ISSN 3023-5669 Journal of Material Characterization and Applications, Vol. **3**, No. 1, pp 1-16 (2025)
www.matcharappjournal.com
https://doi.org/10.5281/zenodo.15322241

EFFECTS OF CLIMATE CHANGE ON HISTORICAL BUILDING MATERIALS: ASSESSMENT AND SUSTAINABLE CONSERVATION SOLUTIONS

Özlem ÖZKAN ÖNÜR

University of İstanbul Nişantaşı, Faculty of Engineering and Architecture, Departman of Architecture, İstanbul, Turkey, ozlem.onur@nisantasi.edu.tr, ORCID ID: 0000-0002-4110-4936

Received 10 January 2025; revised 22 March 2025; accepted 17 April 2025

Abstract:
Climate change poses new and unexpected threats as a growing source of concern in the preservation of historic buildings, causing physical, chemical, and structural deterioration of the original materials of our cultural heritage. These deteriorations seriously threaten both the characteristic aesthetic values and structural integrity of historic buildings and require urgent intervention. The main objective of the study is to develop feasible, economically sustainable, and environmentally sensitive strategies to increase the resilience of historic buildings against climate change. These strategies aim to enhance their resilience against future climate change scenarios while preserving the original character of the buildings. Based on current data obtained from literature research, the effects of climate variability on historic building materials have been examined, and the deterioration mechanisms of these materials under different environmental conditions and their relationships with climate change have been evaluated. As a result of this evaluation, adaptable and sustainable conservation solutions for local conditions have been proposed to prevent or minimize deterioration. These proposed solutions create a holistic conservation strategy by combining the proven wisdom of traditional conservation methods with the innovative possibilities of modern technological approaches. The study aims to contribute to the healthy transmission of cultural heritage to future generations while preserving its authenticity by bringing innovative and sustainable approaches to existing conservation practices.

Keywords: Climate change, preservation, cultural heritage, historical building materials

1. Introduction

Historical buildings are tangible heritage that carry the architectural genius, rich cultural accumulation, and unique artistic expressions of past civilizations to the present day as one of humanity's most precious treasures [1]. The preservation of these structures is significant not only in terms of maintaining aesthetic beauty and cultural richness but also in ensuring the continuity of societies' collective memories and identities [2]. However, climate change has become one of the most important environmental factors threatening the preservation of historical buildings as an increasingly concerning source in recent years [3].

Climatic changes such as variations caused by global temperature rise, sudden and unexpected temperature fluctuations, increasingly intense precipitation patterns, prolonged drought periods, repeated freeze thaw cycles, and more frequent extreme weather events are significantly accelerating the wear and deterioration processes observed in historical building materials. These complex climatic changes are causing the proliferation of both physical and chemical damage in historical buildings, such as increasing rates of cracking, layer delamination, surface and structural erosion, biological deterioration caused by various microorganisms, and chemical dissolution triggered by atmospheric pollutants [4].

Understanding in greater detail the complex effects of climate change, developing resilient and sustainable preservation strategies against these effects, and adapting existing preservation methods according to current climate scenarios have now become an inevitable necessity for the long-term preservation of historical buildings, which are an important part of our cultural heritage, and their transmission to future generations [5]. This study aims to examine the effects of climate change on historical building materials and contribute to the development of sustainable preservation solutions for future generations by evaluating the results.

The effects of climate change on cultural heritage have been addressed by many international studies, especially in the last decade. The UNESCO (2016) report indicated that climatic changes such as temperature increases, extreme precipitation, and sea level rise have led to accelerated deterioration in historical monuments [6]. It has been demonstrated that historical building materials have become more vulnerable to increasing environmental stresses due to climate change, with porous stones suffering serious damage through mechanisms such as freeze thaw cycles, salt crystallization, and biological growth [7].

Research shows decomposition and erosion on stone surfaces [8], biological deterioration and decay in wooden structures [9], and crack formation due to water absorption in brick and mortar systems [10] in building materials exposed to climate change. Additionally, increased temperatures and moisture variations resulting from climate change cause structures to be exposed to thermal stresses and accelerate material fatigue [11]. All these studies emphasize that climate change related effects need to be considered not only in existing building stock but also in new materials used in restoration processes. Thus, it will be possible to develop sustainable preservation approaches and carry historical buildings into the future.

2. MATERIALS AND METHODS

In this study, a literature review method was used to evaluate the effects of climate change on historical building materials and examine the existing knowledge base. Within the scope of the research, peer reviewed scientific articles, technical reports, research projects, and on site field studies published at both national and international levels were thoroughly examined. In particular, the findings regarding the behaviors and deterioration processes of materials used in historical buildings against climate change were analyzed and evaluated.

The following steps were specifically followed within the scope of the study:

In the literature review, a comprehensive examination and evaluation of existing academic studies, publications, and resources related to the research topic was conducted.

- After evaluating material groups that constitute the basic components of the structure, such as stone, wood, brick, and mortar, the physical properties, durability, areas of use in the structure, and changes over time of each material were examined in detail.
- A classification of material deterioration arising from climate change was carried out, and the physical, chemical, and mechanical changes occurring in materials were evaluated based on the obtained data.

