UNCOVERING THE SECRETS OF THE AMAZON CLIMATE IN COLLECTION CONSERVATION: A CASE STUDY OF THE ARTS COLLECTION OF CASA DAS ONZE JANELAS

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UNCOVERING THE SECRETS OF THE AMAZON CLIMATE IN COLLECTION CONSERVATION: A CASE STUDY OF THE ARTS COLLECTION OF CASA DAS ONZE JANELAS

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ABSTRACT

In the complex task of preserving Visual Arts collections, the role of environmental factors is paramount, notably within the distinct Amazon climate. This article examines the environmental elements crucial for conserving Visual Arts collections, focusing on the external environment, macroenvironment, and microenvironment's interplay. It centers on the Contemporary Art collection of Casa das Onze Janelas in Belém do Pará as the primary subject. The aim is to foster critical analysis and offer insights into the

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preservation challenges of this collection in the Amazonian climate. The methodology involved collecting data over three months from two protective environments, utilizing three dataloggers (models HT-70 and HT-900), and meteorological stations for external environmental data. This data was then juxtaposed with contemporary literature in the field, thereby augmenting our analysis with the latest scholarly insights. Preliminary results from the Provisional Technical Reserve indicated an average temperature of 23.72°C and a relative humidity of 69.37%, with the microenvironment showing a slight variation (24.10°C temperature, 63.10% humidity). The Visual Arts Reserve recorded an average temperature of 24.33°C and humidity of 70.92%, whereas its microenvironment presented averages of 26.11°C and 71.46% humidity.
Keywords: preservation; contemporary art; preventive conservation.

RESUMO

No desafio multifacetado de conservar acervos de Artes Visuais, a compreensão dos fatores ambientais desempenha um papel crucial, especialmente em ambientes únicos como o clima Amazônico. Este artigo aborda os fatores ambientais pertinentes à conservação de acervos de Artes Visuais, como a análise e relação do ambiente externo, macroambiente e microambiente. O objeto de estudo é o acervo de Arte Contemporânea pertencente a Casa das Onze Janelas, localizada em Belém do Pará. Objetiva-se desenvolver o pensamento crítico e propor considerações sobre a conservação desse acervo salvaguardado no clima Amazônico. Para fundamentar a discussão, utilizamos da coleta de dados no período de três meses em dois espaços de salvaguarda, feita por três *dataloggers* no modelo HT-70 e HT-900, e estações meteorológicas para os dados do ambiente externo. Além disso, os dados obtidos foram confrontados com o estado da arte da literatura sobre o tema, enriquecendo nossa análise com perspectivas e conhecimentos atualizados. Os resultados gerais na Reserva Técnica Provisória: a temperatura média foi de 23,72°C, com umidade relativa de 69,37%, com ligeiro aumento no microambiente (24,10°C, 63,10%). Na Reserva de Artes Visuais, a temperatura média foi de 24,33°C, com umidade de 70,92%, no seu microambiente, os fatores apresentam média de 26,11°C, 71,46%.

Palavras-chave: preservação; arte contemporânea; conservação preventiva.

INTRODUCTION

This paper presents an essential investigation into the conservation of cultural collections in one of the most challenging and unique regions of Brazil, the Amazon climate. In this case study, the Casa das Onze Janelas Cultural Space (COJAN), located in Belém do Pará, assumes the central role as the research site, and its Visual Arts collection becomes the focus of attention. The specific perceptions, strategies and challenges faced in the preservation of works of Visual Arts in this unique climatic context will be revealed, contributing to the understanding and improvement of the conservation of artistic heritage in the Amazon region.

From this perspective, it is crucial to emphasize several key institutions fundamental to this research. Starting with the Integrated System of Museums and Memorials (SIMM), established in 1998 by the Government of the State of Pará, as part of the Executive Secretariat of Culture of the State of Pará (Silva, 2022). This system was designed with the objective of maximizing the museological potential of Belém's historic center. Its function is to facilitate the integration of museums and memorials in this region (Maranhão; Britto, 2023). The institutions linked to SIMM are the Museum of Sacred Art (MAS), Corveta Museu Solimões, Museu do Forte do Presépio or Museu do Encontro, Museu de Gemas do Pará, Memorial do Porto and Memorial da Navegação, the Museum of Image and Sound , Pará State Museum, Círio Museum and Casa das Onze Janelas Cultural Space (Maranhão; Britto, 2023; Britto; Borges, 2010). Among these, the Casa das Onze Janelas Cultural Space (COJAN) and the Pará State Museum (MEP) will be further discussed.

While MEP serves as a historical museum, narrating both the architectural transformations of its building and Pará's political history (Leão, 2021), it also focuses on visual arts (Mokarzel, 2013). Despite the apparent contradiction between these institutional categories, both align with the collection organization model adopted by SIMM, a technical reserve unified at MEP organized into spaces based on museum typology. This approaches the challenge that not all institutions possess adequate space for safeguarding (Maranhão; Britto, 2023).

Collections are intimately connected to preservation, a comprehensive concept that includes conservation, preventive conservation, and restoration (Bojanoski et al., 2017). Conservation is the array of measures aimed at safeguarding heritage, emphasizing the preservation of both the physical and cultural essence of the items. Preventive conservation, a subset of this discipline, focuses on indirect methods to ward off future deterioration without modifying the materials themselves. In contrast, restoration involves altering an object's appearance to return it to its original condition (Lima; Granato, 2016; Lima, 2017). A key aspect of preventive conservation is the implementation of strategies for assessing behavior and controlling the environment, as highlighted by Gühts and Carvalho (2007). In this paper we focus on environmental control, pivotal in the conservation effort, and aims to mitigate the adverse effects of physical, chemical, biological, anthropogenic factors, and disasters on artworks (Teixeira; Ghizoni, 2012).

The choice of measures for environmental control must be preceded by the planning and application of environmental monitoring, to meet the institution's space needs, collections and investment possibilities. According to the particularities of this case, it was found that the literature on the conservation of collections in countries with hot and humid climates still needs more attention. According to Maria Cláudia Corrêa, "[...] most of the references developed in the world discuss much more the North American and European reality, focusing on regions with a cold climate and with differentiated technology support." (2003, p. 10).

Other significant concepts used in this paper are related to spatial illustration, such as the external environment, the macroenvironment and the microenvironment. In some literature (Froner; Souza, 2008; Souza, 2008), the external environment is appropriated as a macroenvironment. However, for our methodological approach, it was chosen to separate the two concepts and indicate what would be an average environment for the reported macroenvironment, namely Technical Reserves (RT). Therefore, the external environment is established as the space surrounding the safeguarding location, the macroenvironment is the location itself and the microenvironment is reserved for the furniture enclosed within the location.

