Study of the construction techniques, materials and architectural prospectives of ancient monumental structures in Allahabad City, India

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Abstract. This research examines the construction methodologies, materials, and architectural principles employed in creating ancient monumental structures in Allahabad (now Prayagraj), India. Despite being erected over 600 years ago, these structures stand resiliently among the evolution of modern construction techniques and seismic safety standards. The history of Prayagraj can be traced back to ancient times. The city was initially referenced in the ancient Hindu scriptures, known as the Vedas, as a sacred destination. Further, established by the Mughal Empire under Akbar's reign in 1583, Allahabad City witnessed the construction of numerous monumental structures using robust techniques involving stone, brick masonry, and timber materials bonded together with thin mortar and plaster. Many of these ancient edifices, erected during this period, continue to serve various functions today, reflecting the enduring craftsmanship of their builders. In this study, we have identified prestigious monuments for examination, utilizing visual inspection to gain deeper insights into the emphasized construction materials and techniques. Notably, mortar is a critical component in construction and structural connections. Furthermore, our investigation reveals the diverse range of materials utilized for binding, plastering, painting, and other decorative purposes during construction. However, it is evident that some of these monuments have endured significant wear and tear over time, resulting in major cracks and damage to their structural elements and construction materials. Through this exploration, we aim to unveil the intricate craftsmanship and architectural brilliance that characterize Allahabad's ancient monumental structures, while also highlighting the preservation challenges posed by ageing and environmental factors.

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1 Introduction

Masonry construction is the oldest construction in the world, and it is used in places like Asia, Europe, Africa, etc. These techniques and materials were widely used 8000 years ago, combining brick, stone, wood, iron, and other structural materials. Allahabad is an ancient and famous city of Uttar Pradesh, India, known as Sangam. Allahabad is home to numerous historical buildings from the Mughal, British, and post-independence periods. With an estimated population of 1.11 million for the city and 1.21 million for the metropolitan area, Allahabad is the thirty-sixth most populated city in India and the seventh most populous city in Uttar Pradesh according to the 2011 census [1]. The city, originally called Prayag, which means "place of offerings," is renowned for the Sangam, the meeting point of the Yamuna, Ganges, and the fabled Sarasvati Rivers. It is acknowledged as the second-oldest city in India in Hindu texts. For a brief period in 1858, Allahabad was the capital of both India and the Northwestern Provinces. It served as the United Provinces' capital from 1902 until 1920. Situated in southern Uttar Pradesh, the city encompasses a metropolitan area of 63.07 km², or 24.35 square miles. In addition to many state and national agencies, research institutions, and tourism sites, Allahabad is home to many monuments. The Indian Marathon and the Kumbh Mela are two of the most well-known athletic and cultural events that the city regularly hosts. The previous studies have focused on the deep knowledge of old monumental structures as (1) building evaluation and history, (2) geometrical plans, (3) construction techniques, (4) material properties, (5) cracks and damaging maps (6) strengthening and retrofitting (7) renovation and reconstruction, etc.

Many historical monuments have been built in Allahabad to secure its history and values. The construction is way back 40 to 600 years; temples, forts, mosques, churches, tombs, towers, cathedrals, towers, buildings, etc., have been constructed with different materials like brick, stone, wood, etc. These constructions are organized by the availability of local materials used during the structural elements' construction, binding, and decorating. In India, a lot of historical monuments are built from a combination of brick masonry and stone materials [2] it is excellent examples are the *Taj Mahal, Agra; Chhatrapati Shivaji Terminus, Mumbai; Hawa Mahal, Jaipur; Victoria Memorial, Kolkata; Qutub Minar* [3,4]*, Delhi; Gateway of India, Mumbai; Charminar, Hyderabad; Khajuraho Monuments; India Gate, Delhi etc.* These structures have contributed great importance to the country with protection by the Archeological Survey of India, which is preserved and maintained promptly. These structures have numerous types of structural elements of *arches (Round/Still Arch, Parabolic Arch, Segmental Arch/Basket Handle Arch, Horseshoe Arch Four-Centre Arch/Tudor Arch; Lancet Arch, Trefoil Arch, Ogee/Keel Arch Shouldered Arch)*, vaults *(Groined Vault or Cross Vault; Barrel Vault or Tunnel Vault; Gothic Vault; Rib Vault)* and domes *(Onion Dome; Geodesic Dome; Corbel Dome; Oval Dome; Polygonal Dome; Parabolic Dome; Saucer Dome; Sail Dome; Umbrella Dome)*. These architectural elements, from arches and vaults to domes, illustrate the versatility and creativity in structural and decorative design throughout history. Each type has unique characteristics and has been employed in various cultures and eras to achieve functional and aesthetic purposes [5].

Masonry construction for arches, vaults, and domes requires a careful selection of materials to ensure structural integrity, durability, and aesthetic appeal. These materials can be broadly categorized into solid components and binder components. Solid components provide the compressive strength necessary for the stability and durability of the structure. Common solid materials include Stone, Stabilized compressed earth block, Adobe block, Fired solid brick, Plain moulded cement blocks, and Fired hollow brick. Binders are essential for transmitting compressive forces and ensuring the cohesion of the structure. Common binder materials include earth mortar, lime-sand mortar, stabilized earth mortar, cement-sand mortar, and gypsum mortar. Surface protection has been used for renders and roof coverings.