- Existing conservation practices were addressed from a sustainability perspective, and an assessment of conservation approaches was conducted.
- Existing conservation practices were examined in detail from a sustainability perspective and evaluated in terms of both environmental and cultural dimensions. During this evaluation process, current conservation strategies were determined by analyzing the effectiveness, applicability, and sustainability of conservation approaches.
- The data obtained from the study aims to examine the effects of climate change on historical building materials and create a general assessment framework for these effects. As a result of these analyses, significant insights were gained regarding the development and implementation of sustainable conservation strategies necessary for preserving historical structures, and a systematic approach was adopted accordingly.

2.1. Material Analysis

The basic building materials used in historical structures stone, wood, brick, metal, and mortar show different physical and chemical reactions when exposed to changing climate conditions [12]. Each of these materials requires a specialized examination approach due to their unique structural properties and responses to environmental factors. Therefore, it is of great importance to examine each material group separately and in detail, taking into account their specific characteristics [13].

In stone materials, the porosity structure and water absorption capacity are the fundamental factors that determine the material's durability and long term performance [14]. In wood, the natural fiber structure, orientation, and moisture sensitivity directly affect the material's dimensional stability and mechanical properties [15]. In brick, the firing degree and pore structure are critical parameters that determine the material's durability and water permeability [16]. The environmental effects brought by climate change on metals increased humidity, temperature fluctuations, and urban air pollution are causing unexpected rates of corrosion in metals within historical structures [17]. In mortars, parameters such as the type of binder used, mixture ratios, and mechanical strength properties are evaluated in detail. Each of these parameters significantly affects the long term performance of the material [18]. These analyses and evaluations reveal the materials' vulnerability levels and durability characteristics against different climatic stress factors. In this context, they play an important role in determining appropriate intervention methods for the preservation and restoration of historical structures.

2.2. Effects of Climatic Factors on Materials

Climate change brings with it a series of increasingly severe environmental changes that directly affect the preservation of historic buildings. These changes pose serious threats to the sustainability of our cultural heritage. While temperature increases lead to expansion and thermal stresses in building materials, this particularly affects the durability of traditional materials used in old buildings. Changes in precipitation patterns increase the severity of water related deterioration (such as surface erosion, salt crystallization, moisture accumulation, and material dissolution) and threaten the integrity of structures. Freeze thaw cycles cause recurring physical cracks and gradual material loss, especially in porous building materials (such as brick, natural stone, and mortar). The increasing frequency of these cycles can lead to irreversible damage in historic buildings. Increased wind effects can cause not only direct surface erosion but also surface contamination and long term material deterioration through dust and water transport. This presents a significant risk factor, especially for monumental structures in open areas. Additionally, biological growth (moss, fungi, and lichen formation) accelerates and becomes harder to control due to climate change. These organisms create both aesthetic visual pollution on building surfaces and cause structural deterioration. The acids and enzymes produced by microorganisms can alter the chemical structure of building materials, leading to difficult to reverse damage in the long term [19].

2.3. Detection of Deterioration Mechanisms

The types of deterioration occurring in historic building materials due to climate change must be systematically classified and examined in detail. In this context, mechanisms such as blistering and scaling caused by salt crystallization on material surfaces, micro and macro cracks resulting from thermal stresses due to daily and seasonal temperature changes, structural decomposition and spalling caused by freeze thaw cycles frequently seen in winter months, and chemical degradation processes caused by biological organisms such as various bacteria, fungi, and algae are thoroughly examined. The systematic documentation and regular monitoring of both qualitative characteristics and quantitative dimensions of these deteriorations is a crucial step in developing effective conservation and restoration strategies that will preserve the original texture of the structure.

2.4. Conservation Approaches

The comprehensive analysis of new conservation methods and adaptation strategies proposed in the literature, systematic examination of their applicability and effectiveness, evaluation in light of current developments in conservation science, and development of sustainable solutions are of great importance. This evaluation process includes examining current conservation practices from a sustainability perspective, synthesizing current research findings through a methodological approach, reviewing internationally accepted best practices, and developing evidence based recommendations for future conservation work. Additionally, comparative evaluation of adaptation strategies tested in different ecosystems, multi dimensional examination of these strategies' adaptability to local conditions, identification of implementation challenges and success factors, and development of action plans necessary to achieve sustainable conservation goals constitute an important part of this comprehensive analysis.

3. FINDINGS

Research findings on the effects of climate change on historic building materials demonstrate that various climatic changes lead to deterioration of different intensities and durations in material structure and durability. These effects cause changes in the physical and chemical properties of materials and threaten structural integrity. Climatic factors, particularly temperature increases, sudden and continuous fluctuations in humidity, unexpected changes in precipitation patterns, and strong winds, significantly accelerate the deterioration process of historic building materials and shorten the lifespan of structures. These deterioration processes result in significant changes in the texture, durability, and aesthetic appearance of building materials.

