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# A multi-criteria method to assess the acoustic quality in museums

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## ABSTRACT

This paper proposes a multi-criteria analysis model to acoustically characterize a specific type of building: museums. Significant acoustic objective parameters are used and logically weighted (after analysis of questionnaires and interviews for subjective responses of visitors) to find a representative unique index of evaluation of a room, the IAQM (Index of Acoustic Quality in Museums) rated on a scale from 0 (worst) to 20 (best). The acoustic parameters used are: Reverberation Time (RT), weighted standardized sound level difference of facades (D2m,nT,w), Rapid Speech Transmission Index (RASTI), LAeq (from HVAC background noise) and L'nT,w (weighted standardized field impact sound pressure level). The multi-criteria mathematical model is presented and numerically tested with two museums.

## 1. INTRODUCTION

A museum can be acoustically studied regarding several criteria in two areas of analysis: the intrusive noise (exterior, HVAC and visitors) and the room acoustic environment for the art appreciation and speech intelligibility (museum guides). These multiple characteristics may be objectively evaluated by numerical parameters that describe the sound field within rooms. In this paper several significant objective acoustic parameters are used and weighted (after analysis of questionnaires for subjective responses of visitors) to find a representative global index of evaluation of each room in a museum. The acoustic parameters used are: Reverberation Time (RT) (average of 500 and 1k Hz frequency bands), weighted standardized sound level difference of facades (D2m,nT,w), Rapid Speech Transmission Index (RASTI), LAeq (from HVAC background noise) and L'nT,w (weighted standardized field impact sound pressure level).

## 2. SAMPLE

This work uses, as case study, two museums as typical examples: an “old” art museum (National Museum of Soares dos Reis) and a “modern” museum (Contemporary Art Museum of Serralves).

The National Museum Soares dos Reis (NMSR) is installed in the *Palace of the Carrancas* (Porto, Portugal) in a neoclassical building built in 1800 (Figures 1 to 3). In 1934 it was adapted to a museum and in 1992 it was renovated. The Contemporary Art Museum of Serralves (CAMS), also located in Porto, is a typical example of a “modern” museum. The building (1999) designed by the architect Siza Vieira has three floors (total area 12,700 $m^2$) with 14 exhibition rooms (occupying 4,500 $m^2$) almost entirely with double floor height (Figures 4 and 5). The exhibition halls are wide and free of partitions inside (Figure 5).

**Figures 1 to 3:** National Museum of Soares dos Reis (exterior and rooms n. 2 and 16) [1,3].

**Figures 4 and 5:** Contemporary Art Museum of Serralves (exterior and room n. 11) [2,3].

## 3. SURVEY

With the aim of studying the perceived acoustic quality of the museums a subjective acoustic analysis was performed with use of a survey to a group of people representative of the population.

Two surveys were conducted theoretically based on standard ISO 15666[4] (Portuguese NP 4476[5]). They were done in the National Museum Soares dos Reis (NMSR) and in the Contemporary Art Museum of Serralves (CAMS). The main goal was to quantify the discomfort felt subjectively by the different types of noise present in the museums.

