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DEVELOPMENT OF A METHODOLOGY FOR MATERIALS SELECTION TO CONTROL EXHIBITION OBJECTS IN HOUSE-MUSEUMS

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Abstract

In recent years, the damage suffered by collections exhibited in museum rooms or in storage areas has been mostly attributed to their immediate surroundings that is, to an environment characterized by certain environmental conditions that interact positively or negatively in the physical - chemical integrity of the objects. Temperature, humidity, electromagnetic radiation and environmental pollution are considered some of the agents that can deteriorate the collections. Since, generally, it is more difficult to permanently modify the environmental conditions to adapt them to the exposed collections, it is proposed here to adapt the collections to the environmental conditions when it is possible. This paper presents a development of a methodology that compares the levels measured of each environmental condition in a museum room with a table of material sensitivity, to determine the feasibility of exposure of a given object, promoting the controlled exhibition of the collections. The large volume of data obtained from the environmental measurements requires a considerable processing time, therefore, a computational process developed in LabVIEW graphic software is included in the treatment of this special information. This automation constitutes a useful technological tool that allows correcting anomalies and favouring the prevention of collection risks.

Keywords: *Suitable exhibit material; Preventive preservation; Controlled exhibition; environmental conditions; House-museum; FI fluctuation index; Environmental measurement; Interactive software.*

Introduction

Preventive conservation, curative conservation and restoration are terms adopted to define the scope of the measures and actions on an object. While restoration has a direct action on the object being applied when a certain significant part or function is lost, preventive conservation has an indirect action on the object, acting on the environment [1]; for example, controlling environmental conditions or museography.

Within preventive conservation, some measures should begin with the design of the museography - display material: showcases, stands and similar articles, taking into account the material sensitivity of the objects to environmental conditions. The actions should also reach the characterization of these environmental conditions, that is to say, the physical-temporal behaviour of the environment that will be in direct contact with the objects during their exhibition or storage.

In uncontrolled rooms, environmental conditions may be influenced by the natural light,

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outside weather, thermal load contributed by visitors, deterioration in the building envelope, etc. In most cases, the deteriorations suffered by the collections are due to the exhibition in inadequate environmental conditions, to the wrong design of the museum devices (use of acidic construction materials, non-hermetic display cases, incorrect lighting, etc.) and even to the use of the space (wet cleaning of floors, uncontrolled opening of doors and windows, use of air conditioners, etc.). Therefore, it is crucial to understand how the environmental conditions vary inside the Museum [2-4], to identify the origin of the anomalies in a room or showcase and act effectively to correct them. It is also essential to define the actual level of environmental quality, in comparison with expected quality, on the basis of the object's preservation requirements [5, 6].

Much has been discussed about the effect of the environment on preventive conservation. The air temperature and the relative humidity (and their fluctuations) [2-4, 7, 8], the quality of the interior air [9, 10] and both the natural and artificial radiation [11-13], are the principal agents of damage to objects in museums whose effects result in physical, chemical or biological damage [5, 10, 14, 15]. Hydrothermal fluctuation measures the instability of temperature or relative humidity is, both in amplitude and duration; it is considered that a variation in a short period of time is a quick fluctuation (e.g. hourly or daily fluctuation) while a fluctuation in a longer period of time (e.g. weekly, monthly or by season) is a long fluctuation [2-4, 10]. Fire, water, theft or vandalism and dissociation are other agents of deterioration that will not be discussed in this article, but they must be controlled to ensure adequate preventive conservation of heritage.

Different authors have elaborated and implemented strategies to measure and analyse some of the environmental conditions, to detect those that are outside the limits recommended by current standards or specific studies [14, 16-21].

In order to define what types of objects can be exposed in an environment characterized by certain environmental conditions, it is primary to analyse the interaction between environment and object sensitivity. The object sensitivity to environmental conditions will be limited by its state of deterioration, its material composition and the characteristics of the environment where it lived historically.

The objective of this paper is to present the development of a methodology to determine the feasibility of exposure or not of certain objects for a given environmental condition. The methodology is based on the design of interactive software that measures, records and process temperature, humidity, electromagnetic radiation and air pollution. The software summarizes the information processed in terms of mean levels and hydrothermal fluctuations as environmental surveys are carried out daily, monthly or annually. The results are compared with a table of sensitivity of materials made specifically for this development, to finally determine the feasible material to be exposed. Thus, museum curators will be able to obtain useful environmental information that allows them to make decisions about the exhibition or not of a certain object.