3.1. Effects of Climate Change on Historical Building Materials

3.1.1. Stone Materials

Natural stones commonly used in historical buildings are subject to serious deterioration processes due to various environmental factors resulting from global climate change. Extreme temperature changes, sudden freeze thaw cycles, and acid rain caused by atmospheric pollutants, which are among the primary factors, threaten the physical and chemical structure of stone materials. Particularly carbonate stones (such as limestone, marble, travertine) are exposed to accelerated chemical dissolution processes due to increased acidic precipitation, leading to surface erosion and losses, micro and macro level cracks, and eventually irreversible structural weakening. These deterioration processes directly affect the original texture and durability of historical buildings, making conservation work more complex and costly [20]. Various deteriorations and erosions occurring in stones due to acid rain are shown in Figure 1 and Figure 2. These images demonstrate the chemical and physical changes caused by acid rain on stone surfaces.

Figure 1. The effect of acid rain on stones [21-22]

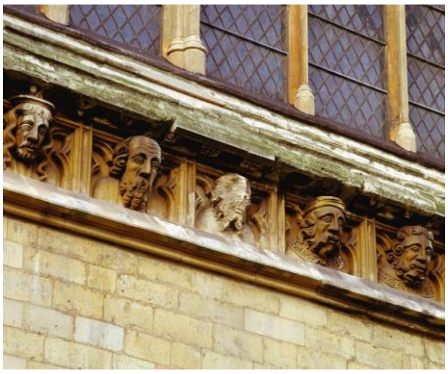

Figure 2. Damage to stonework caused by acid rain [23]

3.2. Wooden Materials

Wood is a natural building material that is extremely sensitive to changes in moisture content and biological degradation. Changes in environmental conditions, especially fluctuations in moisture levels, directly affect the structural integrity of wood. Temperature and moisture fluctuations increasing due to climate change lead to a series of adverse effects on wooden materials: causing the material to expand and contract, forming micro and macro level cracks, and making it more vulnerable to attacks from fungi and various harmful insect species. This situation can significantly reduce wood's natural durability. Additionally, frequently changing moisture balance can lead to serious deformations in wooden structural elements and critical weakening in load-bearing systems, which can jeopardize the long term stability of the structure [24].

3.2.1. Bending and Subsidence in Wooden Materials

As shown in Figure 3, serious deformation problems have emerged in the load bearing systems of wooden structures due to continuously changing temperature and moisture conditions. Under these challenging environmental conditions, the material properties of structural elements have changed over time, bending has begun in load bearing elements, and consequently, subsidence at various levels has occurred in different parts of the structure. This situation threatens the structural integrity of the building and requires immediate intervention.

Figure 3. Bending and sagging in wooden material [25].

3.2.2. Surface Deterioration and Cracking in Wooden Materials

Structural damage such as drying, cracking, and fiber dissolution occurring on wooden surfaces compromises the natural integrity of the material, significantly reducing the structure's resistance to weather conditions. As shown in Figure 4, such damage progressively increases over time, negatively affecting the structure's durability and service life.

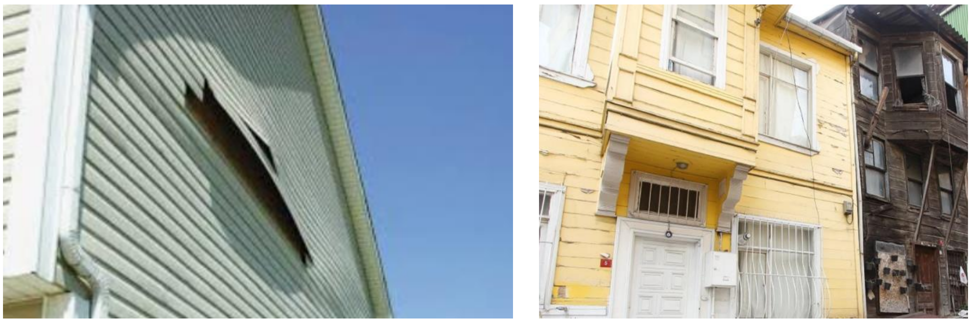

Figure 4. Deterioration on wooden surfaces [26]

3.3. Brick and Tile Materials

Traditional fired clay based brick and tile materials exhibit highly sensitive characteristics to water absorption and freeze thaw cycles due to their porous structure formed during the production process. The micro porous structure of these materials significantly affects their resistance to environmental impacts. As a consequence of climate change, increased severe rainfall, sudden temperature changes, and repeated freeze thaw cycles threaten the structural integrity of bricks, cause surface erosion, and lead to serious reduction in their mechanical strength over time. Additionally, chemical effects such as salt crystallization that building materials are exposed to can cause irreversible damage by leading to expansion and dissolution in the internal structure of bricks and tiles [22]. As shown in Figure 5, various deteriorations and damages that occur over time in building materials, specifically in bricks and tiles, are visually presented.

