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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, Brazil

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ABSTRACT

This research examines the environmental elements crucial for conserving collections. It centers on the Contemporary Art collection of Casa das Onze Janelas in Belém do Pará, Brazil. The aim is to foster critical analysis and offer insights into the preservation challenges of this collection in the Amazonian climate. Data were collected over three months using data loggers and meteorological stations. Preliminary results showed temperature and humidity variations, with average temperatures and humidity levels slightly differing between the Provisional Technical Reserve and the Visual Arts Reserve. These results emphasize the need for tailored conservation strategies in tropical climates, highlighting the unique challenges faced in maintaining stable conditions for art preservation in the Amazon region.

KEYWORDS

preservation of collections, contemporary art, preventive conservation, amazon region

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INTRODUCTION

This paper investigates the conservation of cultural collections in the challenging Amazon climate, focusing on the *Casa das Onze Janelas Cultural Space* (COJAN) in Belém do Pará, Brazil. The study highlights strategies and challenges in preserving Visual Arts within this unique climate, contributing to the understanding and improvement of artistic heritage conservation in the Amazon.

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 1999 by the Government of the State of Pará, as part of the Executive Secretariat of Culture of the State of Pará (Silva, 2022, p. 8). 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, p. 2). The institutions linked to SIMM are the Museum of Sacred Art of Belém (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 of Belém, Pará State Museum, Círio Museum and Casa das Onze Janelas Cultural Space (Maranhão & Britto, 2023, p. 2; Britto & Borges, 2010, p. 162). 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, p. 7), it also focuses on visual arts (Mokarzel, 2013, p. 106). 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, p. 2).

This study focuses on the connection between collections and preservation, encompassing conservation, preventive conservation, and restoration. Conservation aims to protect heritage by preserving both the physical and cultural essence of items. Preventive conservation uses indirect methods to prevent future deterioration without altering materials, while restoration involves modifying an object's appearance to restore its original condition (Lima & Granato, 2016, p. 462; Lima, 2017, p. 6). A key aspect of preventive con-

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servation is assessing behavior and controlling the environment (Gühts & Carvalho, 2007, p.36).

This paper focuses on environmental control to mitigate the adverse effects of physical, chemical, biological, anthropogenic factors, and disasters on artworks (Teixeira & Ghizoni, 2012, p. 15-16). Environmental control measures must be planned and preceded by environmental monitoring, adapting to the institution's needs, collections, and investment possibilities. The research highlights the lack of literature on conservation in hot and humid climates, contrasting with the focus on cold climates and advanced technological support in North American and European contexts (Corrêa, 2003, p. 10).

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

This paper involved a comprehensive literature review on collections conservation and environmental control, establishing a knowledge base and context for data analysis (Lunetta & Guerra, 2023, p. 151). This review also identified knowledge gaps, highlighting areas needing further investigation for conserving 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, by its acronym in Portuguese) was acquired. The collection carried out by the device recorded temperature and relative humidity measurements over a period of four months, from July to October 2023, every 1 hour, to obtain complete daily data.

We acknowledge that the data collection period is limited. However, this dataset represents our current available data, and we

believe that preliminary analyses are as significant as final ones. These initial findings provide a foundational understanding that will guide future, more comprehensive studies.

The data analysis was conducted using a comprehensive case study approach, considering both quantitative and qualitative methodologies. This method allows for an in-depth investigation of complex phenomena within an institution, community, or individual (Lunetta & Guerra, 2023, p. 156). The analysis was carried out in three stages, each focusing on specific environments. First, we evaluated the Provisional Technical Reserve (Provisional TR), including its microenvironment. Next, attention turned to the Visual Arts Technical Reserve (Visual Arts TR)[1], where we also examined a particular microenvironment. For each of the collection sites, some analyzes were carried out:

1. Trend and patterns: We calculated the average or median and variation in temperature and relative humidity. The choice between average and median depends on outliers and data distribution. The median was used for data with many outliers or asymmetrical distribution, while the average was used for symmetrical data with few extreme values, providing an adequate central tendency representation (Bonamente, 2017, p. 109). Medians are particularly useful for minimizing the impact of outliers like spikes in temperature or humidity. These values are essential for the next step.

2. Comparison with ideal conservation data: Data analysis was conducted using previously mentioned ideal values. As shown in Figure 1, the recommended average for a Technical Reserve is a temperature between 17,8°C (64,04 °F) and 21,9°C (71,42 °F) and relative humidity between 40,4% and 59%. For Belém, the average conservation temperature is between 28,91°C (84,04 °F) and 31,59°C (88,86 °F), with relative humidity between 50,59% and 61,21%, as established by Bianca Vicente (2016, pp. 43-48). This stage aims to determine whether new environmental control methodologies are needed or if the current one is effective**.**

3. Data variations: Variations in temperature and relative humidity were quantified by calculating the difference between the highest and lowest values in the dataset. This helps visualize the fluctuation levels during the analyzed period. Calculating these variations is crucial for identifying patterns and anomalies, such as seasonal changes or climate shifts. For example, unusual variations can indicate dry spells or heat waves.