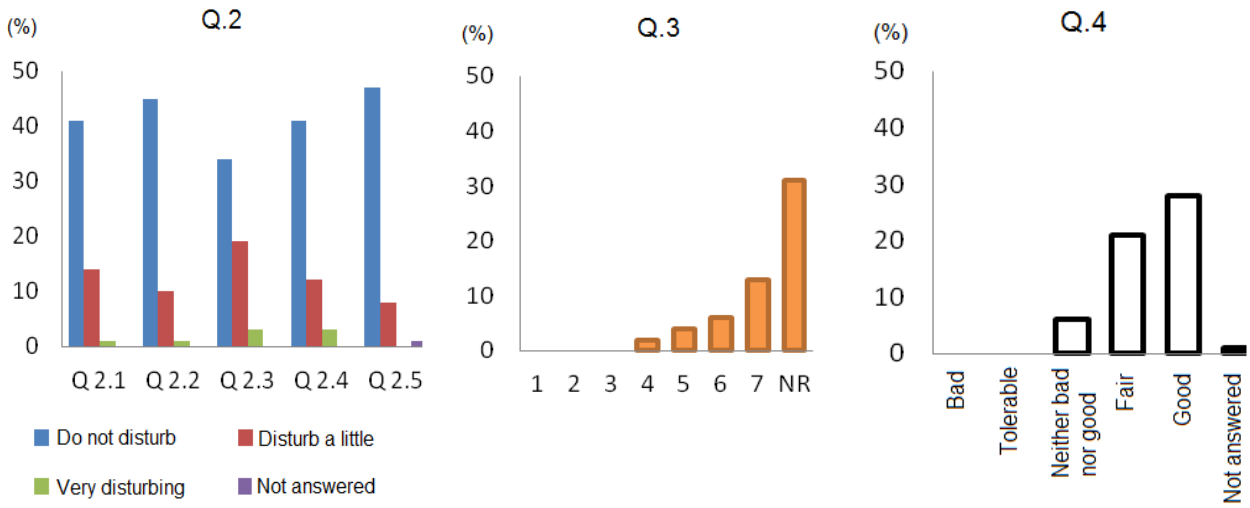
The questionnaires were individually presented to visitors at the end of each visit. Some museum staff members that were monitoring the spaces were also asked to answer the questionnaire.

## A. National Museum Soares dos Reis (NMSR)

The questionnaires presented at the NMSR (56 responses) had the following questions (Q.):
- Gender and age;
- Q. 1. - *What is the reason that made you come to this museum?*
- Q. 2.1 - *Evaluate the following noise: Noise conversation within the room* (Fig. 6);
- Q. 2.2 - *Evaluate the following noise: Noise from other rooms* (Fig. 6);
- Q. 2.3 - *Evaluate the following noise: Impact noise (steps, jumps, etc.)* (Fig. 6);
- Q. 2.4 - *Evaluate the following noise: Exterior noise (traffic, etc.)* (Fig. 6);
- Q. 2.5 - *Evaluate the following noise: Noise from ventilation / heating equipment* (Fig. 6);
- Q. 3 - *How well could you hear and understand the museum guide?* (Fig. 7);
- Q. 4 - *How do you assess this museum in terms of acoustics (noise)?* (Fig. 8).

Figures 6 to 8 show the statistics of some of the responses to the survey. It is noted that in this museum, the noise that bothers visitors the most is the impact noise (steps, jumps, etc.) then, the noise coming from outside, the noise of the conversations in the room, the noise from other rooms and finally the noise from HVAC. Regarding the questions about speech intelligibility of the museum guide and the overall acoustic assessment of the museum, respondents attributed positive quotes.

This museum has an average RT (500-1k Hz) between 1.6 s and 3.1 s in all rooms except n. 7 with a RT of 5.1 s [1,3].




**Figures 6 (left), 7 (center) and 8 (right)**: Results obtained in questions Q. 2 (left), Q. 3 (center) (1-worst, 7 best, NR - No Response) and Q. 4 (right), in the NMSR[1].

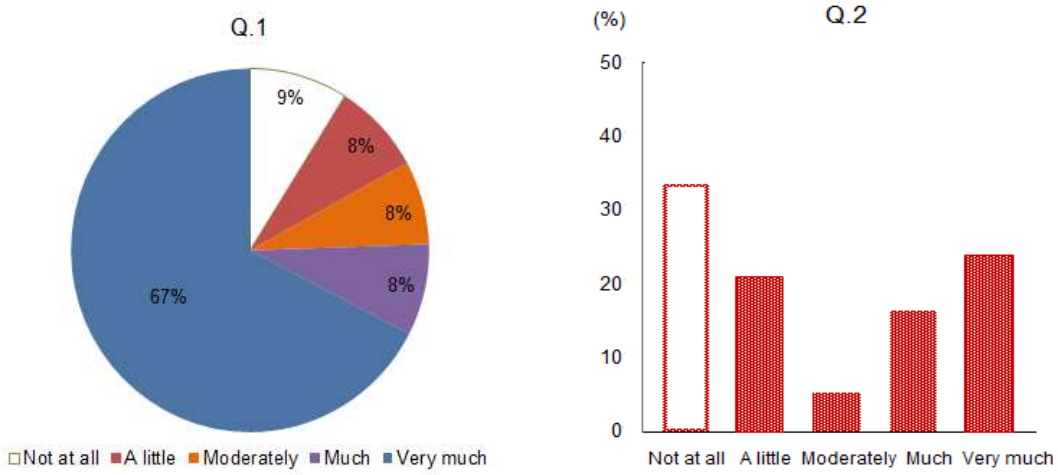
## B. Contemporary Art Museum of Serralves (CAMS)

