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Acoustic Rehabilitation of the Former Royal Tobacco Factory, Headquarters of the University of Seville: a Global Assessment

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Summary
The former Royal Tobacco Factory in Seville is one of the most important civic buildings built in Spain in the eighteenth century, and was also the setting for Bizet's opera Carmen. Since the inauguration of the Law Faculty in 1954 it has served as the headquarters for the University of Seville, with a ground plan of 185×147 m. Major renovation work is currently being carried out following a master plan executed by the University of Seville, and supervised by the Andalusian regional government's Department of Culture. This aims to significantly modify the current uses of many of its spaces and strengthen the building's heritage value. As part of this master plan, a team from the University of Seville's Institute of Architecture and Building Science has carried out an acoustic study of the different spaces within the building, almost all covered with some sort of vault. This will establish the renovations needed to ensure suitable acoustic conditions for the use of these spaces as classrooms, offices, meeting rooms, administration offices, and even a university cafeteria and canteen. The work we are presenting shows a global overview of the methodology used in the study, including an initial survey on site and simulation techniques based on raytracing, to assess different solutions. We also include the conclusions regarding the correction of acoustics and preservation of the building's heritage value to be incorporated into the master plan.

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1. Introduction

The former Royal Tobacco Factory, current headquarters for the University of Seville, is one of the most important industrial constructions built in Europe in the eighteenth century. It has a ground plan of 185×147 m (fig. 1) and it is built on two storeys with large terraces which would have been used to dry tobacco, with eight baroque skylights on the roof providing light for the galleries on the main floor. The original design was carried out by Ignacio Sala, a military engineer, although the main master builder was another military engineer, Sebastian Van der Borch, responsible for the main body of the building and its most representative parts: the centreline of the main façade, the courtyards, galleries, and a large part of the moat, [1] - [3]. This is the tobacco factory where Carmen, the cigar maker universally known thanks to the Merimée novel and the Bizet opera it inspired, worked (fig. 2).

The decision to move the headquarters of the University of Seville to the former Royal Tobacco Factory was taken a few years after the Spanish Civil War, although it was not till 1954, after its adaptation, that the Law Faculty was first opened, followed by the Science Faculty and the Philosophy and Arts Faculty.

Following the move of the Law Faculty to new headquarters a master plan is currently being carried out on the building in order to recover and revalorise the heritage value of the building, whilst maintaining its administrative and educational functions. One of the main aims of this plan is to improve the functionality of the different spaces, including their acoustics. In fact, it is for this reason that the University of Seville requested the help of a research group from the IUACC to devise proposals for acoustic conditioning which would respect the building’s cultural heritage value. The main aim of this paper is to present the methodology developed and the earlier results which have been used as a basis in the decision-

Figure 1. Panoramic view of the Royal Tobacco Factory

Figure 2. The cigar makers in the Tobacco Factory, as seen by Constantin Meunier in 1883.

making process in terms of acoustics when drawing up the aforementioned master plan.

2. Methodology

2.1. Spatial units analysed

In order to carry out an acoustic study of the building, and given its size and many possible different uses, a series of types of spatial units (UE) were defined. In the end this study was limited to six of these, the volumes and coding of which appear in figure 2, adapted to the uses detailed below:

- UE1: Barrel vault model (fig. 3.a). New use: administrative (offices, meeting rooms and archive).
- UE2: Current cafeteria area (fig. 3.b). New use: new cafeteria and two canteens.
- UE3: Pendentive vault model (fig. 3.c). New use: administrative (offices) and educational (classrooms).
- UE4: Pendentive vaults model in series (fig. 3.d). New use: educational (classrooms, in one case with two vaults and in the other with three) or administrative (offices).
- UE5: 1950s groin vault model (fig. 3.e). New use: administrative (two different layouts for offices, work areas and transit) or educational (with two classrooms, the larger of which occupies two modules while the smaller one occupies one, in one case with two vaults and in the other with three).
- UE6: Barrel vaults model in series (fig. 3.f). New use: administrative, (office and work areas).

