Capillary Pathologies in Bogota's Police Museum: Parameters and Diagnosis

Patologías capilares en el Museo de la Policía de Bogotá: parámetros y diagnóstico

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Abstract

This study systematically identifies and analyzes the range of defects affecting the Police Museum's structure using a multifaceted, methodologically rigorous approach. The initial phase consists of an exhaustive visual inspection, with meticulous documentation of all observable anomalies and pathologies. This process results in a detailed defect matrix that categorizes each defect by typology, probable causative mechanisms, and potential sources, whether inherent to the original construction, attributable to material degradation, or resulting from environmental exposure over time. To enhance diagnostic accuracy, visual assessment is integrated with both invasive and non-invasive laboratory investigations. Techniques such as ferroscan analysis detect and map steel reinforcement within concrete elements, while strategic soil sampling provides insights into subsurface geotechnical conditions. Extraction and laboratory examination of wall sections determine moisture content and clarify the extent of water ingress and its impact on construction materials. Additional laboratory tests assess critical variables, including the resistance of building materials to moisture, the integrity of structural steel, the bearing capacity of underlying soils, and the current groundwater table. Synthesizing the results of these methodologies enables a robust etiological analysis of the identified pathologies, allowing for the precise determination of their origins, whether structural, material, environmental, or a combination. Based on these findings, the study develops evidence-based recommendations outlining targeted interventions for the rehabilitation, remediation, or ongoing maintenance of the Police Museum to safeguard its structural integrity and extend its service life.

Keywords
Capillary; pathology; vulnerability

Resumen

Este estudio identifica y analiza de forma sistemática los distintos defectos que afectan a la estructura del Museo de la Policía con un enfoque multifacético y metodológicamente riguroso. La fase inicial consiste en una inspección visual exhaustiva, con la documentación meticulosa de todas las anomalías y patologías observadas. Este proceso da como resultado una matriz detallada de defectos que clasifica cada uno según su tipología, sus posibles mecanismos causantes y sus fuentes potenciales, ya sean inherentes a la construcción original, atribuibles a la degradación de los materiales o resultantes de la exposición ambiental a lo largo del tiempo. Para mejorar la precisión del diagnóstico, la evaluación visual se integra con investigaciones de laboratorio tanto invasivas como no invasivas. Técnicas como el análisis con Ferroscan detectan y cartografían la armadura de acero en los elementos de hormigón, mientras que el muestreo estratégico del suelo proporciona información sobre las condiciones geotécnicas del subsuelo. La extracción y el examen en laboratorio de secciones de muro determinan el contenido de humedad y aclaran el alcance de la entrada de agua y su impacto en los materiales de construcción. Pruebas de laboratorio adicionales evalúan variables críticas, como la resistencia de los materiales de construcción a la humedad, la integridad del acero estructural, la capacidad portante de los suelos subyacentes y el nivel actual de las aguas subterráneas. La síntesis de los resultados de estas metodologías permite realizar un análisis etiológico sólido de las patologías identificadas, lo que permite determinar con precisión sus orígenes, ya sean estructurales, materiales, ambientales o una combinación de ellos. A partir de estos hallazgos, el estudio elabora recomendaciones basadas en la evidencia que describen intervenciones específicas para la rehabilitación, la reparación o el mantenimiento continuo del Museo de la Policía, con el fin de salvaguardar su integridad estructural y prolongar su vida útil.

Palabras clave:
Capilaridad; patología; vulnerabilidad

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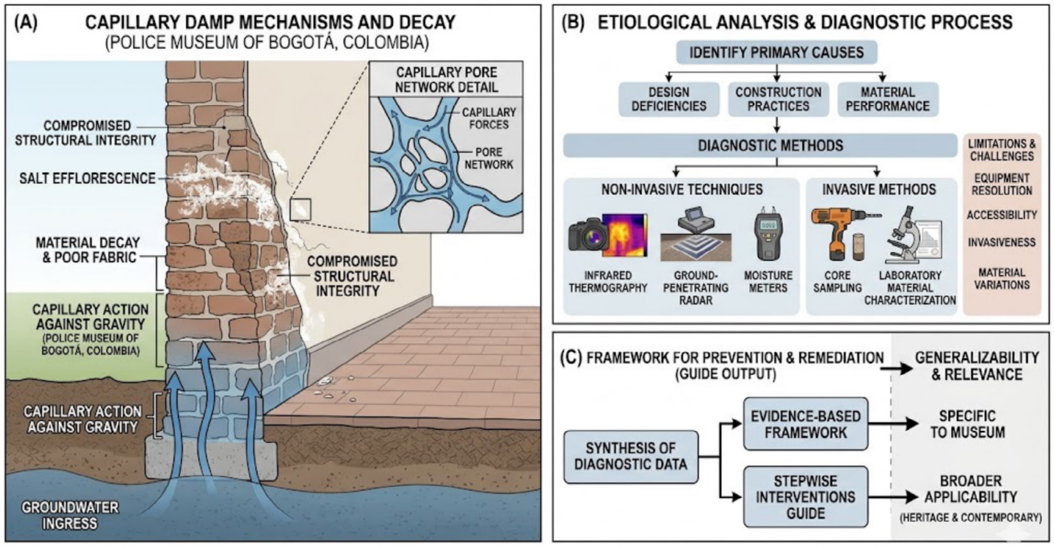
Introduction

Capillary damp, also known as rising damp, is among the most pervasive and damaging phenomena affecting masonry structures worldwide. It is characterized by the upward movement of water from the ground into building walls via capillary action and is considered a recurrent threat to historic buildings [1], [2]. This process occurs when groundwater enters the base of a structure and rises through the masonry's pore network [3], propelled by capillary forces that lift water against gravity. The infiltration of water in historical masonry is widely acknowledged as a significant conservation issue for architectural heritage [4]. Although rising damp can affect modern masonry buildings, its effects are particularly pronounced in historic structures, where traditional construction techniques and materials often exacerbate the problem. Capillary damp endangers the preservation of decorative surfaces and valuable building fabric, promotes salt crystallization and decay, and may compromise the structural integrity of masonry. Despite substantial research efforts, rising damp continues to present significant challenges, especially due to its complex interactions with material properties, environmental factors, and building design [5].

