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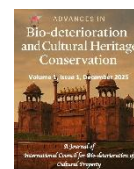
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Editorial

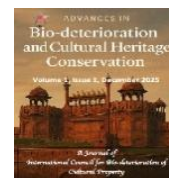
It is a privilege to introduce the inaugural online issue of the Journal of the International Council of Biodeterioration of Cultural Property, published by ICBCP, Lucknow. This first issue marks a committed step toward widening interdisciplinary dialogue between conservation science, heritage management, and environmental conservation. The articles assembled here - edited for this issue - address urgent scientific, and methodological questions that shape how we understand, assess, and respond to biodeterioration across cultural contexts.

As custodians of tangible and intangible heritage, we face unprecedented challenges - from climate volatility and microbial degradation to the ethical stewardship of collections and sites. This issue brings together a spectrum of perspectives and methodologies that reflect the evolving landscape of conservation science. This issue brings three overlapping themes to the forefront: (1) adaptive strategies for climate-driven threats to cultural property, (2) innovations in diagnostics and eco-conscious treatment, and (3) the civic and institutional roles that anchor conservation within broader biodiversity and climate action. Together the contributions map both high-level strategy and grounded case studies, offering readers practical techniques, experimental findings, and reflective frameworks for immediate application and future research.

In this issue collection of papers underscores three priorities for the biodeterioration community. First, strong diagnostics that are slightly invasive enable responsive, evidence-based decisions. Second, chemical innovation must be pursued alongside life-cycle and ecological impact assessments to ensure treatments are truly sustainable. Third, cultural heritage conservation cannot be isolated from biodiversity and climate agendas; museums, custodians, and communities must act as partners in broader environmental conservation. Moving forward, research that couples long-term monitoring with accessible conservation guidelines will most effectively translate science into durable practice.

I thank the contributing authors, and the ICBCP editorial team for their dedication to diligent, scholarly effort and practical relevance. I invite readers to engage with these articles, apply the methods and perspectives within their institutions, and contribute responses or short communications that test and build upon this work. Continued collaboration between scientists, conservators, curators, and communities will be essential to safeguard cultural property in an era of accelerating ecological change. May this journal continue to serve as an inspiration for collaborative conservation and a repository of knowledge for generations to come.

Dr. Praveen Kumar Verma
Editor, ICBCP Journal



Guest Perspective

Conservation Strategies for Addressing Climate Change: Traditional and Modern Approaches

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Introduction:

India is probably the world's largest repository of both tangible and intangible heritage. Much of our cultural heritage is preserved in its monuments and antiquities of various kinds. However, the monuments and antiquities protected and conserved by government organisations make up only a small part of the country's total heritage, and most are disappearing or losing their antiquarian value due to climate change, environmental degradation, pollution, neglect, rapid urbanisation, industrial activities, excessive tourism, and lack of political support. Neglect has been identified as a common cause of decay, which can be prevented before it becomes severe. It is widely recognised that sincere maintenance and repair using local materials and traditional techniques are the most effective methods of conservation. Through research and practical experience, conservators have concluded that traditional building materials and conservation techniques are more sustainable than modern materials like RCC and plastic sheeting, which are often unsustainable.

Heritage and sustainability:

Our country still maintains ancient systems of building technology and the conservation of cultural heritage. The technical details of construction, the merits of local materials, and natural binders are well documented in our ancient texts, such as *Vastushastra* and *Shilpashastra*. These texts, based on the principles of ancient scientific building technology invented thousands of years ago by the *Rishis* (Sages), are universally accepted as our great heritage. Now, the question arises: What is heritage, and what lessons can we learn about conservation from it? Heritage refers to the legacy of the past, both in tangible and intangible forms, inherited through oral traditions to be preserved for the future. These attributes are deeply rooted in moral values, traditional mantras, and ancient wisdom that maintain a balance between living organisms and their physical environment. This can be better understood by recognising the significance of *Panchtatva* or *Panchmahabhutas*, an ancient philosophical concept referring to the five elements of the universe: Earth, Water, Fire, Air, and Sky. The *Rig-Veda* emphasises that the harmonious functioning of these five elements is the basis of all life systems on Earth. This philosophy is reflected in lifestyle choices, such as astronomy, *Ayurveda*, yoga, meditation, and *Vastushastra*.

The relationship between nature and cultural heritage becomes evident through the observation of both manmade tangible and intangible heritage, which is considered a direct response to the elements of natural heritage such as forests, rivers, climate, soil, minerals, flora, and fauna. For built heritage, *Vastushastra* aims to integrate architecture with nature, considering factors such as the movement of the Earth, wind direction, the effect of sunlight, and the nature of soil, geometry, and astronomy. While laying the foundation of a building, the *pan-chang* (five factors) were considered, as well as the positions of the *nakshatras* (constellations), to predict or anticipate potential threats and damage to the building in the future. I am listing here four examples that have sustained the impact of climate change: 'Shri Kedarnath' Temple in the North, 'Mahabalipuram Shore Temples' in the South, the excavated Harappan site at Dholavira in the West, and the terracotta temples of 'Bishnupur' in the East. These heritage sites represent the four geological corners of India.

Let us begin with the North, with the 'Shri Kedarnath' Temple in *Uttarakhand*, which is uniquely positioned with a South-North orientation and entrances and exits from the East and West. This orientation aims to mitigate the threats caused by floods from melting glaciers and other natural disasters. Preventive measures, such as the *Ghorband* wall, were provided all around the temple towards the slope of the Chorabari lake. *Ghorband* is a row of stone slabs erected as per the traditional design in the shape of a horseshoe to divert the flow of the flood channel. Scientific studies of the temple suggest that the right selection of local materials compatible with the design and location in the alpine valley is a

key reason this temple has stood firm for the last 1,200 years, resisting harsh weather, climate change, and natural disasters.

The second site, located in the West, is the excavated Harappan site at Dholavira, Gujarat. This site is famous for its town planning, drainage system, water management system, and the proper use of local materials in its construction, all of which address the impact of climate change, such as extreme heat, drought, and water scarcity. The settlement was provided with an intricate network of both storm and rainwater, as well as waste coming from the residential and other areas.

The third monument is the '*Mahabalipuram* Shore Temple in Tamil Nadu', in the South of India. Despite the volatile rise in sea levels and the impact of the 2004 Tsunami, this temple has remained intact. These Temples, built on hard granite rocks, sustained the strong waves created by the Tsunami of 2004. As the levels of the sea receded to their normal level within a few minutes, a few submerged structures and sculptures were exposed. The groyens erected around the temple also acted as a first line of protection as a preventive measure.

The fourth monument is the terracotta temples of *Bishnupur*, in the East. These temples are a testament to the skill of local craftsmen and the use of proper local materials like lateritic, sandstone, terracotta, well-burnt bricks, and lime mortar made from processing snail shells and sand. These temples have survived to this day, despite the challenges posed by climate change and geomorphology. "During ancient times, our traditional craftsmen and sages had a sound knowledge of chemistry, building materials, architecture, metrology, astronomy, geography, and geology of the site. They were able to anticipate the nature of future threats. When the Titanic sank, Westerners realised how NDP testing and temperature could impact the structural integrity of materials. However, these concepts were already considered by our ancestors, showing that ancient craftsmen had a multidisciplinary scientific approach and were well-versed in the chemistry of building materials.

There are multiple reasons why heritage holds answers for sustainability. There are lessons to be learned from the past, particularly in how these structures have sustained themselves for so long without causing harm to the environment. They have survived the diverse and complex pressures created by socio-economic and developmental activities over the centuries. However, unless the process of decay of our cultural heritage is arrested, settlements will not only lose their ecological balance and aesthetic composition but also the roots on which the continuity and growth of cultural heritage depend. This can only be achieved if the present generation is actively involved in the task of conserving our cultural heritage.

What is Conservation?

Exploring the physical state of cultural heritage in our country, which is threatened by the impact of climate change and natural disasters, highlights the urgency for developing conservation strategies. These strategies must focus on repair, restoration, preservation, rehabilitation, and salvage archaeology. The next question that arises is: What is conservation? While there is no clear, universally accepted definition of conservation, it can generally be defined as the repair of a structure with minimal intervention to its architectural and material integrity. Conservation, restoration, and repair are three different terms, but they are often used interchangeably. Repair is the general term used to address all types of damage, but it does not necessarily mean the structure is being conserved for future generations. Conservation refers to the consolidation and strengthening of the existing structure before applying repair materials. Later, missing or damaged parts are replaced using appropriate original materials. This process follows a sequence: first consolidation, then repair of the damaged portions. The entire process can be termed restoration. Once restored, the structure must be preserved through sincere maintenance and scientific preservation techniques.

Various problems arise in conservation work. The first and foremost challenge is determining the cause of damage. Once identified, it becomes possible to focus on minimising or preventing the main source of damage. Only then does the question of selecting appropriate repair materials and techniques arise. This selection depends on the status of the building, the cause of damage, the materials used, and the environmental conditions to which the structure is exposed. It can vary from object to object, and even for buildings made from the same material in different areas, as environmental conditions can differ significantly. There is no universal "antibiotic" that can be prescribed to repair all types of damage, as in the case of medicine. Our country consists of several climatic zones, various types of soil, and different ecological zones. These distinct factors have influenced local traditions, materials, building typologies, repair techniques, art, and crafts, which have developed over centuries by local craftsmen. A scientific sustainability index has been maintained by examining and testing the material composition and the selection of local materials. For example, the composition of

lime plaster and mortar changes every few kilometres, depending on the local ecology and climate. The local craftsman of each region is the primary carrier of this traditional knowledge of conservation.

Traditional Knowledge of Conservation:

Indian culture has traditional and effective means of conserving its cultural heritage with utmost care and confidence. Ancient builders possessed immense knowledge about building technology, the merits of local binding materials, the selection of ideal locations, and the meteorology, geology, and geography of the place. They used locally available materials in the proper composition, compatible with local architecture and weather conditions. Lime has been used in building construction since the beginning of human civilisation. Local materials have proven to be long-lasting, sustainable, with no polluting by-products, moisture-resistant, and capable of maintaining a healthy living environment. For example, lime is porous and allows buildings to "breathe." It reduces the risk of trapped moisture and damage to the building fabric. It also has anti-fungal properties and self-healing qualities. As water evaporates, lime is deposited and begins to heal the cracks. Ancient builders used local materials to their advantage, often relying on empirical knowledge, even without scientific explanations as to why certain materials worked well. They would say, "Go ahead, use it; it will work." Today, we say, "Go try it; it may work." The difference highlights uncertainty and a lack of confidence compared to the experience-based knowledge of the past. Grading of sand is another important factor to consider, as it affects the pore structure, water-to-binder ratio, workability, and durability of materials. The pore structure is crucial for moisture movement; materials must be able to "breathe," otherwise, they "die" like a living being. The selection of materials is a critical issue that requires knowledge. Even today, Portland cement is used in many restoration projects for buildings originally constructed with lime-based plasters and mortars. While it hardens faster, costs less, and takes less time to restore, it is incompatible with lime-based binders. It gives higher strength, low porosity, and creates mechanical stresses in the structure, leading to distortion. Understanding the materials used is crucial, as any new material must be compatible with the existing ones. For example, simply saying "lime" is not enough; it must be specified which type of lime and how it is produced. Lime used in traditional construction was made by grinding *kankar* (a type of limestone) produced by burning clay from riverbeds, which contains silicates. Today, traditional skills and knowledge in conservation are gradually decreasing as livelihoods are replaced by modern technology and lifestyles. Unfortunately, traditional craftsmen, who relied solely on these skills for their livelihoods, did not document their techniques. These skills and technologies passed down through generations are now at risk of being lost. This is the primary reason why materials and techniques that once worked successfully are now diminishing.

Archaeology, Philosophy and Policy of Conservation:

Before undertaking any conservation work, one must understand archaeology, historicity, philosophy, and the policy of conservation. Let us consider the monument known as the *Sher Mandap at Purana Qila*, which was once the 'library of *Humayun*'. This spot is historically significant in medieval India. One day, as *Humayun* was descending from his library, he heard the *Azzan* (call to prayer). It was customary for the emperor to kneel in reverence upon hearing it. However, while attempting to kneel, he slipped on a polished stone step, hit his head on the sharp edge of the stone slab, and died on the spot. The sharp edge of the stone slab was broken in the fall. This broken slab is still preserved by the Archaeological Survey of India (ASI) to maintain the authenticity of the monument's history. It is extremely difficult to maintain it in its original form, and it costs many times more in energy, expertise, and money to do so. Yet, it must be preserved for posterity.

Another example to understand the policy of conservation is the Tomb of Abdur Khan Khanam, located in South Delhi. Visitors often mistakenly assume that the veneering work of this monument is incomplete or unfinished, which is the main cause of its decay; however, they are unaware of the archaeology and conservation policy behind it. Abdur Khan Khanam was the son of Bairam Khan, the trusted guardian and mentor of Emperor Akbar. A poet known for his *dohas* (couplets) and his command of Sanskrit, he was also referred to as *Rahim*. This tomb was initially built by him for his wife, and later, his body was interred there. Between 1753 and 1757, marble and sandstone from this tomb were reused in the construction of the '*Safdarjung Tomb*'. According to the conservation policy of the Archaeological Survey of India (ASI), a monument must be preserved in its form as it was when brought under central protection. This preservation includes maintaining its original state, which, in some cases, is far more complex than it may initially appear. The first challenge in conservation is to understand the problem, which is often the most difficult aspect. **My question is:** How can one understand the problem if there is no basic research? When we fail to comprehend the issues, it becomes the primary obstacle to successful conservation efforts. Conservation Challenges at the *Taj Mahal* One of the most iconic monuments in India, the *Taj Mahal*, exemplifies the complexities of conservation in the face of climate change, intense tourism, atmospheric pollution, and potential changes in groundwater levels due to irrigation and water abstraction. The *Taj Mahal* has been experiencing minor issues such as cracking of the marble slabs that encase the brick dome. These cracks should be carefully monitored and recorded to detect any emerging patterns of structural movement. The *Taj*

Mahal also faces the risk of seismic activity, although this is a relatively low threat. The nature of the ground beneath the Taj's foundation, as recorded in the '*Badshahnama*' (a contemporary text), indicates that the foundation was laid in subsoil water with stone in lime masonry below the ground and brick in lime above. Due to its proximity to the Yamuna River, the entire foundation was constructed to stand in a compact mass of masonry. The base consists of a series of deep wells filled with rubble and lime inside, and stone masonry on the outside. Piers were placed on these wells at close intervals, joined by vaults above. The construction design incorporated a series of arches rising above the piers to support the masonry bed and adjust the slope within the platform. These arches on the riverside were built in three tiers, which helped to distribute stress and strain throughout the structure. The precise application of tension, stress, and strain is evident in the compact and accurate superstructure, including the great overhanging dome. To counteract the thrust of river water, precautions were taken by strengthening the foundation with wells and abonyboxes along the riverfront. These measures were likely designed to withstand the thrusting force of the river or control the rise of subsoil water. Additionally, the height of the platform was raised to mitigate the threat of flooding. Anticipated Threats and Conservation of the *Taj Mahal*, built to endure the test of time, faces several threats today, some of which were anticipated by its builders. These include water leakage inside the monument, damage to structural elements, and cracks in the veneer stones. To ensure the proper upkeep and conservation of the monument, *Shah Jahan* made provisions for an endowment of 30 villages, yielding annual revenue of '*one lakh*' rupees from rents for shops and residences within the complex. Cracks began to appear in the *Taj Mahal* just four years after its completion. The earliest recorded repair work on the Taj is found in a letter written by Aurangzeb to *Shah Jahan* in 1652. The general layout of the Taj complex includes a formal garden within the inner court, with a central tank, lotus pool, and canals for irrigation sourced from the *Yamuna* River. To maintain uniform pressure and ensure proper distribution of water in the fountains, pots and containers were placed at the bottom of each. Remains of earlier pipelines beneath the street at the site suggest this water distribution method. *The Taj Mahal: A Testament to Scientific Thought*. Today, the *Taj Mahal* stands as a perfect testament to the technical skills and scientific thought of its builders. This is evident in the carefully selected composition of structural materials, the precise use of construction techniques to evenly distribute the dome's heavy load, and the methods employed in laying the foundation. The minute details in the structure, including the inlay work, sculpture, and painting, also reflect the meticulous planning and craftsmanship involved in its creation. In conclusion, the *Taj Mahal* not only showcases the artistic and architectural achievements of its time but also embodies the foresight and scientific understanding that went into its construction, which continues to serve as a model for conservation today.