[1] Technical Reserves are spaces where the collections that are not on display or under scientific investigation are safeguarded (Froner, 2008, p.3).

	Material(s)	Temperature	Relative Humidity	Reference
Organic materials	Acrylic/oil painting	16°C - 25°C	35% - 65%	Hartin; Baker, 2018
	Watercolor	10°C - 25°C (paper)	>65% - 75% <90% critic	Guild, 2018
	Paper	19°C - 23°C 20°C - 22°C	50 and 60% 45 and 60%	Mello; Santos, 2004, p. 8. Teixeira; Ghizoni, 2012, p. 41
	Photography	Avoid high temperatures	30 and 45%	Teixeira; Ghizoni, 2012, p. 45
	Vegetable fibers	> 30°C	40% - 65%	Mason, 2018 Dancause; Wagner; Vuori, 2018
	Animal fibers	< 35°C	> 65%	Dignard; Mason, 2018
	Wood	25°C - 30°C	>20%	Gonzaga, 2006
	Textiles / Fabrics	18 °C - 22°C	40 and 60%	Teixeira; Ghizoni, 2012, p. 55
Inorganic materials	Metals	-	35 and 55%	Froner, Souza, 2008, p. 6
	Rocks and Minerals	15 - 20°C	50% - 55%	Western Australian Museum, without date
	Glass	18°C - 21°C	<40%	Teixeira; Ghizoni, 2012, p. 65 Fahey; without date
	Ceramics / Porcelain	18°C - 21°C	65% - 75% 45% - 55%	Logan; Grant, 2018 Fahey; without date

Figure 1. Parameters used in environmental preservation and control according to the materials present in the cultural assets analyzed (Source: table prepared by the authors, 2023).

4. Inverse relationship between temperature and relative humidity: The association between data was analyzed to identify an inversely proportional relationship, where an increase in temperature increases the air's capacity to retain moisture, while lower temperatures make the air drier (Andrade & Cavicchioli, 2021, p.19). This dynamic is typical in the Northern region of Brazil, characterized by a hot and humid climate. Understanding this relationship is crucial for museum conservation, as measures to control one variable can inversely affect the other. For example, heating a room to reduce humidity can dry the air, potentially harming certain materials. Recognizing this inverse relationship helps in effectively controlling the environment for preservation purposes.

5. Consistency of temperature and humidity levels: The constancy of the data was analyzed using standard deviation to understand environmental variation. Standard deviation, a measure of dispersion, provides insight into the consistency of temperature and hu-

midity conditions. The outlier's method, based on the Interquartile Range (IQR), was also applied (Vinutha, Poornima, & Sagar, 2018, p. 514). Values more than two or three standard deviations from the average were considered outliers. The IQR, a measure of statistical dispersion, helps understand data variability around the median and identify unusually high or low values.

This approach enabled us to examine numerical temperature and humidity values while understanding the surrounding nuances and contexts. This provided a comprehensive view of environmental conditions and their interaction with contemporary art conservation. Based on the results and their comparison with relevant literature, we could outline well-founded and enriching discussions.

BACKGROUND

Established in 2002, the Casa das Onze Janelas museum in Belém do Pará, Brazil, has become a reference for the North region, promoting local and Brazilian art. It plays a crucial role in the local art scene, supporting research, education, conservation, and museological documentation (Mokarzel, 2013, p. 106).

Given the significance of this artistic-cultural heritage, preservation extends beyond safeguarding cultural values. It involves interpreting meanings, both physical and intangible, and examining culture and its economic aspects. Once society recognizes an object's value, its preservation becomes imperative, entrusted to institutions like archives, libraries, and museums (Carvalho, 1997, p. 1). Preventive Conservation and Environmental Control are fundamental to fulfilling the House's preservationist and communicational mission (Corrêa, 2003, p. 1). Before analyzing the collected data, pertinent factors such as Belém's climate, building behavior, storage space organization, collection characterization, degradation issues, and the monitoring system will be discussed.

We must first examine the climate and building before discussing the collection. Most of Brazil, including Belém in Pará, has a hot and humid climate. Over the past 100 years, Belém's climate has been characterized by consistently high temperatures, high humidity, and intense rainfall, especially from December to May, with no well-defined seasons (Bastos et al., 2002, p. 12). Data collected by the Belém automatic station (A201) - PA, operated by INMET, from July 19th to October 24th, indicates an average temperature of 28,55°C (83,39 °F) 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 (68 ºF) and 25ºC (77 ºF) and between 65% and 70% relative humidity (Souza, 2008, p.6).