Conservation standards and proposal of an integral table of material sensitivity

In order to develop this methodology, the following terms were redefined in this paper:

- Environmental conditions: group of variables defined by temperature, relative humidity, illuminance or visible radiation, ultraviolet radiation, temperature associated with infrared radiation and air quality or level of concentration of the atmospheric contaminants.
- FI fluctuation index: proposed index to quickly qualify a space according to its hydrothermal fluctuation. FI is weighted on a scale of four degrees (FI1, FI2, FI3 and FI4) according to the amplitude and speed of a fluctuation.
- Suitable exhibit material: chosen material whose requirements of exhibition matches the characteristics of the evaluated space.

a. Analysis of current standards information

The current standards and studies regarding conservation classify museum materials according to their sensitivity to the environment, recommending the admissible levels of the exhibition. Sensitivity is the level from which a given environmental condition is capable of causing some type of physical, chemical and/or biological damage on the exhibited objects. The list of recommendations for environmental conditions is extensive and based on experiments carried out on organic or inorganic materials, so we quote below, some of the most recent:

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) specifies levels of temperature (hereinafter T) and relative humidity (hereinafter RH) –and their fluctuations– for general collections, chemically unstable collections and special metal collections, according to five classes of control (AA, A, B, C and D) for rooms of General Museums, Art Galleries, Libraries and Archives. Class AA is the strictest and therefore implies a higher energy consumption; class A has the benefit of a reduction of energetic consumption (admitting a certain seasonal fluctuation); class B and C are generally useful and feasible for a lot of small and medium-sized institutions; class D controls only the relative humidity [2]. In the same way, *Michalski* specifies in detail the exhibition limits of T, RH and fluctuations according to the type of material and also classifies them in four categories: low, medium, high and very high. In each category is specified the ranges and life expectancy is also estimated in each category [3, 4].

As far as lighting is concerned, the recommendations of the International Committee of Lighting (CIE) are those usually employed as a criterion of exhibition, where the spectrum of the illuminant, the exposition time and the threshold from which a change in colour is perceptible are taken into account [11, 12, 22]. In this case, the classification of the sensitivity of the material takes into account the damage solely for illuminance E (lx) and specifying the dose of annual exposition permitted called the Ec (klx·hour/year) according to four categories of sensitivity: high, medium, low and irresponsive (no limits) [11]. *Michalski* estimates the time in years required for light to cause a perceptible decolouration or a nearly total decolouration, which is based on the well-known "blue wool scale" of material sensitivity [12]. Regarding the limit of exposition for UV, the CIE establishes as the maximum limit of 75μW/lm for UV radiation when the control of the lighting is partial and 10μW/lm when the total control is possible [11]. However, these levels were adapted to the UV contribution of the standard incandescent lamps of the 70s and, for preventive preservation it is always better to completely block the UV radiation content [11, 12, 22].

At the same time, it has been assumed that the probability of damage attributed to IR radiation is very low or non-existent. However, it can cause a heating effect on the surface of objects. As a result, the heating effect may cause an undesired fluctuation of RH or similar damages such as those claimed to be caused by incorrect levels of T [3, 11, 12, 22]. The above is extremely important because the physical change experienced by the materials is greater when the humidity varies than when the temperature varies.

Finally, nitrogen dioxide NO_2, ozone O_3 and sulphur dioxide SO_2 are considered the most harmful gaseous pollutants in museum collections in general [2, 9, 10]. Deposits of solid particles are considered pollutants, and while they may not necessarily cause damage, they are recognized as altering the aesthetic aspects of the objects [9].

The recommendations quoted above, and other specific ones published by the Canadian Conservation Institute and the Getty Conservation Institute, have their own criteria for the classification of material sensitivity based on experiments and own experiences (some dedicated to specific materials such as photographs, metals, medals, papers, tapestries, etc.).

Thus, the great diversity of available information regarding recommendations for exhibitions, which makes it difficult to determine the sensitivity of a certain object. In some cases, even, a confusion is generated in what we will call sensitivity of an object; for example, the CIE [10] classifies watercolour as being of medium sensitivity based on the level of illuminance, while *Michalski* [3] classifies watercolour as being low sensitivity based on the level of T.

For the development of the interactive software, it was necessary to generate a reference table to obtain the feasible materials to exhibit in a given environment. Therefore, as part of this methodology, an integral table of material sensitivity was created, which considers the most environmental conditions that could cause damage to objects exposed in museums.

This table is based on numerous recommendations (some cited above), and attempts to organize the information and facilitate its use by museum curators when the collections do not show active damage. However, this table, like the other available revisions, should be taken as a reference because each museum can have collections perfectly adapted to other levels of reference (although generally close to those indicated in this integral table). In any case, it was created as a database for the software and accepts modifications as required in each museum or collection.

b. The proposal of an integral table of material sensitivity

The objective was to unify in one table the most recent recommendations regarding to most of the environmental conditions, which cause damage to museum objects and, on the other hand, agree on a single denomination of material sensitivity.

The criteria for its elaboration were to determine to what degree a material is sensitive to environmental conditions. Given that the amplitude and speed of hydrothermal fluctuations can cause serious damage to the exhibits, the FI fluctuation index is included in this table.

The following materials and objects correspond to those mentioned mainly in the current standards and specific studies regarding the damage in museums. In order to clarify the table, an "M code" is assigned, and is explained later. Given that RH is the most critical condition in preventive conservation in museums, this environmental condition is analysed first [23].