Diagnosis and Conservation Strategy:

Practical conservation of monuments depends on the management of environmental resources through periodical inspections to formulate effective conservation strategies. Monitoring the condition of monuments is an activity where scientific inputs and fundamental research play an important role in conservation. Knowledge, understanding, and implementation are three distinct concepts. Knowledge may be available, but it may not be fully understood due to a lack of experience, which can lead to incorrect implementation. This gap can be bridged through fundamental research. However, surveys are often lacking, partly due to a shortage of research and expertise. Today, the main research apparatus is the computer, with data collected through the internet. This approach, however, does not involve direct contact with materials, leading to a loss of the tactile understanding of the subject. Running materials laboratories costs money, and there is little funding available for basic research today. When one seeks funding for basic research, the chances of receiving it are slim. However, there is a possibility of securing funds for applied research, which aims to solve industrial problems and offer a direct return on investment. My question is: without fundamental research, how can one understand the problem? And if one does not understand the problem, how can it be solved? Besides, the amount of resources allocated to Scientific research is relatively limited, and there is still a serious gap in the understanding of the problem and possible solutions in conservation. This issue can be addressed if the science laboratories operated by ASI, NRLC, and the National Museum Laboratory are made accessible to the public and individual conservators for fundamental research, rather than allowing these labs to become inactive.

In conservation, the monument must be understood as a structural, spatial, and environmental system and the chemical composition of the salts present. The Monument must be studied at various levels: first, as a whole; second, as elements of materials such as stone, brick, terracotta, metal, wood, paint, and mortar; and third, as industrial products like cement, artificial polymers and plastic sheets. Today, industries produce chemicals and alkaline sheets that can be used in conservation if applied by expert specialists. The problem arises because local craftsmen, who typically carry out practical conservation, are often not trained in the proper application of chemicals. Additionally, manufacturers of branded industrial products may alter their compositions, which are often trade secrets. This change requires time for testing and evaluation. Another issue is to understand which materials are compatible with the design of the building and its environmental conditions. The selection of materials is crucial and requires knowledge of material strength. The binding material used in conservation must be compatible with the original in both physical and chemical properties. A monument to be conserved must first be assessed to determine the cause and extent of damage. This can be done by analysing structural elements. Chemical analysis can identify the oxide composition and the presence of salts, while

mineral composition can be analysed using techniques like X-ray diffraction or Differential Thermal Analysis (DTA). From these analyses, it can be determined whether the damage is caused by gases such as sulphurous chlorides, which cause visible damage in monuments like the *Taj Mahal* in *Agra*, the *Konark Temple*, the *Jagganath Temple* in *Puri*, and *Mahabalipuram*.

Atmospheric pollution may or may not be an immediate threat to the monument in the *Agra Trapezium Zone*, but it certainly is a cause of concern to the monuments in other cities where pollution levels have reached alarming proportions. For example, the *Red Fort Complex* in *Delhi* is being affected by the pollutants emitted by the increasing traffic vibrations, the thermal power generating plants and railway shunting yards. Damage may be physical, chemical, or a combination of both. Physical damage occurs due to changes in humidity and temperature, while chemical damage results from the interaction of atmospheric gases. In most cases, damage is caused by multiple factors acting simultaneously and subsequently.

The essential conservation measures are formulated as a result of Scientific study of causes and extent of damage, the strength of material and the defects brought about by several other factors, including environmental degradations. Thereafter, plans are drawn up for the repairs to the monuments, which sometimes have to be started with the examination of the foundation, as in the case of monuments in *Qutub Minar* in *Delhi*, where the foundation must be strengthened as an important measure.

In other cases, repairs may involve reconstructing parts of the monument, such as recovering and resetting fallen or missing members, as seen in the temples of *Kiramachi* in *Jammu* and *Mahoba* in *Lalitpur, UP*. If masonry is displaced or bulging, the stones or bricks must be repositioned, and defects in joints must be rectified by removing dirt and loose mortar.

Monasteries or Buddhist *Gonpas* in *Ladakh* are preserved for their murals, centuries-old works of art, *thangkas*, and ritual objects. The conservation process involves scientific and physical cleaning of the murals, along with a detailed study of local materials such as slate stone, clay, twigs, wood, sand, natural polymers, and colours.

The *Iron Pillar* at *Qutub Minar* in *Delhi* is renowned for its exceptional resistance to atmospheric corrosion. It has attracted the attention of metallurgists and scientists. The third-century BC sculpture of the *Didarganj Yakshi* or *Chauri* bearer, with its shining finish, also baffles art historians and conservators, who have yet to discover how it was achieved.

The rock-cut monuments at *Ajanta*, *Ellora*, and *Bagh* require scientific studies of the ground, colouring materials, and filling of voids, as well as consistent monitoring of temperature and humidity. Understanding the climate and environmental conditions is essential for a historical approach to these monuments. The humidity, temperature fluctuations, and air movement in the caves contribute to decay. The impact of tourism must also be assessed, and the establishment of a weather station and measurement of air movement in the caves are necessary steps.

One of the most challenging conservation projects is the repair work at the *Shri Jagannath Puri Temple*. This involves scientific analysis of plaster, chemical treatment, eradication of salts, proper use of polymer for sealing to fix cracks, strengthening masonry repairs, and the replacement of heavy stone members like the *amalaka shila* at the top of the *shikhara*. An important issue is managing the political pressures and interactions with local bodies and temple administration.

Islamic monuments built with *Lakhauri* brick in lime mortar require expertise in repairing their vaults and domes, as well as restoring inlay work, which necessitates training inlay workers. The challenges in conservation posed by the location of some of the monuments in India, for example, the medieval town *Lucknow*, known for its monuments, gardens and water bodies, lies on the bank and adjacent to the *Gomti* river. Excavation at the residency *Lucknow* revealed that the water inlet and outlets were connected with the river *Gomti*, and the town was provided with a highly developed scientific water harvesting and drainage system. But over the years, these outlets have been clogged or damaged due to haphazard construction and heavy encroachments, causing structural damage to the monuments. These problems need to be addressed by improving the drainage system in consultation with concerned ministries.

The churches of *Old Goa*, built of lateritic stone, face their own set of conservation challenges, including the decay of stone masonry and the preservation of interior wall paintings, which require cleaning and preservation. Most of the monuments in the humid tropical climate in India suffer mechanical as well as chemical changes due to biological growth. The problem of biodeterioration of the monuments has been recognised. Research is being done on the mechanism of deterioration, but more research is required to understand whether the biocidal treatment that is being employed affects the building material. These are some issues that need to be further researched.

The ASI operates its own science laboratory in *Dehradun*, in addition to the *NRLC* and *NMI*, which are engaged in the conservation of tangible and intangible heritage. To meet the challenges of climate change and the advent of new

industrial chemicals and products, more scientific studies and research are needed. Meaningful collaboration with sister laboratories such as the NRLC in Lucknow and ANSL in Kolkata is essential.

Multidisciplinary Research:

Multidisciplinary research and work are necessary to address the above-mentioned challenges. Many structural elements and materials are used in building construction. Understanding the hardening process of modern materials like Portland cement mixed with water is a complicated process that requires knowledge of chemistry, both for modern and traditional building materials such as lime, sand, and natural polymers like *urad ki dal* and *begiries*. In some cases, damage or leakage begins before the repair work is completed due to a lack of knowledge and experience. People may recognise that something is missing but lack the expertise to properly address the issue. People knew XYZ, but ABC is missing. A multidisciplinary approach is essential for effective conservation. Experts from various disciplines—such as architects, archaeologists, chemists, building material scientists, silicate and polymer experts, landscape architects, structural conservators, engineers and local craftsmen—must collaborate and contribute their knowledge and skills.

In the ancient past, economic and cultural situations were closely interrelated, and their manifestations in tangible and intangible heritage created a harmonious balance between ecology and society that resonated with a healthy lifestyle and sustainability. Art, craft, and religion were intertwined, and artists and craftsmen enjoyed royal patronage, which contributed to the flourishing of monuments. Today, this ideology no longer reflects traditional values. The holistic approach to human progress is degrading as we undermine both tangible and intangible aspects of our cultural and natural heritage, contributing to climate change, which is one of the existential threats to humanity. Modern materials such as cement, concrete, steel, glass, metals, and industrial chemicals consume large amounts of energy and create high levels of pollution and hazardous waste. Indiscriminate mining of natural resources for building materials causes biodiversity loss, soil erosion, and water contamination. Forests are being exploited for human comfort. Today, the profession has failed to serve the community. One crucial task is education and training, beginning with basic conservation courses at the school level. This would lay the foundation for administrators, bureaucrats, academics, professionals, and the public to engage in meaningful conservation practices, leading to fruitful collaboration.

Education and Training:

Education and awareness about conservation should begin at the grassroots level, in schools and villages, and extend through universities and beyond. Children should be taught basic information about their heritage, including how to draw and understand the structures around them—homes, school buildings, doors, windows, roofs, gardens, etc. They should also learn how to care for everyday objects. This approach will train them to observe their surroundings more attentively and appreciate the significance of their natural resources and ecology. Children can play an active role in promoting awareness of conservation through their parents, relatives, and friends.

The issue of desirable conservation, or community-based conservation, also arises. Because conservation is ultimately for the people. It is the local people who are responsible for either saving or spoiling the monuments. Many temples and other structures lie in disuse in villages and towns. The local communities around these sites are often too small to support their repair and maintenance. Local funds are limited, and there is a lack of expertise and administrative support for conservation efforts. It is essential to explore the functional reuse of these buildings, repurposing them as schools, hostels, libraries, primary healthcare centres, or community spaces to serve basic societal needs. There is an urgent need to establish a "People's Conservation Register" at the grassroots level, addressing these concerns.

In this context, the late Honourable Prime Minister Atal Bihari Vajpayee, in his Independence Day speech of 2003, announced the establishment of three National Missions: on Monuments, Antiquities, and Manuscripts. A key strategy to achieve this goal is organising training workshops in villages and towns on the documentation of both tangible and intangible heritage. Proper documentation of our heritage is crucial for creating a national database that adheres to standardised formats and parameters, which can be used by scholars, researchers, and planners for reference and further research.

The role of language in such training workshops should not be overlooked. English has become the international language of communication in conservation, with most discussions, research, and social media content available in English, as well as other European languages. This poses a challenge for many nations, especially in Asia, where local institutions and organisations working in conservation face difficulties in understanding these languages. There is a need to translate some of the important conservation works, including legislation, into the regional languages or the language of the common people.

Salvage Archaeology:

Archaeologists and historians are extremely concerned about the relevance of salvage archaeological approaches in conservation. Today, the number of ancient sites, mounds, monuments and antiquities has been destroyed by the

construction of dams, railways, highways, etc. Documentation of archaeological and historical data can be done from the areas under threat by photographs and writings. But the excavations of these sites become a consuming task due to complicated official procedures and norms to be followed as laid down in the existing legislation of ASI. The existing legislation does not cover the provision of salvage archaeology. In the present changing circumstances, it is essential to add or amend new legislation on salvage archaeology in the existing legislation.

Salvage archaeology involves relocating historical monuments and antiquities to safer areas. It ensures that cultural resources likely to be affected by destruction and submersion are properly documented, excavated, and conserved before being lost. The salvage operation at Nagarjuna Sagara Dam in A.P. was the first of its kind in India, encompassing documentation, excavation, archiving, salvaging, and replicating now submerged relics. This effort paved the way for many other rescue operations across India. In this process, universities and other educational institutions can play a vital role in conserving and documenting cultural heritage before it disappears, and it may be incorporated into university curricula as a record of lost cultural history.

Administration in Conservation:

Monuments, sites, and antiquities are mainly protected by two pieces of legislation in our country: the Ancient Monuments and Archaeological Sites and Remains (AM & SR) Act and the AAT Act 1972. However, due to certain loopholes in these laws, their enforcement has become challenging. This issue can be addressed by simplifying and reinforcing these acts to make them more effective in practice. Legislation is often ineffective unless actively enforced, especially given delays caused by bureaucracy and differing interpretations of regulations by relevant departments or ministries.

For instance, after an earthquake that caused damage to monuments estimated at 25%, administrative delays in approving estimates, sanctioning funds, and releasing payments resulted in further damage, raising the total damage to 80%. Moreover, the costs of materials and labour increased by 100% due to these delays. This situation highlights the need for special programming in conservation. In regions like *Ladakh* and other Himalayan states, where the working season is limited, conservation work must be conducted during this narrow window. Thus, administrative or legal approval alone will not suffice; a more flexible, practical approach is required. Specific guidelines for conservation work should be developed by the administrators of the concerned ministries and departments. Another example involves the science laboratories at the ASI's *Dehradun* office, which was established in 1917. These labs have become largely non-functional due to the transfer of 90% of the staff to Delhi. Similarly, the NRLC laboratory in *Lucknow* has been managed by a history professor for the past three years. It is important to note that antiquities and works of art housed in museums and science laboratories in our country suffered significant damage during the pandemic years of 2020-2021. The lockdowns further exacerbated the situation, as most museums and laboratories struggled with day-to-day maintenance and the inability to control temperature and humidity levels, resulting in damage to important works of art, particularly manuscripts and paintings.

There is a need to meet the challenges in scientific research through interdisciplinary studies in collaborations with other scientific institutions, which can provide very fruitful results and prepare guidelines for education and training in conservation.

The level of conservation knowledge in the country is a reflection of the training received through workshops and research. Both traditional and modern approaches in conservation should be included in these training workshops. Modern methods are grounded in scientific understanding of materials and their deterioration mechanisms, while traditional knowledge reflects cultural ethics, customs, and values that must be incorporated into conservation management plans.

The ancient building technology and traditional knowledge of conservation are preserved in our text, like *Vastushastra* or *Shilpshastra*. Such heritage exists today. Our ancestors recognised and preserved this heritage for us. Now we must preserve it for the generations to come.