Therefore, buildings that house heritage collections need to establish environmental control systems to adjust temperature and humidity according to its need and in a sustainable manner for the institutions. When standards are not met, institutions in humid tropics often use stringent environmental control systems like air conditioning and dehumidifiers. These systems face criticism due to their susceptibility to defects, shutdowns, and low sustainability linked to cost and maintenance (Maekawa & Toledo, 2001, p.1). This is the case with the MEP, which safeguards COJAN's art collection and faces management challenges.

Relative humidity affects preservation differently depending on the object type, impacting chemical reaction rates and altering physical properties like size, strength, and stiffness (Erhardt & Mecklenburg, 1994, p. 1). Belém has minimal temperature variation but consistently high humidity and significant rainfall, especially from December to May. These conditions challenge the maintenance of stable indoor environments essential for preserving collections. Persistent high humidity and temperature promote mold and mildew growth and accelerate material deterioration, necessitating robust environmental control systems in the museum.

To address these challenges, it is necessary to present the safeguard space. The MEP is located in the Palácio Lauro Sodré, a historic building opened in 1771 (Miranda et al., 2023, p. 222), in the Cidade Velha neighborhood, part of Belém's historic center, close to wooded areas (Maranhão & Britto, 2023, p. 7). The building follows 18th-century Portuguese colonial civil architecture, featuring thick solid walls and high or vaulted ceilings (Figueiredo et al., 2018, p.28). Marina Ribeiro notes that historical constructions act as filters between external and internal environments due to their structural features (2009, p. 403). However, the MEP exhibits unique behaviors, likely due to historic lime mortar on brick walls and floors, which have low thermal and hydraulic inertia. Most building materials have high capillarity, allowing moisture to penetrate walls and influence the internal microclimate (Gewehr, 2004, p. 36).

The thickness of the walls, up to 36 centimeters, plays a crucial role in thermal behavior, as noted by Ribeiro (2009, p. 408). This construction technique, aimed at durability, did not consider heat and humidity exchange. The porous materials facilitate external environmental influence, while the thick walls create inertia. Tem-

perature and humidity fluctuations can damage artworks through size alterations and biodegradation (Gühts & Carvalho, 2007, p. 32). High relative humidity softens hide glue, while low levels cause materials to shrink and stiffen, leading to fracture sensitivity (Erhardt & Mecklenburg, 1994, p. 3). Climate control for repurposed museum buildings requires a unique approach due to physical and structural constraints (Toledo, 2003). Belém's climate makes it impractical to rely solely on air conditioning and dehumidifiers, as high performance demands increase costs..

The MEP's Technical Reserve has a rectangular layout, with administrative rooms, storage rooms, exhibition rooms, and research laboratories. The monitored safeguard spaces are the Technical Reserve for Visual Arts (RT de Artes Visuais in Portuguese) and the Provisional Technical Reserve (RT Provisória in Portuguese), both located on the ground floor. The Visual Arts TR is divided into three rooms, with the central room as the main area. It was equipped to receive Casa's collection, with space optimized after the mezzanine's construction. The furniture includes closed and open shelves, map cabinets, and painting racks. There are eight windows: two in the left room, three windows and a door in the central area, and three windows and two doors in the right room. All windows are closed.

The Provisional TR serves as a workspace for Conservation and Restoration professionals. With the Visual Arts TR at full capacity, some collections were moved here, requiring adapted furniture like shelves (Figure 2e), map cabinets (Figure 2f), and scaffolding for larger items. This furniture is nearly full, 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 to allow airflow.

Control measures aim to minimize damage to collections and artworks, often without significant financial burden (Souza, 2008, p. 21). At MEP, the environmental control system uses air conditioning combined with dehumidifiers. The air conditioning equipment, installed over 10 years ago, experienced malfunctions during the first half of 2023 but returned to normal operation in July after successful corrective measures. In 2023, new dehumidifiers were installed in the collection storage rooms. This system is designed to operate daily, as shown in Figure 3.



Figure 2. 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 (Photographs: by the authors, 2023).