In the CAMS the questions presented three socio-demographic questions, eight questions about acoustics and a question about the motivation that led respondents to the museum. The responses were listed on a *Likert* scale of five points.

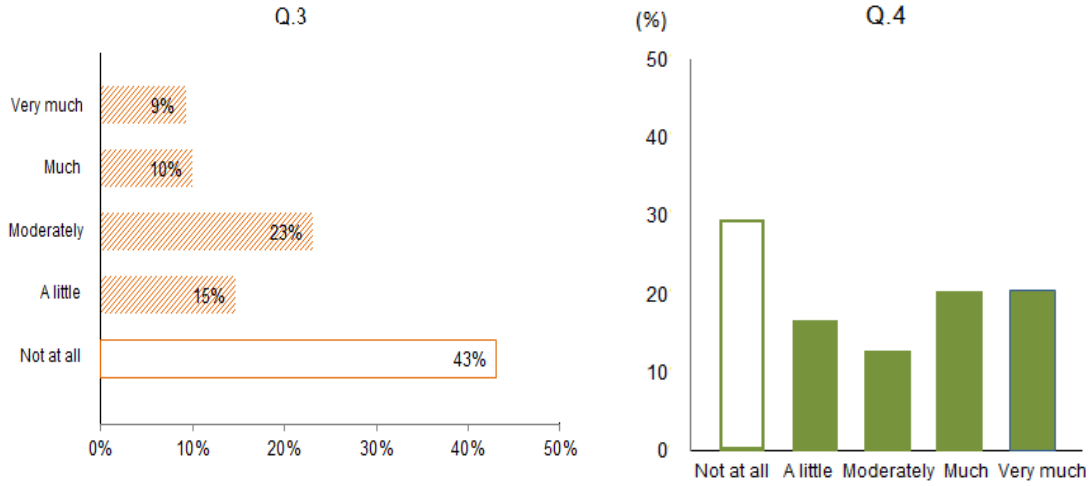
The survey was conducted in a personal interview system and individually held outside the exhibition rooms. The sample had 135 respondents (26% foreigners; 57% male; 38% between 18 and 30 years old and 26% between 31 and 45 years old), all voluntarily requested and without information of the results obtained by objective acoustic parameters. The sample size is about 10% of the number of visitors in the period in which it was performed, accounting for this sample only one questionnaire per family (when it was the case).

The questionnaires presented at the CAMS had the following main questions (Q.):

- Q. 1. - *Do you appreciate the silence in museums?* (Fig. 9);
- Q. 2. - *Did you feel a lot of noise in the rooms of this museum?* (Fig. 10);
- Q. 3. - *Is the noise of cameras annoying?* (Fig. 11);
- Q. 4. - *Is the noise of visitors a nuisance?* (Fig. 12);
- Q. 5. - *Could you hear the guide clearly?* (Fig. 13);
- Q. 6. - *Could you understand the conversations of other visitors?* (Fig. 14);
- Q. 7. - *Could you hear "echoes" in the rooms?* (Fig. 15);
- Q. 8. - *Was the sound of footsteps intense?* (Fig. 16);
- Q. 9. - *What you like the most in this museum? (Exhibitions; Library; Sound Environment; Restaurant; Building; Artificial Lighting; Natural Light).*




**Figures 9 (left) and 10 (right)**: Results from questions Q.1 (*Do you appreciate the silence in museums?*) (left) and Q.2 (*Did you feel a lot of noise in the rooms of this museum?)* (right), in the CAMS[2].