- *RH, T and fluctuation index FI*

Based on the bibliography, five principle exposure ranges of RH were detected: 20 to 30%, 30 to 50%, 35 to 55%, 45 to 55% and 40 to 60% [2, 4, 8, 10, 13-15, 17, 20, 23, 24]; where the M materials were placed, according to their sensitivity to RH as is indicated in Table 1. Then, following the same criteria as with RH, the recommended levels of T were incorporated into Table 1 according to their effect on the object [2-3, 8, 10, 13-15, 17, 20, 23, 24].

The FI fluctuation index arises from the need to include the short and long period fluctuations in the hydrothermal conditions, given that the mean values do not provide enough information regarding the real behaviour of T and RH. This new index is defined in this paper in four levels, according to the risk due to a hydrothermal fluctuation: 'FI1' (very low), 'FI2' (low risk), 'FI3' (moderate risk) and 'FI4' (high risk), as is indicated in Table 2. This scale is the result of organizing the available information about the current standards and specific studies regarding the damage caused by hydrothermal fluctuations [2-4, 7, 24]. The FI index was also incorporated into the integral table. A FI1 index represents the best condition as far as hydrothermal control is concerned and implies a stable environment with controlled fluctuations, suitable for the exhibition of highly sensitive materials (e.g. silk or colour photography) that are chemically and physically stable. The way to calculate the short and long period fluctuations is explained in detail in section III.

However, it is important to consider that the measuring of T may be influenced by the IR radiation, thus, the maximum variation of T is indicated by the equation 1:

$$\Delta_{max}T(°C) = \sum(\Delta T_{T(°C)} + \Delta T_{IR\left(\frac{uW}{cm2}\right)}) \qquad (1)$$

where, $\Delta_{max}T$(°C) is the maximum fluctuation of T in a given environment.

ΔT_T(°C) is the fluctuation of T associated with the thermal changes of the environment.

ΔT_{IR}(°C) is the fluctuation of T given off by the infrared component of the lighting system used (natural or artificial).

Equation 1 values the contribution of IR radiation on the T and, in this way, it has a more effective control both on the fluctuation of T on the fluctuation of RH.

Table 1. Description of types of materials and object in the house-museum with M code and maximum range of environmental conditions (T, RH, electromagnetic radiation and concentration of gaseous pollutants/air quality).

Sensitivity material / object	Category sub-category		Material object Code*	Maximum range of mean RH(%)	Maximum range of mean T(°C)	Maximum level of mean illuminance E (lx) and maximum annual exposure dose Ec (lx.hour/year)	Maximum level of mean UV radiation proportion (µW/lm)	Maximum concentration of gaseous pollutants (µg/m³) / air quality	Maximum fluctuation index FI allowed*
Very high	-	--	M1	30 to 50	0 to 10	50 / 15 000	10	NO_2<5; O_3<2; SO_2<1 *Air quality: free*	1
High	A	I	M2.1	20 to 30	10 to 20	50 / 15 000	10	NO_2<5; O_3<2; SO_2<1 *Air quality: light*	2
		II	M2.2	35 to 55	10 to 20	50 / 15 000	10	NO_2<5; O_3<2; SO_2<1 *Air quality: light*	2
		III	M2.3 M2.4	45 to 55	10 to 20	50 / 15 000	10	NO_2<5; O_3<2; SO_2<1 *Air quality: light*	2
	B	I	M2.5 M2.6	45 to 55	10 to 20	50 / 150 000	75	NO_2<5; O_3<2; SO_2<1 *Air quality: light*	2
		II	M2.7	30 to 50	10 to 20	50 / 150 000	75	NO_2<5; O_3<2; SO_2<1 *Air quality: light*	2
Medium	A	I	M3.1 M3.2	45 to 55	18 to 20	50 / 150 000	75	NO_2<10; O_3<2; SO_2<10 *Air quality: light*	3
		II	M3.3	45 to 55	18 to 20	200 / 600 000	75	NO_2<10; O_3<2; SO_2<10 *Air quality: light*	3
	B	I	M4.1 M4.2 M4.4	45 to 55	15 to 25	50 / 150 000	75	NO_2<10; O_3<2; SO_2<10 *Air quality: light*	3
		II	M4.5 M4.6	40 to 60	15 to 25	50 / 150 000	75	NO_2<10; O_3<2; SO_2<10 *Air quality: light*	3
		III	M4.3	45 to 55	15 to 25	200 / 600 000	75	NO_2<10; O_3<2; SO_2<10 *Air quality: light*	3
	C	I	M4.7 M4.8 M4.9	35 to 55	15 to 25	300 / 600 000	75	NO_2<10; O_3<2; SO_2<10 *Air quality: light*	3
		II	M4.10	30 to 50	15 to 25	300 / 600 000	75	NO_2<10; O_3<2; SO_2<10 *Air quality: light*	3
Low	-	--	M4.11	40 to 60	15 to 25	200 / 600 000	75	NO_2<10; O_3<2; SO_2<10 *Air quality: medium*	3