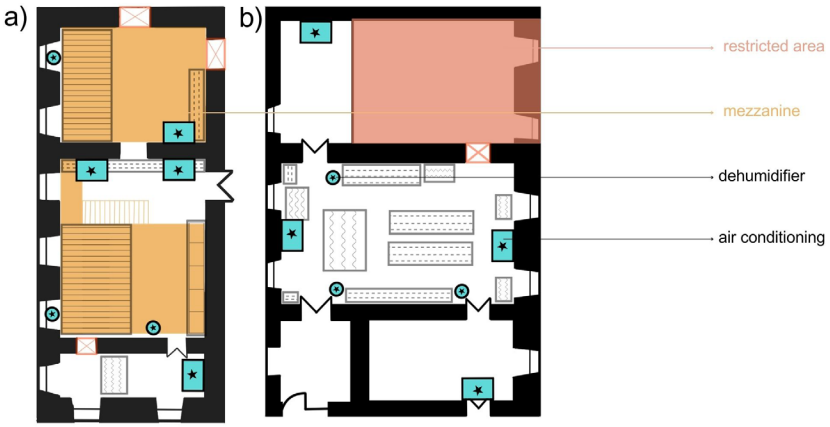


Figure 3. Illustrative drawing of the position of environmental control equipment in monitored spaces. *a)* Visual Arts Technical Reserve. *b)* Provisional Technical Reserve (Source: prepared by the authors, 2023).

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

Currently, monitoring involves sporadic checks with thermo-hygrometers that track temperature and humidity but lack data storage capabilities. Manual logging is challenging due to irregular work schedules, leading to gaps in data collection on weekends and holidays. Consistent data capture requires recording at least three times daily throughout the year, for the period it takes for the equipment to stabilize the values. This can be enhanced by integrating indoor and outdoor readings or using devices with automatic storage, reducing manual effort.

Establishing planning for environmental monitoring is crucial for designing control measures. 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 involves steps such as monitoring, characterization, and evaluation, resulting in a specific report for the environmental control plan (Souza, 2008, p. 7). These steps are presented in the results and discussions of this case study.

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 is relevant to the Visual Arts collection at MEP's RT, which features a diverse range of materials, sizes, and techniques, showcasing local and national artistic contributions. However, this diversity poses significant conservation challenges, especially in the Amazonian climate. To illustrate the diversity within Casa's collection, materials from three surveyed collections[2] were categorized as organic or 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, illuminated signs). This classification follows Teixeira and Ghizoni's recommendations (2012, p. 16).

Determining the optimal relative humidity for preserving artifacts is complex, as adjusting it might reduce damage in one aspect but increase it in another (Erhardt & Mecklenburg, 1994, p. 3). The collection has 213 pieces with organic materials and 839 with inorganic materials. Analysis confirms insights from the literature review, summarized in Figure 1, which highlights a gap in updated literature on conservation values suitable for different climates.

[2] The name of the collections are: FUNARTE, Fundo Z and Diário Contemporâneo de Fotografia.

According to Guimarães and Beck (2007, p. 31), higher temperatures accelerate degradation. They mention that at 25ºC (77 °F) and 70% relative humidity, the asset already shows signs of chemical degradation within 14 years. However, the diversity of materials in the Technical Reserve presents significant environmental control challenges. Ideally, each material type requires specific environmental conditions, but establishing multiple specialized reserves is impractical due to resource constraints. Thus, we use the general average of environmental conditions as an evaluation parameter to find pragmatic solutions.

For comparison purposes, the values established by Guimarães and Beck (2007, p. 31) and those presented in Figure 1 were considered. Therefore, a parameter was obtained for organic materials, where the ideal conditions include an average temperature that does not exceed 23,1ºC (73,58 °F) and not less than 18,6°C (65,48 °F), 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 (62,60 °F) and a maximum of around 20,7°C (69,26 °F), 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 (64,04 °F) and 21,9°C (71,42 °F), 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 specific characteristics that render the application of conventional conservation standards impractical. Most studies presented in the table do not take the Amazonian climate into account, highlighting the need for a conservation study focused on this unique environment. To establish parameters for the sustainable management and environmental control of technical reserves in Belém, insights from Bianca Vicente's 2016 case study on the environmental control of the Curt Nimuendajú Technical Reserve at the Museu Paraense Emílio Goeldi were adopted.

In this research, the author shows that between September and October 2014, the average temperature was 30,25ºC (86,45 °F), while the relative humidity was 55,90%, with variations of 1,34ºC (34,41 °F) and 5,31% respectively. The environmental control sys-

tem 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[3].

Thomson chose 55% RH as a middle ground, balancing an upper limit of 65-70% to avoid mold formation and a lower limit of 40-45% to prevent the deterioration of materials like wood and ivory. He stressed the importance of maintaining a consistent relative humidity, although he noted there was limited evidence regarding the exact stability required (Erhardt & Mecklenburg, 1994, p. 2). 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 (Figure 4a, 4c), cracking, loss of pictorial layer, presence and growth of microorganisms (Figure 4b).

