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HISTORICAL PERSPECTIVE OF THE SULTANATE PERIOD MONUMENTS AND THEIR CONSERVATION USING BIOTECHNOLOGICAL TOOLS

Soma Mondal GHORAI[1,*], Neha KAPOOR[2], Archana TIWARI[3], Shweta PURI[4]

[1]Department of Zoology, Hindu College, University of Delhi, Delhi, 110007, India
[2]Department of Chemistry, Hindu College, University of Delhi, Delhi, 110007, India
[3]Department of Biotechnology, Amity Institute of Biotechnology, Amity University, Noida, India
[4]Department of History, A. N. D. College, Kanpur. Uttar Pradesh, 208012. India

Abstract

Delhi, the capital of India, offers a treasure trove of many sacred groves, water bodies, structures, and precincts that are of historic, aesthetic, architectural, and cultural significance. Efforts have been made mostly to preserve the architectural concepts of the Mughal era, but Delhi has many splendid monuments of the Sultanate era, which need exigent restoration and repair from getting faded into oblivion. Sadly, only the Qutb complex and Nizamuddin Dargah have received much attention from both government and non-government organisations, but other structures have been left unattended. It is also evident that every monument cannot be given due importance, and scores of capital cannot be utilized for their maintenance, but science and technology can offer alternate methods to restore and repair damages to these lesser-known monuments, which can also be considered in the long-term interest of the society from economic, cultural, and environmental viewpoints. This review is an attempt to delve into the architectural marvels of the Delhi Sultanate period, the cause of their deterioration, and the means of their conservation by the use of biotechnological tools, that is, use of essential oils, nanotechnology, and bio-mineralization as an effective, low-cost, eco friendly option to be adapted for future restoration and conservation of our heritage culture.

***Keywords**: Delhi Sultanate Period; Monument deterioration; Prezervation; Essential oils; Nanotechnology; Bio-mineralization*

Introduction

Delhi has a rich historic lineage. The *Mahabharata* contains one of its first mentions, and it is the first place which served for historical evidences in the ancient pan-Indian empires. Delhi also witnessed the transition from Hindu kings to Turk rulers in the early 12th century. During the Delhi Sultanate rule (12–16th century), the emergence of Indo-Islamic architecture and monuments got the centre stage. These monuments are the living witnesses of the golden historic era of over a thousand years and of the pre-independence battles [1]. They now serve the rich culture, traditions, and heritage of India and as a wealth for Indian tourism. Sadly, most of these ancient monuments are in a dilapidated state due to various physical, chemical, and biological processes, as well as anthropogenic activities such as encroachments [2]. The necessity of conservation of ancient monuments represents the history, prosperity, conflicts, and culture of the city, as well as the country. The architecture and historical values help to correlate

* Corresponding author: somamghorai@hindu.du.ac.in

with important events that occurred in heritage areas such as religious, social, and political events [3, 4].

This review is an attempt to delve into the architectural marvels of the Delhi Sultanate period, the cause of their deterioration, and the means of their conservation. This article also hopes to underline not only the well-established methods of restoration work, but also less explored arena of conservation through biotechnological tools. To conserve historic buildings, areas, and monuments, an understanding of the place's historical background and its culture is the primary requirement [5]. Traditionally, there are four main styles of conservation of historic buildings: preservation, rehabilitation, reconstruction, and restoration. Preservation refers to keeping an historic building as close as possible to its original state. This is done by continued repair and maintenance. It focuses on the repair of the existing parts in the building and the retention of the building's original state. Restoration refers to reconstructing those parts of the building that have fallen into decay as imitations of the highest possible quality. This form represents the building at one stage in time and removes any evidence of any other period. Rehabilitation is meant to alter an historic building to meet modern demands, while preserving the historical character of the building. Reconstruction means recreating the vanished parts of buildings by interpretive means. To understand any monument's static and dynamic behaviour, it is important to study the mechanical, chemical, and microstructural properties of masonry mortars and bricks [6].