M1: Video, audio and data tapes, floppy disks, CDs - M2.1: Colour photographs - M2.2: Commemorative medals with silk ribbons - M2.3: Textiles, cotton, linen, silk or wool - M2.4: Newspaper, paper - M2.5: Suits and accessories (shoes, caps and hats, bags, gloves, fans), carpets, tapestries, rugs or works made in loom with knots - M2.6: Graphic works such as pastel, engravings, charcoal, chalk and graphite - M2.7: Prints and black and white photographs - M3.1: Objects of natural history, botanical specimens, furs and feathers - M3.2: Books - M3.3: Leather goods, mineral and alum (boots, bags, harnesses, pods, sandals, quivers, armor) - M4.1: Dyed leather - M4.2: Watercolours - M4.3: Untanned leather (drum skin and quiver) or semi-tanned leather (jackets and coats, handbag, moccasin and leggings) - M4.4: Parchment, papyri and manuscripts - M4.5: Paintings in distemper media and gouache - M4.6: Oils, temperas and frescoes - M4.7: Coins, common medals and artistic medals (strike) - M4.8: General metals: iron, copper, copper alloy (bronze and brass), pewter alloy (tin, copper, antimony and lead), silver, aluminium, and precious metals - M4.9: Stable metals such as gold, silver, nickel and chrome - M4.10: Stone, ceramics, clay, glass, minerals, polishes, jewellery - M4.11: Undyed wood, bone and teeth, ivory, shellac, rubber and plastic.

**The second suffix is included for organizational reasons.*

Table 2. Four levels of FI fluctuation index proposed to assess the effect of hydrothermal fluctuations on the objects
**Any variation less than the weekly/monthly/seasonal variation: whether hourly, daily or weekly is considered.*

Fluctuation index fi	Short fluctuation of T(°C)*	Large fluctuation of T(°C)	Short fluctuation of RH (%)*	Large fluctuation of RH (%)	Categories of sensitivity
FI1	2	5	5	5	Very high, high, medium and low
FI2	2	5	5	10	High, medium and low
FI3	5	5	10	10	Medium and low
FI4	5	10	10	10	Low

- *Visible and ultraviolet radiation*

- Illuminance and permitted annual exposition: the levels of exhibition recommended by the CIE were used according to four categories of sensitivity: high (50lx and 15klx·hour/year), medium (50lx and 150klx·hour/year), low (200 and 600klx·hour/year) and irresponsive (no limits) [11]. Although objects irresponsive to light (e.g. metal, stone, glass, ceramics, jewellery, enamel) may be illuminated at higher levels, it is not necessary to exceed 300lx [10]. Large differences in illuminance between rooms give rise to adaptation difficulties [10, 12, 17] which is why higher levels would not be necessary.

- Acceptable proportion of UV radiation (μW/lm): maximum limit of 75μW/lm when the control of the lighting is partial and 10μW/lm when the control is total [11]. Note that the UV radiation is expressed as the proportion of radiation for each lumen of visible radiation; this convention is the one generally employed in the lighting of museums. In the case of measuring using UV radiometers in $\mu W/cm^2$ or $\mu W/m^2$, the conversion to μW/lm using the data of the measured illuminance must be carried out [10]:

$$(\mu W/lm) \times E(lux) = UV\ radiation\ (mW/cm^2) \qquad (2)$$

- *Environmental pollution*

Finally, suggested limits for the main gaseous pollutants generated by the exterior atmosphere and that reach the interior of the museums are: Nitrogen dioxide: $NO_2<10\mu g/m^3$; Ozone: $O_3<2\mu g/m^3$ and Sulphur dioxide: $SO_2<10\mu g/m^3$ for general collections, and $NO_2<5\mu g/m^3$, $O_3<2\mu g/m^3$, $SO_2<1\mu g/m^3$ for highly sensitive materials [2, 9, 10].

Visible, ultraviolet radiation and environmental pollution levels were also incorporated into Table 1.

- *Categories of material sensitivity*

Once the ranges for each variable were delimited and the FI fluctuation index was specified, the integral table classifying the sensitivity for the M materials was generated according to those established for current standards and specific studies: ‘very high’, ‘high’, ‘medium’ and ‘low’, as shown in Table 1. The notation A, B and C was employed for the categories and the numeration I, II and III for the sub-categories of M materials, in order to achieve better clarity of this table.

Selection of material according to the evaluation of the environment

Figure 1 shows the general diagram of blocks of the interactive software designed to determine the type of material or object that can be exposed in a given environmental condition. In this way, a material will be able to be exhibited if the environmental conditions and the FI index agree with the exhibition requirements of a given object.

Block 1. Measurement and recording of environmental conditions

The first block constitutes the main input of the interactive software and involves the measuring in situ of the variables defined as environmental conditions in the evaluated space: temperature, relative humidity, visible and ultraviolet radiation and environmental pollution or air quality. The measures should be systematic, as far as possible, with a previously established frequency -e.g. several hourly measurements, throughout the day- and recording day and time of measurement.

