

Ways to Address Physicochemical Damage in Earthen Historical Buildings

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Abstract

The preservation of earthen historical buildings is a critical concern in the field of cultural heritage conservation. Over time, these buildings face a variety of challenges, including physicochemical damage caused by environmental factors such as temperature fluctuations, humidity, rainfall, and air pollution. This paper explores the methods and techniques for mitigating physicochemical damage to earthen structures. It discusses the mechanisms of deterioration, such as moisture absorption, salt crystallization, and soil erosion that primarily affect mud brick and adobe constructions. Additionally, the article highlights innovative preservation techniques, including the use of biological and chemical treatments, reinforcement materials, and protective coatings to enhance the durability and structural integrity of earthen buildings. The study further emphasizes the importance of sustainable practices in the conservation of these structures, considering both traditional methods and modern technologies. It aims to provide a comprehensive guide to engineers, architects, and conservation specialists in their efforts to protect earthen historical sites from further deterioration.

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Introduction

Earthen buildings, constructed from materials like mud, clay, and straw, represent some of the oldest and most culturally significant architectural forms in the world. These structures, which have been used for millennia across various regions, are not only important for their historical value but also for their sustainable nature. As the global focus shifts towards environmental conservation, earthen architecture offers insights into creating low-impact buildings that work in harmony with nature. However, earthen buildings are particularly vulnerable to damage from environmental factors like moisture, temperature fluctuations, and biological growth, making preservation efforts critical. This challenge requires a multidisciplinary approach that combines traditional construction knowledge with modern conservation techniques to ensure these buildings' long-term survival.

The preservation of earthen buildings presents a unique set of challenges, largely due to the inherent characteristics of the materials. Unlike more durable construction materials like stone or concrete, earthen materials are susceptible to deterioration over time, especially when exposed to extreme weather conditions such as rain or excessive heat. The moisture absorption, salt crystallization, and erosion that can occur in earthen structures can weaken their structural integrity and lead to irreversible damage. Additionally, biological growth such as mold, algae, and lichen can accelerate the decay of earthen surfaces. The urgency of protecting these structures from further damage is clear, and this necessitates the adoption of both traditional methods and modern technologies to safeguard their authenticity while enhancing their durability.

Recent advancements in conservation science have led to the development of various techniques to address the challenges of preserving earthen buildings. These methods range from biological treatments that protect against the growth of harmful microorganisms to chemical stabilizers that strengthen the structure and improve its resistance to weathering. Moreover, modern reinforcement materials, such as geopolymers and synthetic fibers, have been integrated into restoration projects to enhance the structural integrity of earthen walls without compromising their aesthetic or cultural value. However, it is crucial that conservation efforts respect the traditional craftsmanship that makes earthen buildings unique. As such, the integration of modern materials must be done carefully to maintain the cultural heritage of these structures.

The sustainable conservation of earthen buildings also involves a commitment to environmental responsibility. As these buildings are often located in areas with limited resources, it is important that the methods used to conserve them do not further deplete the environment. For example, the use of eco-friendly treatments and locally sourced materials can significantly reduce

the carbon footprint of restoration projects. In addition, the involvement of local communities in the conservation process ensures that traditional knowledge and practices are preserved, creating a sense of ownership and fostering a long-term commitment to maintaining these structures. This holistic approach to conservation not only ensures the protection of earthen buildings but also contributes to the sustainability of local communities and the surrounding environment.

1. An Insight into Earthen Buildings

1.1. Overview of Earthen Buildings in Historical and Cultural Contexts

Earthen buildings, constructed primarily using natural materials such as mud, clay, straw, and sometimes stone, have been a staple of architecture for thousands of years. These structures can be found across many parts of the world, particularly in arid and semi-arid regions where these materials are abundantly available. Historically, mudbrick, adobe, and cob construction methods have been utilized to create homes, religious buildings, fortifications, and communal spaces. Earthen buildings often reflect the unique cultural, environmental, and technological advancements of their time, making them valuable cultural heritage assets. In many places, earthen construction techniques have been passed down through generations, often modified by local traditions and available resources.

