GC Revista Nacional de Gerenciamento de Cidades
National Journal of City Management

ISSN 2318-8472, v. 13, n. 89, 2025

Degrading action of floods: Damage analysis in historic buildings of the Bairro do Recife (PE)

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Submissão: 19/11/2024
Aceite: 31/05/2025
SANTOS, Júlia Oliveira dos; SILVA, Joyce Ketlly Soares da; ROCHA, Eudes de Arimatéa; VALADARES, Pedro Henrique Cabral; SOARES, Willames de Albuquerque. Ação degradante das inundações: Análise de danos em edifícios históricos do Bairro do Recife (PE). **Revista Nacional de Gerenciamento de Cidades**, *[S. l.]*, v. 13, n. 89, 2025. DOI: 10.17271/23188472138920256163. Disponível em: https://publicacoes.amigosdanatureza.org.br/index.php/gerenciamento_de_cidades/article/view/6163.

GC Revista Nacional de Gerenciamento de Cidades
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ISSN 2318-8472, v. 13, n. 89, 2025

Ação degradante das inundações: Análise de danos em edifícios históricos do Bairro do Recife (PE)

RESUMO

Objetivo – Analisar a relação entre eventos ambientais e a deterioração de materiais históricos pela ação da umidade no Bairro do Recife (PE), propondo estratégias de preservação adaptativa.

Metodologia – Estudo qualitativo baseado em análise documental, revisão bibliográfica e levantamento de campo em seis edificações históricas.

Originalidade/relevância – Investiga a vulnerabilidade climática do patrimônio cultural edificado em áreas urbanas consolidadas, tema ainda pouco explorado.

Resultados – Identificou alta suscetibilidade de materiais tradicionais locais à umidade e salinidade, considerando os riscos iminentes pela localização geográfica e aumento do nível do mar, demandando intervenções específicas de preservação e manutenção das edificações.

Contribuições teóricas/metodológicas – Propõe diretrizes sintetizadas e pontuais para ações adaptativas sustentáveis, compatíveis com os métodos construtivos históricos, considerando autenticidade das edificações.

Contribuições sociais e ambientais – Incentiva parcerias públicas para instrução sobre preservação do patrimônio edificado, especialmente em edificações não-tombadas, promovendo a durabilidade da identidade cultural e sustentabilidade ambiental.

PALAVRAS-CHAVE: Mudanças climáticas. Umidade. Patrimônio histórico.

Degrading action of floods: Damage analysis in historic buildings of the Bairro do Recife (PE)

ABSTRACT

Objective – Analyze the relationship between environmental events and the deterioration of historical materials due to moisture in the Bairro do Recife (PE), proposing adaptive preservation strategies.

Methodology – Qualitative study based on documentary analysis, bibliographic review, and field surveys in six historical buildings.

Originality/Relevance – Investigates the climate vulnerability of cultural heritage in consolidated urban areas, a topic still scarcely explored.

Results – Identified a high susceptibility of local traditional materials to moisture and salinity, considering imminent risks due to geographic location and sea level rise, demanding specific preservation and maintenance interventions.

Theoretical/Methodological Contributions – Proposes synthesized and targeted guidelines for sustainable adaptive actions, compatible with historical construction methods, preserving building authenticity.

Social and Environmental Contributions – Encourages public partnerships to promote awareness regarding the preservation of built heritage, especially in non-listed buildings, strengthening cultural identity and environmental sustainability.

KEYWORDS: Climate change. Moisture. Cultural heritage.

GC Revista Nacional de Gerenciamento de Cidades
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Acción Degradante de las Inundaciones: Análisis de Daños en Edificios Históricos del Bairro do Recife (PE)

RESUMEN

Objetivo – Analizar la relación entre los eventos ambientales y la deterioración de materiales históricos debido a la humedad en el Barrio de Recife (PE), proponiendo estrategias de preservación adaptativa.

Metodología – Estudio cualitativo basado en análisis documental, revisión bibliográfica y levantamiento de campo en seis edificaciones históricas.

Originalidad/Relevancia – Investiga la vulnerabilidad climática del patrimonio cultural edificado en áreas urbanas consolidadas, un tema aún poco explorado.