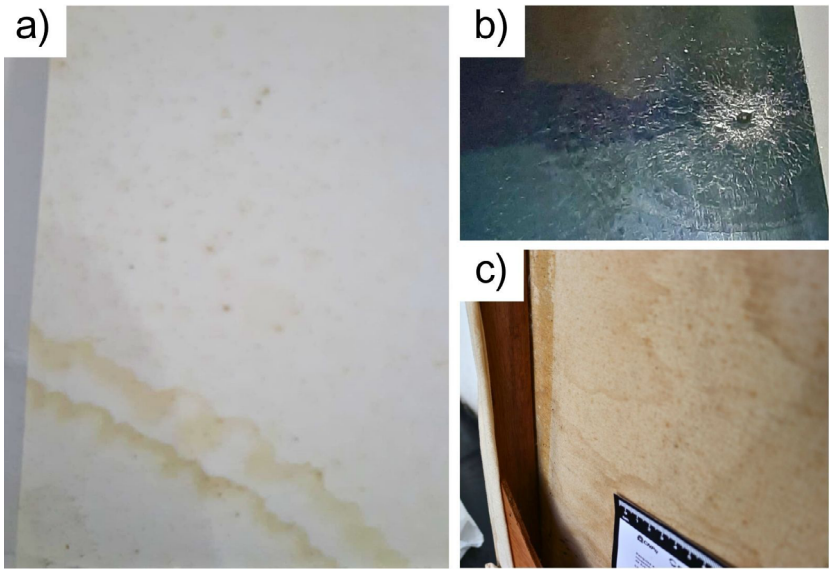


Figure 4. Compilation of pictures of the damaged artworks. *a)* Humidity spot. *b)* Growth of microorganisms. c) Humidity and dirt sports. (Photographs by the authors, 2023).

Although it cannot be said that the damage presented comes only 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 deteri-

[3] 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.

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oration 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

The frequency of environmental data collection is crucial for understanding its impact on preserved materials. Ideal monitoring depends on factors like collection type, museum layout, and regional climate, with continuous recording recommended to capture fluctuations in temperature and humidity (Michalski, 2007, p.14). These variations can significantly affect objects, highlighting the need for environmental control. While monitoring alone does not constitute control, it provides essential diagnostic data for preservation strategies (Souza, 2008, p.7). Automatic and manual tools, such as dataloggers and thermo-hygrometers, enhance data accuracy, with longer recording periods offering deeper insights.

In our analysis, it is crucial to consider the regional climate's impact on the building's internal conditions. The external climate in Belém, characterized by high temperatures and humidity levels, significantly influences the indoor environment of COJAN. Thick walls and traditional construction techniques offer some buffering against external climatic variations, but they also present challenges in maintaining stable internal conditions. The combination of high capillarity materials and considerable wall thickness results in a dynamic exchange with the external environment, affecting temperature and humidity levels inside the building.

Additionally, the technical specifications and performance of the air conditioning units play a vital role in controlling the internal climate. These units experienced malfunctions throughout the first half of 2023, likely because they were over a decade old, which contributed to fluctuations in temperature and humidity within the monitored spaces. The recent installation of new dehumidifiers aims to address these challenges, but continuous monitoring and regular maintenance are essential to ensure optimal performance. Considering these factors, our preliminary analysis highlights the importance of understanding both the regional climate and the building's structural and mechanical systems in interpreting the internal environmental conditions.

The quantitative data highlights the significant impact of the regional climate on the internal conditions of COJAN. External climate

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data collected by the Belém automatic station (A201) operated by INMET between July 19 and October 24 indicate an average temperature of 28,55°C (83,39 °F) and an average relative humidity of 77%. These external conditions sharply contrast with the recommended conservation parameters of 20°C (68 °F) to 25°C (77 °F) for temperature and 65% to 70% for relative humidity. Internally, the Provisional TR recorded an average temperature of 23,72°C (74,70 °F) and relative humidity of 69,37%, with 79% of temperature readings and 98% of humidity readings falling outside the ideal ranges.

Similarly, the Visual Arts TR showed an average temperature of 24,33°C (75,79 °F) and a relative humidity of 70,92%, with 100% of humidity and 90% of temperature measurements exceeding the recommended limits. The malfunctioning air conditioning systems, particularly in early September, further exacerbated these conditions, contributing to temperature variations of up to 9,4°C (48,92 °F) and humidity fluctuations of 27,4%. These data stress the profound influence of the external climate and the hygroscopicity of the constructive materials of the building. The effective air conditioning systems assume a critical role in maintaining stable internal environmental conditions essential for the preservation of the collection.

The initial data analyzed are from the Provisional TR and its Microenvironment. In the first period (Figure 5a), the HT-91 datalogger recorded data for the macroenvironment on a shelf. In the second period (Figure 5b), the HT-91 equipment was relocated to another shelf, closer to the Provisional TR main entrance. The HT-900 datalogger was allocated within the map cabinet on September 6.