1.2. Significance of Preserving Earthen Architecture for Heritage and Identity

The preservation of earthen architecture is vital for maintaining a connection to the past. These buildings hold great cultural significance, as they often represent the living conditions, craftsmanship, and societal structures of past civilizations. Many earthen buildings are key to a community's identity, serving as physical manifestations of their history and traditions. Moreover, they provide insight into the development of building techniques, local economies, and regional adaptations to the environment. Preserving these structures is not just about maintaining old buildings; it's about safeguarding intangible cultural heritage, such as knowledge of traditional craftsmanship and construction methods that have been honed over centuries. Without proper preservation, much of this heritage may be lost to time and natural degradation.

1.3. Sustainability of Earthen Architecture

Earthen buildings are often celebrated for their sustainability, as the materials used are abundant, renewable, and require minimal processing. The thermal properties of earthen structures—such as their ability to regulate temperature and provide natural insulation—make them environmentally friendly, reducing the need for energy-intensive heating and cooling systems. As global awareness of environmental sustainability increases, the principles of earthen construction are being revisited, particularly in the context of eco-friendly architecture. Preserving

these buildings thus not only serves cultural and historical purposes but also aligns with modern efforts to promote sustainability in the built environment.

1.4. Challenges in Preserving Earthen Buildings

Despite their many benefits, earthen buildings face significant challenges when it comes to preservation. These structures are highly vulnerable to environmental factors, including moisture, temperature extremes, and salt crystallization, which can degrade the materials over time. Unlike more modern building materials such as brick, concrete, and steel, earthen materials are less durable and require more maintenance to withstand weathering. In regions where earthen buildings are prevalent, conservation efforts must carefully balance the need for restoration with the need to maintain the authenticity of the structures. Finding sustainable, effective methods for the preservation of earthen buildings remains one of the foremost challenges in heritage conservation today.

2. Physicochemical Deterioration Mechanisms

2.1. Detailed Explanation of the Physicochemical Factors that Cause Damage to Earthen Structures

Earthen buildings face a variety of physicochemical deterioration mechanisms that threaten their structural integrity and longevity. One of the primary causes of degradation is moisture absorption, which can weaken the materials over time. When earthen walls absorb moisture from rain or high humidity, the structure becomes more susceptible to physical changes such as cracking, erosion, and the disintegration of the materials. Salt crystallization is another common problem for earthen buildings, particularly in regions where salts are present in the soil or groundwater. As moisture evaporates from the walls, the salts that are dissolved in the water crystallize, exerting pressure on the surface and leading to the flaking and detachment of layers. These processes, when repeated over time, can significantly reduce the strength and durability of the building.

2.2. Chemical Reactions with Air Pollutants

In addition to moisture-related damage, earthen buildings are susceptible to chemical reactions with pollutants in the air. Pollutants such as sulfur dioxide (SO₂), nitrogen oxides (NO_x), and ozone can combine with water in the air to form acidic compounds. These acidic substances can react with the minerals in earthen materials, causing chemical weathering, dissolution, and surface corrosion. Over time, this leads to the weakening of the structural bonds within the building's walls and foundation. The acidity may also contribute to the erosion of decorative or painted surfaces, causing a loss of aesthetic value in addition to structural degradation.

2.3. Impact of Temperature Fluctuations on Earthen Materials

Temperature fluctuations are another major contributor to the degradation of earthen buildings. Unlike materials such as stone or concrete, earthen materials are more sensitive to rapid changes in temperature. Extreme heat can cause the moisture within the building's walls to evaporate quickly, leading to cracking and shrinkage. On the other hand, freezing temperatures can cause water that has infiltrated the walls to freeze, expand, and create additional cracks. The thermal expansion and contraction caused by these fluctuations can exacerbate the damage over time, particularly in regions where seasonal temperature changes are extreme.