This paper is the product of ongoing scientific initiation research into the environmental issues surrounding the preservation of the House's Visual Arts collection.

It is linked to the Museological Research and Documentation Project of the Visual Arts collection of the Casa das Onze Janelas Cultural Space (sometimes referred here as the house), which seeks to overcome the informational deficiency in the Casa's Visual Arts collection, through research and documentation of the collections. Within this context, documentation and conservation are understood as museological procedures to safeguard the memory and materiality of heritage assets (Bruno, 2014, p. 10). In view of this, the project carries out an integrated approach to these procedures to guarantee the formation of a complete database on the collection.

The objective of this research is to contribute to the development of critical thinking and promote substantial reflections on the conservation of Visual Arts collections preserved in an environment as unique as the Amazon climate. We seek to understand the specific challenges and effective strategies needed to ensure the integrity and durability of these works of art, considering the unique and often challenging environmental conditions of the region. By developing critical thinking and proposing grounded considerations, this study contributes to the advancement of the field of Contemporary Art Conservation, and benefits the preservation of this valuable artistic heritage for future generations.

METHODS AND MATERIALS

To prepare this paper, a comprehensive search of existing literature on collections conservation and environmental control was carried out. The literature review, also known as documentary research, plays a fundamental role in establishing a consolidated base of knowledge on the topic and providing the necessary context for analyzing the collected data (Lunetta; Guerra, 2023). This methodological tool also helped identify gaps in existing knowledge, highlighting areas that require additional investigations in the conservation of works of Visual Arts in the Amazon climate.

At the same time, data was collected regarding the temperature and relative humidity of the monitored spaces at COJAN. The macro and microenvironment readings were carried out by three data loggers in the HT-70 and HT-900 model, respectively, for the external environment, data from the National Institute of Meteorology (INMET) was acquired. The collection carried out by the device recorded temperature and relative humidity measurements over a period of 4 months, starting in July 2023 and October, every 1 hour, to obtain complete daily data.

The analysis of the data obtained was conducted under a comprehensive case study approach, which considered both quantitative and qualitative dimensions. The case study represents a scientific research approach that delves thoroughly into a real phenomenon and its variables. It is equivalent to a detailed and systematic investigation of an institution, community or individual, enabling an in-depth analysis of complex phenomena (Lunetta; Guerra, 2023).

The analysis of the data collected for this study was carried out in three distinct stages, each focusing on specific environments. First, we evaluate the Provisional Technical Reserve, including a microenvironment within it. Next, attention turned to the Visual Arts Technical Reserve, where we also examined a particular microenvironment. For each of the collection sites, five analyzes were carried out:

(1) Trend and patterns: where the average or median and variation in temperature and relative humidity were calculated. The choice between using the average or median to calculate trend and pattern in a data set depends on several factors and includes the presence of outliers and the distribution of the data. If the data presented many outliers or an asymmetrical distribution, the median was used; however, if they were symmetrical and did not present many extreme values, the average was used, which can provide an adequate representation of the central tendency (Bonamente, 2017). Medians are particularly useful for understanding the central tendency of data, as they minimize the impact of outliers such as spikes in temperature or humidity. Such values will be essential for the second step.

(2) Comparison with ideal conservation data: where data analysis was carried out with the previously mentioned ideal values. As established in table 1, the general average recommended for a Technical Reserve with materials of different types, temperature ranges between 17.8°C and 21.9°C and relative humidity between 40.4% and 59%. In addition to these values, the average temperature for the conservation of collections in Belém was adopted, between 28.91 and 31.59ºC, while the relative humidity is 50.59 and 61.21%, a standard established by Bianca Vicente (2016), as local reference. The objective of this stage is to check whether there is a need to think about new environmental control methodologies or whether the one used is being effective in addressing the problem.

(3) Data variations: where variations in temperature and relative humidity were quantified, with the difference between the highest and lowest value in the data set. This quantification makes it possible to visualize the level of fluctuation in these parameters during the analyzed period. Calculating temperature and humidity variation is crucial for identifying patterns and anomalies. Variation helps identify seasonal or long-term patterns. For example, variations in temperature and humidity may indicate climate change or seasonal variations. Anomalies, such as dry spells or heat waves, can be identified through unusual variations.

(4) Inverse relationship between temperature and relative humidity: where the association between data was analyzed, an inversely proportional relationship was sought that represents a typical occurrence, where an increase in temperature can lead to an increase in the air's capacity to retain moisture, while at lower temperatures, the air tends to become drier (Andrade and Cavicchioli, 2021). This dynamic is related to the high temperatures typical of the Northern region of Brazil, which is characterized by a predominantly equatorial, hot and humid climate. This analysis is fundamental to understanding how the region's environmental factors interact within the museum space.

When the relationship was not visible in the scatter plot, the Pearson Coefficient calculation (Udovičić et al., 2007) was applied directly to the data using functions from the data analysis libraries in Python, which automatically calculate the correlation coefficient between columns in the data set. The results here could range from -1 to 1, where: “1” indicates a perfect positive correlation (when one variable increases, the other also increases). This indicates a strong positive correlation between temperature and humidity, that is, when temperature increases, humidity also tends to increase, and vice versa. In the context of conservation, this may mean that environmental conditions are such that both variables are moving together in a synchronous manner. This can help in predicting and controlling the conservation environment; “0” indicates no correlation (the variables are not linearly related) and suggests a weak or non-existent correlation between the two variables. In this case, temperature and humidity operate independently of each other. For conservation, this indicates that changes in one variable (e.g., temperature) do not provide reliable information about changes in the other variable (humidity); and “-1” indicates a perfect negative correlation (when one variable increases, the other decreases). It means a strong negative correlation. Here, an increase in temperature is associated with a decrease in humidity, or vice versa. This may be particularly relevant to this paper, as it suggests that measures to control one variable may have predictable but inverse effects on the other. For example, when heating a room to reduce humidity, you should be aware that this can excessively dry the air, which can be harmful to certain materials. In the context of conservation, a significant inverse relationship is crucial to understanding how to control the environment. For example, if you are trying to reduce humidity to preserve certain materials, an increase in temperature may be an effective strategy if there is a strong inverse relationship.

(5) Consistency of temperature and humidity levels: where the constancy of the data was analyzed to reach values that allow this analysis, the standard deviation analysis was carried out. When evaluating data, focusing on the standard deviation of temperature and humidity measurements reveals fundamental aspects of environmental variation in the monitored area. Standard deviation, as a measure of dispersion, gives us clear insight into the consistency of environmental conditions. The outliers method (atypical values) based on the Interquartile Range (IQR) was also applied. (Vinutha; Poornima; Sagar, 2018). In this method we consider those values that are far beyond the average standard deviation. For example, values that are more than two or three standard deviations from the average are often considered outliers. The Interquartile Range (IQR) was used, which is a measure of statistical dispersion that provides insight into the variability of data around the median. It is a useful tool for understanding the distribution of data and identifying values that are unusually high or low (peaks or dips) compared to the rest of the data set.