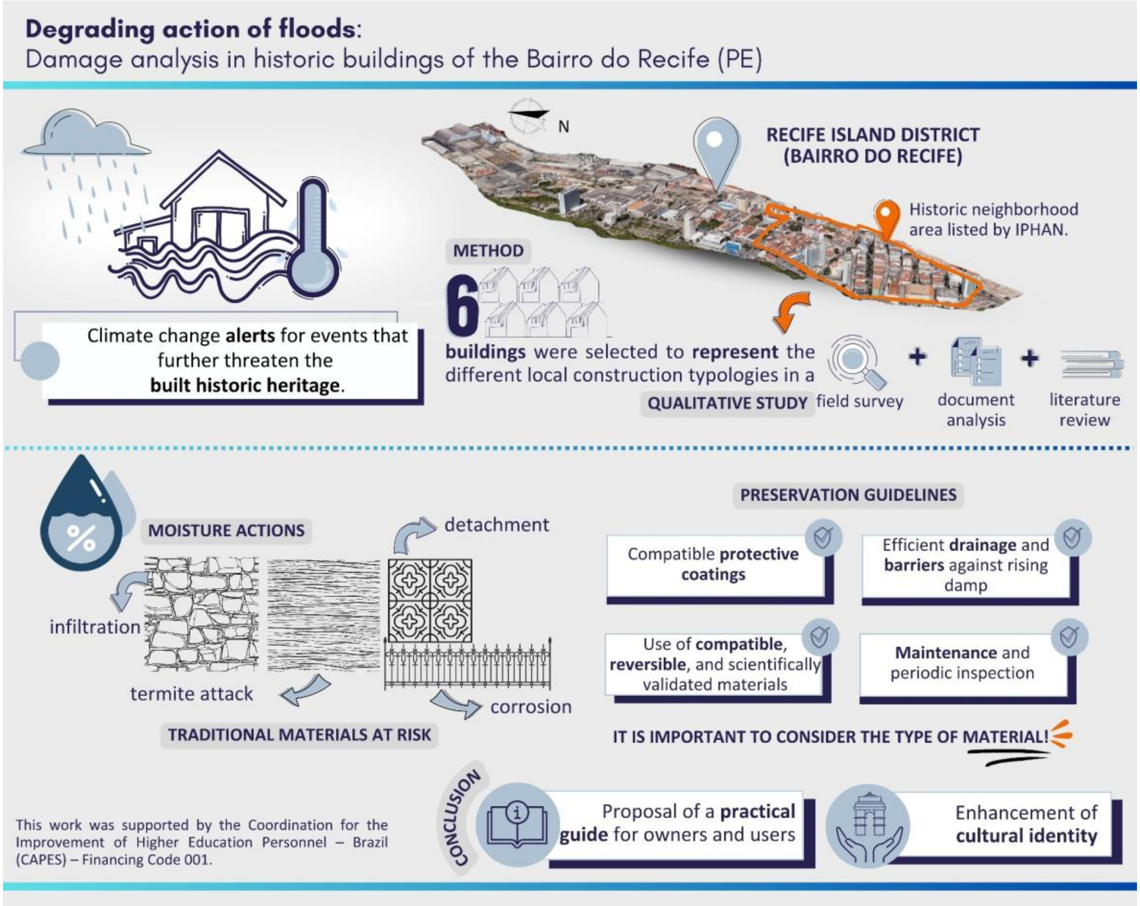
Resultados - Identificó una alta susceptibilidad de los materiales tradicionales locales a la humedad y la salinidad, considerando los riesgos inminentes por la ubicación geográfica y el aumento del nivel del mar, lo que demanda intervenciones específicas de preservación y mantenimiento.

Contribuciones Teóricas/Metodológicas – Propone directrices sintetizadas y puntuales para acciones adaptativas sostenibles, compatibles con los métodos constructivos históricos, preservando la autenticidad de las edificaciones.

Contribuciones Sociales y Ambientales – Fomenta alianzas públicas para promover la instrucción sobre la preservación del patrimonio edificado, especialmente en edificaciones no catalogadas, fortaleciendo la identidad cultural y la sostenibilidad ambiental.

PALABRAS CLAVE: Cambio climático. Humedad. Patrimonio cultural.

GRAPHIC SUMMARY



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1 INTRODUCTION

Floods occur when water from bodies of water overflow their limits, reaching areas that are normally dry. These events are often associated with heavy rainfall and inadequate drainage, resulting from factors such as disorderly urbanization, which leads to soil impermeability and the suppression of natural areas, such as riparian forests (Castro; Alvim, 2024).

In this context, climate change aggravates the problem by intensifying periods of heavy rainfall, especially in more vulnerable cities such as Recife, which according to Melo *et al.* (2021), faces serious socio-environmental consequences due to the lack of adequate infrastructure and the exclusion of part of the population from urban development.

Floods, intensified by climate change, have caused significant damage in urban areas, compromising infrastructure, public health, and social well-being. A recent example occurred in the state of Rio Grande do Sul, where the overflow of the Guaíba River in 2024 resulted in losses exceeding R$ 10 billion and forced the displacement of over 200,000 people (Agência Brasil). Such situations highlight the vulnerability of Brazilian cities to extreme events, with significant material and psychosocial impacts, while also revealing the weaknesses of urban infrastructure that intensify environmental risks (Angelakis *et al.*, 2023; Schueler; Carvalho, 2024).

However, an aspect often overlooked in studies on floods is the impact on built cultural heritage, as noted by Anderson (2023). In Rio Grande do Sul, historic areas of Pelotas and Porto Alegre, such as the Rio Grande do Sul Art Museum (MARGS), suffered significant damage and the National Institute of Historic and Artistic Heritage (IPHAN) is still assessing the extent of the damage caused by the floods to listed buildings.

This scenario inspires concern on the part of researchers and institutions, not only with the aim of preserving lives, but also of reducing losses, including those of a real estate and heritage nature. The United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) released a report in 2021 indicating that Recife ranks 16th among the cities most threatened by climate change in the world.

The IPCC points out that, in addition to geomorphology and low altitude, factors such as inadequate waste disposal, overpopulation, insufficient drainage, and buildings close to the sea and rivers increase Recife's vulnerability to climate change, resulting in frequent flooding. In this scenario, the city's historic buildings deteriorate more quickly, with less chance of recovery. In this context, international studies emphasize the importance of assessing the vulnerability of historic buildings based on the susceptibility of their construction materials, taking into account their elevation and exposure to flood events (Figueiredo; Romão; Paupério, 2021).

2 OBJECTIVES

To analyze the impact of climate change on the built heritage sites located in the listed polygon of Bairro do Recife, with the aim of safeguarding these buildings. In addition, the research presents the vulnerability of the built heritage and provides guidelines for preventive interventions against damage caused by the presence of humidity and possible flooding,

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considering the climate scenario that points to an increase in the frequency and intensity of these events.