The walls and partitions of these spatial units are usually thick, solid, and are rendered in plaster, which makes them clearly reflective. The floors are marble. The vaults, of different types depending on the different spatial units, are also rendered and reflective. Doors tend to be wooden, large, and heavy, with one or two leaves.

Using the basic units stated above as starting points

UE1 – V=678.7 m^3

UE2 – V=1915 m^3

UE3 – V=186 m^3

UE4 – V=538 m^3

UE5 – V=1016 m^3

UE6 – V=2133 m^3

Figure 3. Types of spatial units selected for use in the study.

up to thirteen different computer models of new use units were created, with at least two different hypotheses for coatings. This involves the assessment of almost thirty acoustic models for controlling acoustic conditioning within the framework of the master plan mentioned earlier.

2.2. Experimental measurements

Following the normalised procedure included in ISO regulation 3382-1 [4], measurements were carried out on five of the six spatial units being studied (UE2 was not measured as building work had begun on it). The spaces were empty (only the technical team, of two people, was present) and generally had no furniture of great importance.
Two source positions, situated 1.50 m above floor level, were used. Between 3 (for the smallest module) and 7 (for the larger ones) microphone positions were used, with the microphone positioned 1.20 m above floor level.
Environmental conditions were monitored during the measurement period (one morning). Temperature remained at 25-28 ^{0}C and relative humidity varied between 45 % and 58 %.
The background noise spectrum indoors was also measured, averaging it over 10 minutes. Results allow it to be valued at NCB=45, in terms of the NCB index [5].

The acoustic parameter values were derived from the impulse responses (IR) recorded in each location. These were obtained carrying out sine wave sweep signals (with frequency increasing exponentially with time). Both the frequency range and the duration of each sweep were adjusted to adapt to the conditions of the surroundings in order to obtain a suitable quality IR. Specifically the signal/noise ratio for the octave bands between 125 and 4000 Hz was greater than 45 dB.
The entire process for generating the signal, and recording and analysing the response, was carried out using the DIRAC 4.1 system [6], installed on a laptop computer. The signal input-output to the computer was carried out using a USB ZE-0948 B&K sound device.
The signal generated fed the INTER-M 1000 amplifier and was reproduced by omnidirectional source DO12. The response to impulse in each reception position was captured by a B&K 4165 omnidirectional microphone, with a B&K 2669 preamplifier, connected using a 01dB OPUS signal conditioner with USB device ZE-0948 input.

2.3. 3D Models and calibration process

A 3D model was drawn up for each of the units measured and CattAcoustic v-8.0k software, [7], was used to simulate the acoustic field within each unit. The simulated results are compared with those measured in order to confirm that the values obtained for all other parameters are simulated with sufficient precision, following the model calibration process using reverberation time, [8]. This allows us to rate the acoustic behaviour of the venue with a suitable degree of approximation, using the simulations carried out for frequencies $f>4f_S$, where f_S is what is known as the Schröeder frequency.
The calibration process mentioned involves the adjustment of values of absorption and dispersion coefficients for materials with more uncertain data in order to adjust the simulated reverberation time values to those measured on site, spatially averaged. Calibration is deemed acceptable when the simulated values differ by less than 1 JND (5%) in relation to those measured for each of the octave bands of interest. In this case these differences remained below 3%.
After checking the validity of the 3D models drawn up for the spatial units measured, the 3D models of the new spatial units planned in the rehabilitation process are implemented. In some cases the same unit is implemented with several proposals for spatial occupation, in other cases the new units have been obtained by adding or fragmenting pre-existing ones. Essentially two conditioning proposals have been contemplated for each unit: one in which only vertical enclosures are treated and another in which a specific treatment for the vaults is also added. A total of approximately 30 different models was evaluated. In any case, the treatment solutions proposed must be compatible with the cultural heritage status of the building and follow the master plan, with decisions being taken following the suggestions of the architects in charge of the aforementioned plan.
The aim of the simulation is to predict the values of acoustic parameters after the work has been carried out, and to compare the different coating and finish hypotheses considered for the spatial units. This may act as a basis for decision-making when selecting the most suitable treatments for each of them, depending on what use will be given to them, and their cost.