A comprehensive understanding of the mechanisms underlying capillary action in building structures, particularly as observed at the Police Museum of Bogotá, Colombia, requires a methodical, multidisciplinary approach. Seminal studies, including [6] on moisture transport in porous building materials and [7] on heritage structures, underscore the importance of examining both material properties and environmental conditions to assess and address capillary rise. From this evidence-based perspective, the current investigation aims to identify the parameters that facilitate capillary rise and to critically evaluate how this identification informs the development of effective strategies to mitigate and prevent capillary dampness.

A systematic etiological analysis of capillary-induced deterioration within the structure is essential. This analysis requires identifying the primary causes of capillary damage, which may result from deficiencies in architectural design, construction practices, or the selection and performance of building materials. The diagnostic process should incorporate both non-invasive techniques, such as infrared thermography, ground-penetrating radar, and moisture meters, and invasive methods, including core sampling and laboratory-based material characterization (Figure 1). These complementary approaches support a nuanced evaluation of the structure's pathologies, enabling precise localization and characterization of moisture ingress, capillary pathways, and areas of material vulnerability. However, the inherent limitations and challenges of these diagnostic methods must be acknowledged. Factors such as equipment resolution, accessibility of structural components, and the invasive nature of certain techniques can affect the completeness or accuracy of the assessment. Additionally, variations in material composition and environmental conditions may introduce uncertainty into data interpretation. Recognizing these limitations is essential for maintaining a critical and transparent evaluation process.

Figure 1. Comprehensive Framework for Diagnosing and Mitigating Capillary Damp in Masonry Structures



The synthesis of diagnostic data will underpin the development of a robust, evidence-based framework to prevent and remediate capillary dampness. The study will produce a detailed procedural guide that outlines best practices and stepwise interventions to minimize capillary damage in both heritage and contemporary structures. Although the guide will be based on findings from the Police Museum, it will also identify principles, diagnostic processes, and remediation strategies that are broadly applicable. The text will clearly distinguish recommendations specific to the Museum's unique architectural, historical, and environmental context from those adaptable to other heritage buildings or modern constructions facing similar issues. This distinction will help readers assess the generalizability and relevance of the study's outcomes for various building types and settings. In this manner, the guide will inform future conservation efforts at the Police Museum and contribute valuable knowledge to the broader field of building pathology and preservation.

Conceptual Background

The phenomenon of rising damp is governed by fundamental physical principles and occurs as a sequential process. Rising damp involves the movement of liquid water through capillary pathways within solid, hygroscopic materials such as masonry [8]. This movement is driven by capillary forces generated when liquid interacts with small pores in the solid material, counteracting gravity and enabling water to be drawn from the ground into the wall [3]. At the molecular level, capillarity is controlled by surface tension, which causes water to adhere to solid surfaces and form a meniscus. The interaction between surface tension and the solid determines the contact angle at the interface where water meets the pore walls. In hydrophilic materials, where the contact angle (θ) is between 0 and $\pi/2$, water spreads and wets the surface, forming a concave meniscus and enabling capillary rise. In hydrophobic materials, where the contact angle is between $\pi/2$ and π, the meniscus is convex and water adhesion is poor, inhibiting capillary transport [9]. The interplay among capillarity, surface tension, and contact angle determines water's ability to rise within porous construction materials.

Capillary suction becomes stronger as pore size decreases; if the pore size is fine enough, damp may rise many inches up a wall until the upward suction is balanced by the downward pull of gravity [10]. The height of capillary ascending moisture depends primarily on the radius of the capillary pores—the smaller the radius, the greater the rising height. Capillary rise occurs in hydrophilic materials characterized by pores with radii in the range of 10^{-2} to 10^{-3} mm [11]. Measurements at the National Bureau of Standards indicated that some materials could draw moisture to a height of 20 feet, but for most types of masonry, the height would not exceed 4 or 5 feet [12], [13]. In practical terms, this means that in historic brick townhouses or churches with thick, porous walls, one often observes rising-damp lines about 1 meter above floor level, especially in older European cities. In modern residential buildings, where denser bricks or concrete blocks with smaller pore sizes are used, the visible effects of rising damp are usually limited to the bottom courses of a wall. These real-world cases highlight how the relationship between pore structure and capillary suction directly influences the extent of moisture problems in various types of masonry construction (Figure 2).

Figure 2. Examples of Salt Weathering and Moisture-Related Decay in Brick Masonry Substrates: (a) Poland; (b) Latvia; (c) Germany [11]

[14] developed a foundational analytical framework for understanding rising damp using unsaturated flow theory. Their Sharp Front (SF) model uses clear physical principles and accounts for evaporation and gravity, capturing the observed features of capillary rise in walls. The model proposes that rising damp results from competition between capillary absorption of water at the wall base and evaporation of water from exposed surfaces. When the height of rising damp stabilizes at a steady-state value, the total absorption rate equals the total evaporation rate (U = E) [15]. The SF model assumes that the wall is homogeneous and isotropic, that the capillary

network is continuous, and that the influence of salts or material heterogeneity is neglected. It also assumes uniform evaporation and does not account for transient effects or cases with significant air movement within the wall. As a result, while the model captures key physical processes, it may have limitations when applied to complex or composite masonry systems, or when local conditions deviate from these assumptions.