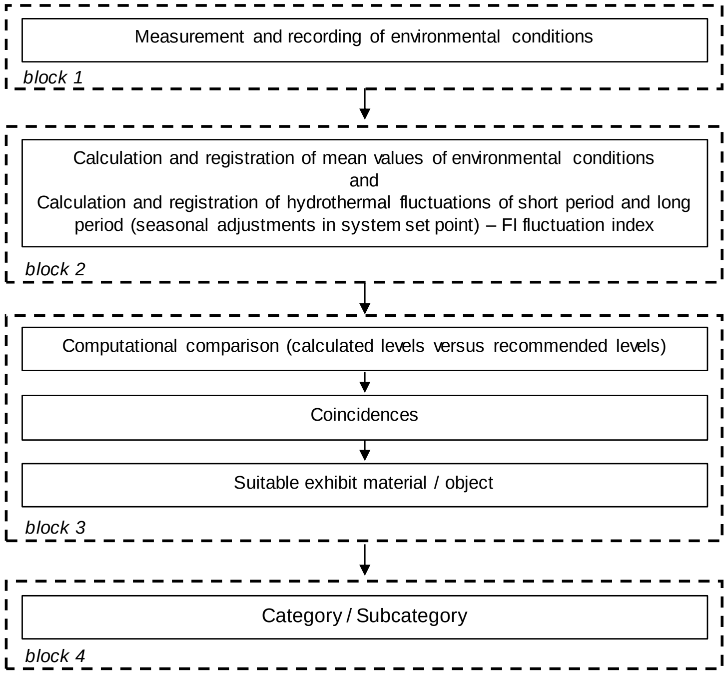

Fig. 1. Methodology of the material selection based on the environmental conditions of the evaluated environment and the specifications of Table 1, in four blocks

Block 2. Calculation of mean values of environmental conditions and calculation of hydrothermal fluctuations of short period and long period (FI index)

In this stage, each one of the recorded data is processed according to the analysed period of study (block 1). This process permits the comparison with Table 1:

• *Mean values of environmental conditions*

The set point of the study period or monthly or seasonal values: average of all the T(°C), RH (%), E(lx), Ec(klx·hs/year), UVR(µW/lm) and NO_2, SO_2, O_3 (or air quality) of the period of study (large period).

• *Hydrothermal fluctuations*

- *Short period fluctuation* or maximum mean hourly and/or daily fluctuation $\Delta T_{h/d,}$ $\Delta RH_{h/d}$: calculated as the difference between the absolute maximum hourly/daily level and the mean level or also the difference between the absolute minimum hourly/daily level and the mean level. Only the biggest difference between the two is considered. The mean level corresponds to the mean of all the registered data in the short period considered (daily and hourly): $T_{h/d}$(°C), $RH_{h/d}$(%). Note that if there is no presence of an infrared radiation component, the maximum fluctuation of the mean hourly or daily T will be given only by the environment's own fluctuations.

- *Large period fluctuation* or maximum mean monthly or seasonal fluctuation ΔT and ΔRH: calculated as the difference between the absolute maximum monthly/seasonal level and the mean level or also the difference between the absolute minimum monthly/seasonal level and the mean level. Only the biggest difference between the two is considered. The mean level is the set point T(°C) and RH(%) specified above.

- *FI fluctuation index,* is finally calculated using the short and long period fluctuation specified above, which, combined, will indicate one of the four indexes of Table 2. When the level of the fluctuations reached indicates an FI index of more than FI4 the exhibition of sensitive materials chosen in Table 1 is not recommended.

It should be considered that T and RH fluctuations must always be slow and in a large period of time, as they cause serious damage to the exhibits, especially those sensitive to changes in humidity [5].

Block 3. Comparison (calculated levels versus recommended levels)

The third block compares the mean levels of the environmental conditions and the FI fluctuation index with those indicated in Table 1. The logic consists in comparing variable by variable selecting those categories and sub-categories of materials/objects where the mean levels (measured and processed) are within the ranges specified by Table 1. The comparison process is shown in figure 2.