This approach allowed us to examine not only the numerical values of temperature and humidity measurements, but also to understand the nuances and contexts surrounding this information. In this way, it was possible to obtain a complete view of environmental conditions and their interaction with the conservation of contemporary art. At this stage, based on the analysis of the results obtained and their comparison with the relevant literature, it was possible to outline well-founded and enriching discussions.

BACKGROUND

In 2002, the house was established as a museum focused on Visual Arts, in Belém do Pará, Brazil (Mokarzel, 2013, p. 106). Since its creation, it has become a reference for the North region and seeks to bring the public closer to local and Brazilian art (Britto; Mokarzel, 2016, p. 137). Therefore, it is an institution of great importance both for the local artistic class and for research and knowledge of art sciences. The authors also highlight that the institution moved the dynamics of the local art system in an unprecedented way and enabled various museological procedures, such as research, education, conservation, museological documentation, among others (2016, p. 138).

Given the significance of this artistic-cultural heritage, which fosters the growth and spread of local artistic endeavors, preservation extends beyond merely safeguarding cultural values for future generations. It encompasses the interpretation of meanings, both physical and intangible, as well as the examination of culture and its economic aspects. The moment society recognizes the value of an object, its preservation becomes imperative, a responsibility entrusted to institutions like archives, libraries, and museums (Carvalho, 1997).

In this way, Preventive Conservation and Environmental Control can be highlighted as fundamental measures to fulfill the House's mission, which is preservationist and communicational in nature (Corrêa, 2003). Before entering into the analysis of data collected by monitoring environmental control, it is necessary to point out pertinent factors that will be discussed, such as: the definition of the climate in Belém, the behavior of the building and organizational aspects of the storage spaces, characterization of its collection and degradation problems encountered, description of the monitoring system and environmental control.

We cannot discuss the collection without first inspecting the climate and the building. Most of the Brazilian territory is covered by the predominance of regions with a hot and humid climate, this dynamic also defines the climate in the city of Belém, in Pará. According to the analysis of the city's climatic aspects over the last 100 years, the climate was characterized by the always high temperature, as well as the humidity level, in addition to the intense rainfall regime, most marked between December and May, without well-defined seasons (Bastos et al., 2002).

Data collected by the BELÉM automatic station (A201) - PA, operated by INMET, from July 19th to October 24th, indicates an average temperature of 28.55ºC and an average relative humidity of 77%. These values are inadequate when compared to the parameters stipulated for the conservation of collections, in a generalized way, with the most widespread standard in the range of 20ºC and 25ºC and between 65% and 70% relative humidity (Souza, 2008). Unfortunately, when this standard is not met, institutions with collection spaces in the humid tropics resort to more stringent environmental control systems, such as the combination of air conditioning and dehumidifiers, which are increasingly being questioned due to their susceptibility. defects and shutdowns, in addition to the low sustainability linked to its cost and maintenance (Maekawa; Toledo, 2001). This is the case of the MEP, a building that safeguards COJAN's art collection and faces challenges in managing the collection.

To address these challenges, it is necessary to present the aforementioned safeguard space. The MEP is located in the Palácio Lauro Sodré, a building of historical value, opened in 1771 (Miranda et al., 2017, p. 222). It is located in the Cidade Velha neighborhood, part of the historic center of Belém, close to wooded areas (Maranhão; Britto, 2023). The building follows the pattern of Portuguese constructions from the 18th century, in the style of colonial civil architecture (Brahyner et al., 2018). It is divided into two floors and follows the interconnected circulation system. Furthermore, it features thick solid walls, with high ceilings or vaulted ceilings. Concerning historical constructions, Marina Ribeiro notes that they serve as filters between the external and internal environments, owing to their distinctive structural features (2009, p. 403). However, the behavior of the reference building has certain particularities that go against this reflection. This can be justified by the hypothesis raised through the reference investigated regarding construction techniques from this period in Belém, such as the use of historic lime mortar on brick walls and floors, materials recognized for their low thermal and hydraulic inertia. Most building materials used in the present or past have a high capillarity rate, becoming moisture channels that penetrate the walls and influence the internal microclimate (Gewehr, 2004, p. 36).

Another point that cannot be denied is the thickness of the walls and their role in thermal behavior (Ribeiro, 2009, p. 408). It was a construction technique widely used to guarantee the durability of the building, without thinking about the gain and loss of heat and humidity or the storage time of these variants. The MEP has walls up to 36 centimeters thick. Therefore, the porous behavior of these materials facilitates the influence of the external environment, while the considerable thickness of the walls results in the inertia of this exchange.

Temperature and humidity are pivotal in environmental control strategies because fluctuations in these factors can lead to damage, including size alterations of artworks and biodegradation from microorganism and insect growth (Gühts; Carvalho, 2007, p. 32). Climate control planning must be distinctly tailored for buildings repurposed as museums due to their physical and structural constraints. These buildings, as valuable as the collections they protect, require a unique approach (Toledo, 2003). Belém's climate pattern, faced by the building, makes it unfeasible to maintain the air conditioning system combined with the use of dehumidifiers, because it requires high performance that overloads this equipment, something that causes more financial expenses.

The spatial organization of the MEP's Technical Reserve is delimited by the rectangular plan, with the distribution of administrative rooms, storage rooms, exhibition rooms and laboratories for research activities. The safeguard spaces monitored in this research are the Technical Reserve for Visual Arts (RT de Artes Visuais) and the Provisional Technical Reserve (RT Provisória), located on the ground floor.

The Visual Arts Technical Reserve (Image 1) is divided into three rooms, the central room is defined here as the main area. It was equipped to receive the House's collection from the beginning, with space better utilized after the construction of the mezzanine. The furniture is characterized by closed and open shelves, map cabinets and painting racks (Image 1a, 1b, 1c). There are eight windows, two in the room to the left of the main area, in this area there are three windows and a door, through which access occurs, and in the room to the right there are three windows and two doors. All window entrances are closed.

Figure 1. Compilation of photographs of the furniture in the monitored spaces. a) Closed RTAV shelves. b) Open RTAV shelves. c) RTAV racks. d) Open shelf of the Provisional RT. e) Scaffolding adapted from the Provisional RT. f) Provisional RT map cabinets, same model used in RTAV. **Source**: Prepared by the authors (2023).