This conceptual model shows that ground moisture is absorbed at the base of a homogeneous, porous wall, and a state of dynamic equilibrium is established as the height of the wetted part varies in response to the evaporation rate on the wall surface [16]. The amount of water absorbed is a function of the porous material's capillary adsorption (sorptivity) and time [8]. In most cases, capillary forces are dominant, and the effects of gravity can be neglected. Furthermore, [14] demonstrated that in walls subject to long-term rising damp, the water content of the wetted region slowly approaches full saturation through molecular diffusion of trapped air.

Capillary transport in masonry, a multi-layered material composed of bricks and mortar joints, deviates significantly from classical capillary transport in a homogeneous material. This deviation is attributed to hydraulic resistance at the brick-mortar interface or to changes in the moisture transport properties of the mortar joint. [17] demonstrated, through X-ray projection measurements, that the pore structure and moisture transport properties of mortar change significantly due to water extraction from initially wet mortar to bricks during curing, and numerical simulations revealed the presence of a hydraulic interface resistance between brick and mortar. Overall, these experiments show that the hydraulic resistance at the brick-mortar interface can significantly restrict moisture movement, thereby limiting the maximum height of rising damp in composite masonry systems. This key finding highlights the importance of considering material interfaces when assessing capillary moisture transport in masonry.

The maximum height of rising damp can theoretically reach, depending on the material, even 15 m; however, in practice, due to the presence of boundaries between materials with different pore sizes (e.g., mortar and brick) and evaporation, the maximum level reached in brick and stone masonry is generally limited to one or two meters [2]. In masonry, the maximum height reached by rising damp and the time to reach steady state vary with several factors, including mortar joint types, the presence of renders, and the surrounding environment [18].

Factors Influencing Capillary Rise in Masonry

The porosity, pore-size distribution, and composition of masonry materials are intrinsic factors that fundamentally determine the extent and rate of capillary rise [19], [20]. Figure 3 illustrates the temporal variation in salt efflorescence visibility on a masonry structure in Rio dei Bareteri-San Marco (Venezia). Comparative analysis of photographs taken before (June 26 and October 26, 2019) and after (November 16, 17, and 25, 2019) the exceptional 2019 flooding event, as well as during the following spring and an extended drought, reveals the pronounced variability and environmental sensitivity of these surface deposits. As a result of this inconsistency, the presence and spatial distribution of salt efflorescence were excluded as reliable indicators for monitoring rising damp.

Figure 3. Photographic Record of the Masonry Structure at San Marco 556 A, Rio dei Bareteri (Calle Erizzo), Captured Across Varying Time Intervals and Contrasting Climatic Conditions [20]

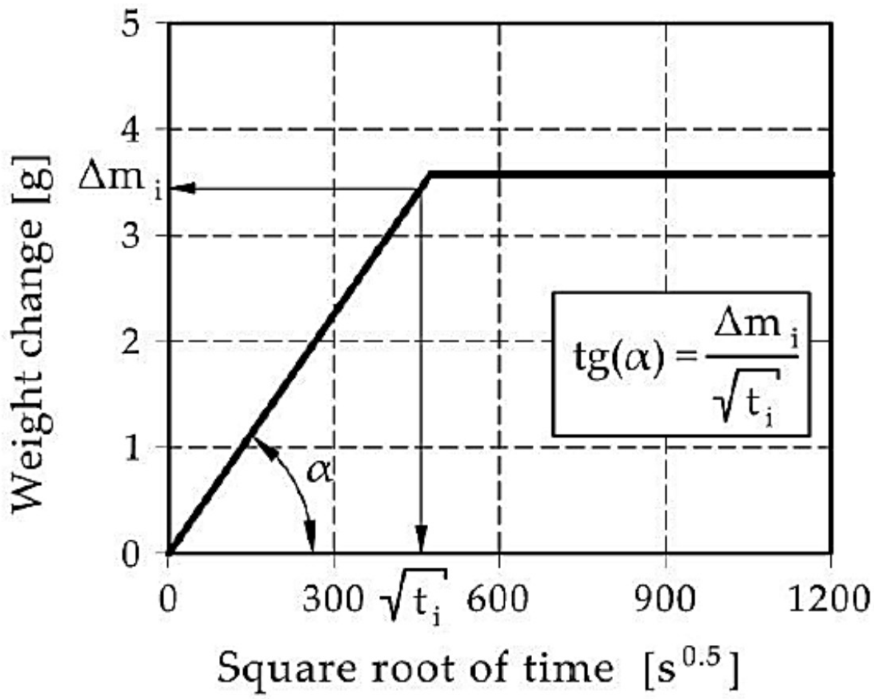
Ceramic bricks, classified as capillary-porous materials, are characterized by relatively high open porosity of about 20–30% with an apparent density of about 1.8 g/cm^3, making them susceptible to wetting [21]. As firing temperature increases from 900 °C to 1,100 °C, the pore size distribution gradually changes, the proportion of pores below 1 μm decreases, and open porosity decreases.

[22] demonstrated that bricks from different sources exhibit distinct relationships between compressive strength, porosity, and water absorption (Figure 4), indicating that properties can differ even within a single building. These material properties have important practical implications for both construction and preservation: selecting bricks or mortars with lower porosity and a reduced proportion of fine pores can help limit the extent of rising damp, while understanding variations in pore structure is essential when designing compatible repair materials or retrofitting existing masonry. For example, using denser, less porous bricks in new construction or specifying repair mortars with compatible yet controlled pore sizes can reduce susceptibility to moisture ingress and long-term deterioration. Awareness of how production methods and raw materials affect masonry properties enables architects, engineers, and conservators to make informed material selections when facing moisture management challenges in practice.

