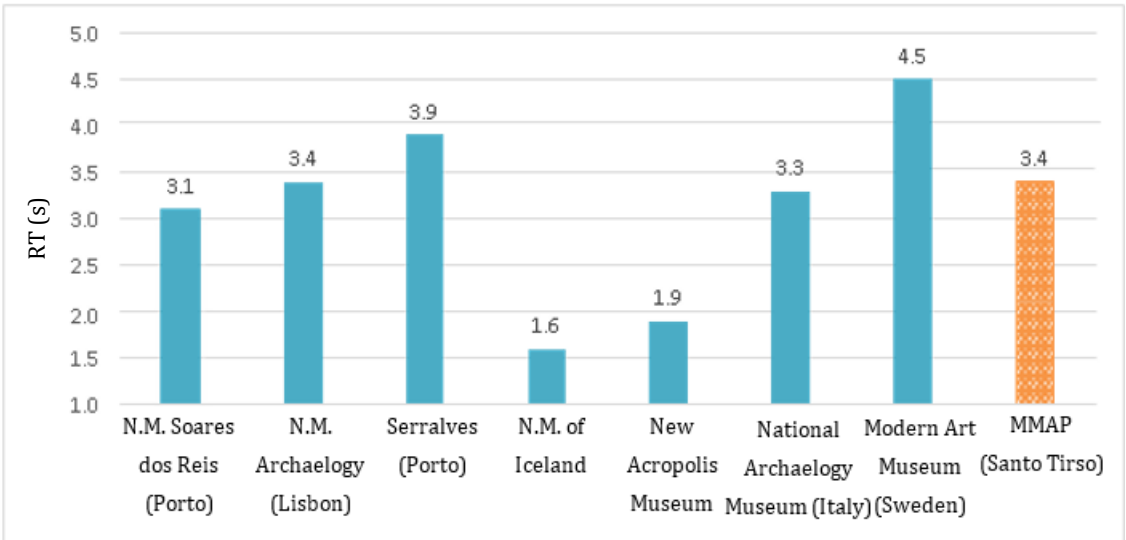

Figure 14: Comparison of average RT (500, 1k, 2k Hz) in all the museums [1, 2, 3].

While the RT values in MMAP are consistent across rooms, the values in different rooms of the National Museum of Soares dos Reis exhibit significant variability, ranging from 1.60 to 5.10 s, the highest value recorded among all the museums. Room 7 notably displays a high value due to the presence of highly reflective surfaces and a modern architectural style. In this museum, a relationship between increased volume and increased RT is apparent.

None of the museums meet the ideal average RT values considered here (between 0.8 and 1.4 s). However, the ones that come closest are the National Museum of Iceland and the New Acropolis Museum, followed by the National Museum of Soares dos Reis, although it is notably more distant from the first two, with significant issues observed in room 7.

5.2. RASTI

For RASTI, the comparison was conducted among the three Portuguese museums, as such tests were not carried out in other publications. Speech intelligibility in museums should not be excessive, but it must provide good conditions for understanding everything that is said in each room. As shown in Table 8, RASTI values generally fall between the categories considered "*poor*" and "*acceptable*". MMAP exhibits the highest values in rooms 3 and 4, while the least favorable value is found in room 11 of Serralves' Museum. Interestingly, the rooms with the largest volumes tend to have lower speech intelligibility values overall.

Considering the recommended value equal to or greater than 0.60, rooms 3 and 4 of MMAP are the ones that come closest to this threshold, followed by room 2 of the same museum, as well as rooms 5 and 16 of the National Museum of Soares dos Reis.