3. Results

In this section the methodology described is applied to a significant spatial unit, UE5, contemplated in the intervention, in order to obtain experimental and simulated data for its initial state, and in the intervention proposals analysed. Figure 4

Figure 4. Interior view and ground floor plan, stating source and receiver positions for UE5.

shows interior views of this unit, as well as a floor plan showing the positions of the source (S1 and S2) and receivers (R1 to R6).

This unit was previously used as a lecture hall in the former Law Faculty. Its total interior surface is approximately 754 m^2, with a volume of approximately 1000 m^3. Using these measurements three different units with different uses were simulated and will be presented at a later stage.

3.1. Experimental measurements in prior condition

Table I shows the average values for T_{30} used in the calibration process for the model, as well as the relative difference in percentages between both of these. We can observe that for all octave bands this difference is lower than 3%. It is also possible to observe these average values (for both source positions) and the standard deviation as a measure of the dispersion of space, central time (T_S) and definition (D_{50}).

Figure 5 shows a representation of the value of the RASTI index vs. the source-receiver distance. The values have been derived using impulse responses that have not been calibrated. This has been done because in all cases there is a predominant effect

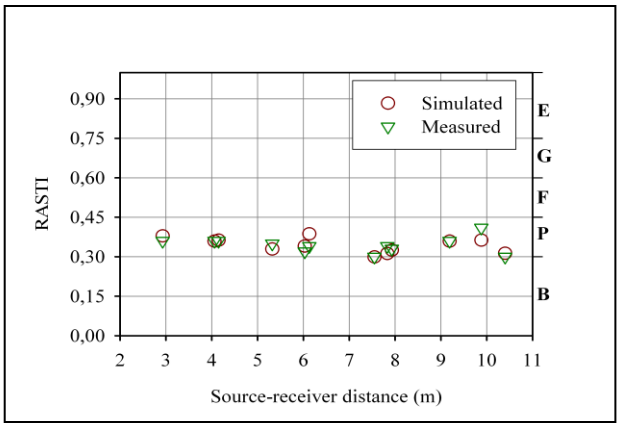

Figure 5. Measured and simulated RASTI index versus source receiver distance.

of the reverberation over that of background noise. The scale on the right-hand side measures the intelligibility value in accordance with the value range of the RASTI index: B, bad; P, poor; F, fair; G, good and E, excellent.

The data from table I show that the values measured and simulated have differences smaller than 1 JND, both for T_S and D_{50}. Spatial dispersion is also very similar, with the exception of lower frequencies where the dispersion of the values measured is lower than that of the simulated ones.

Figure 6. Model of UE5 to simulate previous condition.

Figure 5 shows that measured and simulated RASTI values are very similar for all points, almost regardless of distance, and allow us to qualify the intelligibility of space as *poor*.

The 3D model created to simulate the conditions of the current status is shown in figure 6. Its Schröeder frequency is 137 Hz, thus indicating that the simulated results are reliable from the 500 Hz octave band.

The restoration project contemplates dividing this type of spatial unit into two, with a new use as classrooms (fig. 7(a) and (b)), and the creation of a third unit (fig. 7(c)), attaching additional spaces for administrative use, and also building a mezzanine, so that the two acoustically differentiated subspaces (ground floor and top floor) which we have analysed separately, are configured. Two conditioning options have been simulated for each of these. In the first the side walls are treated with perforated gypsum boards with rock mineral wool (Knauf STO) and a porous-coated finish (STO Silent). In the second the vaults are treated with BASWAPHON 407, a product with a porous finish that can be easily applied to vaults and cupolas. In the case of the unit in fig. 7(c) the removable false ceilings of the mezzanine were assembled with Knauf Danoline. The absorption coefficient values used in the simulation process were taken from the technical data of the manufacturer and the usual bibliography.

The results for each unit and for each proposed finish are shown in figure 8. The simulated values allow waiting for a notable progress in the acoustic behaviour. In particular, the intelligibility, in terms of the RASTI index goes away to place concerning the qualification to *good* or *excellent*.