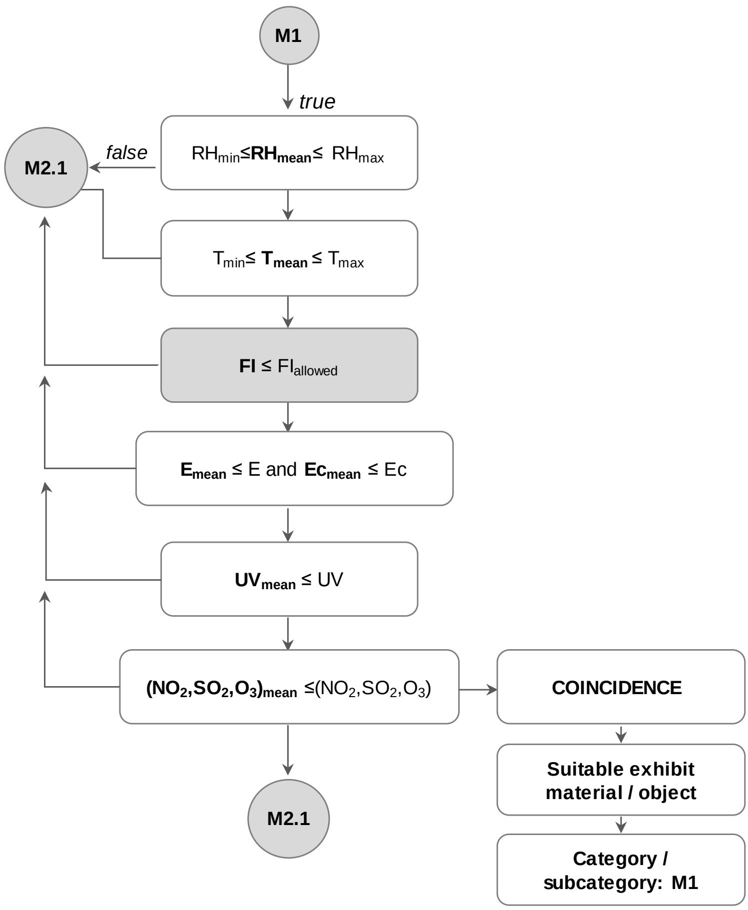

Fig. 2. Process of comparison to determine the suitable exhibit material or object according to the environmental conditions recorded and processed in a given space and the specifications of Table 1

Suppose we have for example a material classified as M1 by Table 1 (very high sensitivity):

1. Verify that the mean RH(%) (or set point) during the period measured is in the range of RH range (30 to 50%) allowed in Table 1 for M1.

2. If a coincidence should occur, the mean T(°C) (or set point) of the study period should be verified to confirm that it is in the variation range required (0 to 10°C) for M1.

3. Verify that the calculated FI fluctuation index is equal to or less than FI index allowed according to Table 1.

4. Verify that E, Ec, UV, NO_2, SO_2, O_3 levels (or air quality), measured and processed, are equal to or less than the levels specified in Table 1.

5. If all the previous comparisons were true, then material M1 is suitable for exposure in the evaluated environment.

6. If some of the previous points are not coincidental in some or all of the columns, the material submitted for comparison should be discarded until the undesired levels are controlled or another environment is chosen. In this way, a selected object can be exhibited under controlled environmental conditions with an allowed FI index, according to the characteristics of its material composition.

The logic explained previously was computerised by means of LabVIEW graphic software of National Instruments Corporation, which permitted the design of an interface for the quick processing of the information reviewed in an environment, efficiently selecting the feasible exhibition material. The interface can be initialized by means of a PC or cell phone and allows data to be recorded with a previously established frequency. The data is stored in Excel spreadsheets, sorted by date and time, and compared daily and monthly with the integral table, also developed in this methodology.

The interface was incorporated into a measuring instrument built to register each of the variables of Table 1, which has different sensors to measure the physical variables. The T(°C) was measured with a thermo-resistant sensor of platinum covered with an aluminium sheet of polythene to isolate the measuring of the incidence of radiation, with an uncertainty in measurement of ±0,3°C (calibration process). The RH(%) was measured with a capacitive humidity sensor (measurement uncertainty: ±3,5%); the illuminance (visible radiation) with a sensitive photodiode in the range of 400-780nm, adapted to the spectral sensitivity of the human visual system V(λ) (measurement uncertainty: ±5lx); the UV radiation with a sensitive photodiode in the range of 280-400nm (±5μW/m^2) and the IR radiation by means of a sensitive photodiode in the range of 800-1100nm (±2μW/cm^2). To evaluate the contribution of both natural and artificial infrared radiation in the temperature fluctuations, we incorporated a temperature sensor of the same characteristics without the protective sheet.

In the case of the atmospheric contaminants in general (with no discrimination between them), an integral sensor of air quality was employed, which indicates, in four levels, the cleanliness of the environment, according to the detection of hanging particles (ppm) in *free*, *light*, *medium* and *high*. To get an approximation of the measuring of the quality of the air with Table 1, *free* was given to 'very high' sensitivity, *light* was given to 'high' and 'medium' sensitivities, and *medium* was given to 'low' sensitivity (see Table 1); this approximation is useful in evaluating the quality of air in the case where no individual meters for atmospheric contaminants are available.

Pilot test of the methodology developed

The objective was to characterise integrally the library of one of the most important museums in the history of the Argentine Independence, the House-Museum of Independence (MCHI) analysing the degree of suitability of the heritage exposed to the environmental conditions of the room.

- ***Description of the case under study***

The MCHI is located in the north-west of Argentina (cca. 1760-1780) in a subtropical climate, with a mean annual T of 21°C (minimum and maximum mean: 15 and 26°C) and a mean annual RH of 72% (minimum and maximum mean: 58 and 90%) [25]. The house was built with rammed earth walls plastered with mud and lime and adobes and it was declared a National Historic Landmark in 1941. The museum does not have mechanical systems for air conditioning and the artificial lighting consists of incandescent halogen lamps, 50W, with a dimming system. Usually, the contribution of natural light is reduced because the windows and doors are kept closed.