Table 8: Comparison of average RASTI values between MMAP and other museums [1, 2, 3]

MUSEUM	**Average RASTI**	
	Subjective	**Objective**
Municipal Museum Abade Pedrosa (Santo Tirso)		
Room 1	*Poor*	0.44
Room 2	*Acceptable*	0.47
Rooms 3 and 4	*Acceptable*	0.55 (best)
Room 5	*Acceptable*	0.53
National Museum Soares dos Reis (Porto, Portugal)		
Rooms 2, 5 and 16	*Acceptable*	0.47 a 0.53
Room 7	*Poor*	0.41
Serralves Museum (Porto, Portugal)		
Room 11	*Poor*	0.40 (worse)
Room 12	*Poor*	0.42
Room 14	*Acceptable*	0.45

5.3. Background Noise

The background noise sound levels from various museums were organized in Table 9. For MMAP, National Museum of Soares dos Reis, and Serralves Museum, the values are provided under conditions where there were no visitors, and the HVAC systems were turned off. For the Turkish museums, the only values available were those with visitors present. In the case of the National Museum of Iceland, the values presented consider the HVAC systems turned on.

MMAP generally exhibits the highest background noise values, notably standing out from the rest of the museums, especially in the 1 kHz band. This museum features numerous windows along the exhibition rooms and the connecting corridor, making it more susceptible to exterior noise infiltration. The Serralves Museum, which stood out as the second museum

with the highest RT, exhibits low values of background noise sound levels, particularly notable in comparison to the other museums. However, this museum is situated in an area where the city's streets are distant from the exhibition rooms, contributing to lower background noise levels compared to other museums. Overall, the values across different rooms demonstrate low variability.

The National Museum of Soares dos Reis (NMSR) (Figure 15) exhibits values slightly lower compared to MMAP. Across every frequency band, NMSR demonstrates inferior values compared to MMAP. Notably, rooms 3, 4, and 5 of MMAP, despite having much smaller volumes than the smallest rooms of NMSR, present significantly higher background noise values. Room 2 of both museums have quite similar volumes, with a difference of 6 dB(A) between them. Regarding the National Museum of Iceland, despite having the HVAC system on, it records a background noise value of 36 dB(A) in the *Gallery of Photography*, which is lower than any of the values observed in MMAP. Even the highest value in *Arc Hall* is only higher than room 5 of MMAP, and both spaces exhibit quite similar volumes.

In both Rahmi M. Koç and Erimtan museums in Turkey, only the values of the equivalent background noise were obtained, which stand out due to their high values. Information regarding whether the HVAC system was operational at the time was not available, but the values were measured during a weekend when both museums experienced high visitor traffic. Situated in the historic center of the city of Ankara, both museums are housed in old constructions, with Rahmi M. Koç museum established in 1994 and Erimtan in 2015, through the transformation of three old houses.

Considering 40 dB(A) as the maximum permissible background noise level suggested in this study for these types of spaces, Serralves Museum is the only one that meets this criterion in all rooms. The National Museum of Soares dos Reis (NMSR) only has rooms 5 and 7 with satisfactory conditions.

Table 9: Background Noise sound levels to 1/1 octave frequency bands of the studied museums.

Freq.	**L_A (dB)**										**L_{Aeq}**
	16	**31**	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**	**(dB)**
Municipal Museum of Abade Pedrosa (Porto)											
Room 1	2.5	13.5	20.2	29.7	42.5	37.8	42.7	39.7	35.6	21.4	47.5
Room 2	4.6	13.1	21.6	28.8	41.4	37.5	42.6	39.1	34.8	22.7	47.0
Room 3	5.2	19.1	26.2	30.5	33.2	36.5	42.1	38.5	30.6	20.1	45.1
Room 4	1.1	5.5	22.1	26.1	29.1	33.8	42.3	36.8	27.4	17.1	44.2
Room 5	1.7	5.9	20.4	26.9	28.4	32.6	40.7	34.5	24.8	16.0	42.6
National Museum of Soares dos Reis (Porto)											
Room 2	0.7	17.0	31.7	32.4	31.3	32.3	36.9	35.1	28.5	15.3	41.5
Room 5	-	2.6	12.7	16.4	18.1	19.7	23.6	24.0	20.0	14.1	29.1
Room 7	-	4.4	16.3	17.1	19.3	24.2	22.1	18.9	17.2	13.2	28.5
Room 16	-	15.4	30.7	34.2	30.9	34.4	37.5	34.8	27.7	15.8	42.0
Serralves Museum (Porto)											
Room 11	-	7.9	9.4	18.1	19.6	26.5	28.7	22.9	15.7	11.7	32.0
Room 12	-	-	2.6	9.2	13.6	18.7	19.8	17.7	14.4	11.5	24.8
Room 14	-	8.0	14.4	15.9	19.8	19.4	19.0	16.8	14.3	11.3	25.8
National Museum of Iceland (with HVAC)											
Arc Hall	-	21.0	30.0	39.0	37.0	37.0	37.0	33.0	30.0	-	44.0
Gall. of Ph.	-	7.0	17.0	20.0	32.0	29.0	30.0	27.0	25.0	-	36.0
Rahmi M. Koç Museum (Turkey) (with visitors)											
	-	-	-	-	-	-	-	-	-	-	95.6
Archaeology and Arts Erimtan Museum (Turkey) (with visitors)											