The Provisional RT serves as a workspace for Conservation and Restoration professionals. With the Visual Arts RT at full capacity, some collections were relocated here, necessitating adapted furniture like shelves, map cabinets, and scaffolding for larger items (Image 1e). This furniture is nearly full, potentially complicating future acquisitions. The area, accessible via two entrances, connects to the project action room, the Preservation, Conservation and Restoration Coordination's meeting room, and a restricted-access electrical wiring room. It features eight entrances, six windows, and two doors, with all windows made of wood and designed to allow airflow.

Control measures aim to minimize damage to collections and artworks, often without significant financial burden (Souza, 2008, p. 21). Within the collection storage spaces of the House at MEP, the environmental control system is carried out by the air conditioning combined with dehumidifiers. The air conditioning equipment was installed more than 10 years ago and remains the same model. For almost the entire first half of 2023, they presented periods of malfunction, when in July of this year the corrective measures were successful and they returned to normal operation. In 2023, new models of dehumidifiers were purchased and installed in the collection storage rooms. This environmental control system was designed to operate daily and the availability of equipment in each reserve can be seen better in Figure 2.

Figure 2. Illustrative drawing of the position of environmental control equipment in monitored spaces. a) Visual Arts Technical Reserve. b) Provisional Technical Reserve. Source: authors (2023).

This environmental control method is widely adopted in countries with hot, humid climates to achieve temperature and humidity levels akin to those in temperate regions (Maranhão; Britto, 2023, p. 11; Ribeiro, 2009, p. 407). However, equipment failures can cause significant fluctuations, undermining stability. To mitigate this, institutions are advised to develop an environmental control monitoring plan that facilitates decision-making across short, medium, and long terms.

Currently, monitoring involves sporadic checks with thermo-hygrometers, which track temperature and humidity but lack data storage capabilities. Manual logging is challenging due to the irregular work schedules of professionals, leading to gaps in data collection on weekends and holidays. To ensure consistent data capture, planning should entail recording at least three times daily throughout the year. This could be enhanced by integrating indoor and outdoor readings or employing devices with automatic storage, reducing the need for extensive manual effort.

Establishing planning for environmental monitoring of storage rooms is crucial to designing environmental control measures, as according to Souza, “Knowledge of the real environment of a collection is only possible through monitoring and recording environmental conditions” (2008, p 7). The effectiveness of environmental control is based on steps systematized by this author, including: monitoring, characterization and evaluation, which ultimately result in the specific report for the preparation of the environmental control plan (2008, p. 7). Within this case study, these steps are presented in the results and discussions.

Souza notes, "The complexity of materials and combinations of museum objects are directly related to their behavior in relation to variations in environmental conditions." (2008, p. 4). This applies to the Visual Arts collection housed in MEP's RT, notable for its diverse material range across the collection and within individual pieces. The assortment of materials, sizes, and techniques showcases the magnitude of local and national artistic contributions. However, it poses significant challenges to conservation efforts, particularly in the Amazonian climate.

To elucidate the diversity within the House's collection, materials from three surveyed collections (FUNARTE, Fundo Z, Diário Contemporâneo de Fotografia) were categorized into two main groups: Organic and Inorganic. Organic materials include painting, paper, photography, wood, textiles, and others (candle, rubber, earth pigment with acrylic resin). Inorganic materials comprise minerals, glass, ceramics, metals, plastic, and others (oil paint tubes, foam spheres, and illuminated signs). The "other" category within these groups represents items that do not fit into another category and are rare in the collection. This classification aligns with Teixeira and Ghizoni's recommendations, grouping materials as organics and inorganics (2012, p. 16).

This categorization reflects the frequency of materials in the artworks: 213 pieces contain organic materials, while 839 feature inorganic materials. An analysis of the materials in the collection confirms insights from the literature review, summarized in Table 1. Notably, the majority of references originate from temperate climates, highlighting a gap in updated literature on conservation values suitable for collections, especially in different climates.

	Material(s)	Temperature	Relative Humidity	Reference
Organic materials	Acrylic/oil painting	16°C - 25°C	35% - 65%	Hartin; Baker, 2018
	Watercolor	10ºC - 25ºC (paper)	>65% - 75% <90% critic	Guild, 2018
	Other documents	39ºC	75%	Michalski; 2000. Corrêa; 2003
	Paper	19ºC - 23ºC 20ºC - 22ºC	50 e 60% 45 e 60%	Mello; Santos, 2004, p. 8. Teixeira; Ghizoni, 2012, p. 41

	Photography	Avoid high temperatures	30 e 45%	Teixeira; Ghizoni, 2012, p. 45
	Vegetable fibers	> 30ºC	40% - 65%	Mason, 2018 Dancause; Wagner; Vuori, 2018
	Animal fibers	< 35°C	> 65%	Dignard; Mason, 2018
	Wood	25ºC - 30ºC	>20%	Gonzaga, 2006
	Textiles / Fabrics	18 ºC - 22ºC	40 e 60%	Teixeira; Ghizoni, 2012, p. 55
Inorganic materials	Metals	-	35 e 55%	Froner, Souza, 2008, p. 6
	Rocks and Minerals	15 - 20ºC	50% - 55%	Western Australian Museum, s/data
	Glass	18ºC - 21ºC	<40%	Teixeira; Ghizoni, 2012, p. 65 Fahey; s/data
	Ceramics / Porcelain	18ºC - 21ºC	65% - 75% 45% - 55%	Logan; Grant, 2018 Fahey; s/data

Table 1. Parameters used in environmental preservation and control according to the materials present in the cultural assets analyzed. **Source**: authors (2023).

According to Guimarães and Beck (2007), the ideal values for preserving collections in general are those closest to 20ºC for temperature and 50% for relative humidity. However, the diversity of materials present in the Technical Reserve represents a significant challenge regarding environmental control. Ideally, each type of material requires a space with environmental conditions adjusted to its specificities. However, the feasibility of establishing multiple specialized technical reserves is limited, both for practical reasons and resource constraints. Therefore, in recognition of this reality and in search of pragmatic solutions, we chose to use the general average of environmental conditions as an evaluation parameter.

For comparison purposes, the standard established by Guimarães and Beck (2007) and those presented in Table 1 were considered. Therefore, a parameter was obtained for organic materials, where the ideal conditions include an average temperature that does not exceed 23.1°C and not less than 18.6°C, while recommended relative humidity levels vary between 43.3% and 61.7%. In contrast, inorganic materials require a slightly higher temperature range, with an average minimum of 17°C and a maximum of around 20.7°C, and a relative humidity spectrum ranging from 37.5% to 56.3%. However, the two Technical Reserves safeguard both organic and inorganic materials, which is why a more comprehensive parameter was established. The recommended maximum temperature average is set between 17.8°C and 21.9°C, while for relative humidity, the ideal average values are between 40.4% and 59%. This parameter makes it possible to efficiently manage the Technical Reserve environment, in order to benefit the majority of stored materials, despite individual variations in their specific conservation needs.