A Novel Heterocyclic Fungicide Plays a Vital Role in Inhibiting Fungal Growth on Cultural Heritage Materials

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ABSTRACT

This research paper presents a technical study on self-synthesized fungicidal compounds - specifically 5-Amino-6-Aryl-3-(5-Aryl-1,3,4-Oxadiazol-2-yl)-5,6-dihydro-5H-2-Thioxo-1,3-Thiazin-4-Ones—designed to inhibit fungal growth on bio-deteriorated cultural heritage materials. The study encompasses experimental analyses, spectral characterization, and antifungal efficacy evaluation of the synthesized compounds. Antifungal activity was assessed using the agar plate technique, wherein the toxicants were incorporated into the agar medium and inoculated with test fungi (*Aspergillus niger* and *Alternaria solani*). The fungicides were applied either as solutions or suspensions in an acetone-water mixture (20:80 v/v) and incubated at $20 \pm 1^\circ\text{C}$ for 96 hours. Comparative analysis was conducted using the commercial fungicide Dithane M-45 under identical conditions. Preliminary screening revealed that the most active synthesized fungicides exhibited antifungal efficacy comparable to Dithane M-45, achieving 74–78% inhibition of fungal growth even at a lower concentration of 100 ppm. These findings underscore the potential of the synthesized compounds as effective agents for the preservation of cultural heritage against fungal deterioration.

Keywords: Heterocyclic fungicides, Cultural heritage preservation, Antifungal activity, *Aspergillus niger*, *Alternaria solani*, Agar plate method, Bio-deterioration, Dithane M-45 comparison

1. Introduction:

Fungi constitute a large group of plants which grow in diverse habitat. They are nucleated, spore-bearing, achlorophyllous organisms which, because of the lack of chlorophyll, are unable to manufacture their food. Thus, they are either saprophytes, obtaining their food from dead organic matter or parasites, obtaining their food from the bodies of living plants and animals. Further, many fungi spoil bread and other foodstuffs. They often cause food poisoning. In addition, fungi cause deterioration, weakening and destruction of papers, cloths, leathers, plastics, woods, stones, paints and other artefacts during storage and use as cultural heritage. Ancient documents, artefacts and archives with historical and academic values are priceless cultural heritage that should be handed down to descendants for generations as a repository of information resources important in future generations as well as the present (Hammer et al, 1999; Singh, 2016; Singh, 2022; Tyagi et al., 2021; Singh & Kumar, 2022).

In an attempt to search for new heterocyclic fungicides, a series of new compounds has been synthesized (Yadav & Singh, 2003). All the synthesised compounds have been well characterised by their elemental analysis, and IR and ^1H NMR spectral data. IR spectra in KBr were recorded on Perkin-Elmer 577 and Perkin-Elmer 993 infrared spectrophotometers (cm^{-1}). ^1H NMR spectra were recorded on a Varian EM-360 (60 MHz), Perkin-Elmer R-32 (90 MHz) spectrometer in CDCl_3 , DMSO-d_6 , and CDCl_3 plus DMSO-d_6 using TMS as internal reference; chemical shifts are expressed in δ .

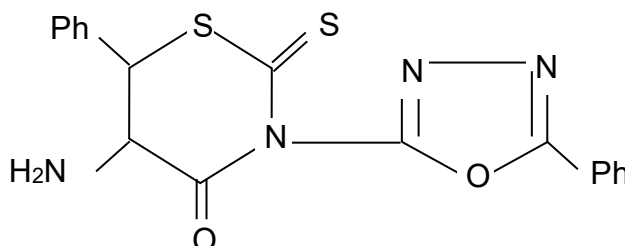


Fig. 1. 5-Amino-5,6-dihydro-6-phenyl-3-(5-phenyl-1,3,4-oxadiazol-2-yl)-5H-2-thioxo-1,3-thiazin-4-one.

A mixture of 41.50 g (0.083 mole) of 5-benzamido-5,6-dihydro-6-phenyl-3-(5-phenyl-1,3,4-oxadiazol-2-yl)-5H-2-thioxo-1,3-thiazin-4-one (Figure 1) and 75 ml of 70% w/w H₂SO₄ (prepared by adding 60 ml of concentrated H₂SO₄ to 45 ml of H₂O slowly) was refluxed for 20-30 minutes. The reaction mixture was poured into cold water, and the desired product was precipitated by adding an excess of concentrated NH₄OH under ice cooling. It was filtered, washed with water and recrystallised from ethanol as light brown needles (Filler & Kobayashi, 1983; De Jesús-Téllez et al., 2021).

2. Research and methodology:

The technical study of self-synthesised fungicides, which play a vital role in inhibiting fungi from cultural heritage (Singh, 2016; Singh, 2022). The synthesised compounds have been designed in such a way that most of them incorporate various toxophorically important groupings for fungi. The author has evaluated the fungicidal activity of twelve compounds by employing the agar plate technique (Singh, 2022; Hosrfall, 1945; U.S.D.A Circular, 1935). In brief, this technique involves the mixing of a toxicant with agar medium (Table 1) and allowing the planted fungus to grow on the surface of cultural heritage. These compounds have been screened for their fungicidal activity against two fungal species, viz. *Aspergillus niger* and *Alternaria solani*. One-week-old cultures of *Alternaria solani* and *Aspergillus niger* were used.

Alternaria solani is a cosmopolitan farm species. In nature, it chiefly occurs as a saprophyte on the surface of paper documents. It is a common occurrence both in cool as well as in warm regions in India and abroad. The pathogen causes injury to the leaves as leaf spot disease and instigates premature defoliation. Finally, it causes rotting of tubers. *Aspergillus niger*, popularly known as the black mould, is worldwide in occurrence. It is chiefly a saprophytic fungus which is widely distributed. It grows on a variety of substrates, including papers, grains, forage products, decaying vegetables, spoiled fruits, leather and dairy products, etc. *A. niger* is also a parasite on human beings and animals, and causes a number of diseases grouped under the name Aspergillosis.

3. Experimental Process:

3.1. Organism:

One-week-old cultures of *Alternaria solani* and *Aspergillus niger* were used.

3.2. Medium:

The following synthetic Czapek's agar medium has been used (Sharma & Pandey, 2010; Zohri & Abdel-Gawad, 1993). The chemical composition of agar medium is shown in Table 1.

Table 1. Composition of Synthetic Czapek's Agar Medium

Sl. No.	Materials	Quantity
1.	Agar	15.00g
2.	Sucrose	30.00g
3.	Sodium nitrate	03.00g
4.	Dipotassium hydrogen phosphate	01.00g
5.	Potassium chloride	00.50g
6.	Magnesium sulphate	00.50g
7.	Ferrous sulphate	00.10g
8.	Distilled water	01.00litre

The antifungal activity of each compound was evaluated at two different concentrations, viz., 1000 and 100 ppm. The compounds were tested either as a solution or suspension in an acetone-water (20:80, v/v) mixture.

Standard solutions or suspensions of different concentrations of each compound, viz., 1000 and 100 ppm, were prepared in an acetone-water (20:80, v/v) mixture. One millilitre of each concentration of test compound was added separately to pre-sterilised Petri plates containing 9 ml of the sterilised Czapek's agar medium (Table 1) to maintain the final concentration of 1000 and 100 ppm. The compound was thoroughly mixed with the medium by rotating the plates on table top, thus swirling the contents. A fungal disc of 5 mm diameter, cut out with the help of a sterilised cork borer from the periphery of a one-week-old culture of test fungus already planted on the Czapek's agar medium, was inoculated in the centre of each Petri plate in an inverted position to bring the mycelia in direct contact with the medium. Petri plates containing 9 ml of Czapek's agar medium and one ml of acetone-water (20:80, v/v) mixture served as controls. The number of replicate assays in each case was three, whereas six replications of the controls were provided. The plates were incubated at 20°C ($\pm 1^\circ\text{C}$) for 96 hrs. No remarkable morphological change was observed in the developing fungi.

A commercial fungicide, Dithane M-45 (a mixed manganous and zinc salt of N, N'-ethylenebisdithiocarbamic acid), was also tested under similar conditions for comparing the results.

4. Expression of per cent inhibition:

After 96 hours, four diameters of the fungal colony intersecting one another at about 45° were measured using a millimetre scale. Inhibition of fungal growth was determined as the difference in growth between control plates and those treated with test compounds. The percentage inhibition of mycelial growth was calculated by the following equation (Clark & Hams, 1953):

$$\% \text{ inhibition} = (C-T \times 100)/C$$

Where,

Average diameter of fungal colony (in mm) in control plates.

T = Average diameter of fungal colony (in mm) in treated plates.

The fungicidal activity displayed by various groups of compounds is recorded in Table3.

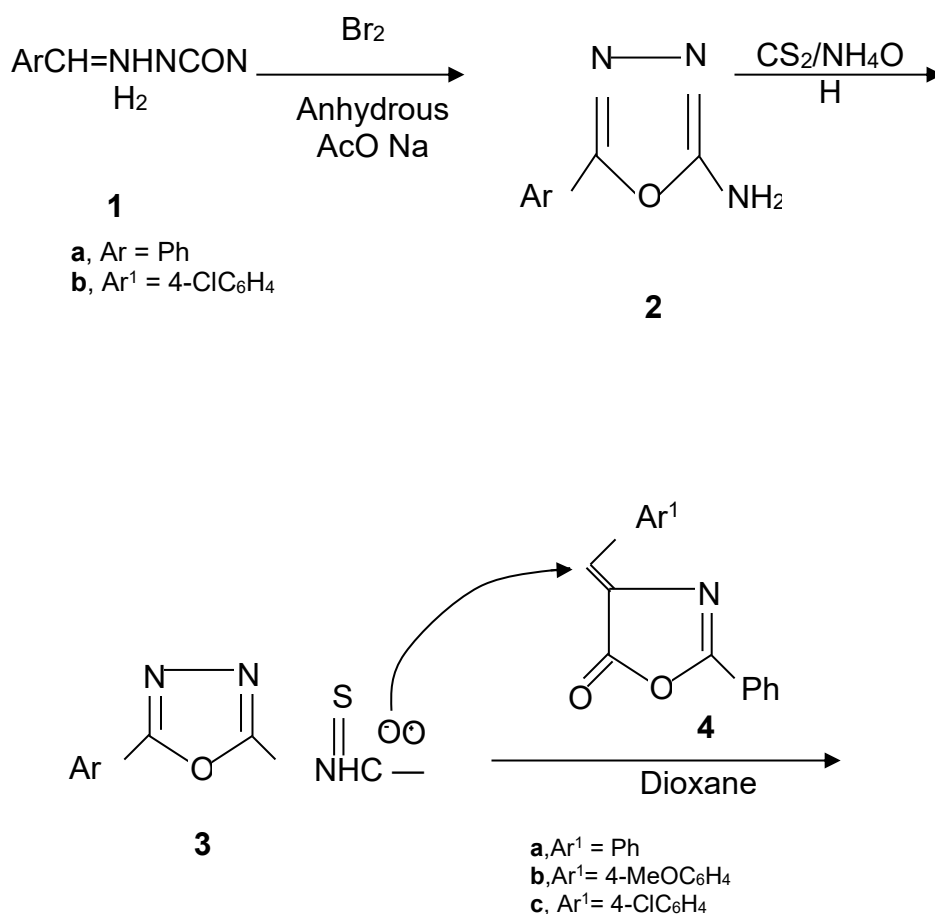
5. Result and discussion:

Twelve such compounds (6a-f and 7a-f) are shown in Figure 2. This series has been evaluated for its antifungal activity, and the screening results are summarised in Table3.

It is evident from the screening data (Table3) that some of the screened compounds have significant fungicidal activity at 1000 ppm against both the test fungi, but their toxicity decreased considerably at a lower concentration (100 ppm). The most active compounds 6d and 6f exhibited the fungi toxicity equivalent to Dithane M-45 at 1000 ppm concentration against both the test fungi, and inhibited 74-78% growth of both the test fungi even at 100 ppm concentration. It was noted that the compounds 6a-f bearing bezamido moiety (Table 2) were more fungi toxic than their amino analogues 7a-f (Table 2). This conforms with the earlier observation (Yadav et al., 1996; Singh et al., 2023).

The screening results demonstrate that the introduction of a chloro or a methoxy group into the phenyl moiety of compounds 6 and 7 augmented their fungicidal action appreciably. This is understandable given the lipophilic character of these groups, which favours permeation of the compounds through lipid barriers in the fungal cell membrane. All the screened compounds were however, marginally more potent against *A. niger* than against *A. solani*.

Figure 2. Steps involved for synthesis of twelve compounds (6a-f and 7a-f)



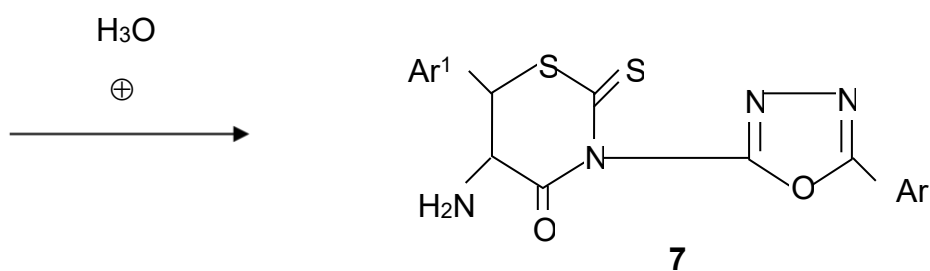
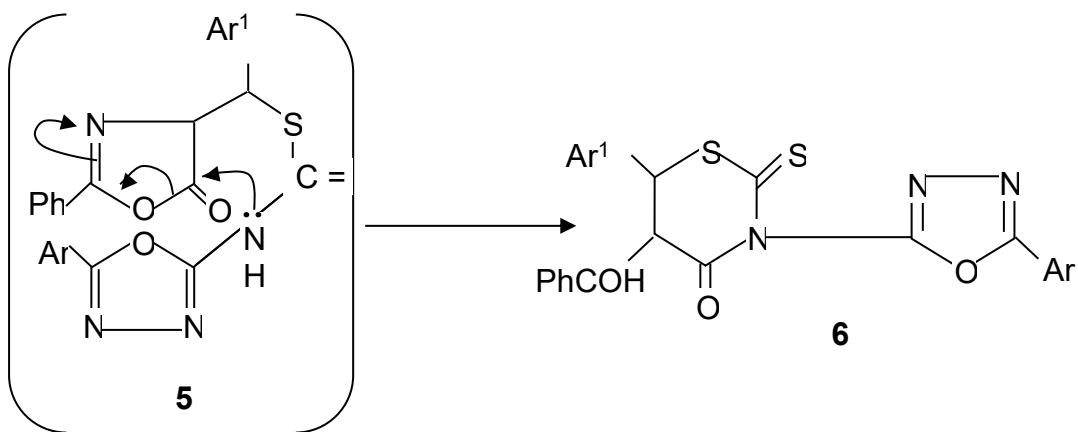


Table 2. Details of Aryl (Ar) groups

6, 7	Ar	Ar ¹	6, 7	Ar	Ar ¹
a	Ph	Ph	d	4-ClC ₆ H ₄	4-Cl C ₆ H ₄
b	4-ClC ₆ H ₄	Ph	e	Ph	4-MeOC ₆ H ₄
c	Ph	4-ClC ₆ H ₄	f	4-Cl C ₆ H ₄	4-MeOC ₆ H ₄

Table 3. Fungicidal screening data of compounds 6a-f and 7a-f

Compound No.	Average % inhibition against			
	Alternaria solani at		Aspergillus niger at	
	1000 ppm	100 ppm	1000 ppm	100ppm
6a	70	47	78	50
6b	72	50	81	53
6c	71	51	78	53
6d	100	76	100	78
6e	69	48	73	50
6f	98	74	100	76
7a	65	43	70	48
7b	68	46	76	51
7c	69	46	74	47
7d	97	66	98	69
7e	64	45	69	48
7f	94	64	95	66
Dithane M-45 (Commercial Fungicide)	100	81	100	83

6. Conclusions:

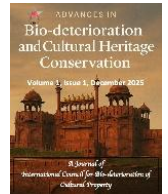
Based on the preliminary screening of the compounds for their antifungal activity, the following conclusions can be drawn:

1. The antifungal action may not be the numerical sum of several toxophoric functions; perhaps it is a congregation of such toxophoric functions, and the role of only a few key factors is important.
2. All the screened compounds inhibit the growth of both the test fungi, i.e., *A. solani* and *A. niger*, to some extent at 100 ppm, hence are antifungal.
3. Unsubstituted phenyl nucleus is less toxic as compared to that bearing methyl, methoxy or chloro group.
4. The most active compounds 6d and 6f (Table 3) displayed the antifungal activity of the order of Dithane M-45 (a commercial fungicide at) 1000 ppm and inhibited 74-78% growth of both the test fungi, even at 100 ppm concentration. Therefore, these compounds evoke further testing at higher dilution and against other harmful fungal species for the archival cultural heritage.
5. Bio deterioration by fungi is a major problem in cultural heritage conservation, not because of damages but also less availability of fungicides for curative as well as preventive conservation options. This study provides us scope to use these types of fungicides to inhibit fungi from cultural heritage.
6. Since all synthesised fungicides have different degrees of efficacy, toxicity for the different cultural heritage as per the requirement, one can apply it in Archives, Museums, and Library and see the effectiveness. So that experiment and studies will help find out new fungicides for the cultural heritage.