The Schröeder frequencies for the spatial unit in fig. 7(a) for each hypothesis are f_{S1}=101 Hz for the first hypothesis and f_{S2}=83 Hz for the second, showing that results are reliable for octave bands of 500 and 250 Hz, respectively. For the space in fig. 7(b) the respective values are 83 and 60 Hz, meaning simulations will be reliable for bands upwards of 250 Hz, and for the unit in fig. 7 (c) the values are 65 and 35 Hz, entailing admissible results for octave bands upwards of 250 and 125 Hz, respectively.

4. Conclusions

In the former Royal Tobacco Factory, headquarters of the University of Seville and the original setting for the opera Carmen, a master plan is being carried out to restore the heritage value of this Seville landmark. It should be noted that acoustic comfort has been a deficiency recognised in the

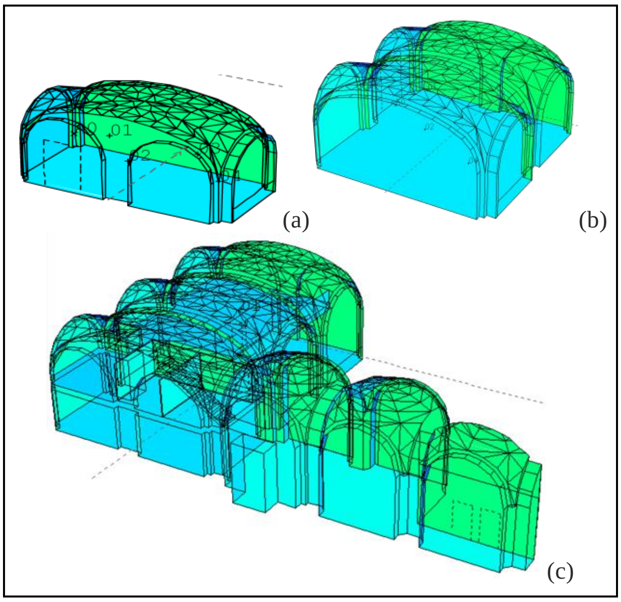

Figure 7. 3D models for the three units into which the initial unit UE5 is divided.

Figura 8. Spectrum values of the acoustic parameters simulated, spatially averaged, in the three units proposed for rehabilitation. Red: unit UE5(a); green: unit UE5(b); blue: ground floor unit UE5(c); cyan: top floor unit UE5(c). (O) Hypothesis-1, (∇) Hypothesis-2.

previous stages. Given this situation, we have presented the methodology used to assess the acoustic rehabilitation process. The calibration of computer models, designed for existing units and based on experimental measurements, has yielded valuable information for use in models of the units included in the rehabilitation process, units which

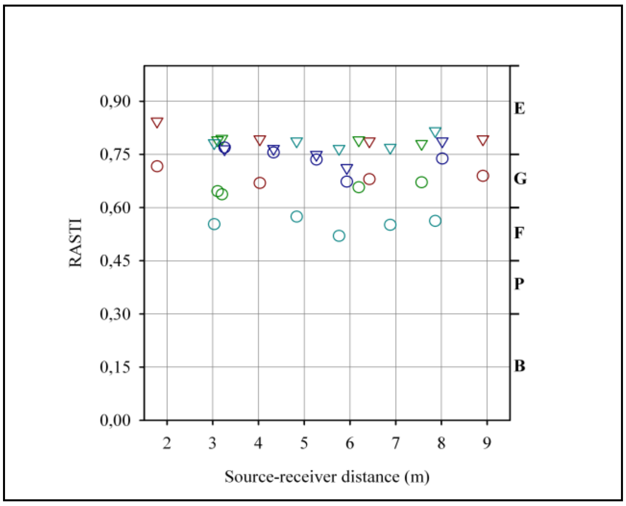

Figure 9. RASTI index simulated, in relation to emitter-receiver distance in the three units proposed for rehabilitation. Red: unit UE5(a); green: unit UE5(b); blue: ground floor unit UE5(c); cyan: top floor unit UE5(c). (O) Hypothesis-1, (∇) Hypothesis-2.

are formed either by division or by aggregation of the previous units.

Finally we have used a pre-existing basic unit to demonstrate the application of the methodology and results. The analysis was guided by two basic criteria: the use of space mainly for teaching and administration, and an intervention which has to be completely respectful of the building's heritage character.

Acknowledgement

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