3 THEORETICAL FRAMEWORK

3.1 Recife, Amphibious City: Historical overview and risks

The city of Recife is the capital of the state of Pernambuco, located on the coast, with, according to the IBGE Census (2022), a population of almost 1.5 million inhabitants in an area of 218.435 km², guaranteeing the position of 9th most populous city in Brazil. Also, according to the IBGE Census (2022), the city heads a metropolitan region formed by 13 other municipalities, totaling a population of almost 3.8 million inhabitants, marking the position of 7th most populous urban agglomeration in the country.

Founded in 1537 as a port town, Recife is the oldest capital in Brazil and was one of the most prosperous regions during the colonial period (Menezes, 1988). The city stands out for its important medical center, high Human Development Index (HDI), strong economy and one of the most relevant cultural scenes in the country.

Recife is a municipality of modest territorial dimensions, resulting in a high population density and a real estate market focused on high-rise residential buildings to compensate for the lack of land. However, this territorial limitation dates to the city's early days, which began as a village in the 17th century, on the outskirts of the port, which existed due to Olinda, then the capital of Pernambuco, whose coast was not suitable for port activities. The village and its port were located at the southern end of a narrow isthmus that began in Olinda, protected by an extensive line of coral reefs. By 1906, Recife had consolidated itself as a city, expanding from this initial nucleus of a few residences, warehouses, commercial points and a small church (Menezes, 1988).

The success of sugar production transformed the port of Recife into one of the busiest in the colony, attracting people from various regions. This led to the construction of increasingly taller, semi-detached houses with up to six floors. With the constant population growth, the rulers adopted land reclamation as a solution to expand the territory, a common practice given the limitations of the narrow and insufficient isthmus. The continental area also offered little possibility of expansion due to the extensive floodplains, which were frequently flooded by the rivers (Menezes, 1988).

Between 1630 and 1654, the Dutch West India Company dominated the Northeast, with Recife as its headquarters. The "Dutch" occupied the Island of Antonio Vaz, carrying out land reclamation, building canals, fortifications and palaces. After the Portuguese-Brazilian reoccupation, the occupation of the isthmus and the island was expanded, and from the 18th century onwards, the continental stretch began to be occupied. The landfill works continued until the mid-20th century, covering the entire municipality, including the isthmus (Batista Filho, 2022) — the origin of the city and today called Bairro do Recife —, resulting in a flat relief, close to sea level, cut through by rivers and canals that form a large estuary.

Bairro do Recife (Figure 1), popularly called "Old Recife", is one of the main examples

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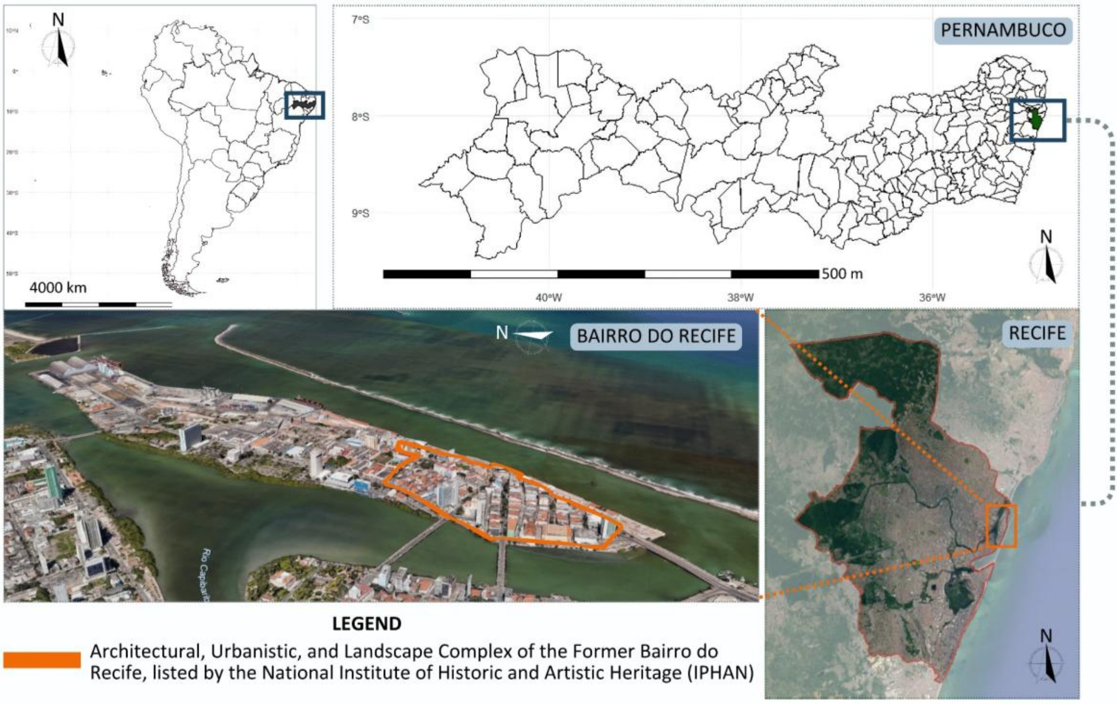
of preservation of the history and urban architecture of Pernambuco. Housing an architectural complex of great historical and cultural value, this area was listed by the National Institute of Historical and Artistic Heritage (IPHAN) and the State Council for the Preservation of Cultural Heritage (CEPPC) of Pernambuco, forming what is known as a listed polygon. This perimeter includes several buildings, streets and squares of significant value, which portray the urban development of the city and still preserve the historical identity of Recife.

Figure 1 – Location of the study area: Bairro do Recife, Recife (PE)



Source: Authors, adapted via R 4.3.3 software and Google Earth (2024).

