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OIL PAINTING COLLECTION: RISK ASSESSMENT, EVALUATION AND MITIGATION STRATEGIES

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Abstract

"Casa dos Patudos", a historic house museum, has a large collection of oil paintings on permanent display. Many of the problems affecting this collection do not have simple answers. Ideal solutions may be too expensive or unattainable. Consequently, an approach to establishing priorities and planning improvements is imperative. The Cultural Property Risk Model was applied to this oil painting collection. The magnitude of the specific risks for this collection were calculated in order to provide a well informed decision making, taking into account the type of mitigation strategies possible to implement in a historic house. The top five hazards affecting this collection were: the high relative humidity values and fluctuations, incorrect handling, increase in paint detachment due to the maintenance of paintings with paint lifting on display, damages caused by wood borers and excessive light exposure. Some of the mitigations actions proposed involve the increase of doors and windows insulation, providing staff training on paintings collection care and preventive conservation, implementation of an integrated pest management program. Although this work was applied to a specific oil painting collection, many other historic houses have oil painting collections under similar risks as the ones reported in this work.

Keywords: *Preventive Conservation; Risk Assessment; Oil Painting; Historic House.*

Introduction

"Casa dos Patudos", a historic house in Alpiarça (Portugal), built in the beginning of the 19th century, was a project of the well-known Portuguese architect Raul Lino and follows the "*Portuguese House*" architecture style. This historical house, now a Museum, was the official residence of an important Portuguese politician, amateur musician, farmer and dynamic art collector, José Relvas. "Casa dos Patudos" holds several collections and art objects, including porcelains, Portuguese tiles, historical furniture, textiles and a valuable oil painting collection, with works from Delacroix, Guerrin, Caravaggio, Fragonard and the only known portrait of the musician Domenico Scarlatti, by Domingo Antonio Velasco. All of the most important Portuguese naturalist and realist painters, including the members of "Grupo do Leão", are represented in this collection.

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Although “Casa dos Patudos” exhibits a large and valuable oil painting collection the resources for its preservation are very limited. The lack of professionals linked to the area of conservation and restoration working in this institution increases the risks for this collection.

Moreover, most of the oil paintings are on permanent display, at the same location, since the Museum opened to the public in 1960. Therefore, there was an urgent need for data to support the “Casa dos Patudos” museum managers to make informed decisions on allocating the limited resources for the oil painting collection preventive conservation. To achieve this goal, the Cultural Property Risk Model (CPRM), developed by Waller [1], was used. This model was chosen because it allows managers, through the identification, evaluation and ranking of the hazards affecting a collection, to make decisions according to the real needs of the collection. Moreover, this model was developed for collections, it is easy to apply and it has been successfully applied to distinct collections such as a mineral collection, plant collection and fish collection of the Canadian Museum of Nature [2], the archival records, artifacts and specimens pertaining to the Royal British Columbia Museum [3] and to paper based collection kept in an archive, “Arquivo Histórico Ultramarino” in Lisbon [4, 5]. This is the first time that the CPRM is applied to an oil painting collection on display, in a historical house. One of the challenges of this work was to find a balance between the best preservation conditions and what is possible to implement in an historic house, in other words, a place which was not originally built for the function that it has nowadays. Furthermore, the testament of the former owner José Relvas, which contains several stipulations regarding the care of the building and its collections, needs to be taken into consideration, even though, in some cases, it does not allow the implementation of certain measures that would help to preserve the building and its collections.

Materials and Methods

The methodology used in this work included: characterization of the building location and its surroundings; detailed inspection of the rooms with paintings on display, including monitoring of environmental parameters and possible insects infestations; characterization and condition survey of the painting collection and interviews with the museum staff. The information gathered through these procedures is presented bellow and it was applied to the Cultural Property Risk Model (CPRM).

Characterization of the building location and its surroundings

“Casa dos Patudos” (Fig. 1) is located in Alpiarça (39º 14´55.5 N and 8º 35´21,6 West), in the central part of Portugal.

The climate of this region is characterized as a markedly Mediterranean climate, with hot, dry summers and cold, wet winters. August is the warmest month with a mean maximum temperature of around 30°C and January is the coldest month with an average minimum temperature around 6°C [14]. Alpiarça is located in a district classified as having high susceptibility to earthquakes (Portugal National Risk Assessment, 2014). In 1909, an earthquake with a magnitude of 6.7 (Richter scale) with the epicenter in Benavente, at 38.6 kilometers from "Casa Patudos" ranked as one of the worst in the country.

Alpiarça is a rural area and therefore there are no apparent problems of pollutants. The main source of pollutants for the House can be attributed to the heavy vehicles using a national road that passes near "Casa Patudos". Accordingly to the Portuguese authorities, the possibility of an industrial disaster that might affect the museum and its collection is practically null, since the industry plants that exist are located in the northwestern area of the county, at about 94.4km

from the museum, and predominant winds usually blow towards the north, reducing further this risk.

Fig. 1. . "Casa dos Patudos" – Alpiarça Museum (2015)

Building inspection and characterization of the exhibiting rooms

"Casa dos Patudos", constructed between 1905 and 1909, was built with a system that reduces the risk of collapsing due to earthquakes, called "Sistema Pombalino". The building has a total area of 3610m^2 and the permanent exhibition rooms occupy a total of 1080m^2. The house is divided in 4 floors with a total of 101 rooms, of which 30 are opened to the public and 25 have oil paintings on exhibition. These 25 rooms were analyzed in more detail (Table 1 and Table 2) since in each floor the rooms have different characteristics that will influence the stability of the paintings and the magnitude of the risks. Although the magnitude of the risks was calculated for the overall collection, the differences between the exhibition rooms were taken under consideration.

Table 1 presents the main building characteristics of the 25 rooms with oil paintings on exhibition and Table 2 describes the illumination conditions and the characteristics of the windows present in those rooms.

The ground floor has 4 areas with oil paintings on exhibition: Entry hall, Exit hall, Tauromachy room and Sacred Art room. While at this level mosaics cover the floor, in all the other levels the floor is made of wood. In the first floor there are 14 rooms with oil paintings on exhibition: staircase hall, first and second family rooms, D. Eugénia living room, music room, columns room, primitive room, Boileau room, Silva Porto room, Green gallery, Dinner room, noble hall, Library foyer and Library.

On the second floor 7 rooms have oil paintings on display: antechamber of José Relvas room, José Relvas room, dressing room, corridor, guest room, João Chagas room and D. Eugénia room. On the third floor there are no exhibition rooms. All the 25 exhibition rooms have fire and motion detectors. However, only two rooms (1st Family room and Green gallery) possess a manual fire alarm, but, as it can be seen in Table 1, most of the rooms have one fire extinguisher and the corridor of the second floor has two.