2.4. Impact of Rainfall and Humidity

The presence of rainfall and humidity in the environment plays a major role in the physicochemical deterioration of earthen buildings. Rainwater can directly penetrate the walls, particularly if the building lacks proper waterproofing or drainage systems. This moisture can lead to erosion, especially if the building's surfaces are exposed to heavy rainfall over an extended period. In addition, high humidity levels can accelerate salt crystallization, as moisture in the air interacts with salts in the earthen material. The combination of rainwater and humidity can promote mold growth and other forms of biological deterioration, further compounding the damage. Proper moisture management and protective coatings are essential to preventing the impact of these environmental factors.

3.Types of Damage to Earthen Buildings

3.1. Specific Damages Related to Mudbrick, Adobe, and Other Earthen Materials

Mudbrick, adobe, and other earthen materials, while offering sustainable and eco-friendly construction options, are inherently vulnerable to various forms of damage. One of the primary types of damage these buildings face is structural weakening. Over time, repeated exposure to moisture, especially from rain or humidity, can cause the materials to lose their original cohesion, leading to the disintegration of the structure. Mudbrick and adobe walls often absorb moisture from the environment, weakening the integrity of the structure. As a result, the walls become more fragile and prone to collapse, particularly when they are exposed to fluctuating environmental conditions like wet and dry cycles or freezing temperatures. In the worst cases, the entire building may suffer from significant instability.

3.2. Surface Cracking and Erosion

Another major type of damage to earthen buildings is surface cracking, which occurs due to the absorption of water and subsequent evaporation. When earthen materials absorb moisture, they expand; however, when the water evaporates, the material contracts, leading to cracks. These cracks can further compromise the structural integrity of the building and allow more moisture to penetrate deeper into the walls, accelerating the deterioration process. Over time, these cracks may

widen and lead to erosion, where the top layers of the material are worn away by the action of water, wind, or human activity. Erosion also occurs when salts present in the soil or groundwater crystallize on the surface, exacerbating the wear and tear of the material. This damage not only affects the appearance of the building but also compromises its structural load-bearing capacity.

3.3. Salt Crystallization Damage

Salt crystallization is a particularly insidious form of damage that affects earthen buildings, especially in regions with high levels of salt in the soil or groundwater. When moisture evaporates from the walls of earthen buildings, salts dissolved in the water crystallize at the surface. These salt crystals expand, creating pressure on the material and causing it to flake off, a process known as efflorescence. This can result in the gradual disintegration of the earthen surface, making it brittle and prone to crumbling. The formation of salts can lead to significant degradation over time, especially if the crystallization process is repeated in cycles. Salt-induced damage is particularly problematic because it often goes unnoticed until it has caused substantial structural damage.

3.4. Impact of Biological Growth on Earthen Structures

In addition to physical and chemical damage, earthen buildings can also suffer from biological growth such as mold, algae, and moss. These organisms thrive in damp and humid environments, and they can grow on the surfaces of earthen walls if the building is not properly protected from moisture. The growth of mold or algae can cause the earthen material to soften and become unstable. In some cases, the biological growth may penetrate the surface of the walls, causing further internal degradation. Mold growth is particularly concerning because it can also present health risks to the occupants of the building. Biological damage accelerates the deterioration of earthen buildings, especially in climates with high humidity or rainfall.

3.5. Impact of Temperature Fluctuations on Earthen Materials

Temperature fluctuations can also contribute to the damage of earthen buildings, as they cause the materials to expand and contract. Mudbrick and adobe materials are particularly susceptible to this thermal stress. During periods of intense heat, the moisture content in the material evaporates quickly, causing the walls to shrink and crack. Conversely, during cold weather, the moisture that has seeped into the walls can freeze, causing the material to expand and further crack. These fluctuations, over time, create a cumulative effect that weakens the structure, particularly when the earthen material has not been properly protected or reinforced. Thermal stress is especially damaging in regions where daily or seasonal temperature swings are extreme.