The heritage exhibited in the library consists of classical texts of the latest historical graphic, museology, conservation, restoration, literature and magazine debates of the XX century.

• ***Brief technical record of the selected works***

Table 3 shows the classification of the most important examples of the collection of the library, including the category of the sensitivity of the material according to Table 1.

Table 3. Classification of material sensitivity for the main objects of the library collection of the House-Museum of Independence of Tucuman (MCHI) according to Table 1. It is also indicated with *true* and *false*, the coincidence or not between the levels measured in situ and those recommended according to Table 1

Name	Material type	Sensitivity material / Code	RH	T	E/Ec	UV	Air quality level	FI allowed
News (1957-1975) The Union (1942-1944)	News papers	**High AIII** M2.4	*false*	*true*	*true/ false*	*true*	*true*	*false*
The work of the genera and species of plants in Argentina (1943-1947)	Black and white drawings and colour drawings	**High BI** M2.6	*false*	*true*	*true/ true*	*true*	*true*	*false*
Secret Acts of the Constituent General Congress of the United Provinces of the River Plate (1816–1819)	Black and white print	**High BII** M2.7	*false*	*true*	*true/ true*	*true*	*true*	*false*
Administration of land post and maritime post of	Manuscript	**Medium BII** M4.4	*false*	*false*	*true/ true*	*true*	*true*	*true*
Tucuman (1775)	Untanned leather	**Medium BIII*** M4.3	*false*	*false*	*true/ true*	*true*	*true*	*true*

**In this case, to guarantee the conservation of the object, the Medium BII category dominates because of the low level of illuminance required for the conservation of the manuscript.*

• ***Measuring of the environmental conditions***

The measurement of the environmental conditions was carried out using the measuring instrument mentioned previously. The measurements were made during a month in June 2017, 24 hours, -winter season-, with a frequency of 5 minutes to analyse the hourly hydrothermal fluctuations in a central part of the room. The library was open to the museum staff from 7:00 am to 5:00 pm and to the public from 10:00 am to 5:00 pm.

• ***Preliminary results of the Integral analysis of the environmental conditions***

Table 4 shows a summary of the data of the environmental conditions processed under the terms of monthly mean values and daily and monthly hydrothermal fluctuations.

The FI fluctuation index is calculated according to the previous explication in Table 2. Given the very low hourly fluctuations, it was considered as short fluctuations the daily variations and as large fluctuations the monthly variations. The comparative analysis of the two sensors of T (with and without insulation) indicated that the difference between the hourly, daily and of the study period (monthly) registered with either of the sensors were not significant. This indicates that, despite having registered a level of IR radiation (the highest level registered was 4μW/cm^2) this was not enough to generate significant thermal changes in the evaluated environment. Therefore, in this case, the calculated T fluctuations were strongly influenced by the library's own fluctuations and little influenced by the IR radiation of artificial and natural lighting.

Table 4. Summary of the processing of data in terms of monthly mean levels and the determination of FI fluctuation index according to the short and large fluctuations of temperature and relative humidity registered during June of 2017 in the library of the House-Museum of Independence of Tucuman (MCHI)

***Monthly* mean level for each environmental condition - June of 2017**					
RH_{mean} (%)	T_{mean} (°C)	E_{mean} (lx)	Ec_{mean} (lxhour/ year)	Proportion of UV radiation (μW/lm)	Air quality
68,2	**13,2**	**21,4**	**71870,4**	**9,4**	**Light**
Maximum *daily* and *monthly* (study period) mean fluctuation for T and RH					
$\Delta T_{d,max}$ (°C) -daily- (short fluctuation)	$\Delta T_{m,max}$ (°C) -monthly- (large fluctuation)	$\Delta RH_{d,max}$ (%) -daily- (short fluctuation)	$\Delta RH_{m,max}$ -monthly- (large fluctuation)	Fluctuation index FI	Materials suitable to exhibit – categories of sensitivity
2,6	**3,7**	**1,5**	**7,0**	**FI3**	**Medium / Low**

Table 3 also indicates with *true* and *false*, the coincidence or not between the levels measured in situ and those recommended according to Table 1.

In relation to archives and documents under study in the library, the room presents bigger problems as far as the mean levels of T and RH are concerned, than in relation to the rest of the environmental conditions; being more critical in this case the highest level of RH. This is to be expected in museum houses where the mean low level of T (13,2°C) and the mean high level of RH (68,2%) have the similar behaviour that exterior conditions (mean outdoor levels in June 2017: 13,3°C and 81%). Hydrothermal fluctuations were kept under control resulting index equal to FI3, very close to FI2. Fortunately, the short fluctuations of RH -daily- were lower than 2% and lower than 10% in the analysed period (June of 2017); this is very important because the organic materials undergo much greater dimensional changes because of the RH than the T.