As it can be seen from Table 2, all the exhibition rooms have artificial lighting. These incandescent light (I) and/or fluorescent lamps (F) are divided by distinct sectors of the house and they are on only during guided visits or during the cleaning process of the rooms.

All windows are made of glass and wood, but most of them have Exterior Wooden Shutters with a Metallic bar Locker (EWSML), which allows them to be closed from inside (Table 2). Most of these windows are original and therefore are not well sealed.

Regarding the entrance of natural sunlight, on the ground floor, the Entry hall is the only room where natural light enters as the result of the opening of the main door when the Museum is open to the public. In all the other rooms of this floor, the windows have wooden shutters on the exterior and those are always closed (Table 2). On the first floor, all the windows that give access to the exterior or balconies also have wooden shutters with metallic lockers, but, during the Museum opening hours, most of these shutters are opened, allowing the natural light to enter (Table2). However, all these windows have unbleached cloth curtains with the exception of one in the Library foyer room. In Silva Porto room there is one window, not reported on Table 2, which doesn't have a wooden shutter.

Table 1. Description of the main building characteristics of the 25 rooms with oil paintings on exhibition. Some rooms have a CCTV system (Closed-circuit television). ✕# indicates the presence of wooden shelves in the room.

Rooms		Walls				Ceiling.		CCTV system	Fire extinguisher
		Stucco	Tiles	Lambri wood	Lambri textil	Stucco	Wood		
0	Entry hall		✕			✕		✕	✕
	Exit hall	✕				✕			
	Tauromachy		✕			✕		✕	
	Sacred art	✕				✕		✕	
1	Staircase hall		✕			✕			✕
	1st Family		✕			✕		✕	✕
	2nd Family	✕				✕		✕	
	D. Eugénia living room			✕		✕			
	Music		✕				✕	✕	
	Columns				✕	✕		✕	✕
	Primitive				✕	✕			
	Boileau				✕	✕			
	Silva Porto			✕			✕		
	Green gallery			✕			✕	✕	✕
	Dinning		✕				✕	✕	✕
	Noble hall			✕			✕	✕	✕
	Library foyer		✕				✕		✕
	Library			✕#			✕	✕	
2	Antechamber	✕				✕			
	José Relvas	✕				✕			
	Dressing room	✕				✕			
	Corridor	✕				✕		✕	2✕
	Guest room	✕				✕			
	João Chagas	✕				✕			
	D. Eugénia	✕				✕			

On the first floor there are 3 rooms with skylights, allowing the entrance of natural light during the entire day without any protection (Table 2).

Until a few years ago, the same happened in Primitives and Boileau rooms, but in 2011 rehabilitation works were done and the glass roof tiles on these rooms skylights were replaced by ceramic tiles. During the same rehabilitation works, improvements were made in order to

prevent water from entering the exhibition rooms. In the attic, a water isolation barrier was applied and the gutter system was replaced.

Table 2. Description of the illumination conditions and the characteristics of the windows present in the 25 rooms with oil paintings on display.

Rooms		Lighting		Windows to the exterior	
		Artificial	Natural	Glass and wood with EWSML	Glass and wood with a trellis
0	Entry hall	**I & F**	×	×	
	Exit hall	**F**		×	
	Tauromachy	**I & F**		×	
	Sacred art	**I & F**		×	
1	Staircase hall	**I & F**	**S**		
	1st Family	**I**	×		×
	2nd family	**I**	×		×
	D. Eugénia living room	**I**	×	×	
	Music	**I**		×	
	Columns	**I & F**	**S**	×	
	Primitive	**F**			
	Boileau	**I & F**			
	Silva Porto	**I**	×		
	Green gallery	**I & F**	×	×	
	Dinning	**I**	×	×	
	Noble hall	**I & F**	**S**	×	
	Library foyer	**I**	×	×	
	Library	**I**	×	×	
2	Antechamber	**I**			×
	José Relvas	**I**	×	×	
	Dressing room	**I**	×		×
	Corridor	**I**	×		×
	Guest room	**I**	×		×
	João Chagas	**I**	×		×
	D. Eugénia	**I**	×		×

Incandescent light bulbs (I), Fluorescent lamps (F). Skylights (S). Exterior Wooden Shutters with a Metallic bar Locker (EWSML)

Oil Painting Collection characterization

This oil painting collection has a total of 235 paints and includes works from distinct artists, schools and countries. Although it comprises works from the XVI century to the XX century, the majority of the paintings belong to the naturalism fine art movement from the end of the XIX century. A high number of paintings (59%) belong to Portuguese artists, nevertheless, the works of artists from six other different countries are also present in this collection: 18% belong to Spanish artists, 9% to French, 5% belong to artists from Flandres and also 5% of the collection presents works from United Kingdom, 3% of the paintings were made by Italian artists and finally USA artists are present in 1% of the collection.

From the 235 paintings on display, 137 are on canvas, 81 on wood, 9 on cardboard, 3 on metal, 3 on glass and 1 on ivory. Therefore, more than 50% of the oil painting collection is made on canvas and around 35% is made on wood.

As previously said, the collection is on permanent display in 25 distinct rooms distributed on 3 floors. On the ground floor 29 oil paintings are exhibited (12.3% of the total collection), on the first floor 172 (73.2%) and on the second floor 34 (14.5%), (Fig. 2).

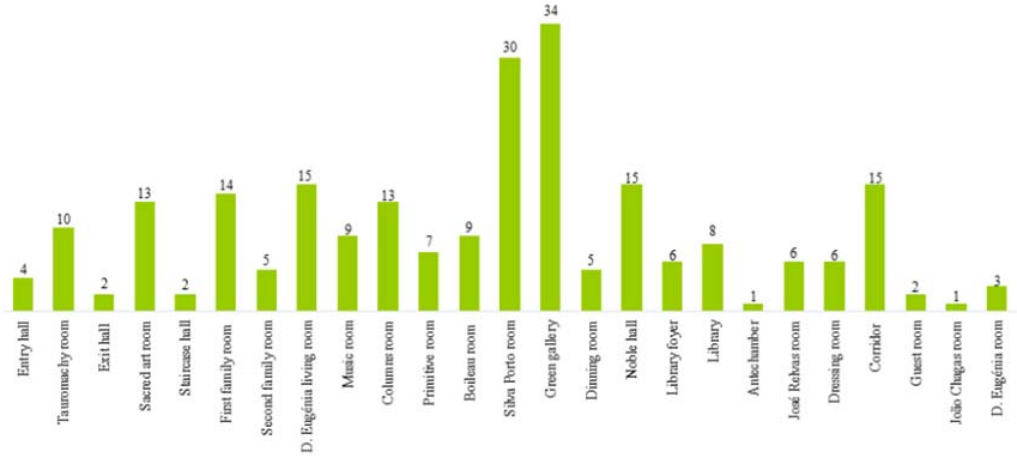

Fig. 2. Number of oil paintings on display in each room

The vast majority of the paintings is in the same place for over 50 years as one of the museum's goals is to keep the house as faithful as possible to the museum course set in 1960. Loans have been the major reason for moving the artworks from their places.