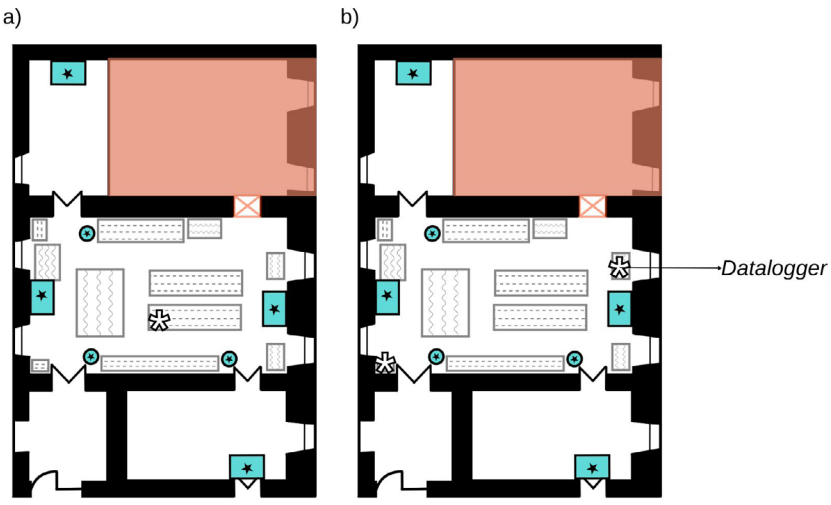


Figure 5. Floor plan illustrating the position of environmental control and monitoring equipment in the Provisional Technical Reserve. *a)* Location during the first period. *b)* Location during the second period (Source: prepared by the authors, 2023).

The enclosed storage (map cabinet) exhibited a notable buffering effect on temperature and relative humidity, highlighting the importance of furniture design in environmental control. The map cabinet, made of solid metal with a sealed design, helps to mitigate fluctuations in external environmental conditions. This buffering effect was evident in the more stable conditions recorded inside the cabinet, with an average temperature of 24,10°C (75,38 °F) and relative humidity of 63,10%. Despite the overall high humidity in the room, the cabinet provided a relatively stable microenvironment with a temperature variation of 8,4°C (47,12 °F) and humidity variation of 20,80%.

The construction materials and design of the cabinet contribute to this stability by reducing the impact of sudden changes in the external environment, thus offering a more controlled setting for the stored items. Furthermore, the collection stored in this furniture consists entirely of paper works. Variations in temperature and humidity may be linked to this material's ability to absorb water, but due to the material and design of the map cabinet, it is suggested that this occurs during handling, when drawers are possibly left open for a certain period. This possibility hinders the stability of the map cabinet's microclimate.

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 6. From July 7 to October 24, 2339 measurements were recorded in the Provisional Technical Reserve (Provisional RT). The analysis for the Provisional RT environment was conducted based on the Figure 6 A and B graph and the collected data, focusing on the average as an indicator of trend and pattern.

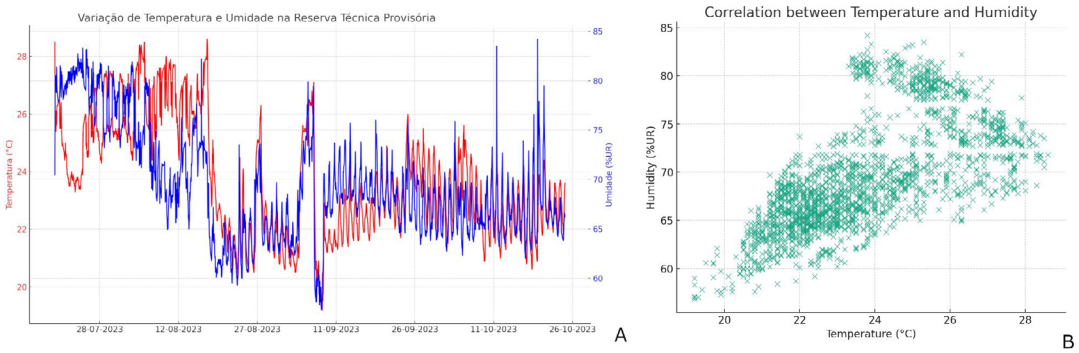


Figure 6. Data collected in the Provisional Technical Reserve *a)* Variation in temperature (in red) and humidity (in blue) over the recorded period. *b)* Scatter plot with correlation between temperature and humidity. (Source: prepared by the authors, 2024).

The average temperature recorded was 23,72°C (74,70 °F), a value that exceeds the ideal upper limit of 21,9°C (71,42 °F), 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 Figure 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, p. 43), 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, demonstrating that the room is consistently colder and more humid than the model proposed by the author. Furthermore, a variation of 9,4°C (48,92 °F) 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 since an inverse relationship is generally expected.