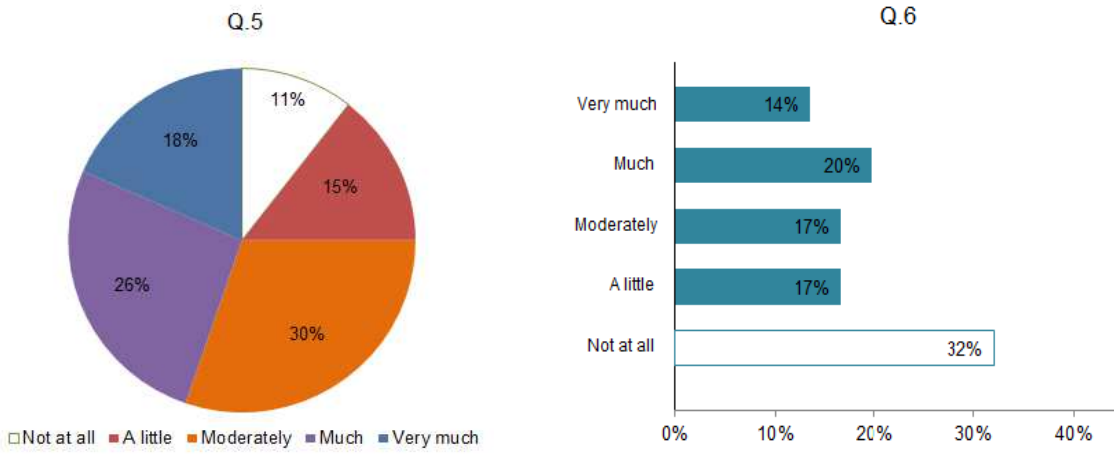



**Figures 11 (left) and 12 (right)**: Results from questions Q.3 (*Is the noise of cameras annoying?*) (left) and Q.4 (*Is the noise of visitors a nuisance?*) (right), in the CAMS[2].

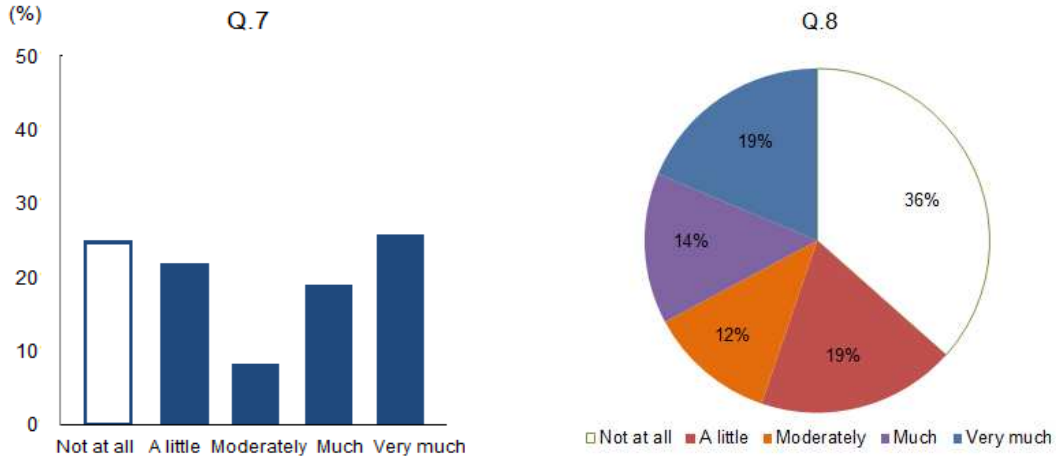
A brief summary of the CAMS survey results shows that:
- 75% of respondents are interested in "silence" in the museums (Fig. 9);
- 45% said hear "echoes" in the showrooms (Fig. 13);
- 41% affirm that they felt noise in the museum (Fig. 10);
- 41% shown themselves troubled by noise from other visitors (Fig. 11);
- 33% admit that the sound of the footsteps of visitors were intense (Fig. 14);
- 25% said that they did not clearly perceive the guide (Fig. 12);

- 20% felt uncomfortable by noise from the photo cameras (Fig. 11);
- The persons visiting the museum because of the exhibits is similar to the number of people who visit it to "admire" the building (for many considered a contemporary architectural master piece).