Oil paintings condition survey

A survey on paintings condition was carried out at an early stage, to help the identification of some of the specific risks and, in a second stage, to support the magnitude of the risk calculations. Therefore, a simple condition report model was developed that could be applied to all paintings of the collection. Condition checking of the front side of all oil paintings on the exhibition was completed. Regarding the checking of the paintings back side, 10% of the collection was examined, including paintings from all rooms, with different supports and from different periods, percentage that was considered a representative sample.

Although the actual collection condition cannot be used to predict its future condition [6], reports are a useful tool since they include information on the damage caused to works of art by a given risk that affects and/or has affected the collection. It is very important to realize if the damages are recurrent and happened in the last decades or happened before the opening of the museum, in order to predict whether they can still be considered or not, a risk to the collection. Therefore, inventory records as well as intervention reports were consulted in the museum archives, in order to chronologically organize the observed damages. Interviews with the museum's staff helped clarify some issues.

The main part of the collection (69%) is in good condition; however, more than half of this percentage was restored in the last 17 years, many of them deeply. Furthermore, it was noticed that some of the paintings recently restored already present conservation problems, like paint layers detachments or cracks. These may be associated with the high fluctuations of relative humidity inside the building.

Monitoring of the environmental conditions

Visible light and the ultraviolet radiation (UV) that reached the surface of all the 235 oil paintings on exhibition were measured (Elsec 764 UV + Monitor), from November to July, at different days and hours. Measurements were carried out during the museum opening period,

according to the actual conditions of each room, that is, with the artificial lights on and open windows (if it was the case). Measurements with artificial lights off were also made in order to determine the museum daylight. Lighting monitoring was conducted monthly, from September 2014 to July 2015, between 12 and 15 PM, when the sunlight is stronger, to get results that reflect the worst case scenario.

The temperature (T) and relative humidity (RH) where continuously monitored (EL-USB-2 + Monitor, Lascar) for a period of 6 months in four different rooms: Sacred art room (ground level) Green gallery (first floor) Noble hall (first floor) and José Relvas room (second floor). These rooms were selected in order to have information on T and RH at the 3 distinct floors. Sacred art room and Green Gallery were chosen also because they are the rooms with a larger number of oil paintings (Fig. 2). The choice of the rooms also took into account punctual measurements of RH and T made previously, in all the rooms at approximately the same time. These measurements showed that the RH and T do not differ so much between the different rooms of the building, with a maximum variation of ± 2.7% in RH and ± 2°C in T. This may be due to the fact that all the doors between display rooms, inside the building, are always open.

Measurement of pollutants inside the building were not performed, however, outside measures provided by an air quality station located in Chamusca (at 18 km of the Museum) were considered in order to identify any possible risks for the collection.

Insect monitoring

Standard sticky traps (Trappit CR Corner, Suterra®,) were strategically placed on all the floors of the rooms with oil paintings on display, and left from May to September, in order to detect insects. Flying insects were also monitored using "yellow insect traps". A guide was used to identify the trapped insects [7].

Risk analysis model

In the present work the cultural property risk analysis model (CPRAM), developed by Waller [1, 2] was applied to the oil painting collection on permanent display in “Casa dos Patudos”. Its application starts with the identification of the 10 agents of deterioration affecting the collection: *Physical Forces; Fire; Water; Criminals; Pests; Contaminants; Light and radiation; Incorrect temperature; Incorrect relative humidity and dissociation*. Dissociation alone was not considered in this first analysis since the institution is not aware of most of the problems that can rise from a detachment to the collection and the authors did not see any relevance in attributing a risk magnitude to less appropriate behaviors.

Each of the other 9 agents of deterioration identified by Michalski [8], can, accordingly to Waller [1], in CPRAM, act in any of the three types of risk, accordingly to its frequency and severity:

- Risk type 1: rare and catastrophic;
- Risk type 2: sporadic and severe;
- Risk type 3: continual and mild/gradual

The combination of an agent and type of risk is known as “generic risks” and 23 generic risks are possible [1]. The specific risks that are affecting the oil painting collection on permanent display in “Casa dos Patudos” were identified based on the information obtained by the methodology steps described above.

Accordingly to Waller [1], the magnitude of each specific risk (MR) is calculated per century and varies between 0 (no loss) and 1 (total loss), based on the following equation:

$$MR = FS \times LV \times P \times E \text{ (always calculated in this order),}$$

where: FS - is the Fraction of the collection Susceptible to the risk. Part of a collection considered vulnerable to a loss in value from exposure to a specific risk; LV = Loss of Value that would occur. It represents the maximum possible reduction in utility, for known or anticipated uses, of FS. It is evaluated in light of the inherent susceptibility, the physical location and the anticipated severity of the specific risk; P = Probability is the estimated chance of occurrence of an event of a given severity during a period of a hundred years (time-span

considered in this model) or the chance of at least one event causing damage taking place over a 100-year period. In this work, the P was calculated based on the frequency of the occurrence of past events; E = The extent at which the FS will actually be affected, and/or the LV realized based upon knowledge of conditions that might mitigate the risk. In this particular analysis, and given the fact that most risk occurrences in this institution were not followed by a complete evaluation of the damage caused, the E value worked as a predictive factor of the magnitude of future risks. More on this subject will be developed on the final comments on the method used. As in Pinheiro et al [4], the E was also calculated in function of the FS.

The MR and one of the variables, probability (P) or extent (E), have the dimension "per century" while the remaining variables are dimensionless ratios (between 0 and 1). For risk type 2 and 3 the Probability is equal to 1, since these two types will always occur in a period of 100 years. For risks type 1, E is equal to 1 since these are catastrophic risks affecting all the collection [1].