Materials that are exhibited in critical conditions are classified as ‘high’ (see Table 3), especially because of the very high levels of RH and the FI index to which they are exposed. Although, generally, the materials have the capacity to adapt very slowly to different T and RH levels, the documents, parchments and manuscript, are highly sensitive materials and it will be very difficult to keep them stable at 68% of RH. These materials require more controlled RH levels, which is why it is necessary to evaluate the means available to reduce humidity, for example, using silica gel in shelves or glass cabinets, control the state of conservation of the building to discard or repair filtrations or limit the humidity by capillarity, etc. The fibres of ‘medium’ materials may undergo drying if T levels remain low for a long time.

During June 2017, the general mean levels of illuminance (E), maximum annual exposure dose Ec, proportion of UV radiation and air quality remained optimal in accordance with Table 1. It can be observed that in *High AIII M2.4 object* (Table 3), the mean level of illuminance was adequate during June of 2017 but, if it is analysed considering the number of hours that the library remains open, the accumulated levels of annual exposition will be greatly exceeded. This means that the level of illuminance (E) or the number of hours of exposure (Ec) should be reduced.

Although the application of the exposed methodology is a pilot test, the first results of the behaviour of the general environmental conditions of the library could be obtained.

The analysis of the MCHI library by means of the proposed methodology explained the state in which the heritage is exhibited, recognising those variables that must be controlled to improve the exhibition or generate a new exhibition in the museum. This study showed that there were objects that should not be exposed under the existing conditions, especially because of the high contents of RH in relation to the impact that there could be on objects made mainly of paper. Also, considering that, although the envelope of the building reduces relative humidity by 12%, it must be considered that outdoor levels can be more harmful to the material exhibited in the library, exceeding 90% in summer. Finally, it is necessary to measure and record for longer periods of time could give more information about the environmental conditions which could also help determine which type of materials or objects could be exhibited at a specific time of year (seasons), knowing beforehand the behaviour of the space.

Conclusions

Control of the environmental conditions in order to guarantee the preventive conservation requires the global analysis of the environment. The proposed methodology considered that the damage to an object is the result of the interaction of a group of variables as a whole and not as an isolated form. Based on the exhaustive analysis of the environmental conditions – temperature, relative humidity, electromagnetic radiation and environmental pollution - it is possible to establish the suitable materials to be exhibited under conditions where the damage is minimized. For example, by detecting the most suitable rooms for the exhibition of the more sensitive materials and those suitable for the less sensitive ones and, elaborate the design of an exhibition in a more controlled way.

Generally, in historic buildings or house-museums, the environmental conditions are generally influenced by exterior conditions, therefore, it is necessary to know beforehand about interior behaviours, before any exhibition. Thus, it is not sufficient to eventually register T and RH, but rather to have a systematic register measuring the variables, preferably several times an hour through the day (with instruments correctly calibrated every one or two years).

The measurement of environmental conditions requires the continuous recording and processing of a large volume of data, which generally implies an extra task on the part of the museum staff. The proposed methodology aims to advance in the automation of a monitoring system for museums that minimizes data processing times and also allows obtaining useful analytical information for specific conservation actions.

The integral table (Table 1) was fundamental for the primary elaboration of the automation system proposed in this methodology. It was prepared by analysing and integrating the exposure levels recommended by specific standards and studies of various institutions and specialists, gathering the necessary information for the analysis of environmental conditions in museums. This table was digitized and entered into the interface developed in LabVIEW, so it can be modified according to the criteria of the curators or the needs of the collections.

The graphic interface was developed together with an instrument measuring environmental conditions for museums (hardware), as mentioned above. The environmental conditions are recorded by the hardware and processed through the interface developed in the LabVIEW graphic software. The information obtained from the data processing, indicates whether or not a certain material may be displayed in a studied environment.

Although currently this instrument is able to simultaneously record the conditions of temperature, relative humidity, electromagnetic radiation and air quality at a single point, from now on it will be expanded to create a central monitoring station. This monitoring centre will have wireless modules that will perform the same task as the instrument developed so far and will also be operated by LabVIEW. These wireless and independent modules will also improve the calibration of each of them, a subject that deserves a separate chapter.

Finally, the graphic interface, the measuring instrument and the integral table, have been used to make different surveys in museum rooms and showcases, with useful results that allow us to continue making improvements and new developments. Even, technological development has obtained on two occasions recognition of innovation in applied research [24, 25].

The main contributions of this methodology are summarized below:

- First, the methodology offers a new method to record and process environmental conditions in museums, facilitating the task of the staff of the museum and reducing the processing times.
- Second, the integral table developed summarizes the information necessary to choose the recommended exhibition levels, according to the material sensitivity of a given object, including the effect of hydrothermal fluctuations (FI index). Its preparation allows adjusting the exhibition levels, according to the criteria of the curators.
- Third, the ordering of the data in spreadsheets, carried out through LabView, allows the museum to have its own environmental records that, in the future, will constitute the historical environmental database of its rooms and collections and will allow the exchange of collections between institutions.
- Finally, the automation of this methodology constitutes a useful technological tool that allows correcting anomalies and favouring the prevention of collection risks.

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