Bird's eye view on the architectural monuments of the Sultanate Period

Today, almost after thousands of years, although most of these buildings built by the sultans or during their reign have either disappeared altogether or lie in ruins now, a good number of mosques and tombs have endured the depredations of time and are the living testimony of the Sultanate Period. The Indo-Islamic architecture of the Sultanate Period essentially grew in three phases [7]. The first phase was marked by the grandeur of architectural marvels by the Slave Sultans (AD 1206–1290), primarily by Qutabuddin-aibak (AD 1206–1290), who was the motivation behind some of the greatest monuments of Delhi. The second phase was that of the Khilji monarchs (AD 1290–1316), which also contributed much to the distinctiveness of the Tughlaq era monuments and forts. The third era witnessed a downfall in architectural activities under the rule of Sayyid (AD 1414–1451) and Lodhi Sultans (AD 1451–1526).

The sultans of Delhi are known for their architectural excellence. Under the patronage of the early sultans, Delhi got a few majestic imperial monuments in the form of royal palaces, forts, mosques, dargahs, mausoleums, and serais [8]. These monuments are a fusion of Indo-Islamic architecture, as they are neither completely Islamic nor purely Hindu. Even before the Sultanate Period, India had its borders with Iran established, and various Iranian influences could be seen even in Hindu relics, which was later refined and matured under the benefaction of Delhi sultans [9]. Interestingly, the Sultanate period Indo-Islamic monuments had their influences from other architectural styles from Mesopotamia, Central Asia, Egypt, North Africa, Southeast Europe, Afghanistan, and so forth [10]. Most of these monuments bore classic signatures of Hindu architectural style because, firstly, the craftsmen employed to build these monuments were mostly Hindus. Secondly, the raw materials used were mostly the ingredients from destroyed Hindu temples or palaces. Lastly, they are all inherently decorative in nature. According to John Marshall, the monuments were an amalgamation of both Hindu and Islamic style of architecture with some distinct features such as Hindu Kalash being replaced by the Islamic dome on the top [11]. Similarly, Hindu techniques of making strong, stable, and graceful ornamented structures were adopted by Muslims in their massiveness, decorative, and graceful style [12].

These monuments became the expression of the victory of the alien rulers on Hindu land, allowing them to display their wealth, power, and supremacy [13]. The Qutb-ul-Islam mosque or 'Might of Islam' was Delhi's 'first Friday mosque' built by Qutb-ud-din Aibak on the site of Rai Piathora's Hindu temple and using the rubble of 27 Hindu and Jain temples. Thus, it was associated with a legacy of violence, torture, and fanaticism, and the sad part is that the mosque is a characteristic proof of iconoclasm among the prominent historians. Qutb Minar (1199–1235) was among the most impressive structures originally started by Aibak as the place for prayer, but later completed by Iltutmish and is hailed as the 'tower of victory'. Iltutmish also built a tomb (1233–34) on his own grave, which, although in a dilapidated state, marked the development of Indo-Islamic architecture. The tomb had domed structures supported on squinters and corbelled square chambers [14]. Ala-ud-din Khiilji founded the city of 'Siri', Jamait Khan Mosque at the shrine of Nizam-ud-din Auliya and the famous Alai Darwaza (1305) at the Qutb Minar and Jamat Khana Masjid (1325) at Nizamuddin. These structures are adorned by characteristic decorative features with calligraphy, geometry, and arabesque. The Tughlaq sultans did not construct much because of the paucity of funds. Although Ghiyas-ud-din constructed the new city of Tughluqabad east of the Qutb area, his own tomb and a palace, these buildings lacked the grandeur and strength, and hence were easily destroyed. Later, Firuz Tughluq contributed to some noteworthy palace-fort known as Kotla Firuz Shah, a college and his own tomb near Hauz-i-Khas [15]. The Lodi and Sayyid Sultans did not do much apart from constructing their own tombs and a mosque, 'Moth-ki-Masjid'. They had a distinctive style where the main tomb chamber was built on an octagonal plan surrounded by arched verandas.