In "Casa dos Patudos" one of the main goals of the Museum is to maintain the works of art at the same place where they were when the house was donated. This issue in this particularly Museum is also reinforced by José Relvas testament. So it was easy to calculate the fraction susceptible after the characterization of the overall collection. Accordingly to Waller [1], LV is the most difficult parameter to estimate, since it's subjective. Sometimes it helps to think about one object rather than a collection. So to facilitate LV calculations and also to be able to compare between different risks, a slight modification to Waller's model was introduced by considering 6 levels of severity for the calculation of the LV, as follows:

LV = 1 – object total loss (e.g. painting robbery);
LV = 0.75 – damage with loss of material and/or that disturbs the reading of the image (e.g. tears, holes, cuts or detachment of polychrome layers);
LV = 0.5 – damage that can compromise the stability of the object and its exhibition (e.g. fading of certain colors);
LV = 0.25 – damages that do not compromise the stability of the object (e.g. oxidation of varnish)
LV = 0.15 – damages that do not compromise the stability of the object nor its exhibition (e.g. surface dust)
LV= 0 – painting with no damages

Results and Discussion

Figure 3 shows the MR results obtained for the specific risks affecting this oil painting collection.

Physical Forces

Region's seismic history and the effects that seismic events could have on the collection were assessed using institutional data given by the Civil Protection Department for the geographical area where the Museum is located. Information about how the paintings are handled by staff and are hung on the walls was also considered. Table 3 presents the magnitude of the risks due to physical forces for this oil painting collection.

Table 3. Identification of the main specific risks due to physical forces, the type of risk and the calculation of the risk magnitude (MR).

Specific risks	Type	MR
The falling of paintings due to a seismic activity	1	FS = 1, PV=0.75, P=0.917 E=0,0468 **MR= 0.032**
The falling of paintings due to problems of the wall fixating system	2	FS= 0.962 PV=0.75 P=1 E=0.017 **MR= 0.012**
Incorrect handling	2	FS= 1 PV=0.25 P=1 E=1 **MR= 0.5**
Increase in paint detachment due to maintenance of paintings with paint lifting on exhibition	2	FS= 0.604 PV=0.75 P=1 E= 0.387 **MR= 0.176**

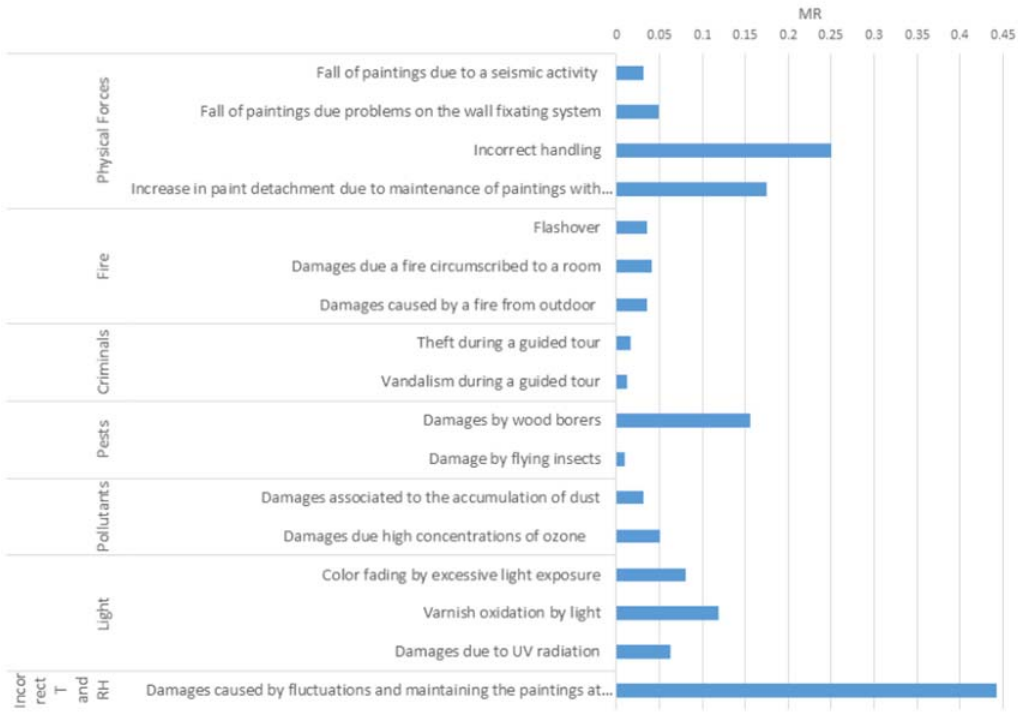

Fig. 3. Magnitude of the main specific risks (MR) calculated for the oil painting collection on display in "Casa dos Patudos"

The falling of paintings due to a seismic activity

In the past 190 years there was a seismic event, with a magnitude of 6.7 on the Richter scale, with the epicenter close to the museum. Although, it is not possible to predict exactly how many paintings will fall from the walls if a seismic event like that happens again, the paintings exhibited at easels and another one that is fixed to the hall by a nail will certainly fall.

The falling of paintings due to problems of the wall fixating system

The wall fixating system is similar in all of the paintings: a hook on the wall and a screw on the frame. There are only a few exceptions, for instance ten paintings are exhibited on easels and one is fixed to the wall by a nail. It is also known that two paintings, in the past fifty year, have fallen from the wall, and in the worst case, the falling caused a huge tear of the canvas.

Incorrect handling

Since the opening of the Museum, the staff working in "Casa dos Patudos" never had training on preventive conservation or collections care; as a result some works of art were already damaged by incorrect handling. As it was reported by the staff, at least one painting has fallen due to incorrect handling. Every painting is handled on a regular basis for loans, cleaning or to apply insecticides in the frame. The loss of value is moderated because the damages will be localized and mainly on the frame. Nevertheless, this risk magnitude presents one of the highest values (Fig. 3).

Increase in paint detachments due to the maintenance of paintings with paint lifting on display

Many paintings on this collection are kept on exhibit regardless of their conservation state. Some of them have serious problems of flaking and with the action of physical forces, such as the gravity, the paint might fall. It was considered that all of the paintings with cracking

might be susceptible to this damage. This risk can also be inputted to institutional dissociation. Moreover, fatigue-like damage (cracks) may already be present in many objects and may be caused by the action of direct physical forces or other agents such as temperature and humidity fluctuations.

Physical forces mitigation strategies

The lack of professionals linked to the area of painting conservation working in this institution increases the risk of damages due incorrect handling. Therefore, it is necessary to invest on human resources with collection care or/and preventive conservation training. In case the budget does not allow hiring new professionals then, a less expensive way, would be to provide preventive conservation and collections care courses to the current museum staff. Also a written procedure regarding handling, display, transport and storage of oil paintings should be made available for all the staff working in "Casa dos Patudos".