The above numbers reveal that the current acoustic environment of the museum is not the best (it has a RT of about 4 s in all main rooms [2,3]).




**Figures 13 (left) and 14 (right)**: Results from questions Q.5 (*Could you hear the guide clearly?*) (left) and Q.6 (*Could you understand the conversations of other visitors?*) (right), in the CAMS[2].




**Figures 15 (left) and 16 (right)**: Results from questions Q.7 (*Could you hear "echoes" in the rooms?*) (left) and Q.8 (*The sound of footsteps was intense?*) (right) in the CAMS[2].

## 4. MULTI-CRITERIA METHOD

The multi-criteria method used to acoustically classify the museums is an additive method (discrete and deterministic). The acoustic parameters considered as decision criteria for assessing the overall sound quality of each room of a museum are:

- Reverberation Time (RT), room average of 500 and 1k Hz frequency bands;
- Rapid Speech Transmission Index (RASTI) room average;
- Equivalent continuous A-weighted sound level of background noise with HVAC equipment, (LAeq HVAC);
- Weighted standardized impact sound pressure level (L'nT,w);
- Weighted standardized sound level difference of a facade (D2m,nT,w).

These parameters were chosen because they numerically illustrate the main acoustic qualities that a museum should have. A relative weight was assigned to each criterion, supported by the

results of the surveys in the museums, which can give a rough idea of the relative importance of each (Table 1).

**Table 1:** Weight of each criterion of the algorithm IQAM.[1]

| Criterion | RT | RASTI | $L_{Aeq}$ HVAC | $L'_{nT, w}$ | $D_{2m, nT, w}$ |
|---|---|---|---|---|---|
| Weight | 0.4 | 0.2 | 0.1 | 0.2 | 0.1 |

**Table 2:** Subjective scale rating of the values obtained by IQAM.[1]

| Grade | *Terrible* | *V. Bad* | *Bad* | *Poor* | *Fair* | *Good* | *V. Good* | *Excellent* |
|---|---|---|---|---|---|---|---|---|
| IAQM | [0; 3[ | [3; 5[ | [5; 7[ | [7; 10[ | [10; 13[ | [13; 15[ | [15; 17[ | [17; 20] |

**Table 3:** Range of values for the normalized criterion of sound level of background noise with HVAC equipment.[1]

| $L_{Aeq}$ (HVAC) (dB) | ≤ 25 | 26 to 27 | 28 to 29 | 30 to 31 | 32 to 33 | 34 to 35 | 36 to 37 | 38 to 39 | 40 to 41 | 42 to 43 | 44 to 45 | 46 | 47 | 48 | 49 | ≥ 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAeq HVAC_N | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 8 | 6 | 4 | 2 | 0 |

**Table 4:** Scale of values for normalized (_N) impact sound insulation index.[1,3]

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| L'nT,w (dB) | ≤ 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 |
| L'nT,w_N | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 |
| L'nT,w (dB) | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | ≥ 65 | |
| L'nT,w_N | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |

**Table 5:** Scale of values for normalized criteria RT [500-1k Hz], RASTI and D2m,nT,w.[1]

| $RT_{[500\text{-}1k\ Hz]}$ (s) | RT_N | RASTI (avg.) | RASTI_N | D2m,nT,w (dB) | D2m,nT,w_N |
|---|---|---|---|---|---|
| [0.0 ; 0.2[ | 0 | [0.00 ; 0.10[ | 0 | ≥ 43 | 20 |
| [0.2 ; 0.4[ | 4 | [0.10 ; 0.15[ | 2 | 42 | 19 |
| [0.4 ; 0.6[ | 8 | [0.15 ; 0.20[ | 3 | 41 | 18 |
| [0.6 ; 0.8[ | 12 | [0.20 ; 0.25[ | 4 | 40 | 17 |
| [0.8 ; 1.0[ | 16 | [0.25 ; 0.30[ | 5 | 39 | 16 |
| [1.0 ; 1.2[ | 20 | [0.30 ; 0.35[ | 6 | 38 | 15 |
| [1.2 ; 1.4[ | 19 | [0.35 ; 0.40[ | 7 | 37 | 14 |
| [1.4 ; 1.6[ | 18 | [0.40 ; 0.45[ | 8 | 36 | 13 |
| [1.6 ; 1.8[ | 17 | [0.45 ; 0.50[ | 10 | 35 | 12 |
| [1.8 ; 2.0[ | 16 | [0.50 ; 0.55[ | 13 | 34 | 11 |
| [2.0 ; 2.2[ | 14 | [0.55 ; 0.60[ | 17 | 33 | 10 |
| [2.2 ; 2.4[ | 12 | [0.60 ; 0.65[ | 20 | 32 | 9 |
| [2.4 ; 2.6[ | 10 | [0.65 ; 0.70[ | 15 | 31 | 8 |
| [2.6 ; 2.8[ | 8 | [0.70 ; 0.75[ | 10 | 30 | 7 |
| [2.8 ; 3.0[ | 6 | [0.75 ; 0.80[ | 9 | 29 | 6 |
| [3.0 ; 3.2[ | 4 | [0.80 ; 0.85[ | 8 | 28 | 5 |
| [3.2 ; 3.4[ | 2 | [0.85 ; 0.90[ | 7 | 27 | 4 |
| [3.4 ; 3.8[ | 1 | [0.90 ; 1.00] | 6 | 26 | 3 |
| ≥ 3.8 | 0 | | | 25 | 2 |
| | | | | 24 | 1 |
| | | | | ≤ 23 | 0 |

A normalized number (_N) from 0 (worst) to 20 (best) was given to each parameter value to achieve an overall *Index of Acoustics Quality in Museums* (IAQM). The normalized ratings (_N) assigned to each value range of the criteria are shown in Tables 3 to 5.
The algorithm to determine the assessment of the museum overall acoustic quality, represented by the IAQM is expressed by (1). The classification scale of the overall acoustic quality of museums, based on IAQM results, is presented in Table 2.

$$IAQM = 0.4\ RT\_N + 0.2\ RASTI\_N + 0.1\ L_{Aeq\ HVAC}\_N + 0.2\ L'_{nT,w}\_N + 0.1\ D_{2m,nT,w}\_N \quad (1)$$

## 5. RESULTS

### A. National Museum Soares dos Reis (NMSR)

The application of the multi-criteria method to the National Museum Soares dos Reis (NMSR) is shown in Table 6.
The parameters DnT,w and D2m,nT,w were not measured. However, in the visit to the museum a value of 12 was attributed to L'nT,w_N because impact noises were not heard from the upper floor, only step noise in the same room.
It was also considered that the sound insulation index of facades in the rooms #2 and #16 had a value of 8 because the windows are poorly insulated; and the rooms #5 and #7 obtained a quote of 12 because they are relatively well insulated.
Room #2 got a positive assessment (IQAM of 13.0) corresponding to *Good*, and room #5 got 10.0 corresponding to *Fair*. The remaining rooms of the museum were considered *Poor* and *Bad* (IQAM of 7.9 and 6.2). When comparing the IQAM results with the questionnaire responses it is observed that there is a slight discrepancy: all respondents reported a positive acoustic quality, while in the multi-criteria method only rooms #2 and #5 have a positive rating. This divergence may be due to the fact that not all criteria in the multi-criteria method were measured. Another possibility is the fact the respondents were in the museum when they responded the survey, and so they may have put the importance of the acoustic quality in second place, being more interested in the collections exposed, which may influenced the attributed overall sound quality to the museum. Another aspect is that the survey was conducted globally, evaluating all the rooms of the museum, while the multi-criteria method was only performed for the four largest museum rooms and individually, and thus more likely to have worse acoustic results. In an average of these four rooms an overall museum IQAM of 9.3 is found, which corresponds to *Poor* but near to *Fair*.