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Role of Natural History Museums in Promoting Wildlife Conservation and Climate change Mitigation

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ABSTRACT

Biological collections are repositories of biological specimens collected over a period, acquired and documented for display as well as research. It includes both plant and animals and their fossils. It may serve as an instrument for public education and a repository of the past. Both in India and abroad, specimens ranging from butterflies to large birds, reptiles, amphibians, fish and mammals are collected and preserved in Natural History Museums. It is a data bank serving as an indicator of the changing environment and preserving material. The preserved specimens are useful for correlation with environmental change. The specimens preserved in the museums are indicators of the past environment. The organisations responsible for keeping track of environmental change value the museum specimens as a data pool. Biological resources preserved in different museums are renewable biological resources for the study of ancient biological diversity and climate change patterns of the last centuries.

Keywords: Scientific research, climate change, natural history, biodiversity, biological specimen

1. Introduction:

Biological Specimens are a set of organisms or parts of them preserved in a public or private collection. It may be preserved through wet and dry preservation techniques. Based on nature of the biological specimen, it may be categorised into two types (Table 1).

Zoological specimens		Botanical specimens	
a.	Eggs	a.	Herbarium
b.	Horns	b.	Wet preserved specimen
c.	Skin with or without head	c.	Seed and grains
d.	Trophy		
e.	Mounted specimen		
f.	Cabinet skin		
g.	Invertebrate specimens		
h.	Wet preserved specimen		

Table 2. Systematic Arrangement of Zoological and Botanical Specimens for Museological Documentation

Biological specimens are important from the point of view of wildlife conservation, scientific research, education and climate change study (Michael 2013). The scientific value of museum specimens is very high, but the rate of acquisition is quite low. A few specimens are collected for preservation, which will be available for future research. A field slip is attached to every specimen, and it is provided with spatial and temporal information of the species. Sex, moulting stage and provenance are also written on the field slip. It gives the migratory pattern and distribution of the species. There are different methods of obtaining and preserving the specimens (Winker 2024). Every specimen is like a reference book; it includes the genetic information of the period when it was collected. This peculiar as well as useful information is very important for scientific research, and at the same time, we cannot get this information from the current species roaming in the wilderness. The genetic analysis of the DNA of Museum specimens is quite difficult, and they can be studied by using modern techniques. (Naoyuki 2020). Each specimen is unique in biology, ecosystem, genetic diversity, space and time. Any museum needs to maintain a detailed record of the history of any specimen. These pieces of information are invaluable for any scholar studying the systematics of the species (Walton 1907). If we assume ourselves in the place of early naturalists, like Alfred Russel Wallace in the Malay Archipelago or Alexander von Humbolt in the Americas in the early 1800s, it would have been very difficult for us to study nature. The notes prepared centuries before by early naturalists are still important.

The animals and plants collected by them describe past and present biodiversity and are very helpful for research in the field of biomedicine and beyond. It is a physical resource available for scientific research. The temporal and spatial data, historical imprints and genetic resources provided by the museum specimen are invaluable. The species information derived from the museum specimens led to cognition and biodiversity cataloguing. The sample can be collected from the tissues, internal and external parasites and the bacteria and viruses in and around. Data can be digitally stored in the museum database, and physical specimens are stored in museum archives as biorepositories (Ripley 1973).

2. Material and Methods:

A) Data set

Museums are important public institutions involved in mass education through informal ways of learning. In the era of climate change, museums are facing challenges. As an established institution, they have the capabilities to combat these challenges. There are 17 SDGs established by the United Nations, and museums are responsible directly or indirectly for most of them. Out of these, SDGs 13, 14, 15 & 17 are responsible for Climate change, life below water, life on land and partnership for the goals, respectively. Museums as a responsible institution are applying several means to fulfil the target set under these SDGs. This study is based on different practices of Museums established worldwide to fulfil the goals of the SDGs. The target of writing this research paper is to identify the area and various practices of Natural History Museums, which are very important and useful for wildlife conservation and mitigating climate change. Through this paper, the information is assembled regarding the sustainable use of energy, and scientific research will be used to explain how these museums are involved in achieving the targets of the SDGs.

B) Methodologies:

a) Museum as a conservation instrument:

Natural History Museums serve as a conservation instrument where people can be educated. It is a matter of concern to educate people residing in the city about the nature and conservation of Natural resources. In this line, the United Nations Conference on the Human Environment was held in Stockholm in June 1972. These Museums are very adept at presenting information collected in past (Johnels 1973). Thorough research in physiology and ecology always needs an understanding of the living matter of a biological unit called a species. The study of fossil records is essential for studying not only the anatomical structure of the species but also the status distribution of species in the past. To conduct the research on physiology, ecology and other aspects of biology, the preserved specimen in any museum plays an important role (Michael 2017). Natural history collections are important for scientific research, biodiversity study, and the taxonomic, evolutionary and ecological aspects of the species. It provides information regarding species' ancient spatial distribution and period of occurrence. The historical distribution can be compared with the modern status distribution of the species, and it is quite helpful in identifying the conservation status of the species. Species cognition, biodiversity cataloguing, protection and management of endangered species are other important aspects of data obtained from museum specimens. These data may be useful in framing various wildlife conservation and management projects (Schmitt 2018). Genetic studies on the preserved specimen may be useful in mitigating diseases prevalent in modern species (Andrew 2016). Based on provenances written on the field slip attached to the specimen, we get information on the past occurrence of the species in a particular area, and it will be helpful in the prevention and control of alien species. Invasive species play a key role in 60% of global Plant and animal extinctions (IPBES PRESS release). The targets set up under SDGs-14 &15 related to life below water and life on land can consequently be fulfilled by applying these efforts

b) Biological specimen:

In the Indian context, biological specimen resources are preserved in:

1. National Museum of Natural History

Representing the floral and faunal diversity of the entire nation, and a few specimens from other countries.

2. Regional/State Museum of Natural History

Representing the floral and faunal diversity of a particular region or State.

Every specimen is a reference book for

1. Taxonomic classification
2. Metamorphic studies
3. Plumage study
4. Emerging disease

From a single specimen, we get multidimensional information about the species. This information can be categorised into two groups: biological or non-biological.

Biological information includes information that can be collected after physical observation or through the study of the chemical composition of viscera, blood, serum, tissues and DNA

1. Morphological
2. Genetic
3. Chemical composition
4. Biological components

Non-biological information is collected from the study of skin, feathers, nails, bones, wet preserved tissues, blood, etc., and it includes:

1. Pollutants
2. Tree element

c) Morphological study:

SDGs 14 and 15 were established to promote wilderness based on the morphological study of any species and conducting detailed scientific research for future wildlife conservation plans. Studying any biological specimen preserved in a Natural History collection is easier than in the wilderness. Sahas Barve, a PhD student from the Smithsonian National Museum of Natural History who is studying bird feathers, which is how birds keep themselves warm, states that “I study bird feathers from different species. Right now, I’m looking at over 250 species and 2,000 specimens. It would be impossible for me to sample those species, and many birds in the field may not be spotted. My westernmost species is from northwest Pakistan-occupied-Kashmir, and my easternmost specimen is from Namdapha National Park in Arunachal Pradesh.” In a further statement, he said. “It would probably take me a decade to do the same research that I did in six months if I had to plan the field logistics for all those places” (News release 22 August 2022).

d) Museums in mitigating climate change:

“Natural history museums and related institutions are devoted to the exploration and study of the biological world by utilising their vast collections as a primary record of life's history and diversity. Thus, their work is critical to our understanding of the richness of life and the magnitude of the impacts resulting from human activity and industrialisation. The degree to which museums and like institutions are successful in their important mission of scientific research and education in the coming years will be pivotal in determining how effectively we deal with the great environmental challenges of the twenty-first century” (Michael 2013). Sustainable Development Goal13 is related to climate change, and it is correlated with all other goals. The museum specimens can be studied for the pollutants present in their skin, feathers, and toe pads, which gives a clue about the contaminants present in the ancient environment and their impact on the present climate change. One such study has been conducted on the specimens present in the Natural History Museum, London and the Swedish Museum of Natural History. The Mercury, Arsenic, Lead and other heavy metal content in the feather shaft of different plumage of the Osprey was studied, and it gives a clue to the ratio of mercury in a particular area, because the mercury content in the blood of the bird is reflected through the shaft (Edelstam 1969). Modern tools and techniques, and novel uses of museum specimens are constantly broadening the impact of museum specimens on various research related to climate change and sustainable development. The contribution of natural history specimens is quite important in the era of the Anthropocene. They are the primary source of information, and extinct species can be learnt only through these preserved specimens. Museums should be promoted to collect and document more biological specimens (Schmitt 2018).

e) Public participation:

Museums have a larger role to play than simply preserving and conserving the heritage to mitigate the external threat of climate change. It has the possibility of changing society and its mindset by organising large debates that can shape the future. Many museums are taking this responsibility by developing exhibitions, public engagement activities and conducting scientific research (Clercq 2003). They are involved in decarbonization practices by minimising those activities that have a direct impact on the environment and, in turn, contribute to reducing the carbon footprint. Museums, in comparison to other sectors, have a minimal impact on climate change, but still, they can reduce their carbon footprints by applying green methodologies in their day-to-day operations, like cafés, buildings and other estates. It can organise an exhibition on the climate emergency (Bai 2024). Museums can conduct more research on the climate emergency. “Museums correspond to a network of responsibility, through which publics are actively engaged rather than just ‘informed’ and where a sense of locality is deepened through understanding the local connections that underlie that sense of place” (Messey 2005).

f) Reduce carbon footprints:

Museums are trusted institutions responsible for education and research, and can play an important role in creating awareness regarding climate change. It works for changing attitudes, enhancing societal efforts, and developing knowledge to address the crisis. Solar panels and minimal use of electricity can be applied as well as promoted by the museums (Harvey 2015). Govt of Uttar Pradesh is deeply involved in the sustainable practices of renewable energy usage. In major museums of the State, solar power plants, rainwater harvesting, and provision are installed as a means for green energy and to reduce carbon footprints.

g) Museum architecture:

Museum design and architecture are important tools in achieving sustainable development goals. A few museums like the Museum of Tomorrow (Rio de Janeiro), California Academy of Sciences (San Francisco), Nigbo History Museum (China), Natural History Museum of Utah (Salt Lake City), Exploratorium (San Francisco) and Zoom Children’s Museum (Vienna) have developed a sustainable design.

3. Results and Discussions:

Findings of the paper identify the clean and green energy practices adopted and scientific research conducted by the museums to achieve the set targets under SDGs 13, 14 &15. The results are drawn from the various scientific research conducted on the biological specimens preserved in different museums both in India and abroad, and at the same time, through a study on the use of renewable energy sources in different museums. Museum architecture and other museum practices are targeted towards reducing carbon footprints, promoting conservation of wildlife and mitigating climate change.

4. Conclusion & Further Scope:

Museums are not only informal education centres, rather they also need to play an important role in achieving the SDGs set by the UN in 2015. In a broader sense, museums are more responsible for SDG 13, 14 and 15, and they are continuously working in a positive direction. The Scientific research conducted by the museums is a boon for wildlife life conservation projects and for curing various diseases in the wild. The museum architecture is an important aspect and needs to be followed strictly to mitigate climate change and reduce carbon footprints. Renewable use of energy should be promoted at a broad level.

This is an emerging field where more natural history museums must be included. The biological specimens should be used as a reference library to gather maximum information regarding any species, which can be utilised for future research in biology and its applied branches. In the field of scientific research, partnerships with expert institutions like Universities and Scientific institutions will give positive results and may lead to the conservation of threatened species at large. The establishment of more sustainable buildings and applying sustainable means to reduce carbon footprints are important to achieve the targets of SDG-17.

5. Statements and declarations:

The author declares no competing interests related to the subject matter.

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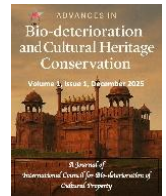
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Determining the Physical Condition of Temple Idols through Non-Destructive Examination: A Case Study

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ABSTRACT

Temple idols play a vital role in India's cultural and religious traditions, yet centuries of worship and ritual handling can gradually degrade their physical condition. This study demonstrates the use of Non-Destructive Examination (NDE) techniques including X-Ray Fluorescence (XRF) and Computerised Radiography (CR) to evaluate the integrity and material composition of metallic idols in a 16th-century Hindu temple. The investigation aimed to determine elemental constituents, identify internal flaws, and assess structural soundness without compromising the sanctity of the artifacts. Results indicated high copper content with trace elements and confirmed the absence of significant defects. These findings offer insights into long-term conservation, reconstitution planning, and preventive care strategies for culturally sensitive heritage objects. The study also affirms the broader applicability of NDE across museums and religious sites, promoting ethically responsible diagnostics in art and archaeology. This approach bridges scientific objectivity with heritage preservation, ensuring minimal intrusion and maximal informational yield.