3.6. Long-Term Effects of Continuous Exposure to Harsh Conditions

The long-term exposure of earthen buildings to harsh environmental conditions, such as prolonged rain, extreme heat, and freeze-thaw cycles, leads to cumulative damage that worsens

over time. In many cases, earthen buildings are built in areas where the climate exacerbates their vulnerability, such as regions with heavy rainfall or frequent droughts. Continuous exposure to such conditions can cause earthen materials to degrade beyond repair, leading to complete collapse in some cases. The gradual accumulation of moisture, biological growth, salt crystallization, and thermal stress creates a vicious cycle of damage that, without proper intervention, results in the total loss of the structure's integrity. The long-term effects of this continuous exposure are often irreversible, making it critical to intervene early to prevent such deterioration.

4. Methods for Addressing and Mitigating Damage

4.1. Introduction to Various Biological Treatments

To address the damage caused by moisture, biological growth, and other environmental factors, several biological treatments can be used to preserve earthen buildings. One of the most effective methods involves the use of natural biocides that are derived from plants, fungi, or other naturally occurring substances. These biocides help to control mold, fungi, algae, and other biological growths that damage earthen surfaces. For example, extracts from neem or garlic can be applied to earthen walls to prevent the growth of harmful organisms. These treatments are not only eco-friendly but also help to maintain the building's authenticity, as they involve natural materials that do not alter the original appearance or texture of the earthen surface. Biological treatments, when used in combination with other preservation techniques, can significantly reduce the rate of deterioration caused by biological factors.

4.2. Chemical Treatments: Stabilizers and Protective Coatings

Chemical treatments such as stabilizers and protective coatings are commonly applied to earthen buildings to prevent water infiltration and to improve their resistance to weathering. Stabilizers, which are chemical agents added to the earthen material, can strengthen the bond between the particles of mud, clay, and straw, making the structure more durable and less prone to moisture absorption. Protective coatings, such as natural resins or synthetic sealants, can be applied to the surface of earthen buildings to create a waterproof barrier that prevents water from seeping into the walls. These coatings also protect the structure from ultraviolet (UV) radiation and environmental pollutants. Chemical treatments not only improve the structural integrity of earthen buildings but also extend their lifespan, especially in regions with high humidity or rainfall.

4.3. Role of Reinforcement Materials

The use of reinforcement materials such as geopolymers or synthetic fibers has gained traction as an innovative solution to strengthen earthen structures. Geopolymers are inorganic materials that can be used to reinforce the structure of earthen walls, improving their load-bearing capacity and resistance to cracking. These materials are often made from locally available resources

such as clay, fly ash, or slag, which makes them cost-effective and sustainable. Synthetic fibers, such as polypropylene or glass fibers, are also added to earthen mixes to enhance the tensile strength and prevent cracking. These reinforcement materials significantly improve the resilience of earthen buildings, allowing them to withstand harsher environmental conditions without compromising their aesthetic appeal or historical value.

4.4. Waterproofing Techniques

Waterproofing is one of the most critical measures for mitigating damage to earthen buildings. Water is the primary cause of many types of deterioration, including erosion, moisture absorption, and salt crystallization. Various waterproofing techniques can be employed, such as applying water-resistant plasters or bitumen-based coatings to the exterior surfaces of earthen buildings. Additionally, proper drainage systems must be in place to ensure that rainwater does not accumulate near the base of the structure. Natural waterproofing agents, such as lime, animal fat, and plant extracts, can also be used to treat earthen materials and protect them from water penetration. Effective waterproofing prevents the absorption of moisture and significantly reduces the risk of long-term damage caused by environmental factors.

4.5. Salt-Removal Techniques

In areas with high salt content in the soil or groundwater, salt removal is essential to prevent the damage caused by salt crystallization. One common technique involves washing the earthen surfaces with water to dissolve and remove the salts that have accumulated. In some cases, chemical desalinization agents may be used to neutralize salts and prevent further crystallization. Additionally, ventilation systems that promote air circulation in the walls can help to reduce moisture buildup, which in turn reduces the likelihood of salt formation. Salt-removal techniques are crucial for preserving the structural integrity of earthen buildings, especially in regions with high salinity levels or areas prone to rising damp.