Regarding the consistency of temperature and humidity levels, the interquartile range (IQR) was 3,1°C (37,58 °F) for temperature and 7,8% for humidity, with standard deviations of 1,99°C (35,58 °F) 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 (63,41 °F) and higher than 29,85°C (85,73 °F) for temperature, and lower than 53,6% and higher than 84,8% for humidity.

Within the Provisional TR, 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.

The analysis of this microenvironment was conducted based on Figure 7 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 (75,38 °F) for temperature and 63,10% for relative humi-

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dity. 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.

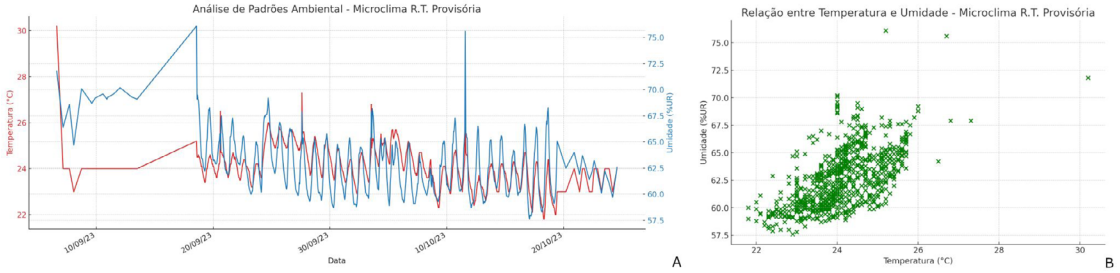


Figure 7. Microenvironment data from the Provisional Technical Reserve. *a)* the red line represents the temperature (in degrees Celsius). The blue line represents the relative humidity of the air (in %RH). *b)* Correlation between temperature and humidity. (Source: prepared by authors, 2024).

When comparing Figure 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, p. 43) 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 (47,12 °F) in temperature and 20,80% in humidity, this indicates greater relative stability compared to the macroenvironment of the Provisional TR. 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 1°C (33,8 °F) for temperature and 4,4% for humidity, with

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standard deviations of 0,86ºC (33,55 ºF) 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 (Figure 8).

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	-

Figure 8. 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 of September. 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 RT 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 19th to September 9th, and the subsequent phase extended from September 9th to December 1st, as illustrated in Figure 9.

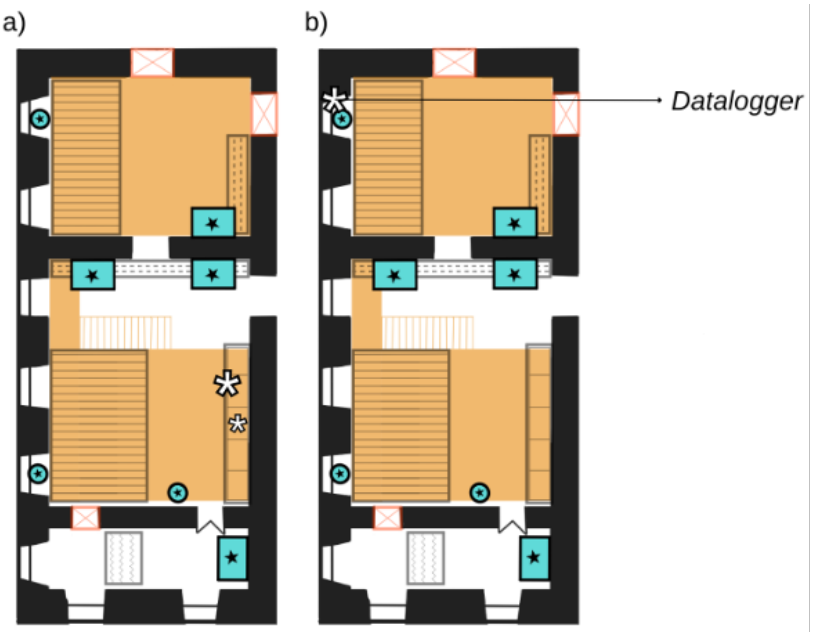


Figure 9. Floor plan illustrating the position of environmental control and monitoring equipment in the Visual Arts Technical Reserve. *a)* Location during the first period. *b)* Location during the second period (Source: prepared by the authors, 2023).

In the first period (Figure 9a), 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 9b), 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 RT (Figure 10).

The analysis of this environment was conducted based on Figure 10 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 (75,80 °F), 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.