Figure 5. Deterioration in brick and tile materials [27]

3.4. Metals

Various metals used in historical buildings, such as iron, lead, copper, and similar materials, have critical importance across a wide range of applications from door hinges to window grilles, from exterior ornamental elements to roof coverings and structural support system components. Each of these metals contributes to both the aesthetic appearance and structural integrity of the building. Environmental changes brought about by climate change, particularly the increase in atmospheric humidity, extreme temperature fluctuations, and intensifying air pollution in urban areas, are triggering corrosion (rusting) processes on metal surfaces in historical buildings at an unprecedented rate. The most concerning aspect of this situation is the continuous increase in atmospheric carbon dioxide (CO_2) and sulfur oxide levels. The increasing concentration of these gases in the atmosphere creates conditions conducive to acidic precipitation, and consequently, renders the metal elements in historical buildings increasingly vulnerable to chemical degradation processes [28].

- Rusting in iron and steel elements weakens the internal structure of the material, leading to cross sectional losses. This situation can result in reduced load bearing capacity of the elements over time, decreased strength properties, and significant weakening of structural performance. Especially in areas exposed to moisture and salt effects, the rusting process can accelerate, reducing the strength of structural elements more rapidly than expected.
- In metals such as lead and copper, surface oxidation occurs due to atmospheric conditions, causing the material to thin over time. While the patina layer formed as a result of oxidation provides an aesthetic appearance, particularly in these metals commonly used in roof coverings and decorative details, it can threaten structural integrity by adversely affecting the physical properties of the material in the long term. The corrosion products formed on the surface of these metals are washed away by rainwater over time, leading to a progressive reduction in material thickness.
- The deterioration and loss of strength in metal connecting elements over time can threaten overall structural stability by weakening critical connections between different components of the structure. This situation can adversely affect the behavior of the structure particularly under earthquake, wind load, and other dynamic forces, potentially leading to irreversible damage in the long term. As shown in Figure 6, the metal material of window grilles has suffered serious structural damage due to corrosion, resulting from the wear and loss of structural integrity of

metal materials through chemical or electrochemical reactions under environmental factors. Wear, decay, and color changes have been observed on metal surfaces due to corrosion, significantly affecting the durability and functionality of the grilles.

Figure 6. Corrosion induced deterioration in metals [29]

3.5. Mortar and Plaster Materials

Lime based mortars and plasters used in historical buildings have a more porous structure compared to modern cement based materials and, due to these characteristics, exhibit much more sensitive behavior against water and moisture effects. The porous structure of these materials increases their interaction with external factors such as moisture and water, which threatens their structural integrity. As a result of climate change, the increase in atmospheric moisture content can cause serious damage to mortar and plaster layers. These damages include dissolution within the material, layer delamination, and loss of surface texture. Additionally, seasonal and daily temperature variations create thermal stresses in these sensitive materials. These thermal stresses can lead to the formation of micro cracks in the material structure over time, the growth of these cracks, and ultimately serious structural problems such as material detachment [30]. As shown in Figure 7, various damages in the mortar and plaster materials of buildings are illustrated. These damages manifest themselves as cracks, spalling, and decomposition observed on the wall surfaces of the buildings.

Figure 7. Deterioration in mortar and plaster materials [31].

4. ASSESSMENT OF RISKS AND DETERIORATION MECHANISMS

4. 1. Temperature Increase and Material Deterioration

Temperature increases have been observed to cause thermal expansion and contraction reactions in materials such as stone and wood. This situation leads to the weakening of structural bonds within the material, triggering crack formation. Additionally, moisture fluctuations resulting from temperature increases cause deterioration in stone structures due to salt deposits and freeze thaw cycles [32].

4.2. Changes in Precipitation Patterns

The increase in precipitation amount leads to serious damage and gradual weakening in the internal structure of porous building materials, particularly brick and stone, by increasing their water absorption capacity. This situation threatens structural integrity by negatively affecting the durability of materials. Furthermore, the increase in moisture levels accelerates material deterioration by causing wood surfaces to rot and promoting mold and fungal growth. This deterioration process leads to the weakening of wood's fibrous structure and significantly shortens the material's service life [33].

4.3. Biological Effects

Increasing moisture levels and temperatures associated with climate change promote the rapid multiplication and spread of various microorganisms and harmful biological organisms. These changing climate conditions accelerate the life cycles and expand the habitats of organisms that particularly thrive in humid and warm environments. Organisms such as fungi and algae easily settle and multiply on building material surfaces. These organisms form colonies particularly on wood and stone materials, gradually compromising their structural integrity, altering their physical and chemical properties, and consequently significantly reducing the durability of structures [34].

4.4. Wind and Erosion

Increased wind speeds create abrasive effects on the surfaces of historic stone and brick structures. This situation can cause serious damage to the exterior facades of historic buildings and threatens the original texture of the structure. Its impact is further increased by wind carried dust, sand, and other particles, causing a continuous erosion process on building surfaces. In particular, erosion occurring on stone material surfaces compromises material integrity and threatens the structure's stability in the long term. This erosion process weakens the mineralogical structure of stones, causes micro cracks to form, and can lead to serious damage including the detachment of stone blocks from the surface over time. This situation poses significant risks not only aesthetically but also in terms of structural integrity [35].