Another significant risk due to physical forces is the increase in paint detachments due to the maintenance of paintings with paint lifting on display. There is an urgent need to remove these paintings from exhibition and stored them horizontally until it will be possible to restore them. This simple action has no immediate cost, but it has an immediate benefice: to stop the loss of paint layers. The consolidation of the paintings should be done as soon as possible and preferably at the museum because the majority of these paintings are too instable to be transported.

Fire

No institution is immune from the risk of fire. Unlike the other agents of deterioration considered in this work, serious damage or total loss of the building, collections, operations, and services can occur [9]. Therefore, it is important that fire prevention and fire control be given the highest priority possible.

The building construction (the presence of wood in the floors, walls and ceilings), the type of collection (in this case made of combustible materials), the current conditions of the electrical system, the presence of a security guard, fire detectors, fire alarms, fire extinguishers and the response time of the fire department, all these variables need to be taken under consideration when the risk of fire is analyzed. Table 4 presents the magnitude of the risks due to fire for this oil painting collection.

As it can be seen from Table 4, the magnitude of the risks due to a fire is relatively low. This is due to the fact that in "Casa dos Patudos", all the rooms have at least one smoke detector system that is connected to the fire department and the museum is located 1 minute away from this fire department. The museum had its electrical system renewed and equipped with manual fire extinguishers placed all over the building. Moreover, it is not allowed to smoke, there are no candles or gas equipment and there is a security guard inside the museum 24h/day. Also, there has never been a fire at "Casa dos Patudos". So, for our estimations we used the frequency of a fire in American museums described in Tétreault [10]. The possibility of the fire spreading to the rest of the building was predicted by the control level.

Table 1. Identification of the main specific risks due to fire, the type of risk and the calculation of the risk magnitude (MR).

Specific risks	Type	MR
Flashover	1	FS= 1 PV= 1 P= 0.035 E= 1 **MR= 0.035**
Damages due a fire circumscribed to a room	1	FS= 0.145 PV= 1 P= 0.28 E= 1 **MR= 0.041**
Damages caused by a fire from outdoor	2	FS= 0.744 PV= 0.05 P= 1 E=1 **MR= 0.037**

Flashover

Flashover refers to the moment of conflagration or complete incineration caused by superheated air or combustibles, which compromises the entire collection.

Damages due a fire circumscribed to a room

The calculation were done taking into account the worst scenario possible, so the room with the most paintings of the house and with the most combustible materials (floor, wall and ceiling made of wood) was chosen, more precisely, the "Green Gallery".

Damages caused by a fire from outdoor

Doors and windows are not well isolated so there is the possibility of damages to the paintings due to outdoor fire combustion products, like smoke and soot. Smoke is the product of combustion, and generally consists of fine particulates and hot gases, while soot refers to the finely divided carbon deposited by flames during the incomplete combustion of organic substances. Both are damaging to the surface of paintings and also to delicate frames.

Fire mitigation strategies

The presence of fire-resistant doors, closed between each room, is usually a measure suggested to prevent a fire started in a room from quickly spreading to other rooms and eventually to the entire collection. However, since "Casa dos Patudos" is a historic house, the implementation of fire-resistant doors between the exhibition halls would significantly alter the building's aesthetics. Therefore, the implementation of these fire-resistant doors is not taken under consideration by the museum management. Moreover, this would be a very expensive measure, not justified by the fact that the magnitude of risk due to a fire inside this museum is very low (Table 4).

Automatic sprinkler systems consist of a network of fixed pipes connected to a water source, with sprinklers designed to discharge water at a pre-set temperature. Automatic fire sprinklers are widely recognized as the single most effective method for fighting the spread of fires in the early stages, before they can cause severe injuries to people and damage to property. Nevertheless, sprinklers are not very well seen in a museum context, because people fear the water damage.

To prevent damage to the collection due to a fire, it is advisable to: do a periodic check of the fire detection system; to check if the connection with the fire department is working, to train all employees on how to use fire extinguishers and to deal with any fire situation, since the promptness of response can dictate the difference between the extinction or the outbreak of the fire. In order to prevent the infiltration of products resulting from a fire combustion occurring outside the museum, windows and doors should be kept closed and an insulation tape should be applied. There are several types of insulation tapes in the market and most of them are inexpensive and easy to apply.

Water

Water damages were evaluated during the building assessment and also the information provided by staff interviews was taken into consideration. For many years, infiltration problems due to broken tiles and clogging gutter resulted in dripping water inside the museum exhibition rooms, affecting some of the paintings. In 2011 a building intervention that solved this problem was done and since then, there were no more infiltration problems. The broken tiles were replaced and a waterproofing system was placed under the roof. The gutter was also changed with a bigger and deeper one. Therefore, nowadays the risks of water damage to the collection are insignificant. Nevertheless, in order to maintain these conditions some strategies for water mitigation risks are proposed.

Water risks mitigation strategies

Although the infiltration problems through the roof have been resolved in 2011 and did not occur again until now, the authors recommend a periodic inspection of the roof (before and after the rainy season) to check the condition of the roof tiles and eventual obstruction of the

gutters. It is anticipated that this measures will be enough to prevent further infiltration problems.

Criminal actions/vandalism

The museum has video surveillance system (CCTV) with 8 cameras outside and 16 inside (Table 1). There is a security guard 24h/day, an employee of the museum during the opening hours to the public and another guard, from a private company, for the remaining period. Motion detectors were also placed in all rooms, windows and doors that open directed towards the outside and an alarm system is located in the building. The electrical panel is turned off when the museum closes to the public, but the CCTV system and the alarm are still running.

The museum only provides guided visits, which decreases the risk of criminal actions or vandalism. However, it is common for a group of visitors to reaches 25 or more people, which is difficult to control in the context of a guided tour, although these large groups are usually accompanied by two guides. However, due to the lack of human resources, this is not always feasible, which can be a problem because there are no cameras in every room and because it is sometimes the security itself that accompanies the visitors, leaving the CCTV cameras without guards. The museum does not have a room or a closet, were the visitors can leave their suitcases and bags. This makes it easier for thieves to steal small objects. Table 5 presents the magnitude of the risks due to criminal actions/vandalism for this oil painting collection.

Table 5. Identification of the main specific risks due to criminal actions/vandalism, the type of risk and the calculation of the risk magnitude (MR).

Specific risks	Type	MR
Theft during a guided tour;	1	FS= 0.017 PV= 1 P=1 E= 1 **MR= 0.017**
Theft during closure hours of the museum	1	**nc**
Vandalism during a guided tour	2	FS= 0.966 PV=0.75 P=1 E=0,018 **MR= 0.013**

nc : not calculated

Theft during a guided tour

It was considered that every painting in exhibition with less than 30 cm x 35 cm and located in rooms without CCTV is susceptible to stealing. A theft during a guide tour with the actual security system already happened; although the object stolen was not a painting, we still believe that the probability is 1. This type of behavior is promoted by the fact that visitors are allowed to carry bags inside the museum.