However, this architectural and cultural wealth also faces significant challenges to its preservation. The city's geomorphological configuration, combined with the influence of the sea, rivers and rainfall, in addition to historical planning problems, exposes the city to increasing risks due to climate change. Since the 17th century, Recife has been dealing with floods aggravated by urban expansion. The Tapacurá Dam was built in 1973 with the purpose of mitigating such impacts; however, in 1975, a flood affected 80% of Recife's population and 25 municipalities within the Capibaribe River basin. In May 2022, the city once again experienced intense rainfall, causing landslides and resulting in a higher number of casualties than in 1975 (Carvalho, 2024).

With the worsening of such events, master plans and municipal land-use regulations in the city have progressively adopted guidelines aimed at mitigating the effects of unregulated urban growth. Soares *et al.* (2023) highlight that green infrastructure techniques—such as rain gardens and green roofs—have been increasingly implemented, with the latter becoming mandatory for new constructions since 2015.

Complementing these strategies is the role of Permanent Preservation Areas (APPs), located in environmentally sensitive zones such as riverbanks and floodplains. Strategically designed to preserve water resources, biodiversity, and soil stability, these areas function as

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natural buffers against floods and landslides. In Recife, where urban occupation exacerbates the effects of rainfall, APPs are essential for environmental conservation and the protection of historical and cultural sectors (Bezerra; Carmo, 2022).

3.2 Degrading action of humidity in buildings

Among the events predicted for the future of climate change, Guedes and Silva (2020) highlight for Recife the alternation between periods of extreme rain and prolonged droughts, in addition to the already observed heat waves. This scenario aggravates the natural process of deterioration of centuries-old buildings, especially in view of the possible exposure to severe flooding. Furthermore, Silva Junior (2020) points out that the average atmospheric humidity of the city, currently around 80%, is already impacting historical materials, intensifying degradation through chemical and biological mechanisms.

Blavier *et al*. (2023) summarize that high relative humidity (RH) levels in the air can facilitate the leaching and corrosion of metals and glass, and the biodegradation of stones and other hygroscopic materials, whose susceptibility to degradation depends on their physical properties and resistance to water exposure (Figueiredo; Romão; Paupério, 2021).

Among these materials, wood also suffers from continuous and wide daily fluctuations in relative humidity, causing internal stresses that, over time, cause cracks and ruptures in the material. Also, the variation in RH is responsible for condensation and evaporation cycles on the surface of materials, favoring the transport, crystallization and accumulation of salts in stone materials (Aste, *et al*., 2019). Despite its mechanical resistance, wood can become vulnerable when exposed to variations in saturation, which promotes mold growth and termite attacks, especially in conditions of low sunlight exposure and high humidity.

In Recife, the water table reaches levels very close to the surface in several areas, contributing to frequently saturated soils, making rising damp a constant problem in buildings. In the Bairro do Recife, this situation is aggravated by high tide, when the water table rises to the surface through drainage elements, even in the absence of rainfall.

Excessively wet soil can cause structural damage, especially in old buildings with foundations made of porous stone materials. In cases of soil expansion, intense mechanical movements can even lead to structural collapse. Futhermore, the constant presence of water at the base of buildings results in rising damp, one of the greatest preservation challenges (Franzoni, 2014), compromising the integrity of the materials, the health of residents and the performance of the building.

Franzoni (2014) e Petronijević, A. M.; Petronijević, P. (2022) also emphasize that moisture-laden materials can promote salt transportation and crystallization (efflorescence), facilitate biological attacks (such as fungi and vegetation), and cause physical damage (such as cracks that allow widespread infiltration) and other chemical deterioration in polluted environments. Moreover, when combined with wind action, moisture contributes to erosion and alveolization of materials, leading to the detachment of ceramic and mortar coatings.

Recent studies indicate that render detachment may be associated with stresses induced by thermal and moisture variations, resulting in blistering and visible separation of the surface coating (Drdácký *et al.,* 2024). This process is exacerbated by the cyclic shrinkage caused by successive wetting and drying, especially in materials with high hygroscopicity, which favors the progressive detachment of finishing layers.

Considering a scenario in which windstorms and cyclones are increasingly causing destruction around the world, another effect that contributes to the accumulation of water in the structure of buildings is directed rain. Dukhan; Sushama (2021) explain that the phenomenon is caused by the amount of rain that passes through vertical planes driven by the winds, and in addition to contributing to the presence of moisture in structures, it transports polluting particles that cause surface dirt in facade coating materials.

Vidal; Vicente; Silva (2019) highlight that, in coastal areas, the presence of atmospheric chlorides, combined with high relative humidity (RH) and temperature, rapidly deteriorates highly hygroscopic masonry, increasing the risk of corrosion. In addition, pollution significantly contributes to soiling, with carbonaceous particles darkening lime-based mortars and stone surfaces, while also promoting corrosion of exposed reinforced concrete structures. Blavier *et al.* (2023) add that high pollution levels also alter water pH, exacerbating carbonate dissolution, metal corrosion, and biological colonization, thus intensifying the darkening of construction materials.

Direct exposure to atmospheric salinity in marine areas accelerates the degradation of even sealants applied to increase the durability of materials such as glass panels, weakening joints and compromising the integrity of the system over time (Mariggiò, 2019). Salinity also induces corrosion, potentially causing stains, loss of transparency, and microcracks in the material.

These phenomena underscore the challenge of preserving historical materials while maintaining authenticity. The constant interaction between the city's peculiar geography, the climate changes already perceived and urban dynamics results in a urgent need to work on specific actions aimed at existing forecasts, especially given the evolution of studies aligned between building pathology and advances in knowledge about the technical behavior of historical materials.