The Sultanate Period also saw the 'trabeate type' of architecture being replaced by the 'arcuate style' by the Turkish rulers. The monuments with such massive arches and domes required heavy stones such as red sandstone and bricks to be laid in the shape of a curve and that too firmly bound together. Thus, lintel, beam, and corbelling were replaced by arches and domes glued together by gypsum. Another plastering material such as lime paste was used to seal away any leakage from roofs, indigo-vats, canals, or drains. Calligraphy and decorative foliage were mainly used to conceal the structure behind the motifs [16].

Type of deterioration observed in the monuments of the Sultanate Period

The deterioration of monuments can generally be divided into two types: intrinsic causes, which are strictly connected to the origin, and different phases of the construction of the historic building and extrinsic causes derived from external sources (Fig. 1). Extrinsic causes are events that may have occurred subsequently or that remained to disturb the building. Extrinsic causes are further divided into two main groups: the forces of nature and those that are anthropogenic. There is a wide range of natural causes, and it is therefore convenient to divide extrinsic causes into three subgroups according to the swiftness of its action; (One) 'natural causes with prolonged action' that include the whole spectrum of chemical, electrochemical, physical, biological, botanical, microbiological, and so forth, actions that slowly drain the life of the building from all its structures, aptly termed 'ageing of the construction'; (Second) as natural causes with occasional disasters that include all exceptional and unpredictable natural disasters such as earthquakes and tsunamis; and (Third) anthropogenic activities that are evoked due to deliberate modifications in the original to the various structures, the functions of the buildings, and the changes in the surrounding environment and underground conditions. It also includes damages caused by human conflict and wars [17-20].

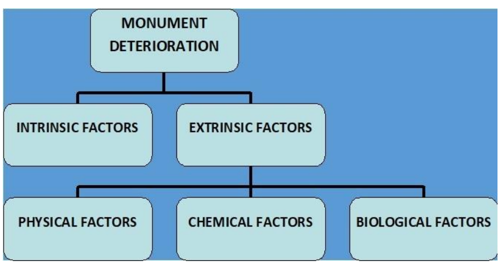

Fig. 1. Factors Affecting Monument Deterioration

The intrinsic causes can be further subdivided into two main subgroups: causes related to the position of the building and those related to its structure, which is more common. The causes related to the structure are generally related to the natural and artificial materials used in the construction of the monument. The monuments were built on demolished Hindu and Jain temples, so it showcases the culture as well as the materials used, such as remnants of fortifications, carved stone pieces from temples, and the Iron Pillar, a metallurgical wonder. Construction was mainly done using local stone (usually Delhi quartzite) and lime mortar, with ironwork for dowels and cramps [21]. Temporary support during the construction of scaffolding and cantering within domes was done by timber and bamboo. Decorated red sandstone and marbles were used for prominent buildings such as Iltutmish's Tomb and Alai Darwaza. The use of cheaper materials and labour was also evident, as the outer and inner faces of the walls were bonded together with a core by roughly cut stones (random rubble masonry) or broken bricks and mortar [22]. The local masons during that period used trabeate and corbelled systems, and applied this knowledge to construct the arches and domes of early Islamic monuments like Quwwat-ul-Islam mosque at Qutub complex and Sultan Ghari complex. However, there are limits to the transition of architectural knowhow, and so the corbelled dome Tomb of Sultan Iltutmish, built in 1235 CE, collapsed under its own weight (Fig. 2).

Fig. 2. Sky is visible from the inside of the Tomb of Iltutmish at Qutb Complex, Delhi, as the dome got broken off due to faulty architectural lapses. Photo credit: Anas Khan - unzip_delhi