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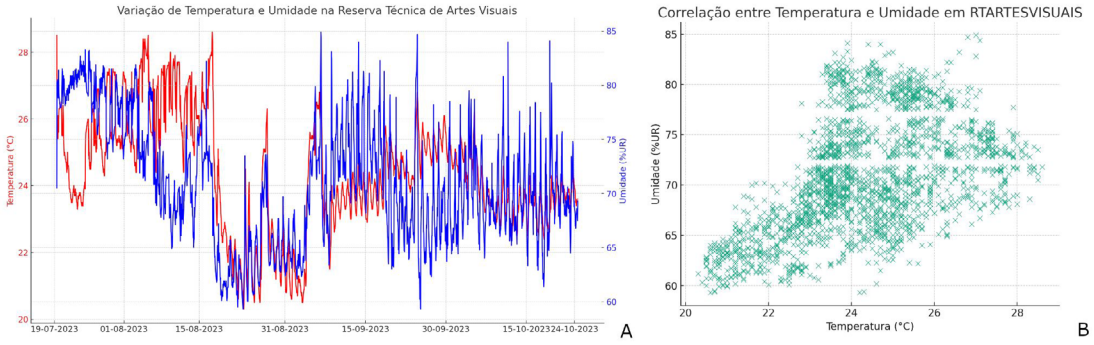


Figure 10. Data from the Visual Arts Technical Reserve. *a)* Temperature (in red on the left) shows how the temperature varied over the recorded period. Humidity (in blue on the right) shows the variation in humidity over the same period. *b)* Correlation between temperature and humidity (Graphic: prepared by the authors, 2023).

When analyzing the data in Figure 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 tendency 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, p.43), it was found that all temperature and humidity measurements were also outside the standard. This indicates that the Visual Arts RT is consistently cooler and wetter than the model proposed for Belém, stressing the need for adjustments in temperature and humidity control.

The observed variation was 8,3°C (46,94 °F) 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 2,2°C (35,96 °F) for temperature and 8,35% for humidity, with standard deviations of 1,73°C (35,11 °F) and 5,63%, respectively, reflecting a moderate variation. Within the Visual Arts RT, microenvironment data collection took place inside a closet. In this confined space, 1184 measurements were documented from July 19th to September 6th, 2023.

The analysis of this microenvironment was conducted based on Figure 11 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 (79 °F), 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 Figure 1, 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.

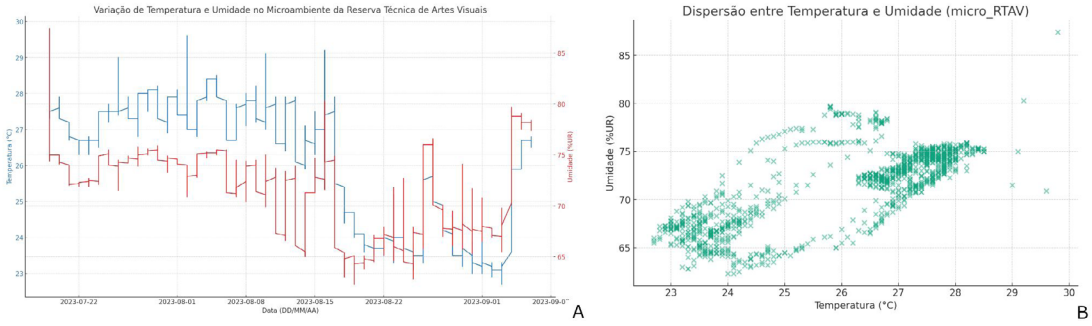


Figure 11. Microenvironment data from the Visual Arts Technical Reserve *A)* Temperature (in red on the left) shows how the temperature varied over the recorded period. Humidity (in blue on the right) shows the variation in humidity over the same period. *B)* Correlation between temperature and humidity (Graphic: prepared by the authors, 2023).

Compared to the standards established by Vicente (2016, p.43) 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 7,1°C (44,78 °F) 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 (37,99 °F) for temperature and 6,7% for humidity, with standard deviations of 1,73°C (35,11 °F) 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

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Arts RT and the Provisional TR 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

This study investigated the materials in the Visual Arts collection at Casa das Onze Janelas and the results of environmental monitoring, revealing challenges in maintaining temperature and humidity due to equipment and material complexity. Excessive heat, high humidity, and constant fluctuations contribute to art degradation. The study also highlights the scarcity of specific conservation references for tropical climates, particularly in northern Brazil.

It is evident, there is a valuable body of scientific knowledge on Preventive Conservation in Brazil, but most studies are limited to the southern and southeastern regions. 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 TR, or its microenvironments, adequate.

Understanding these climatic characteristics is essential for interpreting internal environmental data and developing effective conservation strategies. Considering these factors, our preliminary analysis highlights the importance of understanding both the regional climate and the building's structural and mechanical systems in interpreting internal environmental conditions. These technical details are crucial for accurately interpreting the data and underscore the importance of appropriate storage solutions in conservation efforts.

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 the climatic conditions in Belém are characterized by high temperature and humidity. It defies conventional conservation standards and must be thoroughly studied to implement environmental control systems that meet the needs of the collections and safeguarding institutions. 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 that consider the specific conditions of the northern region of Brazil are suggested. 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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