4 MATERIALS AND METHODS

The research uses as technical support the studies carried out by Montezuma, *et al.,* (2022) for the study "Recife Exchanges – Amsterdam, Holland, Netherlands: International exchange for reinvention of the city", where scenarios for future flooding in Recife were projected, based on climate change and the progressive rise in sea level. The aforementioned authors were concerned with comprehensive solutions on an urban scale aiming at a catastrophic scenario in the city, and among the different strategies presented by the program, it was proposed that the historic center be protected by containment mechanisms, such as dikes and waterproof walls to safeguard heritage areas.

However, the analysis serves as a basis for defining specific interventions that can mitigate damage to materials in historic buildings, prolonging their integrity in the face of gradual consequences in the climate scenario. Using a qualitative approach, the research explores and describes preventive strategies applied to a representative case study. After conducting bibliographic and documentary research on the history and risks to which the city of Recife is

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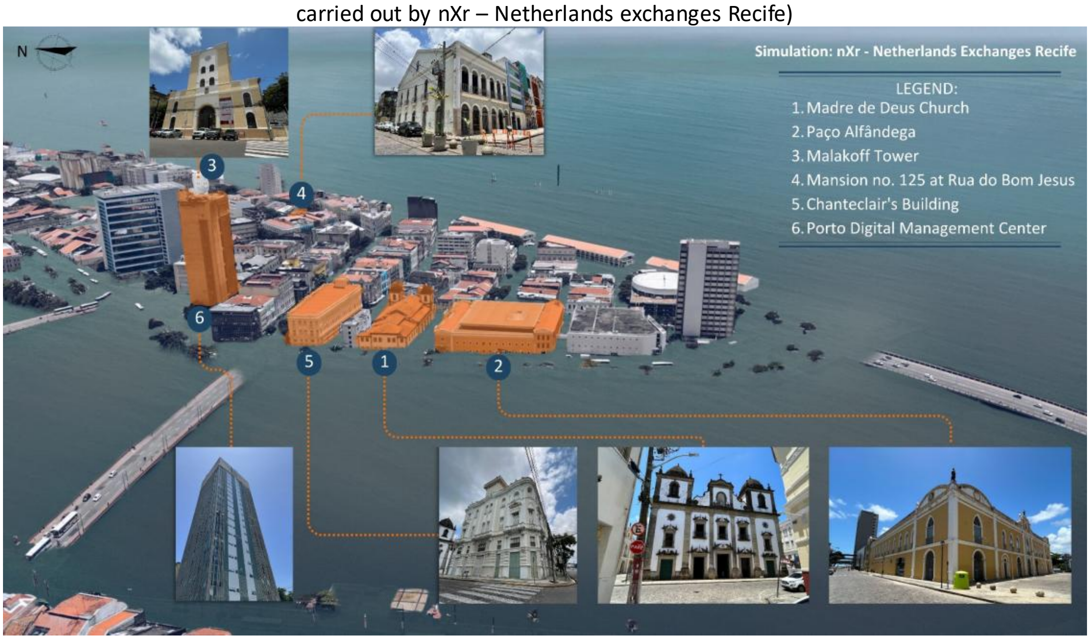
exposed, a debate was raised on the possible deterioration to which historic materials are susceptible due to the action of humidity – whether due to precipitation or periodic flooding.

For the results, the neighborhood of Recife was adopted as the field of study, focusing on the polygon of the Architectural, Urbanistic and Landscape Complex of the Former Bairro do Recife, listed by the National Institute of Historical and Artistic Heritage (IPHAN)[1]. Six buildings were selected for their historical relevance and architectural versatility, considering the diversity of local cladding materials, as shown in Figure 2.

Figure 2 – Location of the historic buildings selected for study (simulation of possible flooding in the Bairro do Recife carried out by nXr – Netherlands exchanges Recife)



Source: Recife Exchanges – Amsterdam, Holland, Netherlands: International exchange for reinvention of the city (2021) adapted by authors (2024). Original image available at: https://recifeexchanges.com/.

As part of the case study, technical visits were carried out to survey the cladding materials applied throughout the evolution of construction technologies in the city. Simultaneously, a literature review identified recent interventions in these buildings, as well as the materials used, especially when not visible.

Photographs of the case studies were taken using the iPhone 13's dual camera system (wide-angle and ultra-wide angle) with 12MP, with a maximum viewing angle of 120°. The materials were listed and presented on an information board, simplifying the information for the next stage of results: the presentation of preservation guidelines and strategies to extend the useful life of the materials and, consequently, of the buildings. The discussion will be based on an in-depth analysis of an updated bibliographic reference, based on proven applications and experiments.

5 RESULTS

[1] Archaeological, Ethnographic and Landscape Inventory Book under no. 119 and in the Fine Arts Inventory Book under no. 614, both dated December 15, 1998.

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5.1 Discussion on vulnerable historically relevant buildings

Since the city's territory originated from a floodplain, which was frequently flooded, and the expansion of the soil is the result of successive landfills, it is not surprising that the water table is quite high (Batista Filho, 2022), whose proximity to the surface increases the rise of humidity in buildings. Thus, humidity is recognized as one of the main agents of deterioration in buildings, especially those of historical significance, as the most common construction materials in the area under study are characterized by hygroscopic properties. As a result, these structures are especially susceptible to anomalies intensified by flood events, which are recurrent in the city's urban context.