Damage due to physical actions includes extremes in temperature caused by freezing or fire, humidity, and heavy wind. The combined effect of high temperature and humidity favours chemical decay. A rise in temperature and humidity also facilitates biological degradation by providing an excellent environment for the development of microorganisms and cryptogams (e.g. moulds, lichen, algae). Chemical and electrochemical causes include all the damages caused to the historic building by the interaction of various chemicals (from pollution), rainwater, and humidity in the atmosphere. These include the damage caused by the accumulation of sulphur and its oxides (e.g. black crust of marble), nitrates, nitrites, and other chemicals. Other damages are categorised as 'botanical causes', which include unmanaged growth of plants, both normal and parasitic vegetation. Plant growth in the immediate vicinity of historic buildings compromises conservation, especially when underground roots undermine the foundations and walls. Seeds are often deposited in the horizontal joints and projections. The fine roots penetrate the interior, grow slowly, and act as wedges and separate and detach elements of the wall structure. Parasitic vegetation such as poison ivy and other vines is more dangerous because it affects the facing and original surface of buildings. Biological causes include all the damage caused by wood-eating insects (woodworms, white ants, termites, ticks, and mites) and rodents. The chemical reactions that result from the droppings of birds that nest or perch on historic buildings cause a lot of damage. *Biodeterioration* or *bioweathering* is the term coined for the impairment of stone monuments rendered by the activity of microorganisms. The mechanism of biodegradation is among the least studied and documented with fewer recent studies. Biodeterioration is not due to one group of microorganisms, but rather is a complete microbial ecology. The colonies of this complex ecosystem include not only bacteria, fungi, algae, and lichens, but also protozoans. Microorganisms are found to colonise some depths within the rocks (endolithic), in the crevices and fissures (chasmolithic), and on the surfaces (epilithic) [23].

Theoretical dynamic analysis by ASI proved that the top two storeys of Qutb Minar are the most vulnerable to seismic forces [24]. Moreover, it suffered damage to its minaret by lightning strikes in 1368 and 1503, and later by an earthquake in 1802. Recently, ASI has expressed concern regarding tilting of the Qutab Minar. It has been observed that a tilt of 25 inches to the southwest occurred probably because of the weak foundation, which was further debilitated by rainwater seepage. Other structures of the Qutb complex also suffered many other forms of damage in due course of time. Alai Darwaza and other domes like the Salimgarh fort have developed numerous meridional cracks on the external surface of the dome, and they seem to recur even after repeated repair [25]. The weakening of the internal tensile strength of the dome has resulted in deeper cavities within its thickness, and it is getting aggravated with more rainwater seepage and extreme temperature variation in Delhi's climate (Fig. 3). This could be inferred from the fact that the architectural technology was at its nascent stage, and the Indian masons could do their best with the available materials, resulting in construction faults [26]. As deliberated by the N K Pathak Superintending Archaeologist, ASI (Delhi Circle), extreme damage has occurred due to the droppings of bats and pigeons that enter through the cracks and cause chemical reactions and physical discolouration of the structures.

Fig. 3. (a) The Detail of cracks in the dome on the exterior surface of the tomb of Alia Darwaza, (b) The damaged dome of Salimgarh fort.

Balban's Tomb (1285) in the nearby Mehrauli Archaeological Park exhibits a sad state of domeless, dilapidated square chamber of random rubble. The cause of its deterioration is unclear; it may be due to either vandalism, faulty construction, or an earthquake (Fig. 4a). The same fate can be seen for Ala-ud-din's Tomb, which too lies in a similar state of despair (Fig. 4b).

Fig. 4. (a) Ruins of Balban's tomb and (b) ruins of Ala-ud-din Khilji's tomb. Photo credit: Anas Khan - unzip_delhi

The Tughlaq era monuments and structures are in a completely deteriorated state because of the laxity of the government to protect it from anthropogenic damage. According to ASI, in all 2,661 bigha of land under the jurisdiction of Tughlaqabad fort, about 1,000 bigha has been illegally encroached upon (Fig. 5a). Certain other structures such as the Tughlaq-era baradari and Lodhi-era mosque were encroached upon and vandalised by locals for years. Sadly, a place like Nabi Karim in Sadar Bazar is used as a godown, and the mosque is used as a garage and tea stalls (Fig. 5b).