Keywords: Non-Destructive Examination (NDE), Temple Idol Preservation, X-Ray Fluorescence (XRF), Cultural Heritage Conservation, Computerised Radiography

1. Introduction:

Religion plays a significant role in people's lives. Every individual has the right to decide for themselves whether to follow any particular religion, to what extent, or not to follow any religion at all. Each religion has its specific norms, which followers may observe to varying degrees. Depending on the religion and how much an individual chooses to follow it, there may be certain actions one is supposed to do or avoid. Similarly, there might be other items or actions that a religion requires, forbids, tolerates, or accepts its followers doing. Adopting the motto "to each his own," some individuals may only show superficial interest in religion, while others may be deeply engaged.

Within each individual's belief system, there is a potential for their sentiments to be hurt by certain events. While these events and the extent to which they hurt someone's feelings vary from person to person, the general behaviour of the world should be one of tolerance towards others' beliefs and sentiments. Although some sentiments may be unintentionally hurt from time to time, intentional hurtfulness must be avoided at all costs. Religion is a personal belief and falls outside the scope of this paper, beyond the introduction.

2. Non-Destructive Examination (NDE):

2.1 What is NDE?

Non-Destructive Examination or NDE involves the determination of the properties and integrity of items without sacrificing their usefulness.

NDE can also be used for determining the integrity of cultural items, along with figuring out the properties and constituents of various items such as textiles, papyrus, sculptures, and statues and so on.

To quote examples from the medical field, inspections such as X-Ray analysis, Endoscopy, CT scan, and Ultrasound are included under NDE.

2.2 Why carry out NDE?

Items of heritage importance are thousands of years old. Once any of them are damaged, they cannot be recovered, which leads to the loss of thousands of years of historical data and evidence. As such, it is essential to conserve such items to ensure their long-lasting lifespan.

2.3 Applications of NDE:

Various applications of NDE include:

- i. Inspection for damage – external
- ii. Inspection for defects – internal
- iii. Material analyses
- iv. Material property assessment
- v. Determination of type of construction
- vi. Determination of the location of damage and defects
- vii. Planning for reconstitution, preservation and conservation

3. The Hindu Religion:

The Hindu religion is one of the oldest, if not the oldest, religions in the world. There are more than a million different deities in Hinduism. Some are considered primary, while others are regarded as avatars or incarnations of others. Every person has a deity they worship. Some individuals do not worship any specific deity and are more flexible in their beliefs. Such people may see all deities as one and pray or worship them equally. Certain followers have a deep reverence for their particular deity. Others do not tolerate any deviation from the teachings and scriptures.

One of the features of Hinduism is idol worship. It is one of the distinctive aspects of Hinduism, whereby an idol of the main deity is installed under the dome or the cope stone of the temple, inside an altar. There is, usually, an idol of the vāhana or vehicle of the deity in question, immediately outside the main altar. This is usually in the form of the animal that is considered to be the vāhana of the deity. Within the surroundings of the temple, there may be additional shrines to secondary deities, with their idols inside. As such, the entire temple complex may be a simple structure containing only the shrine of the main deity, or it may be a complicated structure consisting of numerous shrines.

4. Idol Worship:

As mentioned above, idol worship is an integral and important part of Hinduism. Depending on the deity involved, their incarnation, their symbolism and other factors, some temples and shrines allow the devotees to touch the idols in question. While some others, usually those considered the utmost holy, or those that have a large number of devotees visiting regularly, do not allow the devotees to touch the idols. In any case, every temple has a group of priests dedicated to it, whose purpose is to take care of the idols and carry out daily rituals. Such rituals may include bathing, washing and dressing the idols, applying vermilion and turmeric, offering food, milk and water and so on. Each one of these involves physically touching and handling the idols.

Apart from the daily rituals, most of the deities have annual festivals in their honour, whereby they are revered and worshipped on a much larger scale, and by a much larger segment of the population. Indeed, during such festivals, even those individuals who usually do not visit the concerned temples make it a point to visit them and ask for blessings. During such times, the offerings to the deities are also increased, in both quantity and variety.

5. Idol Construction:

Most of the idols in the temples are made up of different types of metals and alloys. There are instances where stones, ivory, wood and even Plaster of Paris may be used, but such instances are far and few in between. A combination of sand, clay, mud and herbal paint is by far the second most common material of construction. Before the advent of technology, these were the most common materials that were used. Eventually, they made way for metallic idols due to the ease of construction and long-lasting nature.

Idols can either be made in one piece or may be made in a different number of pieces, which can then be joined together. Metallic idols are usually cast as per requirements, whereas marble, stone, and other such items may be produced in parts and assembled. Such types of assemblies are rare and are mainly found in modern temples, which have been built very recently. Generally, temples that are centuries old have their idols made in one piece, although there may be exceptions to this as well.

6. Problems Encountered:

6.1 Physical Problems:

As mentioned above, idol worship in Hinduism involves touching the idols, whether by the priests daily or by the devotees during festivals. The human body has various oils on its skin. These oils are transferred, in minute quantities, to the idols every time they are touched. Though these may be minute in quantity individually, the number of devotees and the years over which they have touched combine to make it a substantial quantity.

Apart from oils, sweat is another problem. Sweat is essentially salty water from the body. This not only causes the idols to come in contact with the water, but also brings the salts and any toxins that may be present in the sweat itself.

A third problem that is encountered is that of fresh water. The idols are bathed, usually twice a day, using fresh water. During festivals, these may increase to more than two times a day. As such, the fresh water has its effect on the idols. Depending on the source and the nature of the freshwater, it may contain different salts and minerals. Each one of them may have its effect on the idol material.

Another problem encountered is due to the anointment. Idols are usually anointed with turmeric, vermilion and other such powders after they are bathed. Such powders, both individually and in combination, may also have a reaction with the idol material.

Offerings are made to the gods in the form of sweets, milk, and other such items. While only milk may be poured on the idol, and even this occurs in the rarest of circumstances, the other offerings are usually only touched at the mouth area of the idol, symbolising the offerings. They may be placed upon the open palms of the hands of the idol, also symbolising an offering. These food items are made up of various ingredients, each with its own constituent chemicals. There may be different offerings every day. All these combinations may result in different effects on the idols.

Another thing to consider is the lamp and the incense sticks. Lamps made up of oil or cooking butter are lit along with incense sticks for the daily rituals of the pooja and prayers. While these are not directly brought into contact with the idols, the heat and smoke can have an effect on the idols, although to a lesser extent.

It must be kept in mind that, although each of the above-mentioned problems may be minute in their own right, the combination of the various factors may have a bigger impact. Also, given that most of the temples are visited by thousands of devotees every year, it may magnify the effects. Adding in the fact that most of these temples and their corresponding idols are hundreds of years old, the cumulative effect of all these minute problems may be a major one.

6.2 Psychological Problems:

As mentioned above, religion and faith are matters that are very close to an individual. There are quite a few individuals in any religion who may believe that nothing can change, and even a small deviation from the routine may be considered unholy.

NDE involves touching, handling and inspecting the idols. As such, it may be extremely difficult, nay on impossible, to convince the concerned personnel of its effectiveness. Even once the personnel are convinced that NDE is useful, they still may not accept the handling of the idols in the way that may be needed for carrying out the NDE.

The general public would also have to be considered. It is not usually possible to shut a temple down for maintenance reasons. However, it can be done, and the general public will simply have to be notified of the same. Similar instances had been observed during the COVID-19 pandemic. It would require convincing the concerned authorities of the general public. It would require an immense satisfaction of the emotions of those sections of the public who may be offended by their deities being handled in a way that, as per them, goes against the norms of the religion.

7. Case Study:

Non-destructive examination of a Hindu temple was carried out in the state of Maharashtra in western India. The purpose of the same was the determination of the constituent materials of the idols, along with the method of construction. The main intention was to be able to plan for the preservation, conservation and reconstitution of the idols under the jurisdiction of the temple. The case for the same is considered under:

7.1 Location:

The details of the temple and its location were as under. The trust in charge of the temple had requested to carry out NDE of the idols.

Name: Shree Balaji Maharaj Temple

Trust: Shree Balaji Sansthān (Trust)

Location: Deulgaonraja Town, Buldhana District, Maharashtra State, India

Date of Inspection: 8th May 2019



Figure 1. Shree Balaji Temple, Deulgaonraja, Buldhana, Maharashtra, India

7.2 Test Idols:

The temple premises consisted of three (3) idols as follows:

1. Lord Balaji
2. Goddess (Devi) Laxmi
3. Goddess (Devi) Padmavati



Figure 2. Idol of Lord Balaji, Deulgaonraja, Buldhana, Maharashtra, India

7.3 Tests Conducted:

The following tests were conducted on the idols:

1. Positive Material Identification (PMI).
2. Computerised Radiographic Testing (CR).

7.3.1 Positive Material Identification:

A. Description:

Positive Material Identification (PMI) involves analysis of metallic alloys to determine their constituent elements.

X-Ray Fluorescence (XRF) is one of the methods for PMI. The equipment used contains a low-energy X-ray tube. The exposed materials reflect the radiation and generate energy, which is received by the detector and shows the constitution of the alloys in the material.

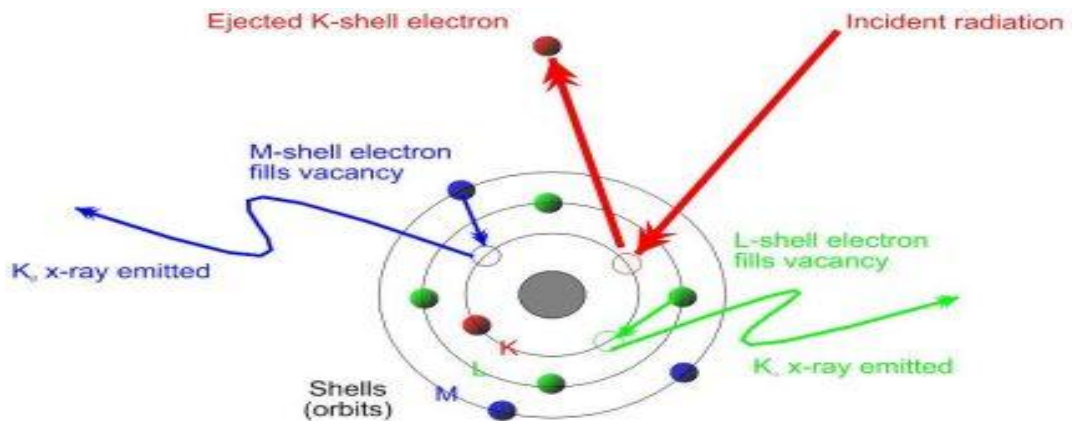


Figure 3. XRF Operating Principle

B. Equipment Used:

Make: Thermo, USA

Model: XL2 980 GOLDD

References: Niton™ XL2 GOLDD XRF Analyser, ASTM Sec. II-A (Relevant Specification)

C. Observations:

Sr. No.	Idol	Cu	Zn	Sn	Pb	Fe	Sb	Mo	Ni	Si
1.	Laxmi	73.66	10.05	6.16	3.86	0.93	0.28	0.10	0.19	4.66
2.	Balaji	76.14	11.17	5.80	5.46	0.85	0.26	0.11	0.18	--
3.	Padmavati	73.89	10.54	5.61	5.17	0.86	0.24	--	0.15	3.37

Table 1. XRF readings for idols

D. Remark:

All three idols predominantly Contain Copper (73 – 76 %), Zinc (10 – 12 %) and Tin (5 – 6 %).



Figure 4. XRF Equipment – Thermo Scientific Niton XL2 GOLDD

7.3.2 Computerised Radiography:

A. Description: Computerised or computed radiography (CR) is a new method of Radiographic Testing. An imaging plate is kept behind the object. A portable X-ray machine is placed in front of the object. The X-rays are switched on and are transmitted through the object. X-rays are attenuated in the object and pass through to the plate. Based on the material encountered, the intensity of X-rays at different points on the plate varies. The plates are scanned in scanners to give a digital image of the internal structure of the sample. This digital image can be shared, analysed and annotated as required.

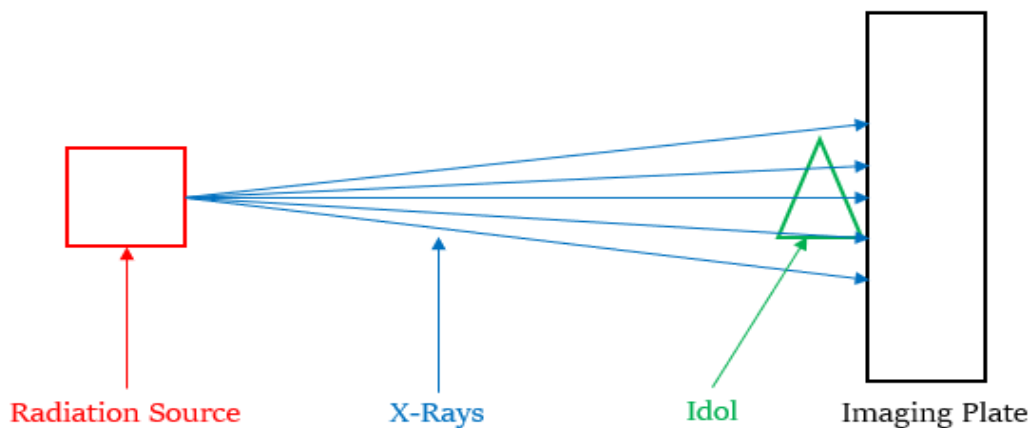


Figure 5. X-Ray Inspection Process

A pulsed X-ray machine was used as a source of ionising radiation. Pulsed X-Ray generates a high-intensity X-Ray burst (pulse) in a very short period. The output dose of each pulse is 2 mR measured 12 inches from the front of the X-Ray generator.

Pulsed X-Ray technology has inherent advantages for field operation compared to conventional constant potential X-Ray machines or radioactive sources.

B. Equipment Used:

Source: Pulsed X-Ray

Make: Golden Engineering

Model: XRS-3 X-Ray Unit

Pulses: 99 x 10

Scanner Make: Carestream

Scanner Model: HPX-Pro

Imaging Plate Model: HRX-Flex

Imaging Plate Size: 5" x 7"

Source to Imaging Plate Distance: 800 mm



Figure 6. X-Ray Source – Golden Engineering XRS-3



Figure 7. CR Scanner – Carestream HPX-Pro

C. Inspection Images:

C.1. Front Side:



Figure 8. Computerised Radiography Inspection Image – Front Side

C.2. Back Side:



Figure 9. Computerised Radiography Inspection Image – Back Side

D. Observations:

1. No recordable indications or defects were observed in any of the three idols.
2. No abnormality observed in any of the three idols.
3. No cracks or disjoint observed in any of the three idols.

E. Remarks:

All three idols were found to be intact and solid. No untoward damage or occurrence observed.

7.4 Recommendations:

1. All idols are found to be in good condition with no severe indication of wear.
2. Regular monitoring of the idols is recommended to determine the trend of wear, especially in areas where contact with human skin and associated chemicals is expected.
3. Recreation and duplication of idols are possible based on the data obtained in the PMI conducted.
4. Data obtained in this study can be used to carry out further studies of other idols and statues in other temples, museums and other such locations.
5. Data obtained in this study can be used to carry out further analyses to understand original design conditions, and the deviation from these original design conditions is caused due to many damage mechanisms that might have caused degradation in material and properties.
6. As the alloy contents are well established, certain precautionary measures such as specific heat treatments or surface property enhancement treatments can be evolved.
7. Online monitoring using NDE, such as IR/Microwave, etc., can be used to predict further damage to these or any other idols.