Theft during closure hours of the museum

Several years ago, the museum already suffered a major robbery during closure period, where many works of art were stolen, including 6 paintings. Afterwards, many improvements in terms of security were made, reducing the probability of a theft like the one that happened before close to zero. Nowadays, the museum has a CCTV system, 24h security guard, an alarm system and movement detectors in all rooms, so it is not possible to predict if it might occur in the future.

Vandalism during a guided tour

Although the museum only provide guided tours it is very difficult to control every person during the context of a large visit, with 25 or more visitors. Although many object might *have been* vandalized over the years, the staff only noticed two cases of vandalism during guided tour.

Criminal actions/vandalism mitigation strategies

As a priority and urgent action is to hire more guides or guards, in order to enhance the security of the guided tours. The risk of theft during the guided tour can still be further reduced significantly if the visitors would leave their bags and coats at the reception.

The following rooms: Primitive room, Dining room, Noble Hall, Guests room, João Chagas room and D. Eugenia room, are very small and do not have CCTV system (Table 1) and sometimes visitors in large groups end up staying alone in one of these rooms. To discourage people from coming too close to exhibits in these rooms, we propose the installation of psychological barriers such as cords, signs, raised platforms, etc. to. These will allow visitors to see the space perfectly, in a more quick way and it will prevent them to disperse from the guided tour group. The implementation of limitation barriers will also reduce the wear caused by visitors in tapestries. These preventive measurements are the easiest and cheapest way to restraint the public direct access to the collections on display.

Finally, the museum possesses six CCTV cameras ready to be installed. So a priority is the installation of five of those cameras in following rooms: D. Eugenia living room; Boileau room Silva Porto room ; José Relvas room and Dressing room.

Pests

The risk considered in this work is the damage caused by insect pests. "Casa dos Patudos" is prone to have insect pests because it is located in a rural area, with doors and windows poorly insulated, it has several collections made of organic materials (e.g. wood, textiles and paper) and there are always vases with fresh flowers, placed in various rooms, due to testamentary obligations. Moreover, the building itself has many elements made of wood and textile materials, such as walls, floors or ceilings (see Table 1).

Recognizing the fact that the insect pests are a risk to the museum and its collections, Alpiarça City Hall hired a pest control company to control insect pests in the "Casa dos Patudos". This company injects an insecticide in form of gel, with a white hue, near the all doors, windows and plumbing. This insecticide, applied 3 or 4 times per year, is Emidacloprid and it belongs to the class of neonicotinoids (IUPAC name: 1- (6-chloro-3-pyridylmethyl) -N-nitroimidazolidin-2-ylideneamine), which attacks the central nervous system of insects through contact or intake. This insecticide is not considered a carcinogen and its toxicity to vertebrates is considered moderate / low and has a lifetime of 6 months, and serves as bait for various crawling insects, termites or even fleas. Please note that although this insecticide has a lifetime of 6 months, the museum applies it more often. Additionally, Cuprinol (Woodworm Killer) from Robbialac is applied, by brush, with some regularity, at least once a year, using a brush, on all paintings, wood grids and frames. This insecticide has Permethrin, a synthetic pyrethroid pesticide that affects the nervous system in insects, causing muscle spasms, paralysis and death. Regarding its effects on humans, permethrin has been classified as a type II or III toxin by the EPA. It is unknown whether if Permethrin, besides being toxic to humans, may cause damage to the paintings.

Damages by wood borers

During the inspection of the building damages caused by wood borers were found on the floor, wainscotings, doors, furniture and of course on the paintings wooden frames, support and stretchers. During the paintings collection survey, damages by wood borers were also observed in several paintings. From 24 paintings inspected, 15 showed damages due to wood borers. Although some of those damages could have occurred many years ago, the presence of recent sawdust on the back of 2 paintings located in different rooms lead us to the conclusion that in some areas the insects are still active. The presence of wood borers was also detected in 5 distinct insect traps. Table 6 presents the magnitude of the risks due to insect pests for this oil painting collection.

Table 6. Identification of the main specific risks due to pests, the type of risk and the calculation of the risk magnitude (MR).

Specific risks	Type	MR
Damages by wood borers (grid, frame, panel)	3	FS= 1 PV= 0.25 P= 1 E= 0.625, **MR= 0.156**
Damages by flying insects	3	FS= 1 PV= 0.05 P= 1 E= 0.208, **MR= 0.01**

Damages by flying insects

The whole collection is equally susceptible to damage done by flying insects since the museum is an open space, where the doors between rooms are not usually closed. During the collection survey, 39 paintings were found with insect debris. Moreover, flying insects were detected by the insect traps, most of them being flies. This insect debris can contain acidic components which affect the paint or the finish on a frame and it's very difficult to remove.

Insect pest mitigation strategies

The constant use of such insecticides should be avoid due to toxicity problems, since the law is constantly changing and also because of the uncertainty whether these products may cause damage to objects [11]. Instead, an Integrated Pest Management program should be put in action [12] by starting **t**o avoid the entrance of insects through museum doors and windows with unobtrusive sealing barrier strips. Splits and holes in wooden doors and windows or their frames should be caulked using builder´s mastic or other appropriate materials. It is urgent to do a survey on all the collections to determine the already infested objects and isolate them to prevent the spread of the infestation to other objects until treatment. It is also essential to monitor the insects with the use of insect traps [12].

Pollutants

The museum is located in a rural area in the center of Portugal, so outdoor pollutants values, from industries and transportation, were not very high. The acids released by the wooden objects on display were not considered a risk, since the paintings are exposed in open space and the rooms rarely have the doors closed to each other in an exhibition area of 1080m2. The possibility of damage to the paintings due to pollutants emitted by cleaning products is 0, since the cleaning of the artworks and surfaces is done without the use of solvents.

The pollutants levels inside the building were not measured in the context of this work. However, the concentration of 5 pollutants (SO_2, NO_2 O_3, PM (<10 μm) and PM (2,5 μm)) inside the building were estimated using the "100, 10, 1" rule of thumb proposed by Tétreault [13]. This rule is only applied to outside pollutants and accordingly to this author the concentration of pollutants outside are reduced by 1 order of magnitude when passing inside a room in a building, and further reduced by 1 order when entering an enclosure in the room. This rule, although it may seems simplistic, it does satisfy the needs of many museums that cannot afford expensive pollutants monitoring, but still require some idea of the order of magnitude of pollutants levels. This rule assumes the absence of indoor-generated pollutants.