The analysis highlights how humidity and the predictability of events such as floods and inundations directly affect the preservation of Recife's historic built heritage, requiring appropriate interventions to ensure their conservation. These buildings, marked by their historical and architectural values, were built with traditional materials, which today reveal vulnerabilities in the face of local environmental conditions. Below, Table 1 presents the selected representative case studies in this research below, they reflect the historical trajectory of the city and form part of its recognized architectural heritage:

Table 1 – General specifications of the historical buildings in the case study

Building	Year of construction	Current type of use	External cladding materials
1. Madre de Deus Church	1706	Religious temple	Stonework covered with fake stone mortar; mixed masonry covered with lime-based mortar and paint; carved stone ornaments and stucco mortar; wooden frames and iron railings
2. Paço Alfândega	1732	Commercial and corporate space	Stone structure coated with fake stone mortar (lime, sand and stone dust); masonry coated with lime-based mortar and paint; iron railings, and wood and glass window frames
3. Malakoff Tower	1855	Observatory, workshop and cultural exhibition space	Mixed masonry in solid bricks and stone, coated with lime-based mortar and paint; wood window frames and iron railings
4. Mansion no. 125, Rua do Bom Jesus	1871	Gallery and coworking and events space	Marble columns and solid brick masonry coated with lime-based mortar and paint, and tiles; decorative elements in lime mortar; wooden frames and wrought iron railings
5. Chanteclair building	1910's	Stage of architectural exhibitions in 2022 and 2023, but currently closed	Solid brick block masonry coated with lime-based mortar and paint; wooden frames and cast iron railings; stucco ornaments
6. Porto Digital Management Center	1969	Science and Technology Institution and Social Organization (OS) - Government of the State of Pernambuco and City of Recife.	Exposed reinforced concrete, ceramic tiles, metal (steel and aluminum) and glass

Source: Authors (2024).

The Madre de Deus Church, built in 1706 by the Congregation of the Oratory of Saint Philip Neri of Pernambuco, is an important religious landmark in Recife. With the growth of the Order, the Oratorian Convent was built in 1732. After conflicts with the imperial government due

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to participation in the Confederation of Ecuador, the Oratorians were extinguished in Brazil, and the church began to be administered by religious brotherhoods, while the convent was ceded to the Santa Casa de Misericórdia. With the development of the port, the convent, known as Paço Alfândega, served as a customs house, sugar warehouse and parking lot, and was requalified in 2003 as a commercial and corporate space (IPHAN, 2007).

Later, the church was given individual heritage status by the National Historical and Artistic Heritage Service (SPHAN) in 1938, and in addition to being attended by regular masses, it is also a popular venue for weddings due to its architectural grandeur and location. While preparing for one of these events, the church suffered a devastating fire in 1971, resulting in it being closed for 30 years until it was properly restored in a long restoration process, and it remains in operation to this day.

The materials found in both 18th-century buildings, such as ashlar masonry coated with stone and lime mortar, as well as mixed masonry, are particularly susceptible to the effects of rising damp, which also affects the render made of imitation stone powder mortar. Additionally, the iron railings are constantly subjected to direct exposure to river water and the action of saline particles carried by sea air.

The Malakoff Tower, built in 1855, is part of the Navy Arsenal complex and is an important observation point in Recife. Built with materials from the Fort, Arco and the Bom Jesus Chapel (Souza, 2019), the tower symbolizes urban resilience in the area, being one of the few buildings that survived the urban reform at the beginning of the 20th century in the region surrounding the ports.

The mansion at no. 125, Rua do Bom Jesus, once housed the first branches of Banco do Brasil and the Post Office in Recife. Today, it is home to the Ranulpho Gallery and a coworking space, and according to the site's guide, ruins of the old Recife Wall were discovered beneath the floor of the house during renovation works, revealing vestiges of Dutch occupation.

Built in the early decades of the 20th century, the eclectic-style Chanteclair Building was initially a residence for port workers and, over time, began to house salons and restaurants, transforming itself into a mixed-use space and the stage for important events in the city. Despite the restoration being completed in 2012, its original coverings remain sensitive to water infiltration, with cracks and detached stucco ornaments.

Representing the modernist school of architecture in Pernambuco, the Digital Port Management Center (NGPD) at Cais do Apolo stands out for its architectural contrast and impressive volume in the region. Architect Acácio Gil Borsoi designed the building as the headquarters of Bandepe, using the foundations already in place for what would have been the headquarters of the Pernambuco Stock Exchange, which was inaugurated in 1969. At the turn of the millennium, it became the management center for Recife's technology park, meeting the initial demands of implementing an agenda for the state's economy (Bento, 2023). Although the project foresees a raised floor in relation to the street, the glass and steel window frames are also deliberately exposed to the action of winds that carry humidity and salinity from the surrounding waters.

Despite recent interventions and regular maintenance aimed at preserving historic buildings, none are immune to the effects of moisture in Recife, whether due to high relative humidity, salinity in airborne droplets, rainfall, or flooding characteristic of the local geography.

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The variety of materials and rudimentary construction techniques, compared to modem technologies, requires specific measures within a broader prevention plan for the city.

5.2 Guidelines for mitigating the effects of moisture

There is a dilemma between protecting historic buildings from constant moisture exposure and preserving their authenticity: regulations often prioritize the preservation of authenticity, which may, in turn, leave buildings more susceptible to damage (Sesana *et al.,* 2018). Nevertheless, guidelines for mitigating these effects consider the nature of the construction materials, with specific solutions that respect historical integrity while also enhancing moisture resistance according to the properties of each material.

5.2.1 Masonry with lime mortars

To protect masonry surfaces composed of stone or bricks, the use of hydrophobic coatings compatible with historical materials is recommended, as they prevent infiltration without compromising the breathability of the materials (Franzoni, 2014; Speziale *et al.*, 2020). Among the options already studied, siloxane-based solvents have proven effective in limiting moisture absorption from wind-driven rain, but insufficient to prevent rising damp (Chen *et al.,* 2023).