- - - - - - - - - - 94.4

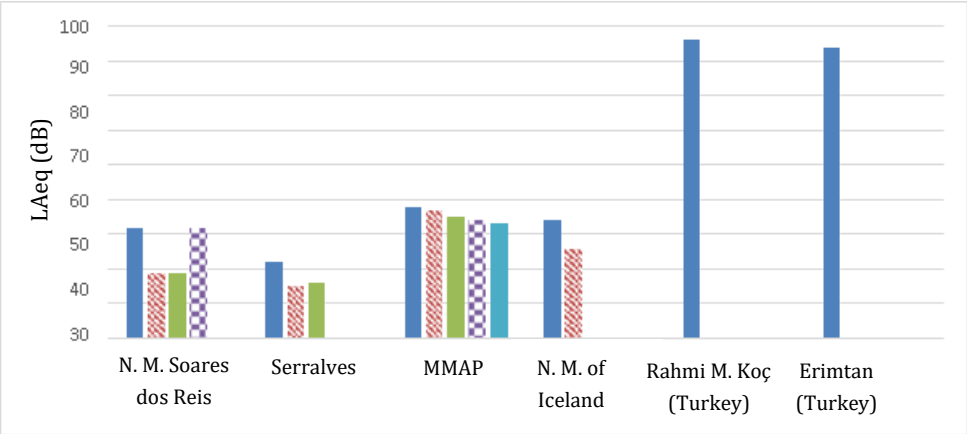

Figure 15: Comparison of the average Background Noise levels of the museums [1, 2, 3].

6. RESULTS

None of the rooms in MMAP meet the ideal proposed values. The average RT values (500/1k/2k Hz) exceed recommended levels, nearly tripling the desirable value. Rooms 3 and 4 exhibit the most excessive results, followed by room 5, corresponding to the three rooms with the smallest dimensions. Even when considering an RT value up to 2.0 s, MMAP still does not yield satisfactory results in any of the rooms. Background noise sound levels surpass the indicated limit, both with no HVAC systems and no visitors, exacerbating with visitors present. The most inadequate rooms are numbers 1 and 2, which are the largest in dimensions. RASTI values also fall short, with this parameter suffering from the poor performances observed in RT and background noise. While ideal speech intelligibility is not achieved, there are adequate privacy conditions in the spaces. Even without present visitors, discomfort due to high RT values, coupled with elevated background noise levels, could detract from an ideal museum experience.

REFERENCES

1. S. Barbosa. *Caracterização Acústica do Museu Municipal Abade Pedrosa (Santo Tirso).* M.Sc. thesis in Civil Engineering, Faculty of Engineering U. Porto- FEUP, 2022.
2. H. Gonçalves. *A Acústica de Museus Modernos. Estudo de caso, o Museu de Serralves (Porto).* M.Sc. thesis in Civil Engineering, Faculty of Engineering U. Porto - FEUP, 2012.
3. L. Garcia. *A acústica de museus tradicionais – Estudo de caso, o Museu Nacional de Soares dos Reis*. M.Sc. thesis in Civil Engineering, Faculty of Engineering U. Porto - FEUP, 2012.