The first principle of capillary transport states that the rate of rise is higher in materials with thick capillaries, while in materials with thin capillaries, the level of rise is significantly higher. At very small or very large capillary radii, both rates and maximum levels of rise reduce to zero [9]. The presence of macropores and larger capillaries increases the rate of capillary saturation but may also allow gravity effects to decelerate moisture ingress [23].

Evaporation is a critical factor controlling the height of rising damp, influenced by temperature, humidity, air movement, and the wall's surface condition. Evaporation processes limit the height of moisture rise through capillary action, and the capillary range subsequently varies over the year, with a greater rise during winter months when evaporative processes are less active. Zones between the capillary rise heights in summer and winter (0.6–1.7 m) experience the most severe deterioration due to seasonal wetting and drying cycles [24].

Figure 4. Tangent of Slope of the Initial Section of the Brick Sample Weight Increments [22]



In Venice, where typical masonry structures are made of clay bricks, lime mortar joints, and plaster erected on salt soil, the relative humidity of over 70% in the atmosphere allows water to pass through porous materials via capillary action [25]. They found that the greater the exposed surface area, the higher the recorded level of rising damp, and that rapid evaporation compensated for capillary suction, slowing the rise of water. [15] calculated, using the Sharp Front model, that capillary rise should vary between 800 mm in summer and 1,200 mm in winter above ground level, though their in-situ measurements in rubble-fill masonry showed this variation was not always present, indicating that composite construction and the lack of capillary pathways can limit rise.

The presence of salt in groundwater significantly exacerbates the effects of rising damp. In coastal areas, rising damp from saline water is a well-known degradation factor for historical masonry [20]. Salts in buildings do not crystallize uniformly across walls but follow unpredictable paths depending on the permeability of the masonry surface [26]. The sequence of salt movement and crystallization begins when groundwater containing dissolved salts rises by capillarity through the pores of the masonry. As the water ascends, it carries these salts with it in solution. When this moisture reaches the evaporation front, usually near or just above the visible damp line on the wall, water begins to evaporate. This evaporation increases the concentration of dissolved salts in the remaining liquid, causing some less soluble salts to reach saturation first and crystallize in the lower zones of the wall. As water continues to move upward, more soluble salts travel higher before they concentrate and crystallize, sometimes at or above the height of active evaporation. This results in a vertical distribution or fractionation of salts, in which the least soluble salts precipitate in the lowest zone, a middle zone forms where salt crystallization leads to the greatest damage, and the uppermost zone remains damp due to the accumulation of the most soluble and deliquescent salts [27].

[19] demonstrated in tsunami-affected areas that enhanced capillary pressure from salinated soil significantly influenced the persistence of salt attack and rising damp, with rising damp heights being relatively high within 500 m of the shoreline. The salt commonly comes from soil beneath and is carried up into walls by rising damp, where evaporation causes supersaturation and crystallization [27].

Scientific Forefront

[28] conducted a comprehensive pathological assessment to systematically identify, categorize, and evaluate the spectrum of structural deterioration observed within the Cobaleda family residence. The research was designed to elucidate not only the observable symptoms of distress but also the multifactorial etiological mechanisms—including geotechnical, material, environmental, and construction-related factors—that contribute to the degradation of the built environment. Central to this inquiry was quantifying the financial implications of remedial interventions, thereby providing a holistic basis for informed decision-making regarding structural rehabilitation and long-term asset preservation.

The scope of the investigation was deliberately limited to the first floor of the residence, a methodological choice that enabled a focused, granular analysis of the structural elements most vulnerable and most deteriorated. Through the deployment of an array of diagnostic tools—including exploratory surveys, standardized defect-identification protocols, and a detailed symptom-and-crack matrix—the study achieved a nuanced understanding of the spatial distribution and severity of the pathologies. The methodological framework was anchored in established technical standards such as the Colombian Technical Standard NTC 4325 and the guidelines promulgated by the Colombian Society of Engineers (SCI), which collectively ensured the rigor, reproducibility, and scientific validity of the diagnostic process.

The principal pathologies identified included differential settlement, vegetation growth near structural elements, widespread moisture ingress, efflorescence, and pervasive capillary moisture. These findings highlight the multifactorial causes of structural deterioration in regional residential buildings, emphasizing both environmental and construction-related vulnerabilities.

The site surveys revealed that the structure lacks a foundation and that adequate waterproofing was not applied to prevent ground moisture from entering the building. Site surveys indicated that the structure lacks a foundation and that adequate waterproofing was not implemented to isolate the building from ground moisture, resulting in capillary moisture damage. These challenges are prevalent in similar residential structures in the region, where insufficient foundations and the absence of protective barriers against soil moisture have led to recurring settlement and water-related deterioration. Addressing these widespread issues requires improved construction practices and region-specific solutions to enhance structural durability. It is advisable to establish a regular schedule of building inspections focused on moisture control, early detection of cracks or settlement, proper cleaning of drainage systems, and prompt repair of minor defects such as chipped plaster or small fissures. Routine waterproofing treatments on vulnerable surfaces and monitoring for vegetation growth near the foundation can further prevent moisture ingress and settlement. These preventive maintenance measures are essential for extending the structure's lifespan and minimizing the risk of further deterioration.

Figure 5. (a) Efflorescence and Mortar Cracking; (b) Bulging and Cracking of the Plaster [29]

Several alternatives were developed to address the existing damage. The selected solution involved constructing a proper, waterproof foundation to ensure structural stability and manage settlement and ground moisture. Additionally, a wall functioning as an air chamber was proposed, incorporating a pipe and a water management filter at the base to maintain ground aeration and control capillary moisture.

The study identified an effective method for managing capillary moisture in structures and emphasized the need for proper soil waterproofing at the foundation interface. The study titled "Pathological Study of the Puente Aranda Fire Station – City of Bogotá" primarily sought to develop a methodology to improve facility conditions based on existing damage, with the objective of ensuring the safety of personnel. The case study focused on the Puente Aranda fire station in Bogotá. The methodology involved visual inspection using damage matrices to record the type, location, and possible origins of defects. The inspection identified several pathological defects, including leaks, capillary moisture, dirt, fissures, cracks, and corrosion of the roof structure [30].