Fig. 5. Expanding encroachments within Tughlaqabad Fort, which is a ruined fort in Delhi built by Ghiyas-ud-din Tughlaq, the founder of Tughlaq dynasty. (b) Used and abused structure structure of Nabi Karim. Photo credit: Priyanka Sharma of sodelhi and Anas Khan

Delhi has also underdone huge industrialisation, leading to the emission of combustible products and gases. When reacting with rainwater, acidic substances cause etching, erosion, and dissolution of alkali stones, mainly sandstone and marble, resulting in the deterioration of the exposed surface (Fig. 6a). Rainwater is usually acidic as it combines with carbon dioxide, and therefore, has a pH of 5.0. Therefore, when they come in contact with calcareous stone and masonry, it causes a series of solutions, dissolution reaching the salt crystallisation stages (Fig. 6b). It is believed that wetting and drying is an inevitable part of the process leading to salt crystallisation damage to stonework. Over the years, the Sultanate era monuments such as the Adham Khan's Tomb were subjected to these chemical assaults and now show damage through deposition of salt and salt crystallisation due to environmental pollution.

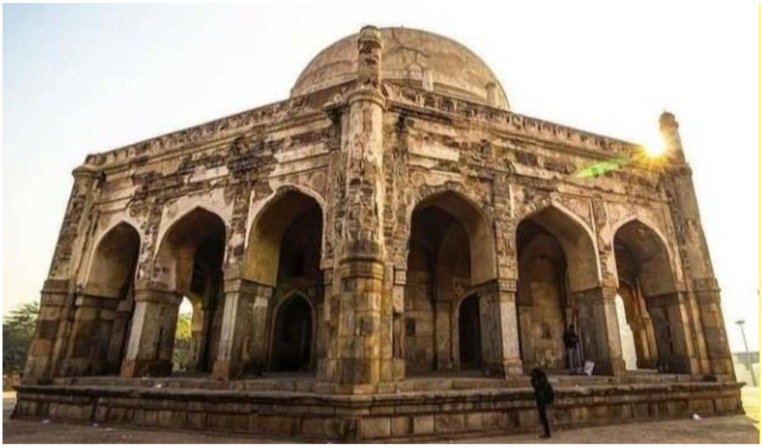

Fig. 6. Chemical leaching on the surface of Adham Khan's Tomb. Photo credit: Yash Sampat - info@monumentsofdelhi

Most magnificent mosques were built by the Sayyid/Lodhis era in the 15th century, mostly in Kotla Mubarakpur and Hauz Khas and Mehrauli areas of Delhi. Khairul Manzil Masjid is one such example that is deteriorating due to algal and vegetation growth (Fig. 7).

Fig. 7. Extensive algal growth is seen on the façade wall of the Masjid. Photo credit: Anas Khan - unzip_delhi

The Sundar Nursery, the Khilji-era Jamaat Khana Masjid, and the tomb of the Mughal-era poet Abdur Rahim Khan-i-Khanan suffered immensely due to chemical leaching, rainwater seepage, and growth of microorganisms on its surface. Biodegradation is one of the major causes of decay of stone and mortar in these heritage buildings. Excreta from bats and pigeons enhance the multiplication of other biological agencies to produce a number of biogenic acids depending on their metabolic activities. The heterotrophic bacteria can flourish nicely in damp and warm conditions producing many organic acids such as citric, lactic, succinic, and ketoglutaric acids, whereas certain autotrophic bacteria are capable of producing even nitric and sulfuric acids. Similarly, algae, fungi, and lichen are reported to give out acids such as oxalic, malic, glycolic pyruvic, succinic, and so forth. Since most of the Sultanate era monuments are constructed using stones and mortar, the acids generated by these biogenic components are expected to cause biodeterioration to a great extent. Biodegradation of stone masonry works causes progressive decohesion and transformation of stone material and imparts undesirable aesthetic effects to the substrate. The presence of monument decay and stone deterioration alters the chemical behaviour of the original material and thus can be portrayed by the change in appearance, coherence, and strength of the structure.

The Sultanate era also had in its glory many Baolis, spanning the entire Delhi area. The 14th century "Ugrasen ki baoli" in central Delhi is in ruins**,** completely dried up, and in rubble (Fig. 8a). There are other Baolis like Hindu Rao Baoli situated behind the ruins of Hindu Rao Hospital, which are now a pit of slime and a makeshift garbage dump. This was mainly due to the indiscriminate dumping of medical and organic waste (Fig. 8b).