8. Conclusion:

This case study demonstrates the successful application of Non-Destructive Examination (NDE) techniques – X-Ray Fluorescence and Computerised Radiography – in assessing the condition of centuries-old temple idols without compromising their ritual integrity. The findings validate NDE as an effective, respectful approach for identifying material composition and structural soundness in culturally sensitive artifacts. The absence of defects in the tested idols reinforces their durability, while the generated data enables replication, conservation planning, and preventive monitoring.

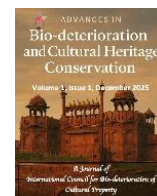
Beyond the immediate context, the methodology holds promise for broader adoption in heritage conservation, particularly in museums, religious sites, and archaeological research. Its integration into routine care protocols can enhance long-term artifact preservation, and guide reconstitution efforts when necessary. Future work should focus on refining NDE standards, incorporating complementary diagnostic tools, and fostering collaborative frameworks between scientists, conservators, and faith communities – ensuring ethically sound stewardship of heritage objects.

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Sketched in-house by Injotech India Private Limited
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Bio-Deterioration of Cultural Property and Their Eco-Friendly Conservation

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ABSTRACT

Biodegradation of microorganisms poses a serious threat to cultural property, with fungi being one of the most destructive agents. This study evaluates the antifungal efficacy of ethyl acetate seed extracts obtained from *Pongamia pinnata*, *Annona squamosa* and *Azadirachta indica* against five fungal species - *Aspergillus niger*, *Rhizopus stolonifer*, *Curvularialunata*, *Penicillium* species and *Cladosporium cladosporioides*, isolated from heritage sites. Using agar well diffusion and MIC techniques, concentrations of the extracts (5-40 mg/mL) were tested for inhibition zones. *A. indica* showed the highest antifungal activity, especially against *C. lunata*. Comparative analysis with streptomycin underlines the feasibility of plant-based antimicrobials as eco-friendly alternatives to synthetic chemicals. The results support integrating phyto-extracts into preventive conservation strategies to reduce microbial degradation while maintaining environmental integrity. These findings are in line with NRLC's commitment to sustainable heritage conservation and demonstrate the potential of medicinal plants in developing biodegradable fungicide formulations for monument conservation.

Keywords: Antifungal activity, Medicinal plant extracts, Cultural heritage conservation, Microbial biodeterioration, Eco-friendly fungicidal agents.

1. Introduction:

The bio-deterioration and scientific conservation of cultural property is also an important issue for conservators, conservation scientists, curators, research scholars and various kinds of institutions. The problem of the conservation of cultural property like manuscripts has been going on since man acquired the knowledge of writing. Writers have always been concerned to preserve their writings for future generations, whatever means or resources they have or had. Palm leaf manuscripts constitute our most precious national heritage as rare pieces of recorded knowledge. These manuscripts are not only a powerful means of preserving our literary, linguistic, artistic and cultural heritage but also the only source of the unknown and unknowable. Therefore, every possible effort should be made to save these treasures and assets for future generations [1]. [5According to the World Health Organisation (WHO), various medicinal plants are a major source of obtaining various types of medicines and chemicals, which have environmentally friendly properties. More than %80of the people in developed countries use traditional medicine from medicinal plants. Medicinal Plant Medicines are compounds obtained from various parts of medicinal plants [.[2Research has shown that the use of crude extracts and their phytochemistry from various parts of plants is very important in medical treatments. Many plants have been used due to their antimicrobial properties, which are due to secondary metabolites synthesised by the plants [.[3Medicines obtained from such plants can also be used for such fungi, algae, lichen, moss, germs, viruses and microorganisms that damage our heritage; that is, these medicinal plants can also be used to prevent the bio-deterioration of monuments and cultural assets caused by microorganisms. There are many medicinal plants whose extracts are being used at the National Research Laboratory for the Conservation of Cultural Property, Lucknow, to prevent the growth of microorganisms at the laboratory level.

Neem (*Azadirachta indica* A. Juss.) is perhaps the most useful traditional plant in India. Each part of the neem tree has some traditional property and is thus commercially exploitable. *A. indica* (Neem - leaf, bark and seed) are known to contain antibacterial and antifungal activities against different pathogenic microorganisms and antiviral activity against vaccinia [4].

***Annona squamosa* Linn.** is a small evergreen tree that is cultivated throughout India for its fruits. It is known as custard apple, sugar apple, sweet apple in English, sharifa in Hindi, and sitaphal in Telugu. Different parts of *A. squamosa* are used in folkloric medicine for the treatment of several disorders and are beneficial for cardiac diseases, diabetes, hyperthyroidism and cancer. *A.* is traditionally

used for the treatment of epilepsy, dysentery, worm infestation, constipation, haemorrhage, dysuria, fever, thirst, ulcers and also as an abortifacient [5].

Pongamia pinnata is a species of tree, found in eastern and tropical Asia, Australia, the Pacific Islands, including Lucknow, India. It is the only species of the genus *Pongamia*. Indians know and recognise it as Karanja. *Pongamia pinnata* seeds generally contain oil, protein, starch, crude fibre, etc. Karanja seed oil contains oleic acid, which is used for lamp oil, soap making and as a lubricant. Karanja oil contains a high amount of triglycerides, which causes it to taste unpleasant. The fruits, shoots and seeds are used in traditional medicine. Research has found that Karanja (*P. pinnata*) seed oil has strong antimicrobial activity. As a result, seed extracts have displayed a strong area of inhibition on bacterial and fungal strains [6].

Keeping in view the properties of various medicinal plants, NRLC Lucknow studied the role of microbial flora in the degradation of cultural assets and used extracts of medicinal plants along with commonly used chemicals for controlling the growth of microorganisms responsible for the degradation of monuments. For the study, standard fungi were procured from the laboratory of CSIR-MTCC, Chandigarh, India and extracts of *Pongamiapinnata*, *A. squamosa* and *AzadirachtaIndica* (Neem) were used for competitive evaluation of antimicrobial activity against pathogenic cultures of various fungi collected, and it was successful. However, the present study is an attempt to find out the antimicrobial activity of the above medicinal plants and compare that activity with commonly available antibiotics.

2. Materials and Methods:

2.1. Extraction of plant material by Soxhlet apparatus:

Seeds of medicinal plants, i.e. Karanj, Sitafal and Neem, were purchased from the local market in Lucknow, India and evaluated for their antifungal activity through the disc diffusion assay technique. The seeds were washed thoroughly with tap water, followed by sterilised distilled water and shade dried for a few days and then powdered with the help of a blender. These crushed materials were extracted sequentially in ethyl acetate solvent with the help of a Soxhlet apparatus, approximately 08 hrs per day for three days [7]. Resulting extracts were evaporated and concentrated to dryness using the rotary evaporator at 50°C.

2.2. Test microorganisms:

Five fungal cultures, *Aspergillus niger*, *Rhizopus stolonifer*, *Curvularialunata*, *Penicillium sp.* and *Cladosporium cladosporioides* were used in the present study. All the tested strains/slant culture of fungi was obtained from the laboratory of CSIR-MTCC, Chandigarh, India. Pure fungal cultures were grown in potato dextrose broth at 28°C and maintained on potato dextrose agar slants at 4°C [8].

2.3. Agar-well diffusion method:

The assay was conducted by agar well diffusion method. About 15 to 20 ml of potato dextrose agar medium was poured into the sterilised petri dishes and allowed to solidify. A fungal lawn was prepared using a pure culture strain. 1 ml of fungal strain was spread over the medium using a sterilised glass spreader. Using flamed sterile borer, wells of 4 mm diameter were punctured in the culture medium [6-7]. Required concentrations of serially diluted extracts (5, 10, 20 and 40mg/ml) were added to the wells. The plates thus prepared were left for diffusion of extracts into media for one hour in the refrigerator and then incubated at 37°C. After incubation for 48h, the plates were observed for zones of inhibition. Disc diffusion method was followed by taking the antibiotic Streptomycin sulphat. The plates were examined, and the minimum inhibitory concentrations were measured [8-10]. The diameter zone of inhibition was measured and expressed in millimeters. Di methyl sulfoxide (DMSO) with streptomycine sulphate was used as a negative control. The experiments were conducted in triplicates. Percentage inhibition of fungi growth by the leaf extracts was calculated using formula [6,9].

$$FG = \{(Dc - Dr) / Dc\} \times 100$$

$$FGI = 100 - FG$$

Where-

FG= fungal growth in %

Dc= Diameter of control (mm)

Dr=Diameter of test (mm)

FGI= Fungal Growth Inhibition in %

Table: 1- Antifungal activity of ethyl acetate crude extracts of seeds of *Annona squamosal* and *Azadirachta indica*

Samples	Conc. of extracts (mg/ml)	Diameter of inhibition zone (in mm)				
		<i>Aspergillus niger</i>	<i>Rhizopus stolonifer</i>	<i>Curvularialunata</i>	<i>Penicillium sp</i>	<i>Cladosporium cladosporioides</i>
<i>Pongamia pinnata seed extract</i>	5	-	3	-	4	-
	10	-	5	-	6	-
	20	5	8	-	9	4
	40	8	10	5	11	6

<i>Annona squamosa</i> seed extract	5	--	--	6	--	--
	10	6	--	9	7	--
	20	9	7	11	10	9
	40	13	11	14	12	13
<i>Azadirachta indica</i> seed extract	5	--	8	8	--	--
	10	5	10	11	--	7
	20	7	11	13	9	10
	40	11	14	16	11	13
Control(DMSO)		--	---	--	--	--
Streptomycin	100 µg/ml	19	21	20	23	21

--No inhibition zone

3. Result and Discussion:

In the present investigation five fungal cultures were tested to determine the antifungal activity of ethyl acetate seed extract of *Pongamia pinnata*, *Annona squamosa* and *Azadirachta indica*. The values given in tables -1 are the mean of the three observations. The ethyl acetate seed extract of *P.pinnatta* showed maximum of 11.00 mm inhibition for *Penicillium* sp with 40mg/ml followed by *Rhizopus stolonifer* (10 mm), *Aspergillus niger* (8 mm), *Cladosporium cladosporioides* (6 mm) and *Curvularialunata* (5mm). The ethyl acetate seed extract of *A.squamosa* showed maximum of 14.00 mm inhibition for *Curvularialunata* with 40mg/ml followed by *Cladosporium cladosporioides* (13mm), *Aspergillus niger* (13mm), *Penicillium* sp (12mm) and *Rhizopus stolonifer* (11mm). The ethyl acetate seed extract of *Azadirachta indica* revealed maximum inhibition at 40mg/ml for *Curvularialunata* (16 mm) followed by *Rhizopus stolonifer* (14mm), *Cladosporium cladosporioides* (13mm), *Aspergillus niger* (11mm) and *Penicillium* sp (11mm).

The standard streptomycin at 100 µg /ml showed the highest inhibition in *Penicillium* sp (23mm), followed by *Rhizopus stolonifer* (21mm) and *Cladosporium cladosporioides* (21mm), *Curvularialunata* (20mm) and *A.niger* (19mm). The negative control used DMSO with streptomycin, could not show inhibition against all the tested fungal strains. Our study shows that ethyl acetate seed extracts of *P. pinnatta*, *Annona squamosa* and *Azadirachta indica* maximum inhibited the growth of *Curvularialunata*. The finding report also supported by other scientists [11]. From agar well diffusion and disk diffusion methods, obtained that there were marked differences between the activities of the plant extract and the pure antifungal drugs (Streptomycin). Such significant differences are normally present when crude (unpurified) plant extracts are compared with pure drugs that are already in clinical use [7]. In our investigation, ethyl acetate seed extract at 40mg/ml concentration highly inhibited *Curvularialunata* at both seed extract results. Result interpretation was done based on the zone of inhibition created due to the antifungal properties of the plant extracts. This study was an effort to prove the use of herbal medicines in the developed world because they are rich source of novel drugs and their bioactive principles form the basis in medicine, nutraceuticals, pharmaceutical intermediates and lead compounds in synthetic drugs. Plant based products/ extracts are cheaper alternatives to the development of synthetic drugs.

4. Conclusion:

The antifungal efficacy of *Azadirachta indica*, *Annona squamosa*, and *Pongamia pinnata* seed extracts was assessed against key fungal strains affecting heritage artifacts. Neem extract exhibited the highest inhibition zones, indicating strong fungicidal potential. Sitaful and Karanj also showed notable activity. These results support the integration of plant-based antimicrobials into eco-friendly conservation practices. Given their effectiveness and environmental safety, such phyto-extracts offer promising alternatives to synthetic chemicals for sustainable monument preservation.

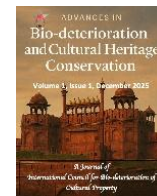
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Advances in Bio-deterioration and Cultural Heritage

Battling Biodeterioration: Strategies for the Conservation of Cultural Heritage

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ABSTRACT

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Cultural heritage sites and artefacts serve as invaluable testaments to human history, yet they remain vulnerable to biodeterioration - a process driven by microorganisms, fungi, algae, and lichens that accelerate material degradation. This deterioration results in structural instability, discolouration, and the gradual loss of historical and artistic value. Gaining a deeper understanding of biodeterioration mechanisms is crucial for developing effective conservation strategies. This paper examines the biological factors contributing to cultural heritage degradation and explores modern methods to mitigate their effects. Preventive conservation measures, such as environmental regulation, specialised material treatments, and protective coatings, are essential in curbing microbial growth. Recent advancements in biocidal techniques, including nanotechnology-based treatments and natural antifungal agents, have demonstrated effectiveness in eradicating harmful organisms while preserving the structural integrity of heritage materials. Additionally, innovative biotechnological solutions, such as microbial-based cleaning processes and bioengineered protective layers, offer sustainable alternatives to conventional chemical treatments. This study underscores the necessity of interdisciplinary collaboration among microbiologists, conservation specialists, and material scientists to develop long-term preservation strategies. Public engagement and the enforcement of protective policies further strengthen efforts to safeguard cultural heritage. By merging scientific advancements with traditional conservation practices, it is possible to protect these historical assets from biological deterioration while minimising environmental harm. This paper provides insights into the ongoing fight against biodeterioration and highlights evolving strategies aimed at preserving cultural and artistic treasures for future generations. Protecting heritage from biological threats is not only a scientific imperative but also a cultural duty to safeguard humanity's legacy.

Keywords: Biodeterioration, Conservation, Heritage, Biocidal, Nanotechnology, Bioengineering

1. Introduction:

Biodeterioration refers to the degradation of materials caused by the metabolic activities of living organisms, particularly microorganisms such as fungi, bacteria, algae, and insects (Fierăscu et al., 2020). Within the context of cultural heritage, this process can lead to significant damage to artefacts, including stone monuments, wooden structures, textiles, paintings, books, and even archaeological sites (Sterflinger & Piñar, 2013).