The study concluded that the structural defects were minor and could be addressed through targeted maintenance measures, such as plaster replacement. The findings underscored the importance of implementing proper preventive maintenance, as the identified defects were manageable through routine maintenance practices.

[31] conducted a pathological study of the educational institution using comprehensive testing. The sample consisted of the educational institution in Guamal, Meta. The qualitative methodology incorporated both invasive and non-invasive laboratory tests to establish parameters for analyzing the building's seismic vulnerability. Non-invasive tests included visual inspections, infrared thermography to detect subsurface moisture and delamination, and ultrasonic pulse-velocity testing in accordance with ASTM C597 to assess the integrity of the concrete. Invasive tests included core sampling of concrete per ASTM C42 to determine compressive strength and carbonation depth, as well as extracting rebar samples to test for corrosion. All procedures adhered to relevant national and international standards. Several critical pathologies were identified, including cracks, fissures, and moisture.

The study concluded that the building is not suitable for rehabilitation due to the high associated costs. A comparison between rehabilitation and reconstruction, considering compliance with current regulations and plans to add a second floor, indicated that rebuilding is preferable. Based on the cost-benefit analysis, rehabilitation is not a viable alternative. The study highlighted the importance of conducting comprehensive tests to analyze parameters and perform seismic vulnerability assessments, using data to determine the building's condition and structural defects, with a consistent focus on protecting human life. Structural assessments enable the determination of the extent of damage in each scenario.

In their influential study "Capillary Moisture and Its Effect on Building Deterioration in the Coastal Area of the Historic Center of Santiago de Cuba," [32] conducted a multidimensional analysis to clarify the spatial distribution and determinants of structural deterioration. Their methodological framework integrated environmental variables such as groundwater depth, soil typology, ambient temperature, relative humidity, solar radiation, and prevailing wind patterns using advanced geographic information system (GIS) technologies. The study design included three phases: systematic investigation of pathologies, scenario-based analytical modeling, and construction of predictive spatial deterioration models.

The research included a sample of 1,002 urban lots, 76% of which exhibited capillary moisture phenomena that required invasive diagnostic tests. This methodological rigor allowed the authors to map deterioration patterns with high spatial resolution and examine the multifactorial causes involved. The GIS-based approach enabled detailed data visualization and spatial correlation. However, the authors noted methodological limitations, including dependence on the accuracy and completeness of environmental datasets and challenges in integrating temporally variable factors. Additionally, the use of invasive testing, while necessary for empirical validation, may restrict the generalizability of results to other geographic or architectural contexts, highlighting the need for methodological refinement in future studies.

The study concluded that the use of a location and referencing system, combined with soil and material testing, enabled the determination of the moisture content in construction materials, soil characteristics, and the influence of groundwater level. The analysis indicated that additional variables should be incorporated and that more advanced systems should be employed prior to building construction. These findings suggest that future research should develop comprehensive predictive models integrating a wider range of environmental and material factors. For construction practices, the results emphasize the importance of systematically assessing site-specific conditions using advanced GIS and monitoring technologies to inform material selection and building methods that prevent moisture-related deterioration.

This study demonstrated that, using the reference system, moisture damage can be linked to soil conditions such as the water table and the moisture content of construction materials. These variables contribute to increased moisture levels in buildings through capillary action.

[33] primarily examined moisture-induced pathologies in both interior and exterior walls. The study covered 250 m² of the seaside promenade, corresponding to a sample of 25 homes, and employed a descriptive cross-sectional design. Visual inspection identified the pathologies present and evaluated maintenance practices in homes exposed to moisture and salinity from the seafront. The study found that 80% of the sample exhibited capillary moisture. Compared with [32], which also identified capillary moisture as a significant issue in coastal environments, both studies underscore its prevalence in such regions. While [32] used a GIS-based approach incorporating environmental variables to model deterioration spatially, [33] focused on direct observation and analysis of residential wall pathologies. This methodological difference provides complementary perspectives: [32] offers broader spatial understanding, whereas [33] provides detailed, case-specific insights into residential structures.

The study concluded that two types of pathologies were present: capillary moisture (8%) and seepage moisture, with capillary moisture identified as the primary issue. Recommendations included using moisture-barrier paints and installing waterproofing between the ground and the foundation for future construction in the area. While these measures are generally effective in reducing moisture ingress, their implementation may be constrained by factors such as cost, required technical expertise, and material availability. Retrofitting existing structures may also present challenges, especially in older buildings where structural modifications are not feasible. Therefore, although the recommendations are theoretically sound, careful consideration of local constraints is essential for successful and sustainable implementation.

This study emphasized the necessity of thoroughly assessing the soil water table at construction sites to protect structures from ground moisture. Additionally, building materials should be selected based on soil and environmental factors affecting the structure. The design must also be adapted to protect against both inherent soil moisture and external agents.

[34] analyzed the main pathologies resulting from the use of cement in church restoration. The study focused on two ancient structures, including a church declared a historic landmark in 1941. The methodology involved visual inspection and analysis of construction material parameters. Repairs in the mid-20th and early 21st centuries used concrete and structural elements such as beams and columns. Following these repairs, the incidence of pathologies in the church increased. Two main pathologies were identified: moisture from roof leakage and capillary seepage. The cement altered the behavior of the adobe, which naturally evaporates water, but this ability was compromised when plaster or cement was applied, leading to increased structural issues. These findings on material choice align with those of [32] and [33], who also emphasize the importance of selecting materials suited to local environmental and soil

conditions. While the earlier studies highlight the impact of moisture on building deterioration and the need for proper material selection, [34] demonstrate that inappropriate material interventions, such as introducing cement into adobe structures, can exacerbate moisture-related problems. Collectively, these studies underscore the necessity of considering both original building materials and local context in restoration and construction decisions.