Unfortunately, apart from Qutb complex and few others which were identified to be of national importance by the government and Archaeological Survey of India, most of the other monuments remain deprived and 'unprotected'. Often, it is reasoned out that it is physically not possible to protect each structure, but at least an effort can be made to revive some and use them to generate revenue so that the economy produced can be used to conserve, protect, and most importantly, promote these important sites [27].

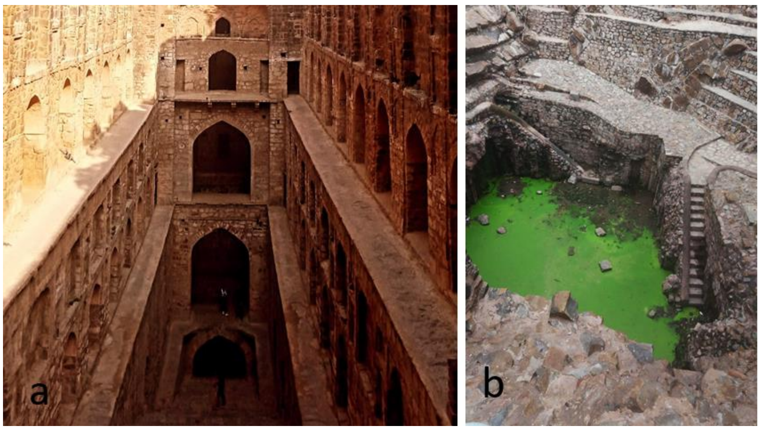

Fig. 8. (a) Completely dried up "Ugrasen ki baoli" (b) Dilapilated condition of Hindu rao baoli.

Conservation of sultanate era monuments with special emphasis on biotechnological tools

The first conservationist of India in the Sultanate era was Sultan Firoz Shah Tughlaq, who gave priority to the restoration of decaying edifices and structures over new building projects. When a lightning struck the Qutub Minar in 1369 AD, totally knocking off the uppermost minaret, then Sultan Firoz Shah Tughlaq not only restored the damage, but also added two more storeys to it. It was subsequently repaired by Sikandar Lodi (1489–1517) and by Major R. Smith of the Royal Engineers in 1829. Moreover, the entire Qutb Complex was added to and repaired by the many dynasties that followed the sultanate era, including the Mumluks, Ala-ud-din Khilji, Feroz Shah Tughlaq, and Sikandar Lodi [15].

The conservation of Sultanate heritage is carried partly by the Archaeological Survey of India, which functions under the Ministry of Culture and partly by Agha Khan Trust. Structures like those of the Qutb complex are overseen by The Ancient Monuments and Archaeological Sites and Remains Act 1958, updated as The Ancient Monuments and Archaeological Sites and Remains (Amendment and Validation) Act, 2010. The Indian National Trust for Art and

Cultural Heritage (INTACH), set up in 1984, as well as the Aga Khan Development Network (AKDN) established in 1988, are the two autonomous non-government organisations that had taken great initiative in restoration work [28].

Efforts are continuously made to restore the monuments in their aesthetic, cultural, and historic glory by following two main preservation methods: firstly by "structural conservation," which includes making the foundation of the damaged monuments strong enough so that they become resistant to natural disasters such as earthquakes and floods. It also oversees the removal of the cement layers and lead-based paints that harmed the core structure made of stone. In addition, removal of vegetation, weeds, algal growth, and so forth are undertaken to bring back the aesthetic nature of the monuments. The second method is 'chemical preservation'; where the monuments are chemically treated with organic and inorganic consolidants to prevent further deterioration due to acids and inorganic gases present in the atmosphere. Wood structures are cleaned using pesticides such as xylophene and DDT, while cleaning of terracotta and stone structures is done using clay mortar, slaked lime, and brick dust. Chemical treatment also protects the monuments from organic agents such as moss, algae, and lichens, which grow on the monuments [29].