The effects of biodeterioration on cultural heritage are considerable:

- a) **Physical damage:** Some organisms can weaken or alter materials structurally. For example, fungi can infiltrate stone, leading to cracks and crumbling, while insects burrow into wood, compromising its stability (Sterflinger & Piñar, 2013).
- b) **Chemical changes:** The metabolic byproducts of these organisms may react with the material's components, leading to staining, discolouration, or the formation of corrosive substances that can weaken the artefact's structure (Sterflinger & Piñar, 2013).
- c) **Aesthetic deterioration:** Biodeterioration often affects the visual appearance of cultural heritage by causing discolouration, surface growths, or biofilm formation, which can diminish the artefact's aesthetic and historical value (Sterflinger & Piñar, 2013).

- d) Loss of historical data:** In severe cases, biodeterioration can destroy artefacts, leading to the irreversible loss of cultural and historical information (Geweely, 2023).

Understanding how biodeterioration occurs is essential for designing conservation strategies that effectively safeguard cultural heritage.

1.1. The Importance of Conservation Strategies:

Developing robust conservation strategies is critical for several reasons:

- a) Preserving Cultural Heritage for Future Generations:** Cultural heritage, encompassing sites, artefacts, and traditions, represents the tangible and intangible legacy of human civilisation (Nugroho & Hardilla, 2020). Effective conservation ensures these valuable resources remain accessible for future generations to study, appreciate, and connect with their history. Without proper preservation, these unique historical links could be lost forever. Appelbaum (2021) highlights the significance of conservation in maintaining our connection to ancient heritage and culture.
- b) Safeguarding Cultural Identity and Diversity:** Cultural heritage plays a fundamental role in shaping both individual and collective identities. Halim & Ishak (2017) emphasise that communities often view conservation as a means of reinforcing their identity by preserving their cultural legacy. When heritage is lost, communities may experience a weakening of their sense of belonging, reducing the richness of global cultural diversity. The social value of conservation extends beyond individual communities, reflecting a shared responsibility to protect and maintain cultural heritage (2025).
- c) Boosting Economic Growth and Tourism:** Cultural heritage conservation contributes to economic development, particularly through tourism. Rani et al. (2018) highlight the increasing recognition of heritage preservation as an economic resource. Well-maintained heritage sites attract visitors, generating income and creating employment opportunities within local communities.
- d) Supporting Sustainable Development:** Conservation is closely tied to sustainability, as preserving cultural heritage also means protecting the surrounding environment and historical context (Rani et al., 2018). By integrating heritage preservation into development strategies, societies can adopt a more balanced approach that respects both natural and cultural landscapes.
- e) Enhancing Knowledge and Historical Understanding:** Cultural heritage provides invaluable insights into past societies, technological advancements, artistic expressions, and historical lifestyles. Jokilehto (1999) notes that while safeguarding heritage is an ongoing challenge, it remains essential for deepening our understanding of history. The study and preservation of cultural artefacts and sites contribute to expanding human knowledge, stimulating intellectual curiosity, and enriching collective learning.

Implementing effective conservation measures protects not only physical artefacts and historic locations but also the intangible cultural values, narratives, and traditions they embody. By doing so, we ensure that the diversity and richness of human experience continue to inspire and educate future generations.

2. Research on biodeterioration:

Research on **biodeterioration** spans multiple disciplines, including microbiology, materials science, archaeology, and art conservation. A key area of study involves understanding how different organisms interact with materials and contribute to their degradation. Sterflinger & Piñar (2013) provide a comprehensive overview of microbial deterioration, emphasising the influence of factors such as material composition, climate conditions, and cleaning methods on the process.

Another focus of research is identifying the specific organisms responsible for biodeterioration. For instance, Vanin et al. (2021) explore the impact of insects on archaeological materials and highlight the potential for misinterpretations if modern insect activity is mistaken for historical infestations. Similarly, Sterflinger & Piñar (2013) examine the role of fungi, bacteria, and algae in the deterioration of stone and other structural materials.

3. Current Conservation Approaches:

Efforts to prevent and mitigate biodeterioration incorporate various conservation strategies:

- a) Preventive Conservation:** This method aims to create conditions that discourage microbial growth and minimise the risk of infestation. Common strategies include regulating temperature, humidity, and light exposure, as well as adopting proper cleaning techniques. Aerobic (2022) highlights the role of oxygen levels and relative humidity in bacterial growth, suggesting that controlling these factors can help limit microbial activity.
- b) Remedial Conservation:** When deterioration has already occurred, remedial treatments are required. These may involve cleaning, reinforcing weakened materials, or applying biocides. Geweely (2023) discusses recent advancements in conservation, including the use of nanomaterials for cleaning and protection. Additionally, research is exploring the potential of natural products as eco-friendly biocides (Fierăscu et al., 2020).
- c) Innovative Material Development:** Advances in materials science are driving the creation of new conservation materials. Baglioni et al. (2021) highlight the potential of nanoparticles, gels, and composite materials for cleaning, protecting, and strengthening artefacts.

Ongoing research is necessary to improve existing methods and develop more effective conservation strategies. Geweely (2023) stresses the importance of interdisciplinary collaboration and cutting-edge technologies in conservation. Key areas of investigation include assessing the long-term effects of treatments, creating environmentally sustainable biocides, and exploring the applications of nanotechnology in cultural heritage preservation (2022).

4. Knowledge Gaps and Future Research Directions:

Despite progress in understanding and addressing biodeterioration, several areas require further exploration:

- a) **Long-Term Effects of Conservation Treatments:** More research is needed on the long-term impact of conservation treatments, particularly new materials like nanomaterials. Evaluating any potential unintended consequences or delayed negative effects is essential to ensure that treatments remain beneficial over time. Round-robin testing of conservation materials is vital for refining methods and assessing their effectiveness (Geweely, 2023; Thickett & Lankester, 2012).
- b) **Development of Environmentally Friendly Biocides:** Traditional biocides often pose environmental and health risks, making the development of eco-friendly alternatives a priority. Further studies are needed to identify effective, non-toxic solutions for controlling biodeterioration while minimising harm to humans and ecosystems (Geweely, 2023).
- c) **Impact of Climate Change:** Changing environmental conditions due to climate change may influence the rate and severity of biodeterioration. Rising temperatures, humidity fluctuations, and other climatic shifts could alter the ways cultural heritage materials degrade. Research is necessary to anticipate these changes and develop adaptive conservation strategies (Thickett & Lankester, 2012).
- d) **Interactions Between Multiple Organisms:** Much of the existing research focuses on the impact of individual organisms, yet biodeterioration is often driven by interactions between multiple species. Studying these complex relationships will provide a deeper understanding of degradation processes and help develop more precise conservation techniques (Sterflinger & Piñar, 2013).

While substantial advancements have been made in biodeterioration research and conservation, continued interdisciplinary efforts are crucial to refining preservation methods and safeguarding cultural heritage for future generations.

- a) **Standardising Testing and Evaluation Methods:** Establishing standardised methodologies for assessing the effectiveness of conservation treatments is essential. Uniform testing protocols will enable more reliable comparisons between different materials and methods, improving decision-making in conservation practice. Round-robin testing and clear guidelines are necessary to ensure consistent and comparable results across studies and projects.
- b) **Improving Accessibility and Affordability of New Technologies:** Many cutting-edge conservation techniques, such as nanomaterial-based treatments, require specialised knowledge and costly equipment, making them inaccessible to smaller institutions or organisations in developing countries. Research is needed to develop more cost-effective and widely available conservation methods. While some resources exist to help institutions set up conservation labs and manage conservation businesses, further efforts are required to disseminate this knowledge and promote affordable, practical solutions.

Addressing these challenges will contribute to making conservation strategies more effective, sustainable, and accessible, ensuring that cultural heritage is preserved for future generations.

5. Types of Biodeterioration:

5.1. Physical Biodeterioration:

Physical biodeterioration refers to the structural damage or alteration of a material caused by living organisms. Unlike chemical biodeterioration, which results from metabolic byproducts and reactions, physical biodeterioration is driven by mechanical processes. Máčalová et al. (2021) discuss "biocorrosion" as a form of biodeterioration that disrupts material properties.

Key mechanisms behind physical biodeterioration include:

- a) **Penetration and Growth:** Certain organisms, such as fungi and plant roots, infiltrate materials, leading to cracking, weakening, and eventual disintegration. Sterflinger & Piñar (2013) describe fungi as highly erosive to stone, while insects burrowing into wood can compromise its structural stability (2024).
- b) **Physical Disruption:** Organisms such as burrowing animals, insects, and microorganisms create tunnels, voids, or surface damage within materials. Khalil et al. (2009) demonstrate how biodegradation in soil negatively affects a material's mechanical properties over time.
- c) **Expansion and Contraction:** Growth and metabolic activity of organisms can cause localised swelling and shrinking in materials. This internal stress can result in cracking, flaking, or delamination, particularly in composite materials with multiple layers. Fluctuations in relative humidity can further exacerbate these effects (2024).
- d) **Erosion and Surface Wear:** While "wear and tear" (Mitchell, 1871) generally refers to damage from regular use, in the context of biodeterioration, it also includes physical erosion caused by organisms moving across surfaces or accumulating waste products. Chang et al. (2020) discuss wear and tear alongside other physical and chemical degradation mechanisms affecting biobased composite materials.

Physical biodeterioration can significantly compromise the structural integrity and aesthetic value of cultural heritage objects. Fierăscu et al. (2020) highlight how such deterioration threatens the survival of historical artefacts, emphasising the importance of understanding these processes to develop targeted conservation strategies.

5.2. Chemical Biodeterioration:

Chemical biodeterioration occurs when microorganisms alter a material's chemical composition through their metabolic activities, leading to degradation. Mácalová et al. (2021) describe how microorganisms involved in cement biocorrosion release acids and other byproducts that impact their chemical integrity.

Key mechanisms of chemical biodeterioration include:

- a) **Acid Production:** Many fungi and bacteria generate organic acids as metabolic byproducts, which react with materials, causing dissolution, etching, and structural weakening. This process is especially damaging to materials like stone, concrete, and metals. Sterflinger & Piñar (2013) emphasise how fungi contribute to stone erosion through acid production.
- b) **Oxidation and Reduction:** Certain microorganisms can facilitate oxidation or reduction reactions, altering the material's chemical state. These changes can affect colour, solubility, and overall stability. Bala et al. (2022) discuss how bioremediation processes use microbes to break down pollutants by enzymatic conversion into less harmful compounds.
- c) **Hydrolysis:** Some microorganisms produce enzymes that break down complex molecules via hydrolysis, weakening organic materials such as polymers. This process can lead to material softening, reduced strength, and increased vulnerability to further deterioration. Cunningham (1936) notes that the hydrolysis of cellulose and other wood components contributes to the degradation of timber in seawater.
- d) **Metal Corrosion:** Microbial activity can accelerate metal corrosion through the production of corrosive byproducts and the formation of biofilms, which create localised electrochemical environments conducive to deterioration. Mácalová et al. (2021) describe how algae play a role in biocorrosion, affecting the stability of cement composites.
- e) **Pigment Degradation:** Some microorganisms metabolise or chemically alter pigments, leading to fading, discolouration, and changes in the appearance of painted surfaces or dyed fabrics. Fierăscu et al. (2020) highlight how biodeterioration can cause irreversible damage to cultural heritage objects.

Chemical and physical biodeterioration often work together. For instance, acids produced by microorganisms can weaken materials, making them more susceptible to structural damage from penetrating organisms. Understanding these chemical interactions is essential for developing effective conservation strategies.

5.3. Aesthetic Biodeterioration:

Aesthetic biodeterioration refers to changes in the visual appearance of an object due to biological activity. These alterations may not always compromise structural integrity but can significantly impact an artefact's aesthetic and cultural value. Fierăscu et al. (2020) discuss how biodeterioration affects the visual appeal of cultural heritage, while Agapakis (2012) explores the role of decay in aesthetic transformations over time.

Examples of aesthetic biodeterioration include:

- a) **Discolouration and Staining:** Many microorganisms produce pigments that stain materials. Algae, fungi, and bacteria commonly cause discolouration on surfaces such as stone, wood, and textiles. For example, black stains on marble are often attributed to dematiaceous fungi. Sterflinger & Piñar (2013) highlight microbial contributions to discolouration in cultural heritage objects.
- b) **Biofilms:** Microbial biofilms form complex communities on surfaces, creating slimy, discoloured patches that can impact both aesthetics and structural integrity. Geweely (2023) examines the role of biofilms in the biodeterioration of heritage artefacts.
- c) **Surface Alterations:** Lichens, mosses, and other organisms can grow on surfaces, modifying their texture and overall appearance. While such growths may be valued in certain contexts, they can also obscure important details or be considered undesirable. Examples of moss-covered stone surfaces are documented in *Mostly Signs (Some Portents)* (2015), while MacWright (2022) provides visual references of surface transformations due to environmental factors, although it may not specifically focus on biodeterioration.

Aesthetic biodeterioration can diminish the cultural and historical value of artefacts, necessitating conservation efforts to preserve their original appearance and significance.

- a) **Loss of Gloss or Sheen:** Biodeterioration can cause polished surfaces to become dull, resulting in a matte appearance. This is particularly noticeable in materials like polished stone, painted surfaces, and specific textiles.
- b) **Changes in Translucency:** In translucent materials such as stained glass, biodeterioration can lead to clouding or increased opacity, reducing light transmission and altering the intended visual effect.

Although often given less attention than structural deterioration, aesthetic biodeterioration plays a significant role in how cultural heritage is perceived and valued. Alterations in appearance can change the interpretation and perceived authenticity of an object, ultimately diminishing its cultural and historical importance. Recognising these visual changes is essential for developing conservation strategies that address both the physical stability and visual integrity of heritage materials.

6. Factors Influencing Biodeterioration:

Environmental conditions have a major impact on biodeterioration, with temperature, humidity, and light being particularly significant.

6.1. Temperature:

Temperature directly affects the metabolic activity of microorganisms. In general:

- a) Warmer temperatures within an optimal range accelerate microbial growth and metabolic processes, speeding up biodeterioration.
- b) Extremely high temperatures can kill certain microorganisms, though some species are adapted to survive and even thrive in extreme heat.
- c) Lower temperatures slow microbial metabolism, reducing biodeterioration rates.
- d) Temperature fluctuations can stress materials, making them more vulnerable to damage.

Sterflinger & Piñar (2013) discuss how climate conditions influence the deterioration of cultural heritage materials.

6.2. Humidity:

Humidity, or the moisture content in the air, is a crucial factor in biodeterioration:

- High humidity promotes microbial growth by providing necessary moisture, particularly facilitating the spread of fungal spores.
- Many materials, such as wood, textiles, and paper, absorb moisture from the air, creating ideal conditions for biodeterioration.
- Roman et al. (2023) highlight how prolonged exposure to high humidity contributes to deterioration, especially in marine environments.
- Fluctuating humidity levels cause materials to expand and contract, which can lead to physical stress and degradation.

Conversely, low humidity can suppress microbial growth, though it may also cause certain materials to become brittle and more susceptible to physical damage. Sterflinger & Piñar (2013) emphasise that climate and environmental exposure significantly impact the deterioration of cultural heritage objects.

6.3. Light:

Light, particularly ultraviolet (UV) radiation, contributes to the degradation of materials, making them more vulnerable to biodeterioration. UV exposure breaks down chemical bonds in organic materials, weakening their structure and making them more susceptible to microbial attack. Roman et al. (2023) note that prolonged exposure to sunlight accelerates the deterioration of wood surfaces. Additionally, damage from radiation is cumulative and irreversible, with its severity depending on both intensity and duration of exposure (2020).