Materials and Methods

The National Police Museum was selected for its designation as a national cultural heritage site by decree. This non-profit institution is open to the public, situated in the prominent La Candelaria neighborhood, and is surrounded by other museums.

The police acknowledge the need to preserve the building to ensure its continued operation as a museum that serves the public and presents the history of the National Police throughout the institution's existence.

A visual inspection of the building was conducted through a systematic walk-through of all accessible floors and rooms (Figure 6). The inspection involved observing surfaces directly and using a flashlight to improve visibility in dimly lit areas. No specialized diagnostic tools were employed at this stage. Several lesions were identified on different floors. This information is recorded in the technical data sheets, which describe the identified lesions and pathological processes.

Figure 6. (a) Exterior Facade of the South Courtyard; (b) Interior Facades of the National Police Museum

During this inspection, five pathological processes were found on different floors of the building. These included:

1. Dampness on the facade walls, observed primarily on the eastern and western sides of the building, where water infiltration is visible on interior and exterior surfaces

2. Dampness on the walls and ceilings of the exhibition halls, affecting several rooms on the second and third floors, resulting in discoloration and peeling paint

3. Dampness on the tongue-and-groove ceiling of the fourth floor, seen in the central part of the ceiling, where moisture marks have developed along the wood panels

4. Dampness in the basement walls, particularly along the northern section, leading to notable deterioration and musty odors

5. Cracks in the basement walls, located near support columns and along the southeast wall, which may impact structural integrity and require further assessment

The information necessary for the study was gathered through several methods. Visual inspection provided first-hand observations of building lesions and their locations. Historical and contextual data about the building were obtained from publicly available online sources [35], [36]. To further verify and supplement this information, direct communication was conducted with the architect responsible for building maintenance at the National Police. Technical data sheets and inspection notes were compiled on-site. Together, these sources provided details on the building's construction period, architectural features, current condition, and the specific pathological processes observed.

The building dates from 1923 to 1926 and is a historical landmark. Therefore, any modifications or repairs must be authorized by the relevant authorities. Due to the building's age, there is no information or documentation regarding its construction. Therefore, information was gathered from the internet, and its accuracy was verified with the architect responsible for building maintenance at the National Police.

To achieve a comprehensive diagnosis, three key studies are planned: an architectural survey, a vulnerability study, and a materials identification analysis. The architectural survey will be conducted by the technical team from the Department of Architectural Conservation within the next four weeks, including mapping of all observed lesions and construction features. The study vulnerability will be carried out by a licensed structural engineer, who will identify possible construction standards and assess the building's structural risks, with results expected six weeks after the architectural survey is completed. Materials identification, including absorption analysis, will be performed in collaboration with an external materials laboratory, with results anticipated within three weeks of sample collection. The findings from these studies will be used to develop a targeted repair and conservation strategy. All proposed interventions will be aligned with the requirements for historical buildings and submitted to the relevant authorities for approval. The project manager will coordinate the studies and ensure all recommendations directly inform the design and execution of repairs.

The building under investigation was a four-story exhibition hall, constructed in 1923 and situated in the city center, which served as a venue for public exhibitions and events. The subsequent analysis delineated five principal pathological issues identified within the structure.

Moisture From Seepage

In the ceiling and interior wall of the third-floor exhibition hall, there is a slab from the fourth floor finished with vitrified tiles. The slab was not waterproofed prior to this finish, so rainwater and water from building cleaning seep in. The water seeps in at the junction of the wall and the slab; it is also possible that the construction materials have a high degree of absorbency, all of which causes moisture in the walls and deterioration of the ceiling finish, leading to peeling. Remediation steps may include waterproofing the slab to prevent further water infiltration, repairing damaged ceiling finishes, and replacing any highly absorbent construction materials with more moisture-resistant alternatives. Proper sealing of the junctions between walls and slabs should also be considered to ensure durable repair [37].

Regarding the moisture observed on the third floor, a watertightness test was performed on the fourth-floor slab to determine whether the moisture originated from rainwater infiltration or from water used during floor maintenance. Furthermore, a sample was extracted from the moisture-affected wall area to evaluate the degree of absorption of the wall materials and to determine the thickness of the plaster. The ceiling material in this area was also analyzed.

A moisture meter was employed to rigorously quantify the moisture content within the materials, in accordance with established standards such as ASTM D4444 (Standard Test Method for Laboratory Standardization and Calibration of Hand-Held Moisture Meters) and ASTM F2659 (Standard Guide for Preliminary Evaluation of Comparative Moisture Condition of Concrete, Gypsum Cement, and Other Floor Slabs and Screeds Using a Non-Destructive Electronic Moisture Meter). Furthermore, the temporal evolution of moisture was systematically monitored across both dry and rainy seasons to ascertain whether moisture content exhibited seasonal variability—namely, increasing during periods of elevated precipitation, decreasing during arid intervals, or remaining relatively constant over time.

Moisture by Absorption

The ceiling joists absorbed water from a leak in the sloped roof. The deterioration and substandard repair of the roofing system allowed rainwater infiltration, resulting in progressive rot and degradation of the timber ceiling components. Verification was conducted to ascertain whether the roof structure was indeed composed of wood and to evaluate the extent of its deterioration [38]. The primary physical damage was a fissure in the roofing system, which facilitated water ingress and subsequent moisture accumulation within the timber elements affected by the leak. While the secondary physical damage was further exacerbated by the absence of preventive maintenance and the implementation of inadequate repair interventions [39].