However, the northern region of Brazil has particularities that make the application of this standard unfeasible. As a parameter for sustainable management and environmental control of technical reserves in Belém, considerations from the case study on environmental control of the Curt Nimuendajú Technical Reserve of the Museu Paraense Emílio Goeldi, developed by Bianca Vicente (2016), were adopted. In this research, the author shows that between September and October 2014, the average temperature was 30.25ºC, while the relative humidity was 55.90%, with variations of 1.34ºC and 5.31% respectively. The environmental control system used in the Curt Nimuendajú Technical Reserve focuses on controlling humidity, to contain biological proliferation in the collection. It is an alternative air conditioning system, and despite not reaching the standards established by Conservation literature, the collection is in a good state of conservation[5].

On the other hand, the problems of degradation in the collections at MEP are intrinsically linked to the instability of environmental conditions over the years. It is noteworthy that organic materials, the majority in the collection, are the most affected. The main damages found in these works are: moisture stains, cracking, loss of pictorial layer, presence and growth of microorganisms.

Although it cannot be said that the damage presented comes from the climatic conditions of the safeguard spaces, constant variations in temperature and humidity can aggravate this damage. The direct relationship between climatic conditions and the deterioration of materials reinforces the importance of adaptive strategies for preservation in environments such as the northern region of Brazil. Therefore, the data collected during the environmental monitoring of this research provide a safe assessment of the relevance of these values applied within the Amazon climate.

RESULTS AND DISCUSSIONS

Before presenting the environmental monitoring outcomes, it's essential to address data collection frequency. The regularity of environmental data recording significantly affects the analysis and comprehension of how these conditions impact the preserved materials. Discussing this aspect enables a more precise and contextual evaluation of the gathered data.

The ideal frequency of collecting temperature and relative humidity data in museums depends on several factors, including the type of collection, the size and layout of the museum, as well as the climatic conditions of the region. It is recommended to continuously measure and record environmental parameters around the clock to achieve a comprehensive understanding of the setting. This approach is warranted because temperature and relative humidity can fluctuate considerably over the course of a day, week, or year. Such frequent changes can impact many of the museum's objects in various ways, underscoring the necessity of controlling these factors to ensure the collection's preservation (Museums Galleries Scotland, 2009; Michalski, 2007).

To ensure proper environmental control in museums, particularly for delicate collections and crucial areas, continuous monitoring of temperature and relative humidity is advised. It's critical to understand that while environmental monitoring itself does not

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[5] This system consists of two blower fans located outside the building, which deposit filtered air inside the Reserve through two central ducts on the ceiling of the room. The air circulates throughout the room and is removed through two ducts positioned on the side walls, connected to exhaust fans in the external area. Furthermore, the system activates internal fans when the relative humidity is lower in the external area of the Reserve compared to the internal part, in order to reduce humidity.

constitute control, it generates diagnostic data that informs environmental control strategies (Souza, 2008, p. 7). Various methods and devices, including both automatic and manual tools like dataloggers and thermo-hygrometers, are employed to record these key parameters. The level of insight into the environmental conditions enhances with the length of the recording period.

The initial data analyzed are from the Provisional Technical Reserve and its Microenvironment. In the first period (Figure 3a), the HT-91 datalogger recorded data for the macroenvironment on a shelf. In the second period (Figure 3b), the HT-91 equipment was relocated to another shelf, closer to the RTP main entrance. The HT-900 datalogger was allocated within the map cabinet on 06th September.

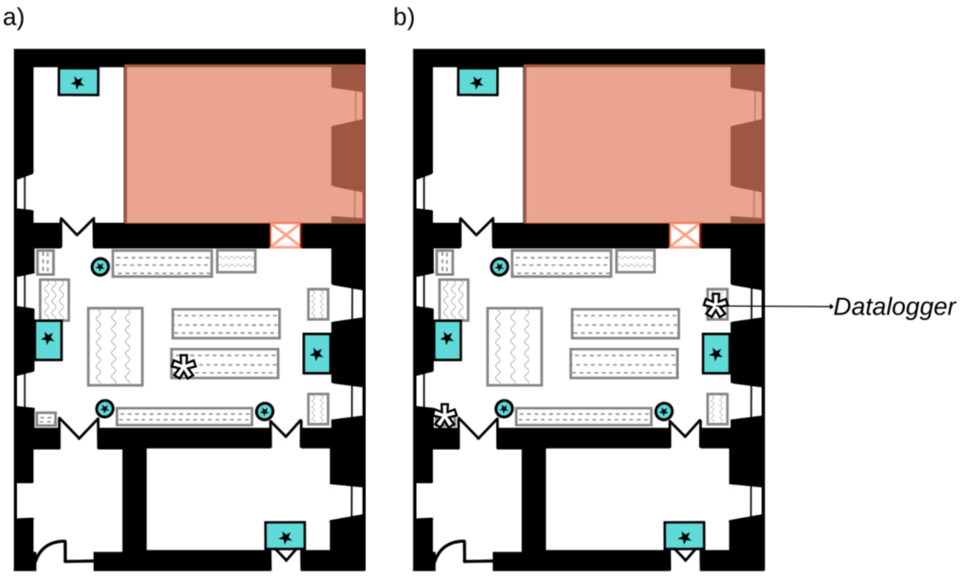
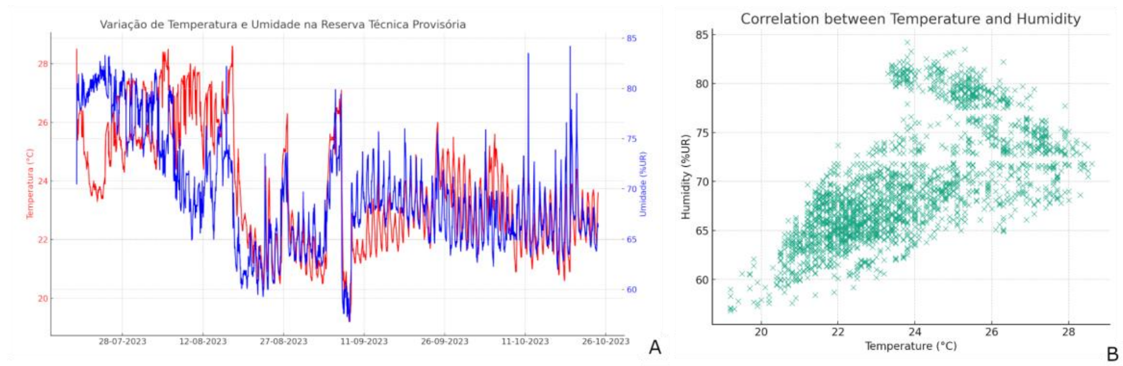


Figure 3. Floor plan illustrating the position of environmental control and monitoring equipment in the Provisional Technical Reserve. a) Location during the first period. b) Location during the second period. **Source**: authors (2023).