4.5. Social and Economic Effects

The effects of climate change create multifaceted social and economic challenges in the preservation of historic buildings. These challenges seriously affect both local governments and cultural heritage experts. Increasing repair costs, unexpected increases in building maintenance requirements, and restoration processes taking longer than planned make sustainable preservation of historical heritage increasingly complex. Particularly sudden weather events and environmental changes caused by climate change necessitate the reassessment of traditional methods used in preserving historic buildings [36].

5. SUSTAINABLE PRESERVATION SOLUTIONS

5.1. Stone Preservation Methods

Waterproofing Applications: Specially developed waterproof plasters or protective chemicals are used to protect stone structures against water. These applications ensure the structure's longevity while preventing moisture and water related damage.

Mineral Based Surface Protection: Mineral based protectors that don't alter the stone's natural structure and appearance are applied to stone surfaces. While these protectors allow the stone to breathe, they also provide protection against wear from external factors. These products, specially formulated to preserve the natural appearance, maintain the stone's original texture.

Sandblasting or Surface Cleaning: Enhances material durability by thoroughly cleaning surface dirt, old coatings, and deposits. This process reveals the stone's original appearance while ensuring more effective application of new protective coatings.

Surface Consolidants: A protective coating can be applied to the surface to increase the stone material's durability. These consolidants strengthen the stone's porous structure, increasing its resistance to wear from external factors and extending its lifespan.

5.2. Wood Preservation Methods

Insecticide and Fungicide Applications: Insecticides and fungicides can be applied to wooden surfaces against pests. These chemicals ensure the wood's longevity and preserve the structure's integrity by preventing various harmful organisms from damaging the wood.

Wood Protective Paints and Varnishes: Water resistant varnishes and protective paints are typically used to make wood resistant to external factors. These materials form a protective layer on the wood's surface, providing protection against UV rays, rain, snow, and other weather conditions.

Wood Polish and Oils: This method prevents water penetration while preserving wood's natural appearance and prevents issues like cracking and drying. Natural oils deeply penetrate wood fibers, providing both protection and enhancing wood's texture and color.

Heat Treatment and Drying: When wood is dried and heated, it becomes unsuitable for insects and fungi. During this process, the wood's moisture content is reduced in a controlled manner, and high temperature treatment transforms it into a structure where microorganisms cannot survive.

5.3. Metal Preservation Methods

Galvanization: Zinc coating is applied to prevent rusting of metals like steel and iron. During this process, the metal surface is first cleaned, then a zinc layer is applied through an electrochemical process or hot dip method. Zinc coating extends the metal's lifespan by creating both a physical barrier and providing cathodic protection. This method is commonly preferred for outdoor metal structures, bridges, poles, and barriers.

Painting: Protective paints applied to metal surfaces increase the material's resistance to rust and other environmental effects. These paints form a protective layer by adhering to the metal surface and act as a barrier against harmful effects of moisture, sunlight, and chemicals. This method, commonly preferred for protecting outdoor metal structures, significantly extends metal's lifespan through regular maintenance and repainting when necessary.

Lubrication and Anti Corrosive Sprays: Specially formulated sprays or oils are applied to metal surfaces to prevent oxidation and rusting. These products create a protective film layer on the metal surface, preventing contact with moisture, salt, and other corrosive substances. This application, an important part of regular maintenance, is frequently used on moving metal parts, machine components, and sensitive metal surfaces. The lubrication process also prevents metal part wear by reducing friction.

Hot Dip Galvanizing: This is the process of immersing metal material in a molten zinc bath at high temperature. In this method, the metal surface first undergoes chemical cleaning processes and is then immersed in a zinc bath at approximately 450°C. During immersion, a metallurgical bond forms between the metal surface and zinc, providing superior resistance against rust, corrosion, and other external factors. This protection method is widely used in preserving construction steel, steel construction elements, and industrial equipment.

5.4. Adobe and Brick Preservation Methods

Maintaining High Contact Areas: Preventing water transfer between the foundation and ground of adobe structures is critically important for the building's longevity. To break ground contact, waterproofing layers (such as concrete or stone pavements) may need to be added under the walls. These layers enhance the strength and durability of adobe walls by protecting the building's foundation from moisture and water damage.

Ground Protection: Adobe walls can absorb moisture when in direct contact with soil, which can compromise structural integrity. Therefore, the ground around adobe structures should be graded to properly divert water away. Additionally, supplementary measures such as drainage channels and gravel fill can be added around the structure to effectively remove rainwater.

Exterior Insulation: Waterproof coatings can be applied to the outer surface of adobe walls. These coatings can be made from natural materials (for example, clay, cement, lime mortar) and should be renewed with regular maintenance. The use of natural materials provides an environmentally conscious approach while allowing the building to breathe.

Oil and Natural Coatings: Lime plasters are applied to protect the outer surface of adobe walls. While lime expels moisture, it also increases the durability of the structure. These plasters should be periodically inspected and renewed when necessary. The use of natural lime plasters both preserves the aesthetic appearance of the structure and provides long-term protection.