With respect to the moisture identified on the fourth floor within the exhibition area, remedial actions included replacing fractured roof tiles and strategically removing a segment of the ceiling to facilitate direct inspection of the underlying roof structure, which is presumed to be timber, given the building's historical context. Where moisture-induced deterioration of the wooden structural components was corroborated, restoration or substitution of compromised elements was undertaken to reestablish structural soundness. Furthermore, the installation of comprehensive waterproofing and protective systems was planned to mitigate the risk of recurrent moisture intrusion in this area.

Capillary Moisture

The basement walls showed evidence of moisture from capillary rise from the subsoil, manifested as surface staining, detachment of finishing materials, and cracking. This pathological process also led to malodorous conditions within the affected spaces. Primary physical damage was manifested through expansion or fissuring at the interfaces between structural elements, thereby facilitating the upward migration of moisture. Secondary physical damage was attributable to the absence of a foundational design that incorporated effective isolation from the subgrade, thereby precluding capillary rise of groundwater or soil moisture [39].

In the moisture-impacted basement, a crack-monitoring device was used to assess fissure activity and quantify its dimensions. Core sampling was undertaken to facilitate geotechnical analyses, including characterizing soil properties, determining groundwater table elevations, and assessing bearing capacity.

Given the observed cracking in the basement, a comprehensive structural vulnerability assessment was conducted. As the edifice was built in 1923—predating the implementation of the NSR-10 seismic resistance code—and lacked a column-and-beam framework, the evaluation was conducted under assumptions and methodologies appropriate for masonry structures.

Issue Prioritization

Among the array of identified pathological manifestations, structural fissuring and capillary moisture ingress within the basement constituted the most acute, high-priority risks, given their potential to undermine the building's structural stability and occupant safety. These issues warranted immediate diagnostic and remedial intervention. Moisture-related issues in ancillary areas, including the sloped roof, facade, and upper levels, remained significant but were deemed of secondary urgency compared with the foundational vulnerabilities. It was therefore advisable to allocate resources primarily to the comprehensive assessment and repair of the basement to safeguard the structure's long-term integrity.

Atmospheric Moisture

The facade walls exhibited staining and detachment of surface finishes, attributable to environmental moisture and direct precipitation. These pathological changes were exacerbated by architectural features that promoted water accumulation and hindered effective drainage in localized areas of the facade. Further analysis was required to determine the adequacy of construction materials and the presence or absence of waterproofing measures. Primary physical damage was primarily caused by direct exposure of facade elements, the development of efflorescence, and persistent moisture infiltration. Secondary physical damage resulted from architectural designs that impeded proper rainwater drainage, insufficient preventive maintenance, or the implementation of suboptimal repair strategies [39].

Material sampling was conducted in the moisture-impacted sections of the wall to evaluate the absorptive properties of the construction materials and to ascertain the thickness of the applied render.

ening and disintegration of the masonry—could not be excluded. The fissures were predominantly vertical, originating at the floor and extending upward, with greater severity in zones with marked moisture ingress. A comprehensive crack-mapping campaign was undertaken, including precise measurements of crack width, length, and orientation. The spatial distribution and severity of these fissures were rigorously documented to elucidate primary etiological factors and inform the formulation of effective remediation strategies.

Results

Capillary Moisture Damage

The issue was identified as capillary moisture in the basement walls, caused by water rising from the ground. This process caused the finished material to peel and flake and produced unpleasant odors due to persistent moisture. Capillarity was observed as water was absorbed by the brick due to its inherent porosity (Figure 7).

Figure 7. Capillary Moisture

The pathological processes identified in the preliminary diagnosis were further delineated through material analysis to determine the extent of absorption in the affected materials. Soil samples were collected for geotechnical testing to establish the groundwater table. Based on the results of these analyses, the most suitable repair methods and mitigation strategies were identified, including selecting appropriate waterproofing systems, improving drainage around the building, and replacing compromised materials. This step facilitated the establishment of necessary resources, the prioritization of actions, and the creation of a realistic timeline for implementing repairs.

Damage Due to Absorption

The ceiling material on the fourth floor of the building absorbed water from a leak in the sloped roof; cracks in the roof tiles were attributed to material deterioration or structural movements caused by settlement. A comprehensive inspection was undertaken to determine whether the roof structure comprised timber or metal and to evaluate the extent of moisture-induced deterioration. A combination of visual inspections (to detect staining, warping, and visible damage), non-destructive moisture meter testing, and core sampling in discreet areas was employed to ascertain the condition and typology of the roof support structure. For settlement assessment, visual crack mapping was performed, crack meters and telltales were installed to monitor ongoing structural movement, and, where feasible, level surveys were conducted to identify differential settlements across the structure. These settlement examinations were essential for verifying the building's structural condition, especially given the absence of historical documentation [40].

A section of the ceiling was removed to identify the material of the roof support structure and to determine whether it was affected by moisture. Inspection of the entire building enabled assessment of additional cracks and determined whether the basement crack extended to the uppermost floor (Figure 8).

Figure 8. Moisture Due to Absorption

Damage Due to Water Infiltration

Moisture was observed on the third floor, where the slab lacked the requisite waterproofing, attributable to either a construction error or a design flaw. This condition caused expansion at the wall-slab joint, thereby facilitating rainwater infiltration into the exhibition halls. The brickwork absorbed infiltrated water due to its inherent porosity (Figure 9).

Figure 9. Moisture Due to Water Infiltration

A watertightness test was conducted on the fourth-floor slab to determine whether the moisture originated from rainwater infiltration or water used for floor maintenance, thereby confirming the absence of waterproofing. The test followed procedures outlined in industry standards, such as ASTM E514, which involved flooding the slab with water for a specified duration and monitoring the underside for signs of leakage or dampness. Prior to testing, drainage outlets were temporarily sealed, and observations were recorded at designated intervals to ensure a consistent and reliable assessment of waterproofing performance. A sample was taken from the moisture-affected wall to determine the degree of absorption of the wall materials and to establish the thickness of the plaster.