Apart from the above-mentioned methods, several other traditional methods have been employed to eradicate biofilms, such as the use of biocides that combine quaternary ammonium compounds and benzalkonium chloride and the use of ultraviolet radiation [30]. The goal is to reduce the concentrations of contaminants and preserve the quality and stability of the material. Biofilms that were formed on the stone monuments were removed using chemical components with Na_2CO_3 and $(NH_4)_2CO_3$ as the main constituents. The use of chemicals containing Na_2CO_3 and $(NH_4)_2CO_3$ has been associated with several problems. After the chemical application, distilled water is needed in large quantities, and safety of the workers is of a great concern as well. Therefore, the use of methods that involve the use of polishing and chemical treatments is not very recommended [31].

Alternative Methods for Repair, Restoration, and Conservation

Biocleaning as an alternative to chemical or mechanical use for repair and restoration is the recent development in the conservation of monuments; the use of various strains of microorganisms can be dispensed in cleaning or eradicating other microorganisms that cause monument deterioration. The enzymes released from these biotic sources can help to restore the damage caused by bacteria and fungus. The use of biotechnology as an alternative method for repair, restoration, and conservation is a much safer and environmentally friendly tool, as essential oils, biomineralization, biological compounds and silver and nanoparticles [32].

Essential Oils

In recent studies, the use of essential oils (EO) has been investigated for tackling the growth of fungi on cultural heritage monuments. Extraction from parts of various plants and their subsequent distillation produces essential oil. Hence, in their concentrated form, these essential oils are hydrophobic volatile chemical compounds with characteristic odour and have a variety of uses in various types of industries [33].

Essential oils extracted from aromatic plants belong to the family Lamiaceae: *Lavandula angustifolia, Origanum vulgare,* and *Rosmarinus officinalis.* Essential oils of various other kinds such as cinnamaldehyde (95%, from *Cinnamon* sp.), citral (95%, from *Lemongrass* sp.), citronellol (95%, from *Rosae* sp.), cuminaldehyde (98%, from *Cumin* sp.), eucalyptol (99%, from Eucalyptus sp.), eugenol (99%, from *Clove* sp.), limonene (95%, from *Vitric plant* sp.), linalool (97%, from *Coriander* sp.), menthol (99%, from *Mint* sp.), and thymol (99% purity, main constituent of thyme) were also experimented upon but the observed results for all were not as desirable. Only thymol, eugenol, and cinnamaldehyde were able to restrict fungal growth properly and for a long time.

Antifungal agents have the capacity to disrupt with any stage of the asexual life cycle of fungi and these essential oils not only act upon removing the previously occurred growth, but also work upon inhibiting any further growth. The only observed problem with some of the essential oils is that they tend to evaporate easily at room temperature because they are volatile. Essential oils have been used to remove biofilm layers from paintings, frescoes, and walls of monuments. They have been used to eradicate fungal growth on Roman mural painting in Pompeii, Italy [34]. Thus, the use of EO for conservation should also be applied to Indian monuments, as they are readily available in our country.

Eugenol Biocide

Eugenol is a natural biocide extracted from clove oil and is an allyl chain-substituted guaiacol. Eugenol was identified and isolated from volatile clove extracts using the Tween and Span series of emulsifiers and water. Treatment with eugenol biocide helps in degrading the biofilm from the monument's surface by disintegration of the mycelium epithelial layer, causing discolouration. By calculating the measurement of ATP before and after eugenol treatment, an approximate 80% removal of biofilm was observed from the surface to which the biocide was applied. The use of eugenol biocide has several advantages over traditional methods. Eugenol biocide is eco-friendly, non-toxic, and does not result in a change in the original colour of the structure. In addition, it does not result in a change in weight either, which implies that the use of biocides does not cause any secondary weathering or damage to the stone material [31].