Data regarding pollutants concentration, measured hourly during one year (2004), from a national air quality station, located at 18km from the museum [14], were used to estimate the inside concentration of nitrogen dioxide, sulphur dioxide, ozone and particulate matter (PM) using the "100, 10, 1" rule of thumb proposed by Tétreault [13]. The results are presented in Table 7, together with the maximum pollutants concentration proposed by other authors.

Table 7. Average values (and standard deviation) of atmospheric pollutants concentration (μg/m^3), estimated to "Casa dos Patudos" are presented to together with the maximum pollutants limits proposed by other authors as quality targets for museums.

Pollutants	SO_2	NO_2	O_3	PM (<10 μm)	PM (<2,5 μm)
"Casa dos Patudos"	0.1 (±0.1)	0.5 (±0.3)	6.9 (±2,6)	1.4 (±0,9)	0,7 (±0,6)
[13] **J. Tétreault** [A]	0,1	0,1	0,1	-	0,1
[15]**G. Thomson**	10	10	2	-	-

[A] Concentration limit to prevent any damage to a period of 100 years [13].

As it can be seen from Table 7, the average concentration values of O_3 and PM (<2,5 μm) exceed the ones proposed by the other authors. The NO_2 value is a bit over the limit

suggested by J. Tétreault [13], but still within the limits proposed in the literature. Table 8 presents the MR calculated for the pollutants inside "Casa dos Patuscos".

Table 8. Identification of the main specific risks due to pollutants, the type of risk and the calculation of the risk magnitude (MR)

Specific risks	Type	MR
Damages associated to the accumulation of dust	3	FS= 1 PV= 0.15 P= 1 E= 0.208 **MR= 0.031**
Damages due high concentrations of ozone (O_3)	3	FS= 1 PV= 0.05 P= 1 E= 1 **MR= 0.05**

Damages associated to the accumulation of dust

The oil painting collection is on display in an open space, without closing doors between rooms, and the building inspection shows us that the doors and windows were not well isolated allowing the outside air to pass through them. On the risks associated with the pollutants (Table 8), it was considered the risk of damaging the paintings by dust accumulation on their surfaces. The fine ($PM_{2.5}$) and the coarse particles (PM_{10}) concentrations were estimated. Fine particles (PM < 2.5μm) are particularly damaging, because they discolor or soil the surface and promote abrasions. Soiling changes the visual appearances of the paintings by darkening their surface. Dust accumulation can also provide an attractive foraging place for insects, and can initiate mold growth. Moreover, dust cleaning works of art is a delicate process that requires trained conservators.

Damages due high concentrations of ozone

Ozone is able to attack materials by breaking apart any double bonds between carbon atoms. There are several studies regarding the fading of paintings colorants due to the O_3 erosion of exterior painted surfaces and the attack on the organic binder in the paint [16].

Pollution mitigation strategies

Doors and windows can be fitted with sealing barrier strips to reduce the entry of gaseous pollutants. This has the added advantage of reducing dust levels. After the implementation of this measure, the real concentration of O_3 inside the museum as well as the particles concentration should be measured in order to verify if further actions need to be taken regarding these pollutants.

Light and ultraviolet radiation

Light can induce color fading on paintings and it also has an effect on the paint binding medium, particularly for oil paints which will darken, and on surface varnishes, which also discolors over time. The exposure of oil paintings to ultraviolet (UV) radiation (290-400nm), as part of natural light, is the most damaging. UV radiation causes yellowing, chalking, weakening, and/or disintegration of materials. Since UV radiation is not necessary for the good visibility of the works of art, it should preferably be eliminated. Regarding visible light, although it also causes chemical changes in many materials used in paintings, good lighting is essential to observe the works of art on display. Therefore, accepting that a certain level of light is absolutely necessary means the acceptance of a certain level of damage [17]. Table 9 presents the literature recommendations for visible light and UV light maximum values for paintings on display. However, it should be borne in mind that the exhibition of paintings to visible light should always be as low as possible (50Lux), as long as it provides a good view of the object.

Table 9. Maximum limit of visible light and UV light suggested by the literature for oil painting collections on display

Reference	Lux (lumen/m^2)	UV (μW/lumen)	UV (mW/m^2)
[15]	200 +/- 50	75	15
[18]	150	75	11.25
[19]	150	75	11.25

The magnitude of the risks caused by light and UV radiation were calculated based on data from Table 2 and the values that reached the surface of all the 235 oil paintings on exhibition were measured during collection survey (Table 10). The results show that the risk of surface varnishes oxidation is superior to the risk of color fading by light.

Table 10. Identification of the main specific risks due to light and UV radiation, the type of risk and the calculation of the risk magnitude (MR).

Specific risks	Type	MR
Varnish oxidation by light	3	FS= 0,936 PV= 0,25 P= 1 E= 0,509 **MR= 0,119**
Color fading by light	3	FS= 1 PV= 0,25 P= 1 E= 0,327 **MR= 0,082**
Damages due to high values of UV radiation	2	FS= 1 PV= 0,5 P= 1 E= 0,128 **MR= 0,064**

Varnish oxidation by light

The varnish will be darkened by the action of light. To calculate the loss in value it was considered the fact that the varnish is a superficial coat and does not affect the stability of the object. The extension of the hazard was calculated by the amount of paintings with yellow varnish.

Color fading by light

The extension of color fading was calculated by comparing the values of Mlx h from each painting in exhibition with the values described in [19]. For the calculations, it was considered that all oil paintings have colorants ISO Blue wool standard #4 (medium sensitivity).

Damages due to UV radiation

The damages due to UV radiation alone are difficult to calculate because the distinct rooms have different light sources (see Table 2). To estimate the extension of the damage for the collection it was considered that each painting with an UV level higher than 75μw/lumen will be damaged in the next 100 years.

Light and UV radiation mitigation

The most simple measure, and cost free, to limit the damages caused by exposure to natural light, it would be to keep closed the wooden windows during the guide visits period. The worst problem related to natural light occurs in the rooms with skylights: Noble hall, Columns rooms and Staircase hall (see Table 2). So, in order to reduce the damages done by exposure to natural light in these rooms, artificial light, that present a relatively low UV radiation value, should be used by alone.

Temperature and relative humidity

Figure 4 shows the results from temperature (T) and relative humidity (RH) continuous measurements for a period of 6 months in the Green Gallery room (first floor). The data obtained for the other rooms are very similar, since there are no doors closed between the different rooms and the same air circulates all around the house.