Vegetable Oils or Waxes: Applying natural vegetable oils or waxes to adobe surfaces prevents moisture absorption and ensures longevity. When applied at regular intervals, these natural preservatives increase the water resistance of adobe walls and add an extra layer of protection while maintaining the surface's natural appearance.

Protection Against Insects and Pests: Adobe structures can occasionally be invaded by insects and pests. Protection against such threats can be provided through organic pesticides or natural substances. Regular inspections and preventive maintenance practices minimize the damage that pests can cause to the structure. An environmentally friendly protection approach can be adopted by using natural insect repellents and plant extracts.

6. CLIMATE RESILIENT RESTORATION TECHNIQUES

Keeping Contact Areas Elevated: Preventing water transfer between adobe structures' foundation and ground is crucial for the structure's longevity. To break ground contact, waterproofing layers (such as concrete or stone pavements) may need to be added under walls. These layers enhance adobe walls' stability and durability by protecting the foundation from moisture and water damage.

Ground Protection: Adobe walls can absorb moisture when in direct contact with soil, compromising structural integrity. Therefore, the ground around adobe structures should be sloped to effectively divert water. Additionally, drainage channels and gravel fill can be added around the structure to ensure effective rainwater removal.

External Surface Insulation: Waterproof coatings can be applied to adobe walls' external surfaces. These coatings can be made from natural materials (such as clay, cement, lime mortar) and should be renewed with regular maintenance. Using natural materials provides an environmentally conscious approach while allowing the structure to breathe.

Oil and Natural Coatings: Lime plasters are applied to protect adobe walls' external surface. While expelling moisture, lime also increases the structure's durability. These plasters should be periodically inspected and renewed when necessary. Using natural lime plasters both preserves the structure's aesthetic appearance and provides long-term protection.

Vegetable Oils or Waxes: Applying natural vegetable oils or waxes to adobe surfaces prevents moisture absorption and ensures longevity. When applied regularly, these natural protectors increase adobe walls' water resistance and add an extra protection layer while preserving the surface's natural appearance.

Protection Against Insects and Pests: Adobe structures can occasionally be invaded by insects and pests. Against such threats, protection can be provided with organic pesticides or natural substances. Regular inspections and preventive maintenance practices minimize damage that pests can cause to the structure. An environmentally friendly protection approach can be adopted using natural insect repellents and plant extracts.

Water and Moisture Insulation (Hydrophobic Protection)

- Increased precipitation due to climate change raises the risk of moisture and water leakage. Particularly, the increasing frequency of sudden weather events and heavy rainfall makes the need for water and moisture insulation in buildings even more crucial. Insufficient insulation can threaten the structural integrity of buildings and cause moisture-related damage to interior spaces. Therefore, implementing an effective hydrophobic protection system is critical for ensuring the longevity of structures.
- Waterproof exterior coatings are applied using silicon based solutions and nano technological hydrophobic materials. These coatings create a protective layer on the building's exterior surface,

preventing rainwater penetration while allowing the building to breathe. The application process is carried out in layers by professional teams after detailed cleaning and preparation of the surface.

- Foundation insulation provides protection against groundwater. This process is carried out using waterproofing membranes, drainage boards, and special insulation materials at the building's foundation level. Proper application of foundation insulation prevents groundwater from seeping into the structure, preventing moisture and dampness problems and ensuring the long term durability of the building's load bearing system.
- Roof drainage systems are crucial for effectively removing rainwater from the building. These systems collect water from the roof surface through gutters and safely convey it to ground level via downspouts. Additionally, proper sizing of gutter sections and downspouts ensures water drainage without overflow even during heavy rainfall. Regular maintenance and cleaning of all these components is essential for the system's efficient operation.
- Wall coverings are renewed with natural materials, particularly lime plaster. These traditional materials have a microporous structure that allows the building to breathe. The use of natural materials both optimizes the water vapor permeability of walls and provides effective resistance against water and moisture from the external environment. Additionally, these materials contribute to sustainable building practices with their environmentally friendly properties and positively affect the indoor air quality of the building.

Wind and Erosion Resistance

- Building surfaces can experience wear and deterioration over time due to wind-carried sand particles and heavy rain. This phenomenon is particularly noticeable in areas exposed to wind.
- Specially developed coatings are preferred to provide resistance against wear. These include mineral based plasters, silicone enhanced coatings, and special protective paints. These materials extend the lifespan of building surfaces and reduce maintenance requirements.
- Various architectural elements are used to protect building facades from external factors. These include wide eave extensions, movable or fixed shutters, sun breakers, and rain shields. These protective elements both extend the life of the building and contribute to energy efficiency.
- It is possible to reduce wind effects through natural solutions. Wind direction and intensity can be controlled particularly through vegetation arrangements and strategic tree planting. For example, windbreaks created around the building provide both protection and offer an aesthetically pleasing landscape appearance.

Protection Against Freeze Thaw Cycles

- By using freeze resistant special mortars and surface coatings, damage to the structure in cold weather conditions is prevented and its longevity is ensured.
- By installing effective water drainage systems on building surfaces, rainwater and snow melt are quickly diverted away from building walls and prevented from accumulating, thus avoiding moisture related damage.
- Through thermal treatment applied to wooden building materials (enhancing material durability and lifespan through controlled high temperature heat treatment), they are made more resistant to external weather conditions.