Silver Nanoparticle for Restoration and Conservation

Silver has proved to be a strong antimicrobial agent in many studies for many years. Silver is environmentally safe, has low toxicity to humans and other life forms, and is thermally and chemically stable [35]. With the advent of advanced technologies such as nanotechnology, it has been discovered that distinctive physicochemical properties are possessed by nanoparticles (NPs) with sizes <100nm. These particles could help solve several medical, agricultural, and environmental problems in the world. Silver nanoparticles (AgNPs) show high reactivity and have been proven to have an effective action in countering the growth and metabolism of a wide range of microorganisms such as bacteria [36]. The commercialisation and public use of AgNP is due to the advancement of research on its use in biological systems [37, 38]. AgNPs are known to penetrate algae, plants, and fungi, both directly and indirectly [39]. Direct toxic effects are considered by the chemical composition and surface reactivity, which impact the photosynthetic or respiratory processes of these organisms. Indirect toxic effects are caused mainly by physical restraints, the release of toxic ions (e.g. metal NPs) or the production of reactive oxygen species [40]. Many environmental parameters, such as humidity, pH, and temperature, also affect the toxicity of AgNPs. Studies have shown that silver nanoparticles when used alone or in combination with copper [41, 42] or titanium dioxide [43, 44], have a great biocidal effect on heterotrophic microorganisms. Effective results with AgNPs were obtained in diminishing the deterioration capability of many strains of bacteria and pathogenic fungi [45, 46], moulds [47], algae such as *Aspergillus niger* [48], *Cladosporium* growth on gypsum [49], and termites [50]. The underlying mechanism of action is the activation of a biochemical cascade after the AgNP interferes with the membrane proteins, thus initiating cell division among these microorganisms [51]. The concentration of reactive oxygen species (ROS) increases after the entry of nanoparticles by endocytosis or diffusion through the plant cell wall and plant plasma membrane, leading to mitochondrial dysfunction. As a result, ROS damage the surrounding nucleic acids and proteins by causing oxidative stress [52]. In most cases, the degradation of chloroplasts by AgNP treatment is dose- and time-dependent, which causes the photosynthetic activity of the cells to decrease, resulting in an inhibition of aerial algae growth.

Bio-mineralization treatment

Bio-mineralization treatment is an alternative process that was developed based on the ability of bacteria to induce calcium carbonate precipitation so that natural development biological mortars and patina on limestone is achieved [53]. Spraying of affected surfaces with bacteria along with nutritional medium containing calcium and urea helps in forming several micron-thick protective surface coatings of $CaCO_3$. This method was successfully carried out on a 16th century Mughal era monument, Salabat Khan Tomb in Maharashtra. Many such crack remediation programmes have been successfully done through the bacterial biochemical activity to fortify strength and permanence to the concrete structure in India, as well as abroad [54, 55]. Prof. M. Singh, a researcher from the Delhi-based National Museum Institute of History of Art, Conservation and Museology, has been the forerunner in advocating this technology. The microbial populations of *Bacillus sp.*, *Arthrobacter sp.*, *Agromyces indicus*, and *Aquamicrobium sp.* species, which causes white patches on black basalt rock, can otherwise be used to cement the structures made of stone and marble [56]. This technology bears strong futuristic capability to restore the monuments of the Sultanate era, as they are basically made up of sandstone and marble.

Conclusions

Delhi's rich cultural heritage includes not only the popular monuments and gardens, but also the sacred groves, water bodies, structures, areas, and precincts that are of historic, aesthetic, architectural, and cultural significance. Delhi has a rich history and different rulers and dynasties, each contributing to its cultural richness by the uniqueness of its architectural marvels. The conservation of heritage buildings should be considered in the long-term interest of the society from an economic, cultural, and environmental viewpoint. Although efforts are being made by the designated authorities to repair, restore, and conserve these heritage buildings, it is still impossible to physically restore innumerable small and large monuments scattered all over Delhi. Thus, apart from the traditional restoration methods, which require large amounts of masonry, workforce, capital, and raw materials, alternate methods should be employed to conserve many such heritage wealth. In this review, we present the importance of alternate technologies, such as the use of essential oils, nanotechnology, and bio-mineralization as an effective, low-cost, ecofriendly option to be adapted for future restoration and conservation of our heritage culture.

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