A moisture meter was employed to determine the moisture content of the materials. Additionally, analyses were conducted during both dry and rainy seasons to verify moisture behavior—specifically, whether it increased, decreased, or remained stable over time.

Damage Caused by Atmospheric Conditions

Due to the architectural design, certain areas allowed water to stagnate; this water penetrated the existing material, inducing moisture and detachment of the facade finish. It was also possible that the facade was not waterproof, a deficiency attributable either to a construction error or a design flaw (Figure 10).

Figure 10. Moisture Due to Atmospheric Conditions

The structure also exhibited deterioration of the wooden doors on the facades due to prolonged exposure to environmental factors, including sunlight and water. Studies were required to determine whether the wood used was suitable for outdoor application. Additionally, the structural design may not have adequately protected these elements. This study did not analyze the damage or pathological processes affecting the wooden doors and windows, as the scope was limited to moisture-related issues impacting structural and wall elements. The assessment of wooden doors and windows may be addressed in a subsequent phase of the project, contingent upon scope expansion and resource availability. Furthermore, a sample was collected from the moisture-affected wall area to determine the degree of absorption of the wall materials and to measure the plaster thickness.

Cracks in the Walls Due to Settlement

Cracks in the basement walls may have been caused by differential settlement of the building or by water rising due to capillary action or groundwater, resulting in swelling and subsequent cracking of the material. Settlement monitoring was undertaken to determine the condition of the structure. Crack gauges (crack meters) were installed across identified cracks in the basement walls to monitor crack width and progression over time. Additionally, periodic visual surveys and precise level surveys were scheduled to document any changes in elevation or new crack formations, thereby facilitating the identification of ongoing or new settlement. These monitoring activities were planned at regular intervals to ensure timely detection and intervention.

In the damp basement, measurements were taken with a crack meter to assess crack activity and dimensions. A soil study was conducted to determine the soil characteristics, groundwater table, and bearing capacity. Given that the basement exhibited cracks, it was essential to perform the structural analysis (Figure 11).

Figure 11. Crack Due to Settlement

Conclusions

The systematic diagnostic evaluation of the National Police Museum in Bogotá, Colombia, provides a definitive etiological roadmap for the interconnected moisture- and structural-related pathologies jeopardizing this cultural heritage site. By transitioning from macro-level visual inspections to high-resolution material and geotechnical characterization, this study successfully isolated distinct, localized moisture mechanics across the building's four levels.

The investigation yields several critical conclusions and forward-looking implications for historic preservation:

Prioritization of Foundational Vulnerabilities: The coexistence of capillary moisture ingress and vertical cracking in the basement poses the greatest risk to the structure's long-term stability. The absence of an original damp-proof course or subgrade isolation allows unhindered groundwater absorption through the highly porous historic brickwork, meaning remediation of this zone must take immediate precedence over aesthetic or upper-level repairs. Remediation should focus on installing a retrofitted physical damp-proof course using techniques compatible with heritage masonry, such as low-pressure injection of silane-based water repellents or, when feasible, installing a physical membrane at accessible wall junctions. Additionally, localized repointing with lime-based, moisture-tolerant mortars and the implementation of an internal perimeter drainage channel (French drain) at the basement slab can provide supplementary subgrade waterproofing and structural stabilization while respecting the integrity of the historic fabric.

Etiological Diversity of Moisture Ingress: While capillary action governs basement deterioration, upper-level defects are driven by distinct mechanisms. These include rainwater seepage from unwaterproofed vitrified tile slabs on the fourth floor and localized architectural drainage deficiencies causing atmospheric dampness on the exterior facades. This underscores that historical building pathology cannot rely on a single diagnostic assumption.

Methodological Framework Validity: The integration of non-destructive testing (e.g., infrared thermography and moisture meters) with invasive laboratory verification (e.g., core sampling and geotechnical water-table tracking) proved essential. This hybrid approach circumvents the limitations of equipment resolution and fluctuations in environmental data, establishing a reproducible blueprint for evaluating complex, heterogeneous masonry structures without causing extensive damage to the historic fabric. Moreover, methodology offers inherent adaptability: the selection and sequencing of diagnostic tools can be customized based on building typology, material composition, and site-specific climatic exposures. For example, in timber-framed buildings or structures in drier climates, alternative moisture-detection techniques and target areas can be emphasized to ensure the framework remains effective and relevant across diverse conservation contexts.

Broader Impact on Architectural Conservation: The evidence-based remediation framework and procedural guide generated from this study extend beyond the immediate needs of the Police Museum. By cleanly distinguishing between site-specific environmental variables (such as Bogotá's local water table and clay masonry properties) and universal engineering principles, this work serves as an adaptable diagnostic and maintenance manual for both heritage and contemporary structures globally facing severe rising damp.

Ultimately, executing the targeted, phased interventions outlined in this study will effectively arrest active degradation pathways, preserve the architectural legacy, and extend the operational lifespan of this invaluable national landmark. The recommended sequence of interventions is as follows: first, address subgrade waterproofing and structural stabilization by installing a retrofitted damp-proof course and improving basement drainage to halt groundwater ingress. Next, proceed with localized repointing of masonry using compatible lime-based mortars, and repair vertical cracks to reinforce areas affected by moisture and movement. Following these foundational actions, focus on remediating upper-level defects by improving roof slab waterproofing and correcting drainage deficiencies on exterior facades. Each phase should be implemented using minimally invasive techniques to protect the historic fabric, with careful documentation and monitoring to guide subsequent steps and avoid unnecessary intervention. This sequenced approach minimizes risk to the building's integrity while supporting effective project planning and long-term conservation outcomes.

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