The rotational system of the macroenvironment was segmented into two periods: the initial spanned from July 19 to September 6, and the subsequent from September 6 to December 1st, as depicted in Figure 3. 2339 measurements were recorded in the Provisional Technical Reserve (Provisional RT) From July 7 to October 24.

The analysis for the Provisional RT environment was conducted based on the Graphic 1 A and B graph and the collected data, focusing on the average as an indicator of trend and pattern.



Graphic 1. Data collected in the Provisional Technical Reserve A) Variation in temperature (in red) and humidity (in blue) over the recorded period. B) Scatter plot with correlation between temperature and humidity. **Source**: authors (2024).

The average temperature recorded was 23.72°C, a value that exceeds the ideal upper limit of 21.9°C, indicating that the room tends to be hotter than recommended. Likewise, the average relative humidity of 69.37% exceeds the ideal upper limit of 59%, suggesting that the room often has a high relative humidity level.

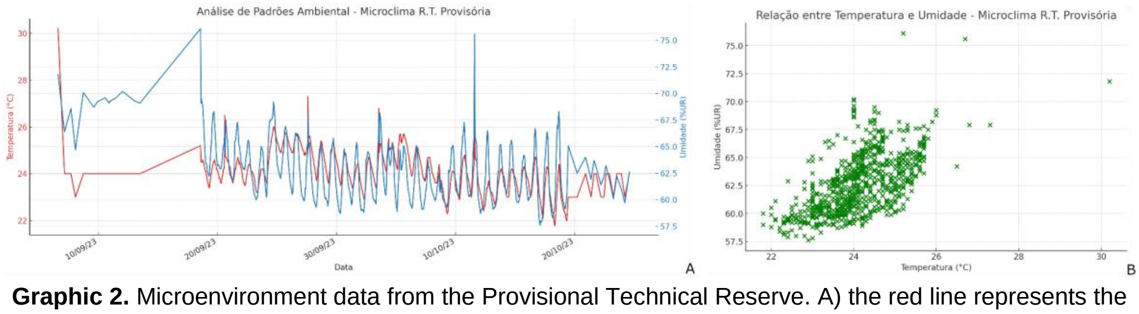
When comparing the data to Table 1, which establishes the ideal standards, it was identified that 1850 temperature measurements and 2303 relative humidity measurements were outside the ideal standards. In the results, approximately 79% of temperature collections and 98% of humidity collections did not meet these criteria. This suggests a high trend for both measurements, something that indicates the need to optimize the climate and humidity control system or study other equipment possibilities for this strategy.

Comparing the standards established by Bianca Vicente (2016), considered suitable for museum storage spaces in Belém, also reveals discrepancies. In the analysis, all 2339 temperature and 2253 relative humidity measurements were outside these standards and this demonstrates that the room is consistently colder and more humid than the model proposed by the author.

Furthermore, a variation of 9.4ºC in temperature and 27.4% in humidity was observed, resulting in greater instability in the measured conditions. The inverse relationship between temperature and relative humidity showed a moderate positive correlation of 0.64, which is atypical as an inverse relationship is generally expected.

Regarding the consistency of temperature and humidity levels, the interquartile range (IQR) was 3.1ºC for temperature and 7.8% for humidity, with standard deviations of 1.99ºC and 5.61%, respectively. This reflects significant variation in the data, with the presence of extreme values. Outlier limits were identified as lower than 17.45°C and higher than 29.85°C for temperature, and lower than 53.6% and higher than 84.8% for humidity.

Within the Provisional Technical Reserve, the collection of microenvironment data was conducted inside a map cabinet. In this area, 1203 measurements were taken from September 6 to October 24, 2023. During the monitoring, it is noteworthy that between September 14 and 19, there were gaps in the data recording. Hence, this interval was omitted from the analysis.



Graphic 2. Microenvironment data from the Provisional Technical Reserve. A) the red line represents the temperature (in degrees Celsius). The blue line represents the relative humidity of the air (in %RH). B) Correlation between temperature and humidity. **Source**: authors (2024).

The analysis of this microenvironment was conducted based on Graphic 2 A and B and the collected data, focusing on the median as an indicator of trend and pattern. The median observed was 24.10°C for temperature and 63.10% for relative humidity. These values indicate that the furniture tends to be hotter than recommended, as the median temperature exceeds the upper limit of the ideal range. Furthermore, relative humidity often exceeds the ideal upper limit of 59%, something that suggests that inside the map cabinet there is generally a high level of humidity.

When comparing Table 1, which defines the ideal standards, it was found that 1201 temperature measurements and 1176 humidity measurements were outside these standards. Almost 100% of temperature measurements and approximately 98% of relative humidity measurements did not meet these criteria. This indicates a predominance of temperatures and humidity above ideal, something that also suggests the need for adjustments in temperature and humidity control.

Compared to the standards established by Bianca Vicente (2016) for Belém, 1202 temperature measurements and 877 relative humidity measurements were also outside this standard. Measurements showed that the cabinet is consistently cooler and with slightly higher humidity than the model presented by the author. This indicates the need for environmental adjustments to align room conditions with typical Belém weather conditions.

The variation observed was 8.4°C in temperature and 20.80% in humidity, this indicates greater relative stability compared to the macroenvironment of the Provisional Technical Reserve. This means that closed furniture presents a certain resistance to variations in temperature and humidity, and has the potential to serve as an envelope for the conservation of these collections. Due to the significant presence of outliers, the inverse relationship between temperature and relative humidity method was not used. The interquartile range (IQR) was 1ºC for temperature and 4.4% for humidity, with standard deviations of 0.86ºC and 3.23%, respectively, with greater consistency and stability.

When reading the data recorded for the Provisional RT microclimate, several temperature and humidity outliers were identified on specific dates (Table 2).

Temperature Outliers	**Relative Humidity Outliers**
06/09/2023 14:57:27 30,2 06/09/2023 15:57:27 26,7 06/09/2023 16:57:27 26,9 06/09/2023 17:57:27 26,9 06/09/2023 18:57:27 26,8 06/09/2023 19:57:27 26,5	06/09/2023 15:57:27 77 06/09/2023 16:57:27 77,8 06/09/2023 17:57:27 78,4 06/09/2023 18:57:27 77,8 06/09/2023 19:57:27 77,2 06/09/2023 20:57:27 75,3 06/09/2023 21:57:27 73,1
20/09/2023 15:01:26 26,5	-
27/09/2023 14:28:30 27,3	-
03/10/2023 12:53:13 26,8	-
11/10/2023 13:56:48 26,7	11/10/2023 13:56:48 75,6
18/10/2023 05:56:48 22 18/10/2023 06:56:48 21,8 18/10/2023 07:56:48 21,8	18/09/2023 13:59:03 76,1
19/10/2023 06:56:48 22 19/10/2023 07:56:48 22	-

Table 2. Temperature and Relative Humidity outliers by date, hour and value. **Source**: authors (2023).