Climate Adaptation in Material Selection

- Each building should be repaired with materials suitable for its climate because different climate conditions affect building materials in different ways, and choosing the right materials extends the building's lifespan.
- In humid regions, vapor permeable, water repellent coatings are selected. This prevents moisture accumulation, inhibits mold and fungus formation, and allows the building to breathe.
- In dry climates, elastic mortars are preferred to prevent cracking and melting. In these regions where temperature differences are high, special attention must be paid to the expansion and contraction properties of materials.
- The use of local materials both adapts to the climate and preserves the building's originality. Furthermore, since local materials are compatible with the region's traditional construction techniques, they facilitate maintenance and repair operations in the long term and reduce costs.

7. CONCLUSION

Climate change is creating deep and lasting effects on the preservation of historical buildings. Climatic factors resulting from global warming, such as increasing temperatures, changing precipitation patterns, continuous fluctuations in humidity levels, and intensifying winds, are significantly accelerating the deterioration rate of building materials that form the foundation of historical structures. This rapid deterioration process is particularly observed in traditional building materials such as stone, wood, and mortar, posing serious threats to the structural integrity of historical buildings. These findings, obtained through research and field observations, clearly demonstrate the need to develop new and comprehensive preservation strategies to ensure the sustainability of traditional building materials, preserve the original character of historical buildings, and support their transmission to future generations.

In response to the growing impacts of climate change, traditional and modern materials used in the restoration and preservation of historical buildings, along with application techniques, need to be comprehensively reviewed. The integration of current materials science research and innovative biotechnological developments into the field of conservation is crucial for making traditional materials more resistant and durable against changing climate conditions. During this integration process, improving the physical and chemical properties of materials and increasing their resistance to moisture and temperature changes should be among the priority objectives. Additionally, the use of environmentally friendly materials with low carbon footprints and the adoption of long-term sustainable preservation strategies are critically important to mitigate the negative effects of climate change on structures and leave a sustainable heritage for future generations.

For the long term preservation of historical buildings, detailed and sustainable conservation and restoration plans, specially adapted for each structure, must be developed with climate change in mind. During the preparation of these plans, the architectural features, historical value, and current condition of the structure should be comprehensively evaluated and documented. The success of preservation efforts depends on the implementation of regular monitoring and periodic maintenance programs. These plans should include a holistic approach that considers not only material and building physics but also environmental factors and biological effects. In particular, risk factors such as moisture control, temperature variations, air pollution, and natural disasters, as well as the potential effects of microorganisms and harmful organisms on the structure, should be examined in detail and necessary precautions should be taken. Additionally, future threats should be anticipated and protective measures developed by considering the geological characteristics of the building's location and urban transformation plans.

In conclusion, regulations and innovative approaches that take into account the effects of climate change in the preservation of historical buildings will ensure the healthy transmission of our cultural heritage to future generations. For the sustainable preservation of these valuable works, changes in atmospheric conditions, extreme weather events, and environmental factors should be carefully evaluated, and preservation strategies should be shaped accordingly. A multidisciplinary approach should be adopted in this process, ensuring collaboration between architects, restorers, environmental engineers, and conservators, and sustainable solutions specific to each structure should be developed by considering local climate, topography, and material characteristics.

REFERENCES

[1] C. İ. Gençer, Kültürel mirasın korunmasında iklim değişikliğinin oluşturduğu tehditler. Mimar.ist, 1, 24–31 (2017).

[2] B. Şener, İklim değişikliği ve tarihi çevre. Mimar.ist, 32–39 (2017).

[3] M. D. Yılmaz, Hava kirliliği ve iklim değişikliği tarihi eserlere de zarar veriyor. Anadolu Ajansı. (2023). https://www.aa.com.tr/tr/yesilhat/iklim-degisikligi/hava-kirliligi-ve-iklim-degisikligi-tarihi-eserlere-de-zarar-veriyor/1821950.

[4] D. Loctier, & M. C. Yılmaz, İklim değişikliğinin kültürel miras olan tarihi eserler üzerindeki etkileri neler? Euronews (2018).

[5] C. Daly, Climate change and the conservation of cultural heritage: A review of impacts and implications. The Historic Environment: Policy & Practice, 5(3), 228–240 (2014).

[6] UNESCO, UNEP, & Union of Concerned Scientists. (2016). World heritage and tourism in a changing climate. United Nations Environment Programme.

[7] M. A. Lacasse, An overview of durability and climate change of building components. Canadian Journal of Civil Engineering, 46(11) (2019).

[8] Y. Eren, Genel jeoloji: Ayrışma ve erozyon. Slideum. (2012).

[9] S. N. Kartal, Tarihi ahşap yapılarda biyotik/abiyotik bozunmalar ve koruma/bakım önlemleri. Restorasyon ve Konservasyon Çalışmaları Dergisi, 16, 51–58 (2016).