**Table 6:** Values of the parameters, normalized criteria (_N) and IQAM for the four tested rooms of the NMSR and museum average.

| Room # | RT(500-1k) | | RASTI | | $L_{A,eq\ HVAC}$ | | $L'_{nT,w}$ | | $D_{2m,nT,w}$ | | IQAM | Result |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (s) | _N | - | _N | (dB) | _N | (dB) | _N | (dB) | _N | | |
| 2 | 1.6 | 17 | 0.53 | 13 | 47 | 6 | *na* | 12 | *na* | 8 | 13.2 | *Good* |
| 5 | 2.6 | 8 | 0.47 | 10 | 40 | 12 | *na* | 12 | *na* | 12 | 10.0 | *Fair* |
| 7 | 5.1 | 0 | 0.41 | 8 | 45 | 10 | *na* | 12 | *na* | 12 | 6.2 | *Bad* |
| 16 | 3.1 | 4 | 0.47 | 10 | 42* | 11 | *na* | 12 | *na* | 8 | 7.9 | *Poor* |
| average | - | - | - | - | - | - | - | - | - | - | 9.3 | *Poor* |

*na* – not available * not measured with HVAC, predicted value

## B. Contemporary Art Museum of Serralves (CAMS)

The Table 7 shows the results of application the multi-criteria method to the Contemporary Art Museum of Serralves. Although the parameters L'nT,w and D2m,nT,w were not measured, was attributed to L'nT,w_N the values of 6 to rooms #11 and #14 because they had a noisier wooden floor coverings, and for D2m,nT,w_N a value of 15 was attributed because all rooms are well insulated from the outside.

The results of the application of the multi-criteria method to this museum show that two of the three rooms tested got a negative assessment (room #11 an IQAM of 5.5 and room #14 an IQAM of 6.6) corresponding to *Bad*. Room #12 showed better results, although still *Poor* (IQAM of 7.2). The average acoustic quality of the rooms of CAMS has a classification of *Bad*.

These results of the multi-criteria method are consistent with the opinion of visitors (demonstrated in the responses to the questionnaires) since, despite the lack of public sensitivity to the acoustics in museums, 41% affirms they felt noise in the museum. For this result contributed strongly the high RT values, but the low RASTI values.

**Table 7:** Values of the parameters, normalized criteria (_N) and IQAM for the three tested rooms of the CAMS and museum average.

| Room # | RT(500-1k) | | RASTI | | $L_{A,eq\ HVAC}$ | | $L'_{nT,w}$ | | $D_{2m,nT,w}$ | | IQAM | Result |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (s) | _N | - | _N | (dB) | _N | (dB) | _N | (dB) | _N | | |
| 11 | 4.3 | 0 | 0.40 | 8 | 41 | 12 | *na* | 6 | *na* | 15 | 5.5 | *Bad* |
| 12 | 4.0 | 0 | 0.42 | 8 | 27 | 19 | *na* | 11 | *na* | 15 | 7.2 | *Poor* |
| 14 | 4.0 | 0 | 0.45 | 10 | 27 | 19 | *na* | 6 | *na* | 15 | 6.6 | *Bad* |
| average | - | - | - | - | - | - | - | - | - | - | 6.4 | *Bad* |

*na* – not available

## 6. CONCLUSION

It is observed that opinions about the acoustics in museums are still very divided, noting that this subjectivity is due to set of several factors, among others, to the cultural level, the fact that there still is little sensitivity to Acoustics in Portugal, and yet the difference of quality standards of each person.

Nevertheless differences were found between the questionnaires responses in the museums being the newer (CAMS) reported with more acoustic problems.

The IQAM method and values supported the subjective findings.

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