In addition, it is important to implement chemical or physical barriers in the foundations to prevent the rise of moisture from the ground through the porosity of the walls (Bracciale *et al.,* 2020). Facilitating evaporation and controlling humidity levels inside the building help to minimize the effects of moisture. Reapplications of lime-based mortars are recommended to preserve the integrity of surfaces and to prevent infiltration and cracking, while joint sealants may also be necessary to reduce water ingress (New Jersey, 2019). It is also essential to establish efficient drainage systems around the foundations to reduce water pressure on the structures (Lefevre, 2021).

5.2.2 Wood

Wood frames and other structures, due to their ability to absorb moisture, require hydrophobic varnishes that act as protective barriers, preventing degradation of the material. As well, antifungal and pest treatments are necessary to prevent biological deterioration of the wood. Ensuring adequate ventilation in areas with wood frames is another important measure, as this helps to minimize the accumulation of moisture and, consequently, the proliferation of mold (Sobón; Bratasz, 2022).

5.2.3 Railings and metal structures

To protect railings and other iron or metal structures, the application of antioxidant coatings and anti-corrosive paints is essential. These coatings help prevent corrosion caused by

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sea spray and constant exposure to humidity (Lefevre, 2021). Periodic inspections are essential to detect early signs of corrosion, which allows the reapplication of protection before the damage becomes irreversible. In cases of advanced corrosion, it is necessary to replace railings and metal parts that are severely compromised.

5.2.4 Glass

For glass in historic buildings, such as stained-glass windows, the installation of external protection systems (EPS) is essential to prevent stains, discoloration and water accumulation, while sealants prevent infiltration and condensation (Bernardi *et al.*, 2013). In modern facades, such as Porto Digital, physical coatings, such as films, and chemical treatments reinforce the glass. Films provide a barrier against impacts and abrasion (Vacche, 2019), while chemical treatments, such as resins, protect micro-cracks against moisture, reducing corrosion and crack growth (Overend, 2007).

Marine exposure requires thorough cleaning and maintenance to preserve the durability and aesthetics of glass surfaces, especially in preventing the formation of microbial biofilms on glass. Macedo *et al.* (2021) point out the absence of standardized protocols for preventing microbiological biodeterioration in glass; therefore, frequent maintenance and adequate ventilation are the most recommended measures to prevent further problems.

5.2.5 Reinforced concrete

To preserve the exposed concrete of a historic building without altering its aesthetics, it is recommended to apply transparent water repellents that protect against moisture, maintaining the material's breathability (Moraes, 2023). Crack monitoring is essential to detect corrosion, with localized repairs carried out to halt the progression of the resulting electrochemical process. In cases of section loss or disintegration, the damaged concrete is removed, the reinforcement bars are cleaned (repassivation), and additional reinforcement is added. Due to sea spray and pollution, corrosion inhibitors should be discreetly applied, and gentle, periodic cleaning is recommended to remove dirt and efflorescence while preserving the surface.

5.2.6 Ceramic tiles

Botas; Veiga; Velosa (2017) emphasizes that surviving tiled façades featuring 19th-century patterns are living testimonies of the techniques and materials used during the early stages of semi-industrial mass production. The authors also note that these elements still present structural differences among themselves, and that interventions (whether on the tile or the adhesive mortar) must follow criteria of compatibility, durability, and reversibility.

Whenever possible, traditional materials should be prioritized in interventions, and the use of new materials requires scientific evidence of their compatibility. Curval (2015) investigated the use of organosilanes to functionalize the glazed surface and ceramic body, creating a promising water-repellent layer for humid environments. However, further research

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is needed on the durability of this protection under marine salinity and UV radiation, which may accelerate degradation.

In areas susceptible to moisture and mold growth, it is recommended to ensure proper ventilation and, when necessary, apply antifungal agents. The presence of biofilms accelerates the accumulation of soiling and the penetration of aggressive substances, promoting the degradation of the glaze and compromising the shine and surface integrity of the tiles (Coutinho *et al.,* 2019).

In façade tiles, it is essential to carry out regular inspections, maintain joints in good condition, and repair any emerging cracks to prevent infiltration and detachment. The continuous monitoring of stains and salt crystallization on the surface helps avoid future structural damage to the ceramic body and mortars, preventing irreversible losses such as glaze erosion or even partial or total disintegration of the piece.

Tejeda; Beltrán (2023) emphasize that interventions such as consolidation, cleaning, or reintegration should be minimal, aiming to preserve the material and visual integrity of the historic object. The adoption of three-dimensional digital models, digitally integrated and georeferenced databases can facilitate the preventive planning of interventions on façade tiles, especially in the face of risks associated with moisture and the loss of original material (Santos *et al.,* 2020).

6 CONCLUSION

This study highlighted the vulnerability of Recife's historic buildings to flooding and moisture, aggravated by climate change, and proposed specific interventions to protect these heritage sites without compromising their authenticity.

Paving the way for a preventive approach based on practical and accessible methods, the flowchart in Figure 3 synthesizes these guidelines, aligning the discussed results into resilient preservation measures applicable to traditional materials found in Bairro do Recife and commonly present in other urban areas facing similar climate-related challenges.