4.6. Combination of Methods for Long-Term Preservation

The most effective preservation of earthen buildings typically involves a combination of techniques. Biological treatments, chemical stabilizers, reinforcement materials, waterproofing, and salt-removal methods can all be used in tandem to address the various types of damage that earthen buildings may face. By integrating traditional preservation practices with modern technologies, conservationists can create sustainable solutions that protect earthen buildings while maintaining their historical and cultural value. Long-term preservation requires continuous monitoring and adaptation to changing environmental conditions, ensuring that earthen structures remain stable, resilient, and visually appealing for future generations.

5. Sustainable Conservation Practices

5.1.Emphasis on Using Traditional Preservation Techniques Alongside Modern Materials

Sustainable conservation practices for earthen buildings involve a balanced approach that combines the wisdom of traditional techniques with the advantages of modern materials and technology. Traditional methods, such as using local materials, mud-based plasters, and natural binding agents, are integral in preserving the historical authenticity of earthen structures. These techniques have been refined over centuries and are specifically tailored to the environmental conditions of the region. However, these methods alone may not always suffice to protect the buildings from the challenges posed by modern environmental factors, such as climate change and pollution. Modern materials like reinforced concrete, geopolymers, and protective coatings can offer greater durability and resistance to weathering while ensuring that the building's historical integrity is maintained. The key is to integrate these materials in a way that complements the traditional fabric of the structure without altering its visual or cultural characteristics.

5.2. Consideration of Environmental Impacts in Conservation Methods

Sustainability is a crucial aspect of conservation, particularly when dealing with earthen buildings that rely on natural resources. The conservation of earthen structures should prioritize methods that do not negatively impact the environment. For example, the use of biodegradable treatments and non-toxic chemicals in preservation efforts ensures that the integrity of the surrounding ecosystem is not compromised. Additionally, sustainable conservation practices focus on using locally sourced materials, which reduces the environmental footprint associated with transportation and minimizes the depletion of non-renewable resources. Techniques such as rainwater harvesting, natural insulation, and solar energy integration can be incorporated into conservation projects to enhance energy efficiency and reduce the need for external power sources. The goal is to create a harmonious balance between maintaining the historical value of the building and promoting eco-friendly practices that contribute to the long-term health of the environment.

5.3.Integration of Modern Technology with Traditional Methods

Incorporating modern technology into traditional conservation practices has proven to be a highly effective strategy. Techniques such as 3D scanning and digital modeling can be used to accurately assess the condition of earthen buildings, providing detailed information on areas of deterioration and helping to plan for targeted interventions. Geotechnical analysis and structural reinforcement methods, such as the use of fiber-reinforced composites or carbon nanotube-based materials, are also increasingly being used to strengthen earthen walls and foundations. These modern technologies enhance the precision and efficiency of conservation efforts, while still respecting the cultural heritage of the building. By combining these cutting-edge tools with traditional skills—such

as lime plastering, masonry restoration, and earth reinforcement—conservators can ensure that earthen buildings are preserved effectively and sustainably.

5.4. Sustainable Resource Management and Community Involvement

Sustainable conservation also involves resource management that is rooted in local knowledge and practices. It is important to involve local communities in the conservation process, as they are often the custodians of traditional knowledge and skills that have been passed down through generations. By engaging local people in the restoration and maintenance of earthen buildings, conservation projects can become more sustainable and culturally relevant. Moreover, community-based management ensures that resources are used efficiently and that conservation efforts are in harmony with local lifestyles. The collaborative nature of these efforts fosters a sense of ownership and responsibility, ensuring that earthen buildings are preserved not just for today but for future generations.

6. Case Studies

6.1. Examples of Successful Restoration Projects

Several successful restoration projects of earthen historical buildings highlight the effectiveness of various conservation methods. One such example is the restoration of the Alhambra Palace in Spain, which involved the use of traditional mud-based plasters combined with modern geopolymer technology to repair deteriorated sections of the building. Similarly, the restoration of the Kasbah of Ait Benhaddou in Morocco utilized local materials such as rammed earth and lime mortars, along with advanced weatherproofing techniques to prevent future damage from moisture and salt crystallization. In both cases, the use of locally sourced materials ensured that the authenticity of the structures was maintained while also improving their durability against environmental wear and tear. These projects demonstrate how a combination of traditional methods and modern technologies can work harmoniously to preserve historical earthen buildings.