As it can be seen by figure 4, the museum has a huge problem of relative humidity fluctuations. In the winter, the termohygrometers registered 90% RH in some rooms, and fluctuations of around 20% in only 48h were also observed. In the summer, the relative humidity levels are around 45% but it can go as low as 39,5%, as seen in Table 11. The museum has dehumidifiers in almost all the exhibition rooms. These equipments are working most of the time, but they are not capable of maintain a stable RH or within the levels suggested by the literature (Table 12). This is a common problem on historical houses, due to fact that, old, original windows provide poor insulation and the air from outside enters and circulates inside these historic houses.

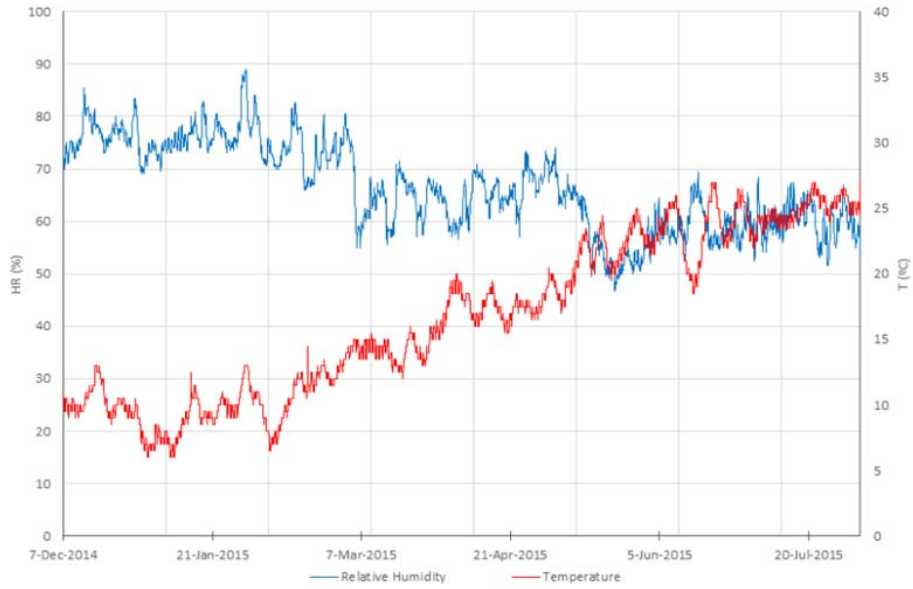

Fig. 4. Temperature (T) and relative humidity record from December 2014 to the end of July 2015 in the Green gallery (first floor).

Table 11. Resume of the maximum, minimum and average values of relative humidity (RH), and temperature (T) recorded in the Sacred art room, Green Gallery, Noble hall and José Relvas room, during a period of 6 months.

Room	Sacred art	Green gallery	Noble hall	José Relvas
HR min. (%)	48	46.5	44	39.5
HR máx. (%)	78	89	89	90.5
HR average (%)	65.6	66.4	63.1	62.4
T min. (ºC)	9.5	6	9	8
T máx. (ºC)	26	27	26	27.7
T average (ºC)	17.7	16.7	19.9	17.9

Table 12. Relative humidity (RH) values levels suggested by the literature to the interior of museums.

Literature reference	HR (%)
[15]	50 - 55 ± 5
[18]	40-65
[20]	40 - 60

Although average values of RH are between 62.4% and 66.4%, the problem is the huge difference between maximum and minimum values. The same problem occurs with the temperature values recorded (Table 11). Temperature inside the exhibition rooms has an average variation of 19ºC between summer and winter. However, temperature values during the summer season are higher than 25°C. Those values are superior to the maximum values of temperature suggested in the literature (between 20 and 25ºC) to prevent any damage to the objects [21].

The paintings collection survey showed that in this specific collection many paintings, some of them recently restored, present damages related to the fluctuations of relative humidity.

Damages caused by RH fluctuations and maintaining the paintings at high levels of RH

MR = 1 (FS) x 0.75 (LV) x 1 (P) x 139/235 (E) = **0.443**. Although some paintings are more susceptible than others to the RH fluctuations, for example, if they have backing board they will respond to the RH slower than the ones without a backing board, to this MR calculation it was taken into account that all paintings were equally susceptible to be damaged by RH fluctuation. Other damages caused by RH fluctuations could be warping of the wood, causing undulations on the support; the oxidation of the nails that are tacking the canvas to the stretcher, cracking and consequently detachment of the paint. All paintings in exhibition that have these damages, were taking into account to calculate the extension of the damages.

Incorrect temperature and relative humidity mitigation strategies

There are several damages of the paintings as a result of fluctuation and maintenance of the collection at incorrect RH and T values. The first step in order to control these two agents of deterioration is to increase the windows and doors isolation, to reduce the air exchanged with the outdoor. The second step is to continue monitoring the environmental conditions with termohigrometers, to see if the first action together with use of the ventilation/dehumidification, in every room, will be enough to maintain the RH between 50% and 60% and the T around 18-20ºC. The implementation of a HVAC system that allows controlling these parameters in a historic house is a very expensive and complex task, since it is not allowed to change the building aesthetic and the stability of the structure has to be taken under consideration. This is why the application of a HVAC system, in historic houses, is usually not recommended. However, there are some cases in which HVAC systems were successfully implemented in historical buildings in order to control RH and T [22]. Nevertheless, simple and low cost measures need to be considered first.

Conclusions

"Casa dos Patudos" exhibits a large and valuable oil painting collection, but the resources for its preservation are very limited while the needs are almost limitless. The lack of professionals linked to the area of conservation and restoration working in this institution increases this collection risks. Moreover, most of the oil paintings are on permanent display, at the same location, since the Museum opened to the public in 1960. The application of CPRM to this collection allowed the identification, evaluation and ranking of the hazards affecting this collection and it will allow the managers to make a decision according to the real needs of the collection. The high relative humidity values and the extreme fluctuations, the incorrect handling of the paintings, the increase in paint detachment due to the maintenance of paintings with paint lifting on display and the damages caused by insects, are some of the most important risk affecting this oil painting collection. In order to help the decision making several risks mitigation strategies were proposed such as the immediate removal of the paintings with paint lifting from exhibition. It was also proposed that doors and windows should be fitted with sealing barrier strips to reduce the entry of pollutants, insects and to stabilize the levels of RH and T inside the museum and reducing energy costs.

One of the challenges of this work was to find a balance between the best preservation conditions and what is possible to implement in a historic house, in other words, a place which was not originally built for the function that it has nowadays. Moreover, the testament of the former owner José Relvas, regarding the building and its collections, had to be taken into consideration even though, in some cases, does not allowed the implementation of certain measures that would help the preservation of the building and its collections.

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