In the first week of September, the air conditioning system in this area experienced multiple malfunctions, potentially explaining the anomaly observed on the 6th. On that day, a significant influx of people was noted within the Provisional RT from 2pm to 5pm, followed by a slight decrease in these disturbances. The 6th, 20th, 27th of September, and 11th of October were designated for removing data collection equipment, which may account for the observed outliers. On the 18th and 19th of October, no definitive explanations for the anomalies were identified, but furniture movement was discounted as a cause. Instead, a surge in power outages or failures in the environmental control systems was deemed more likely during this timeframe.

The map library is where most works on paper are stored, which are packaged in paper envelopes. The result of this is a large volume of hydrophilic materials, something that can justify the humidity values within this microclimate.

The Visual Arts Technical Reserve serves as the principal area for protecting the House's Visual Arts collection. The rotating macroenvironment system was segmented into two phases: the initial one spanned from July 19 to September 9, and the subsequent phase extended from September 9th to December 1st, as illustrated in Figure 4.

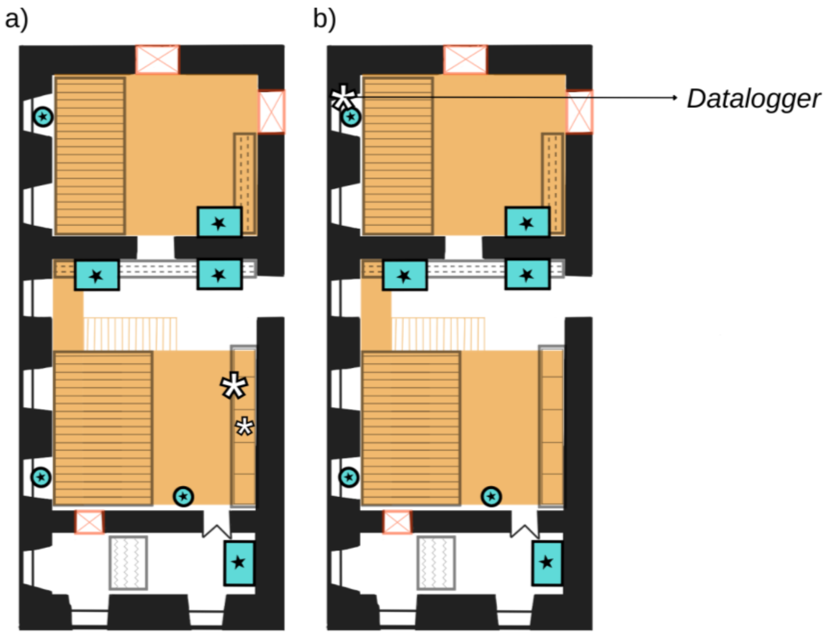
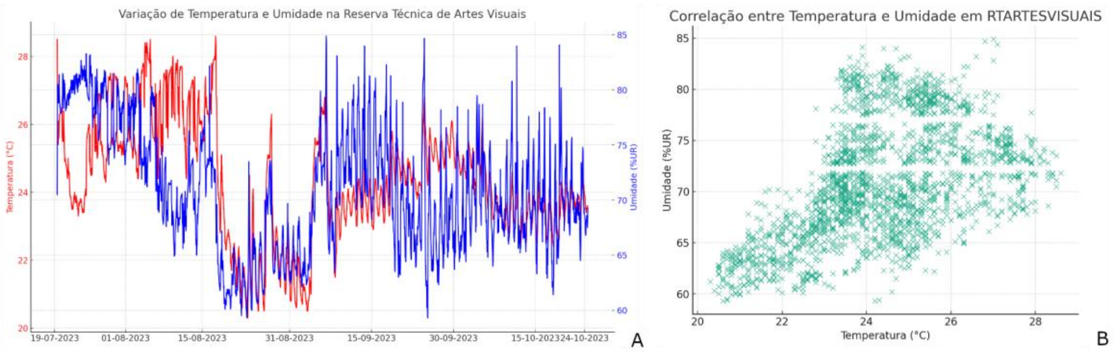


Figure 4. Floor plan illustrating the position of environmental control and monitoring equipment in the Visual Arts Technical Reserve. a) Location during the first period. b) Location during the second period. **Source**: authors (2023).

In the first period (Figure 4a), the HT-91 datalogger recorded data for the macroenvironment on the cabinet while the HT-900 datalogger was placed inside the same furniture. In the second period (Figure 4b), the HT-91 equipment was relocated behind the racks, close to a dehumidifier, while the HT-900 datalogger began to collect the microenvironment from another storage space from the end of this period. From July 19 to October 25, 2340 measurements were taken in the Visual Arts Technical Reserve (Graphic 3).



Graphic 3. Data from the Visual Arts Technical Reserve. a) Temperature (in red on the left) shows how the temperature varied over the recorded period. Humidity (in blue on the right) shows the variation in humidity over the same period. b) Correlation between temperature and humidity. **Source**: authors (2023).

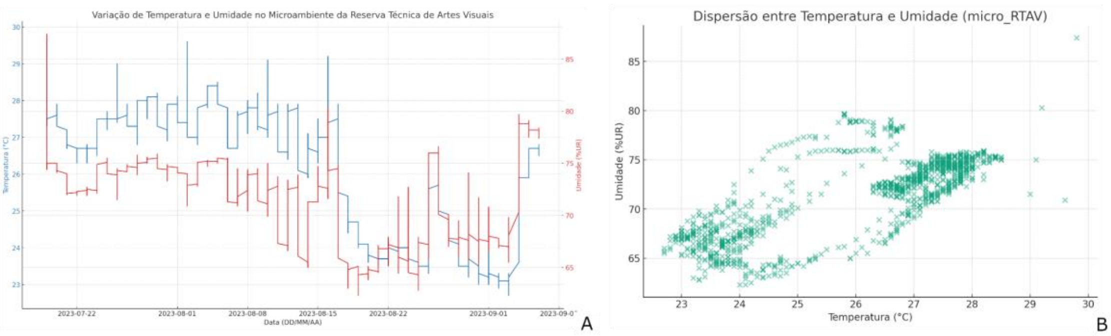
The analysis of this environment was conducted based on Graphic 3 A and B and the data collected, focusing on the average as an indicator of trend and pattern. The average temperature recorded was 24.33°C, and exceeded the ideal upper limit, which suggests that the room is generally warmer than recommended. Furthermore, the average relative humidity of 70.92% significantly exceeds the upper limit of ideal, which indicates that the environment often has a consistently high level of humidity.