6.2. Lessons Learned from Restoration Projects

From these case studies, several valuable lessons have been learned that can be applied to future preservation efforts. One of the key takeaways is the importance of comprehensive condition assessments before starting any restoration work. Detailed analysis of the building's material composition, moisture levels, and structural integrity allows conservators to design targeted interventions that address the most pressing issues. Another lesson is the need for collaborative conservation efforts that involve various stakeholders, including architects, engineers, local craftspeople, and community members. This multi-disciplinary approach ensures that all aspects of the building's preservation are considered, from structural stability to aesthetic value.

Furthermore, these case studies highlight the necessity of sustainable design principles, including the use of environmentally friendly materials and techniques that minimize environmental impact.

6.3. Challenges Faced in Restoration Projects

Despite the successes, restoration projects involving earthen buildings also face significant challenges. One of the main issues is the difficulty of sourcing traditional materials in urbanized areas, where modern construction practices have replaced traditional ones. This can lead to a lack of expertise in using these materials, making it harder to replicate the original construction techniques. Additionally, earthen buildings often suffer from chronic water damage, which can be difficult to address without disrupting the structure's aesthetic integrity. In some cases, external factors such as urban development or climate change can further complicate preservation efforts. These challenges underscore the importance of adaptive conservation strategies that remain flexible and responsive to the evolving conditions surrounding earthen buildings.

6.4. Role of Local Communities in Restoration

Local communities play a critical role in the success of restoration projects. In the case of the restoration of earthen buildings in Togo, local artisans and builders were trained in traditional construction methods, ensuring that the knowledge was preserved and passed on. This hands-on involvement not only ensures that conservation techniques are tailored to the local context but also empowers communities by providing them with valuable skills and employment opportunities. Moreover, involving communities in restoration efforts fosters a sense of ownership and pride in the preservation of cultural heritage, ensuring that these buildings are cared for long after the restoration is complete.

Conclusion

Summary of Key Findings and Recommendations for Conservation Specialists
The preservation of earthen buildings requires a balanced approach that integrates both traditional knowledge and modern technology. The key findings from this study emphasize the importance of sustainable conservation practices that respect the cultural and historical significance of earthen structures while addressing the challenges posed by environmental degradation. Biological treatments, chemical stabilizers, reinforcement materials, and waterproofing techniques are all critical in preventing further deterioration. Furthermore, a multidisciplinary approach involving architects, engineers, conservationists, and local communities is essential to ensure that conservation projects are both effective and culturally sensitive. It is recommended that conservation specialists prioritize local materials, community engagement, and long-term monitoring to ensure the ongoing preservation of these buildings.

Call for a Multidisciplinary Approach

The successful preservation of earthen historical buildings depends on the collaboration of various disciplines. Architects bring design expertise, engineers provide technical solutions, and conservationists focus on preserving cultural integrity. However, it is equally important to involve local communities, who are often the custodians of the building's cultural and historical significance. By working together, these different groups can ensure that preservation efforts are both technically sound and culturally appropriate. A multidisciplinary approach ensures that all aspects of the building's preservation are considered, from the materials used to the environmental impact of conservation methods.

Future Directions for Preservation

Looking forward, the future of earthen building conservation lies in embracing innovative, sustainable techniques that incorporate both modern technology and traditional craftsmanship. The integration of eco-friendly materials and green building practices into conservation efforts will help to protect these structures from the growing challenges posed by climate change and urbanization. Moreover, the use of digital tools such as 3D scanning and virtual modeling can significantly enhance the accuracy and efficiency of restoration projects. Ultimately, the goal is to create conservation strategies that are both effective and sustainable, ensuring that earthen buildings remain part of our cultural heritage for generations to come.

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