Beyond UV radiation, visible light can also contribute to deterioration, particularly in the form of discolouration and fading of pigments and dyes, which leads to aesthetic biodeterioration. Research from 2021 highlights how exposure to light can cause noticeable discolouration over time.

The interaction of temperature, humidity, and light is a key factor in determining the rate and severity of biodeterioration. For instance, high temperatures combined with elevated humidity levels create optimal conditions for fungal growth, leading to extensive material degradation. Understanding these environmental interactions is essential for developing targeted conservation strategies.

7. Biological Factors in Biodeterioration:

The types of organisms involved play a fundamental role in biodeterioration. A wide range of biological agents contribute to material decay, and understanding their mechanisms is crucial for implementing effective preservation techniques.

7.1. Fungi:

Fungi are among the most significant contributors to biodeterioration, particularly in humid environments. They produce enzymes that degrade organic materials such as wood, textiles, and paper. Sterflinger & Piñar (2013) emphasise the destructive impact of fungi on stone and building materials, particularly due to their production of acids. Bomble et al. (2017) discuss the role of fungi in breaking down lignocellulose, a key component of plant materials. Conservation professionals, including microbiologists and restorers, have developed checklists to mitigate fungal degradation (Trovão & Portugal, 2021). Mold, a type of fungus, thrives in damp conditions and can damage a wide range of materials (2023). Additionally, fungi play a significant role in carbon cycling and organic matter decomposition (Gao, 2022).

7.2. Bacteria:

Bacteria contribute to material degradation through acid production, oxidation-reduction reactions, and biofilm formation. These processes allow bacteria to deteriorate diverse materials, including stone, metal, and synthetic polymers. Sterflinger & Piñar (2013) highlight the role of bacteria in biodeterioration alongside fungi. Bher et al. (2022) describe bacterial degradation as a "biotic mechanism" affecting polymer stability. Some bacterial species require oxygen for their activity, as noted by Aerobic (2022). Additionally, research by Biswas et al. (2013) identifies bacterial and fungal involvement in the deterioration of rock paintings.

7.3. Algae:

Algae are primarily associated with aesthetic biodeterioration, as they grow on surfaces and cause staining or discolouration. In some cases, they can also contribute to physical and chemical deterioration. Mácalová et al. (2021) examined how algae play a role in the biocorrosion of cement composites.

7.4. Lichens:

Lichens, which are symbiotic organisms composed of fungi and algae, can grow on various materials, leading to both aesthetic and structural damage. They contribute to erosion and weathering, particularly on stone surfaces.

7.5. Insects:

Insects cause significant physical damage through tunnelling, boring, and chewing. This is especially problematic for wooden structures and artefacts. Research from 2024 highlights the role of insects in wood deterioration. Sterflinger & Piñar (2013) also mention how insects, along with microorganisms and lichens, contribute to the degradation of cultural heritage objects.

7.6. Plants:

Higher plants, particularly their root systems, can exert mechanical pressure on materials, leading to cracking and structural damage. This is a major concern for historical buildings and archaeological sites, where plant growth can accelerate the deterioration of stone and masonry.

8. The Role of Material Properties in Biodeterioration:

The vulnerability of different materials to biodeterioration depends on their inherent characteristics, environmental conditions, and geographic location. Often, multiple organisms interact simultaneously, forming a complex network of deterioration processes. Understanding and addressing the impact of each contributing factor is crucial for developing effective conservation strategies.

8.1. Material Susceptibility to Biodeterioration:

The composition and structure of materials significantly influence their susceptibility to microbial attack. Some materials provide an ideal environment for microorganisms, while others offer greater resistance.

Organic Materials:

Organic materials, such as wood, paper, textiles, and leather, are particularly prone to biodeterioration since they serve as a nutrient source for microorganisms, including fungi and bacteria. Sterflinger & Piñar (2013) highlight wood's susceptibility to fungal decay, while Lazzari & Reggio (2021) examine the degradation of plastics in artistic works. Chang et al. (2020) emphasise the role of durability in bio-based composites. The chemical makeup of these materials—including cellulose, lignin, proteins, and starches—affects which microorganisms can colonise and degrade them. For instance, wood with a high lignin content tends to be more decay-resistant than varieties with lower lignin levels.

Inorganic Materials:

While inorganic materials like stone, concrete, and metals are generally more resilient to biodeterioration than organic substances, they are still vulnerable. Microorganisms can accelerate their deterioration through acid production, oxidation-reduction reactions, and physical disruptions. Sterflinger & Piñar (2013) discuss microbial involvement in the deterioration of stone and concrete. Research from 2025 explores the characteristics of stone, while Mácalová et al. (2021) previously examined algae-induced biocorrosion in cement composites. Factors such as porosity and chemical composition play a crucial role in determining a material's susceptibility to microbial colonisation and degradation.

Synthetic Polymers:

Plastics and other synthetic polymers vary in their resistance to biodeterioration. Some degrade relatively quickly, while others are highly resistant due to their chemical structure, crystallinity, and additives. Lazzari & Reggio (2021) provide insights into plastic degradation, and Chang et al. (2020) discuss the durability of bio-based composites, which often combine synthetic polymers with natural fibres. Khalil et al. (2009) investigate the biodegradation of recycled polypropylene composites, showing how soil burial impacts their properties over time.

Moisture Absorption:

A material's ability to absorb and retain moisture is a key factor in its susceptibility to biodeterioration. High moisture content fosters microbial growth. Roman et al. (2023) describe how humid environments, particularly marine settings, contribute to wood decay.

Surface Properties:

The texture, roughness, and porosity of a material influence microbial attachment and colonisation. Rough surfaces provide more adhesion points for microorganisms, facilitating their establishment. Research from 2025 addresses surface finishing techniques for stone, which can impact its resistance to biodeterioration, though not explicitly in this context.

9. Implications for Conservation:

A thorough understanding of material properties is essential for designing effective preservation strategies. Recognising which materials are most vulnerable to biodeterioration helps inform the selection of materials for different environments and guides the development of targeted treatments to prevent or mitigate microbial damage.

9.1 Conservation Strategies:

- a) Preventive conservation encompasses all measures and actions aimed at avoiding and minimising future degradation or loss of cultural heritage.

This proactive approach prioritises the creation and maintenance of a protective environment, rather than directly intervening with the materials and structures of the items. (2022) Key aspects of preventive conservation include:

Environmental Management: Controlling factors like temperature, humidity, light, and pollutants that can contribute to deterioration. (Imamura, 2018) This involves maintaining stable environmental conditions to prevent physical stress and establishing unfavourable conditions for biological growth.

Storage and Handling Protocols: Utilising chemically stable, archival-quality storage materials and training staff on proper handling techniques to minimise accidental damage. (Reyden, 1994)

Integrated Pest Management: Implementing programs that prioritise non-chemical control methods to prevent infestations. (Preventive Conservation Primer, 2024)

Emergency Preparedness Planning: Developing comprehensive strategies to ensure a swift and effective response to unexpected events, mitigating potential damage to collections. (Preventive Conservation Primer, 2024)

Preventive conservation is a cost-effective strategy that safeguards cultural heritage by addressing potential risks before they cause harm. Its benefits extend to a large number of objects simultaneously, making it an efficient approach to long-term preservation (Imamura, 2018). Establishing clear collections care policies and guidelines ensures consistent and appropriate preservation practices across an institution (Reyden, 1994). Preventive conservation is a proactive and cost-effective approach that safeguards cultural heritage for future generations. By mitigating potential risks before they cause harm, preventive conservation facilitates the long-term preservation of valuable collections (Lambert, 2014). Additionally, focusing on creating a stable, protective environment benefits a wide range of objects simultaneously, making it a highly efficient preservation strategy (Imamura, 2018). The importance of accessibility for sustainable use is emphasised, which is enabled by the implementation of effective preventive conservation measures. Preventive conservation is an ongoing process that necessitates regular monitoring, assessment, and adaptation to changing conditions.

Remedial conservation addresses existing biodeterioration, aiming to stabilise the object and prevent further decay. It involves direct interventions and treatments, often following a thorough assessment of the damage and its underlying causes. Common remedial conservation methods include cleaning, consolidation, biocide application, disinfestation, structural repairs, and restoration. The choice of remedial conservation methods depends on the specific object, the type and extent of biodeterioration, and the available resources. Minimal intervention and the use of reversible treatments are crucial considerations. Collaboration between conservators, scientists, and other specialists is often essential for the effective implementation of remedial conservation. While specific case studies are not provided, further research into recent publications and consultation with conservation professionals would yield more detailed examples of treatment approaches.

10. Challenges and Future Directions:

- a) Implementing effective conservation strategies involves navigating a complex landscape fraught with challenges. Cost is a significant hurdle, as comprehensive conservation programs often necessitate substantial financial investment in materials, equipment, specialised expertise, and ongoing maintenance (Huq & Puthuvayi, 2024). Limited budgets can constrain the scope and effectiveness of conservation efforts, particularly for smaller institutions or those in developing countries.
- b) Another obstacle is the accessibility of advanced analytical techniques. DNA sequencing for identifying biodeteriogens or non-invasive imaging for assessing structural damage may not be readily available or affordable for all institutions (Ayoola et al., 2024). This disparity in access can impede the ability to accurately diagnose problems and implement the most appropriate treatments.
- c) The potential long-term effects of conservation interventions are also a crucial consideration. While some treatments may be effective in the short term, they may have unintended consequences over time. For instance, certain biocides can be harmful to the environment or pose risks to human health, and some restoration materials may degrade or react with the object, causing further damage (Rathoure & Ram, 2024). The reversibility of treatments is a key principle in conservation, allowing for future interventions as knowledge and technology evolve. However, not all treatments are fully reversible, and the long-term impacts of certain interventions may not be fully understood (Fraschetti et al., 2018).
- d) Furthermore, integrating conservation strategies with broader societal goals, such as sustainable development and tourism, can present additional challenges (Freitas & Koskowski, 2020). Balancing the preservation of cultural heritage with economic development and public access requires careful planning and collaboration among various stakeholders. Raising public awareness about the importance of conservation and securing long-term political and financial support are also essential for the success of any conservation program (Paoli et al., 2020).
- e) **Deepening the Understanding of Microbial Communities:** Further research is essential to fully comprehend the intricate interactions within microbial communities that contribute to biodeterioration. (Sterflinger & Piñar, 2013) emphasises the pivotal role of diverse microorganisms, including bacteria, archaea, fungi, and lichens. This research should focus on studying the specific metabolic pathways involved, the influence of environmental factors, and the development of resistance to biocides. Advanced molecular techniques, such as next-generation sequencing, offer promising tools for characterising these complex communities and their dynamics. (Geweely, 2023) also highlights the importance of cutting-edge tools like mass spectrometry and next-generation sequencing in heritage conservation.
- f) **Developing Novel and Sustainable Treatments:** There is a continuous need for the creation of innovative, environmentally friendly, and sustainable conservation treatments. This includes exploring new biocides with reduced toxicity, as well as alternative approaches like the utilisation of beneficial microorganisms to control biodeteriogens, or the development of novel protective coatings. Several treatment categories, such as cleaning, desalination, and consolidation, indicating the necessity for ongoing innovation in these areas, have been mentioned.

- g) Long-term assessment and monitoring of conservation treatments are critical for understanding their efficacy and any unintended impacts over time. Some study highlights the complexities involved in studying historical materials and techniques, underscoring the need to evaluate treatment effectiveness, identify potential consequences, and devise adaptive management strategies. Continuous data collection and analysis are essential for refining conservation practices and ensuring their sustainability.

Interdisciplinary collaboration is emphasised as a key element in effective heritage conservation (Geweely, 2023). Successful preservation efforts require input from diverse specialists, including conservators, scientists, engineers, and art historians. Fostering communication and collaboration across disciplines is crucial for developing comprehensive approaches to addressing biodeterioration challenges.

- h) Addressing Climate Change Impacts: Extensive research is urgently required to examine the effects of climate change on biodeterioration. It highlights the significant impacts of climate change on biodiversity, indicating that shifts in temperature, humidity, and precipitation patterns can directly influence microbial growth and exacerbate decay processes. Comprehending these intricate interactions is crucial for devising adaptive conservation strategies that effectively address the challenges posed by a transforming climate (Lelyveld, 2019).

11. Conclusion:

Key research reveals the intricate interplay of microbial activity, environmental influences, and human intervention in the challenge of cultural heritage biodeterioration (The British Council Strategic Literature Review: Climate Change Impacts on Cultural Heritage, 2023; Sterflinger & Piñar, 2013) (Ballard et al., 2022). These insights have significant implications for the protection and stewardship of our shared cultural legacy:

- a) Biodeterioration is a multifaceted process: Diverse microbial communities, including bacteria, archaea, fungi, and algae, play a pivotal role in the deterioration of cultural materials. The specific mechanisms vary based on the material, environmental conditions, and microbial species involved. Understanding these complex interactions is crucial for developing targeted conservation strategies.
- b) Environmental factors exacerbate biodeterioration: Climate change, with its associated shifts in temperature, humidity, and precipitation patterns, is expected to accelerate biodeterioration processes. Adapting cultural heritage management practices to these evolving environmental conditions is necessary. Additional factors, such as pollution and tourism, also contribute to the problem.
- c) Conservation strategies must be tailored and sustainable: Effective conservation requires a holistic approach that considers the specific material, its environment, and available resources. Sustainable and environmentally friendly treatments are essential to minimise long-term impacts and leverage cultural heritage as a resource for climate mitigation and sustainable futures.
- d) Technological advancements offer new tools for conservation: Advanced analytical techniques, like DNA sequencing and non-invasive imaging, provide valuable insights into the causes and extent of biodeterioration. These technologies can inform more precise and effective conservation treatments. However, access to these technologies remains a challenge, particularly for smaller institutions or those in developing countries.

Interdisciplinary collaboration and ongoing monitoring are essential for addressing the complex challenges of biodeterioration. Researchers, conservators, engineers, and other experts must work together, as emphasised in (Geweely, 2023). Continuously evaluating the effectiveness of conservation treatments, identifying any unintended consequences, and adapting strategies accordingly are crucial, with advanced technologies playing a role in monitoring cultural heritage (Masini & Soldovieri, 2017). Cultural heritage has significant potential for sustainable development, as Billore (2021) highlights its social significance and ability to contribute to urban planning and sustainable tourism. (Necissa, 2011) further underscores the economic value of cultural heritage and its role in sustainability.

Engaging local communities is vital for cultural heritage conservation. (Al-Thahab, 2020) Discusses the importance of community responsibility, as involving local stakeholders can increase awareness, promote stewardship, and ensure the long-term success of preservation programs. Additionally, Hall & Ram (2015) indicate that indigenous culture and heritage are increasingly relevant in discussions about climate change. By addressing these key findings and their implications, more effective and sustainable strategies can be developed to protect cultural heritage from the damaging effects of biodeterioration and ensure its preservation for future generations. (Resilient Cultural Heritage, 2017) mentions a shift towards focusing on 'resilience' in heritage management, suggesting the need for flexible strategies that adapt to change.

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