[10] Encapsulations Down Under. How climate change is impacting building integrity. https://www.encapsulationsdownunder.com/blog/how-climate-change-is-impacting-building-integrity/.

[11] S. S. Assefa, D. G. Fikremariam, The impact of climate change on heritage buildings: A review. Journal of Building Engineering, 44, 102570 (2021).

[12] M. L. Sousa, S. Dimova, A. Athanasopoulou, G. Rianna, P. Mercogliano, V. Villani, M.Nogal, H. Gervasio, L. Neves, E. Bastidas-Arteaga, & G. Tsionis, Expected implications of climate change on the corrosion of structures. EUR 30303 EN, Publications Office of the European Union (2020).

[13] LISUN Group. Sıcaklık ve nemin malzeme yorgunluğu üzerindeki etkisinin çevre odaları ile değerlendirilmesi. https://tr.lisungroup.com/haber/teknolojik-Haberler/S%C4%B1cakl%C4%B1k-ve-nemin-malzeme-yorulmas%C4%B1-%.

[14] A.D. Öcal, & M. Dal, Doğal taşlardaki bozunmalar (2016).

[15] L. Reinprecht, Biological degradation of wood. In Wood Deterioration, Protection and Maintenance, Wiley (2016).

[16] C. J. Tait, F. M. Khalaf, A. Kermani, Review of water ingress characteristic of stressed masonry. Journal of Materials in Civil Engineering, 13(5), 332–339 (2001).

[17] Savfer Metal. (n.d.). Tarihi yapıda demir malzemenin korunma ilkeleri. https://savfer.com/tarihi-yapida-demir-malzemenin-korunma-ilkeleri/.

[18] M. Açıkgenç, M. Karataş, Z. Ç. Ulucan, Elâzığ yöresine ait atık tuğla ve kireç taşı tozunun kendiliğinden yerleşen harcın mühendislik özelliklerine etkisi. Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 19(6), 249–255 (2013).

[19] Y. Guo, & M. Li,. Climate change and the conservation of cultural heritage buildings: A review of strategies and approaches. International Journal of Architectural Heritage, 12(5), 728-748 (2018).

[20] J. F. Petersen, D. Sack, & R. E. Gabler, Fundamentals of physical geography, 292–293 (2010).

[21] https://scied.ucar.edu/image/acid-rain-damage.

[22] https://pubs.usgs.gov/gip/acidrain/5.html.

[23] https://fineartamerica.com/featured/2-acid-rain-damage-to-stonework-martin-bondscience-photo-

library.html
[24] R.E. Ibach, (2013). Biological properties of wood. Handbook of Wood Chemistry and Wood Composites, 2, 99–126 (2013).
[25] Ö. Yılmaz Karaman, & M. Tanaç Zeren, Geleneksel Türk konutunda kullanılan ve kâgir sistemi destekleyen ahşap yapısal elemanların önemi ve bozulma nedenleri (Ahşabın önemi ve bozulma sorunları, duvar sistemi içindeki destek elemanları, geleneksel Türk evleri). DEÜ Mühendislik Fakültesi Fen ve Mühendislik Dergisi, 12(2), 75–87 (2010).
[26]https://empowerwomen.create.vista.com/tr/unlimited/stock-photos/406154610/stock-photo-red-brick-wall-real-wall-old-brick-house-close/
[27]https://www.google.com/search?q=tarihi+AF+cephe+%BCzey+Bozulm1+ve&a.
[28] M. Bouchar, P. Dillmann, & D. Neff, New insights in the long term atmospheric corrosion mechanisms of low alloy steel reinforcements of cultural heritage buildings. Materials, 10(6), 670 (2017).
[29] Ö. Özkan Önür, & Ö. Yerli, Yerli, Sivil mimarlık örneklerinden Ayşe Sezgin Evi'nin restorasyonu, Mimarlık, Planlama ve Tasarım Alanında Araştırma Makaleleri, Gece Kitaplığı Yayın Evi, Kitap Bölümü, Yayıncı Sertifika No: 15476 (2022).
[30] ASTM International. (2022). Standard test method for rate of water absorption of masonry mortars ASTM C1403-22a.
[31] https://www.google.com/search?q=tarihi+yapıların+harç+ve+sıva+bozulması&.
[32] C. M. Grossi, & P. Brimblecombe, Effect of long term climate change on historic buildings. Building Research & Information, 35(5), 570–576 (2007).
[33] D. Camuffo, Microclimate for Cultural Heritage: Conservation, Restoration, and Maintenance of Indoor and Outdoor Monuments (2019).
[34] R. A. Blanchette, T. Nilsson, G. Daniel, & A. Abad, Biological degradation of wood. In R. M. Rowell & R. J. Barbour, Advances in Chemistry Series, 225, 141–174 (1990).
[35] P. Brimblecombe, Climate Change and Museum Collections of Historic Buildings and Their Contents, Routledge. 33–45 (2014).
[36] Traditional Building Historic preservation's response to climate change. https://www.traditionalbuilding.com/opinions/restoration-resiliency-climate-change.