When analyzing the data in Table 1 that defines ideal standards, it was observed that all 2340 humidity and 2112 temperature measurements were outside these standards. This means that 100% of humidity measurements and around 90% of temperature measurements did not meet ideal criteria, highlighting the constant challenge of maintaining the room at desired parameters, with a bias towards higher than ideal temperatures and humidity.

Furthermore, when comparing these results with values from research carried out in Belém, such as that by Bianca Vicente (2016), it was found that all temperature and humidity measurements were also outside the standard. This indicates that the Visual Arts Technical Reserve is consistently cooler and wetter than the model proposed for Belém, highlighting the need for adjustments in temperature and humidity control.

The observed variation was 8.3ºC for temperature and 25.6% for humidity, indicating significant variations in the measured conditions. The inverse relationship between temperature and relative humidity showed a moderate positive correlation of 0.49. The interquartile range (IQR) was 2.2ºC for temperature and 8.35% for humidity, with standard deviations of 1.73ºC and 5.63%, respectively, reflecting a moderate variation.

Within the Visual Arts Technical Reserve, microenvironment data collection took place inside a closet. In this confined space, 1184 measurements were documented from July 19 to September 6, 2023.



Graphic 4. Microenvironment data from the Visual Arts Technical Reserve A) Temperature (in red on the left) shows how the temperature varied over the recorded period. Humidity (in blue on the right) shows the variation in humidity over the same period. B) Correlation between temperature and humidity. **Source**: authors (2023).

The analysis of this microenvironment was conducted based on Graphic 4 A and B and the collected data, focusing on the average as an indicator of trend and pattern. The average temperature in the microenvironment was 26.11°C, significantly above the ideal upper limit, which indicates that it tends to be consistently warmer than recommended. At the same time, relative humidity averages 71.46% and considerably exceeds the ideal upper limit, something that suggests that the environment maintains a consistently high level of humidity.

When analyzing the data in Table 1, which defines ideal standards, all 1184 temperature and humidity measurements were outside these standards. This highlights the ongoing challenge in maintaining the microenvironment within ideal limits, with an inclination towards temperatures and humidity above ideal.

Compared to the standards established by Vicente (2016) for Belém, it was observed that 1179 temperature measurements and all 1184 humidity measurements were also outside the standard. Measurements indicate that the microenvironment is consistently colder and wetter than the model proposed for Belém, something that suggests the need for adjustments in environmental control. The observed variation amounted to 7.1ºC for temperature and 25.1% for humidity, indicating significant fluctuations in the monitoring data. The inverse relationship between temperature and relative humidity showed a moderate to strong positive correlation of 0.77. The interquartile range (IQR) was 3.33°C for temperature and 6.7% for humidity, with standard deviations of 1.73°C and 3.95%, respectively, reflecting a moderate to high variation.

For this measurement, a relative humidity outlier was found in the record on July 19th, at 09:26:13, at a value of 87.4%, with no justifications provided for defining this deviation.

Both the Visual Arts Technical Reserve and the Provisional Technical Reserve face significant challenges in maintaining temperature and humidity within ideal standards. In both reserves, conditions of excessive heat and high humidity prevail, which can be harmful to sensitive materials and adversely affect the conservation and presentation of works of art. It is crucial to implement effective climate and humidity control solutions to create an adequate environment that complies with recommended standards, both for Belém and the rest of the literature. It was observed that, particularly in the first week of September, failures in the air conditioning system negatively impacted humidity records. Continuous monitoring and adjustments to environmental control systems are essential to ensure that ideal conditions are achieved and maintained to ensure the integrity of artistic heritage.

CONCLUSION

In this paper, we investigated both the complexity of the materials present in the Visual Arts collection at Casa das Onze Janelas, and the results of the environmental monitoring of spaces that store this collection. The main results reveal that both monitored spaces present challenges in maintaining the balance of temperature and humidity values, whether due to the equipment used for environmental control or the complexity of the materials present in the collections. From the analysis of both quantitative and qualitative aspects of the results, it was discovered that conditions of excessive heat and high humidity, as well as the constant fluctuation of these values, contribute to the degradation of works of art.

Efforts aim to understand the typology of materials by distribution between organic and inorganic groupings and the ideal environmental conditions for their preservation. To this end, a table was created that compiles the temperature and humidity values recommended for conservation according to the aforementioned distribution. When comparing the data obtained with the existing literature, it was noted the scarcity of specific references for tropical climates, especially in the northern region of Brazil. Therefore, we opted for the research developed by Bianca Vicente (2016), where she considered that the values found in the Curt Nimuendajú Technical Reserve, despite not following conventional standards, did not affect the collection. From data comparison, in none of them were the levels found in the Provisional and Visual Arts Reserve, or its microenvironments, adequate.

The spaces for safeguarding the Visual Arts collection at Casa das Onze Janelas face significant difficulties in maintaining temperature and humidity within ideal standards, whether due to conditions of excessive heat and high humidity or the complexity of the materials that make up the collection. Furthermore, the study revealed that climatic conditions in Belém, characterized by high temperature and humidity, defy conventional conservation standards. The region's hot and humid climate, with significant variations in precipitation, differs from the temperate climates where most collection conservation guidelines were developed.

It is worth recognizing the limitations of this study, which reflect the lack of updated references for tropical environments. Still, the results offer a valuable basis for future research and contribute significantly to the advancement of knowledge in the area, where adaptations are suggested that consider the specific conditions of the northern region of Brazil. Furthermore, the need to maintain temperature and humidity monitoring was highlighted so that the environmental control system can be reevaluated or modified. Likewise, more in-depth studies are recommended on the influence of the Amazon climate on the conservation of modern and contemporary Visual Arts collections.

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No potential conflict of interest was reported by the author(s).

AUTHOR CONTRIBUTION STATEMENT

Bruna Maria Araújo de Melo Maranhão
Ideas; formulation or evolution of general research goals and objectives; Conception and design of the study; literature review; data acquisition; data analysis and interpretation; preparation of the manuscript; intellectual review of the manuscript; final approval of the version submitted to the journal.

Jessica Tarine Moitinho de Lima
Ideas; formulation or evolution of general research goals and objectives; Conception and design of the study; literature review; data acquisition; data analysis and interpretation; preparation of the manuscript; intellectual review of the manuscript; final approval of the version submitted to the journal.

Sue Anne Regina Ferreira da Costa
Literature review; data acquisition; preparation of the manuscript; intellectual review of the manuscript; final approval of the version submitted to the journal.

Rosangela Marques Britto
Literature review; data acquisition; preparation of the manuscript; intellectual review of the manuscript; final approval of the version submitted to the journal.

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