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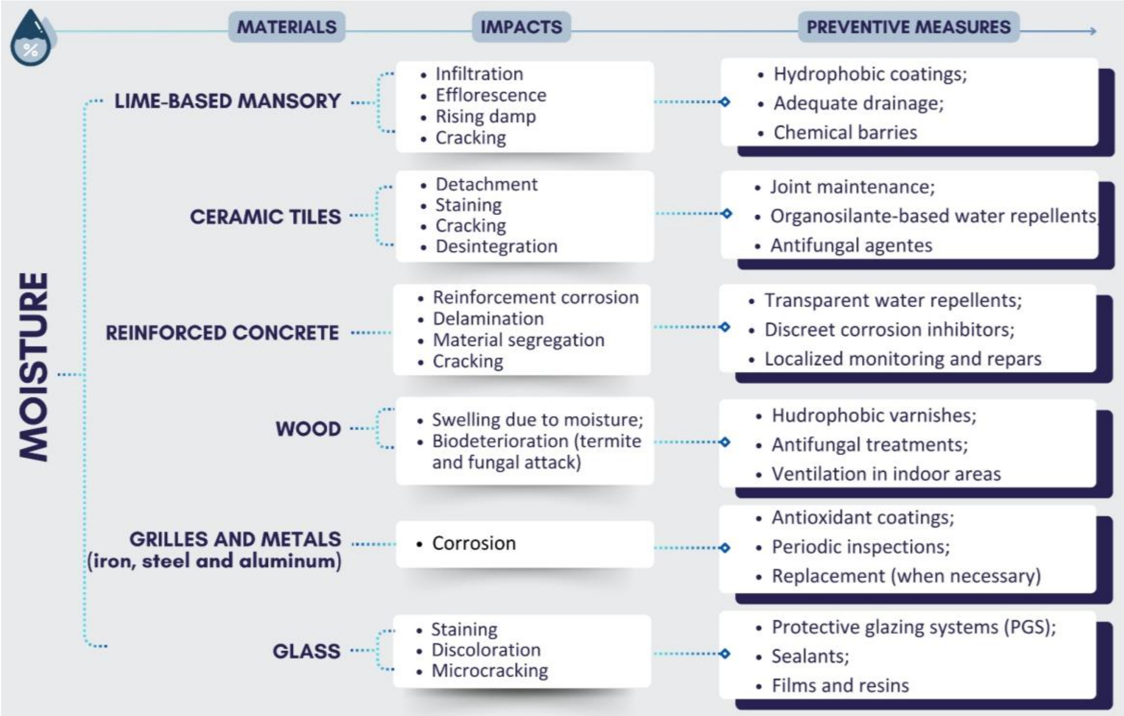
Figure 3 – Flowchart-summary of the impacts caused by the action of humidity on each material and respective preventive measures



Source: Authors (2024).

Initiatives such as "Cities and Floods: A Guide to Integrated Urban Flood Risk Management for the 21st Century" (Jha; Bloch; Lamond, 2012) and the "Climate Change Adaptation Guide for Federative Entities" (Margulis, 2017), at the national level; in the state context of Pernambuco, the "Climate Risk and Vulnerability Analyses" (Recife, 2019) and the "Coastal Erosion and Climate Change Vulnerability Atlas" (Pereira *et al.*, 2015), highlight the importance of urban requalification and the modernization of drainage systems, in addition to reinforcing public awareness of flood risks.

However, the analysis carried out reveals the urgent need to make specific strategies accessible to mitigate the impacts of humidity and flooding on Pernambuco's historic heritage. The creation of a practical guide aimed at owners and managers of these buildings is essential to disseminate good practices and raise awareness in society. Inspired by models such as the "Flood Mitigation Guide for Historic Properties" (New Jersey, 2019), it is recommended to implement a collaborative project between local educational institutions and the public authorities, promoting safe interventions that value the city's cultural and historical identity in the face of imminent climate risks. These actions contribute to the proactive and sustainable preservation of heritage, integrating protection and awareness for the benefit of future generations.

Acknowledgements

This work was supported by the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES) – Financing Code 001.

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National Journal of City Management

ISSN 2318-8472, v. 13, n. 89, 2025

DECLARATIONS

CONTRIBUTION OF EACH AUTHOR

- **Conception and Design of the Study**: Eudes de Arimatéa Rocha, Júlia Oliveira dos Santos e Joyce Ketlly Soares da Silva
- **Data Curation**: Júlia Oliveira dos Santos, Joyce Ketlly Soares da Silva, Eudes de Arimatéa Rocha, Pedro Henrique Cabral Valadares e Willames de Albuquerque Soares.
- **Formal Analysis**: Júlia Oliveira dos Santos e Joyce Ketlly Soares da Silva.
- **Founding Acquisition**: Programa de Pós-graduação em Engenharia Civil da Escola Politécnica da Universidade de Pernambuco.
- **Investigation**: Júlia Oliveira dos Santos, Joyce Ketlly Soares da Silva, Eudes de Arimatéa Rocha, Pedro Henrique Cabral Valadares.
- **Methodology**: Júlia Oliveira dos Santos.
- **Writing – Inicial Draft**: Eudes de Arimatéa Rocha.
- **Writing – Critical Review**: Júlia Oliveira dos Santos e Joyce Ketlly Soares da Silva.
- **Final Review and Editing**: Júlia Oliveira dos Santos.
- **Supervision**: Eudes de Arimatéa Rocha, Pedro Henrique Cabral Valadares e Willames de Albuquerque Soares.

DECLARATION OF CONFLICTS OF INTEREST

We, **Júlia Oliveira dos Santos**, **Joyce Ketlly Soares da Silva, Eudes de Arimatéa Rocha, Pedro Henrique Cabral Valadares** and **Willames de Albuquerque Soares,** declare that the manuscript entitled "**Degrading action of floods: Damage analysis in historic buildings of the Bairro do Recife (PE)**":

1. **Financial Relationships**: This work was carried out with the support of the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES) – Financing Code 001.
2. **Professional Relationships**: No professional relationships relevant to the content of this manuscript that could impact on the analysis, interpretation or presentation of the results were established.
3. **Personal Conflicts:** No personal conflicts related to the content were identified.