Finally, the study focused on the important historic monuments selected after a survey of Allahabad. The survey was conducted after the 2015 Nepal earthquake. Based on the visual inspection survey, this study has been based on the main key points of the ancient structures of construction practice, structural materials, actual conditions, etc. However, the construction materials and techniques were used during the construction in their own time. The cracks and damage patterns have been properly identified on the structures. Mainly focused on the construction techniques, most structures have been designed by the massive construction techniques used for load transfer through the superstructure to the substructure. After the survey, the precious structures viz., Allahabad fort, Khusro Bagh, Allahabad public library and all saint cathedral church are considered due to lot of gathering presence at every time, and it is the most attractive places of Allahabad city.

This study aims to analyze the structure, material characteristics, decorative elements, and construction techniques of historical monuments in Allahabad. It will examine these structures' internal and external workmanship and architectural design. The focus is to showcase the effective use of existing materials in reflecting cultural and religious beliefs through architecture. Mughal architectural tradition, significantly influenced by the availability of construction materials and economic strength, relies heavily on structural and construction ideas and materials such as stone, bricks, timber (construction), and lime surakhi (binding).

Mughal constructions have represented the religious architecture in forts, mosques, tombs, etc., constituting the most highly developed forms. These structures, decorations, and construction materials are used for the Mughal mosques and tombs of Allahabad and their associated aspects. The study has tried to determine the impressions of the structural, architectural perspective and its ornamentations on contemporary and subsequent structures of the previous era. Nowadays, Allahabad is still developing in terms of architecture, mixing modern designs with its diverse historical background. The city's monuments and buildings embody a continuous conversation between tradition and modernity, blending historical aspects with fresh design principles.

2 Historical background of Prayagraj

Prayagraj, located in Uttar Pradesh, India, is a major tourist spot that numerous tourists visit yearly. Having a rich and glorious history, Prayagraj is home to many historical monuments from different periods of Indian history shown in Fig. 1. These consist of Khusro's tomb in Khusro Bagh, established in the medieval era under Mughal governance, All Saints Cathedral in Civil Lines, erected during the British Raj, and Alopi Devi Mandir in Alopi Bagh, one of the most ancient Hindu temples [1]. The city is embellished with various historical landmarks, including the Allahabad Fort constructed by Emperor Akbar in the Mughal period and the old Hanuman Temple situated close to the Sangam. Prayagraj is famous globally for the Kumbh Mela, a sacred event for Hindu pilgrims that has been happening for centuries and has drawn numerous visitors. Some other notable attractions include the Mayo Memorial Hall, Allahabad Public Library, All Saints Cathedral Church, and Allahabad University, which were constructed during the British Raj. These locations and various modern landmarks represent distinct eras in the city's diverse past.

In the medieval era (before 1526) [6], small structures were constructed using locally available materials such as straw, wattle, daub, cob, logs, and lumber. The choice of building materials varied based on different requirements, such as longevity and defensive capabilities, as well as cost in terms of materials and time. Base materials, which constituted the bulk of the project, played a crucial role. While most buildings utilized several materials in their construction, the finalized structure was primarily defined by the material used. Straw might seem very lightweight, and it is seldom found in archaeological digs of medieval

settlements. However, it was a major component during the Middle Ages and was commonly used in construction.

In most cases, these structures were supported by a lightweight wooden frame. Wattle and daub, a composite building material used for making walls, consisted of a woven lattice of wooden strips called wattle, which was then spread with a sticky material typically made from a combination of wet soil, clay, sand, animal dung, and straw. Its modular nature and ease of construction made it an excellent building material. Wattle and daub were sturdier than straw and provided better insulation from the elements. Cob, like wattle and daub, is also a composite material. Traditionally, English cob was made by mixing clay-based subsoil with sand, straw, and water, often using oxen to trample the mixture. Workers placed the earthen mixture in layers on a stone foundation and trod it onto the wall in a process called cobbing. Cob buildings often used a stone foundation instead of wattle and daub or straw structures because of the dense clay content, needing a strong base to hold up the rest of the building.

Cob walls were commonly around 24 inches thick, featuring inset windows that gave houses a unique interior look. These thick walls have great thermal mass, which helps to keep the interior warm during winter and cool during summer. Cob's durability allowed for the creation of lasting buildings in areas where it was abundant due to its long lifespan. Unlike wattle and daub buildings, cob structures did not rely on timber frames; instead, timber was mainly utilized for forming doorways, windows, internal passages, and room dividers. The flexibility of the cob made it possible to create distinctively curvaceous walls, adding to a one-of-a-kind architectural design. Cob houses were also very fire-resistant, making them perfect for durable buildings.

Fig. 1. Site visit of old monumental strutcures in Allahahad

In most cases, their roofs were covered with thatch, although timber or clay were utilized in some instances. Wooden logs and planks were essential elements in medieval building projects. Wooden framing and roof structures were common in many houses, highlighting the significance of wood in construction during the Middle Ages.

3 Historical monumental structures of Prayagraj city

Mughal architecture was instrumental in its time and impacted later periods due to its creative structural ideas, materials, and practicality. The utilization of materials for aesthetic purposes and successful techniques relied on the incorporation of advanced technologies. Moreover, the creation of impressive buildings depended on regular materials, talented workers, creative concepts, as well as socio-economic and geographical aspects. These components combine to produce structures with enduring aesthetic appeal and functionality. Throughout the Mughal period (1526-1857), a unique architectural style thrived in India with the support of the Mughal emperors. This era is known for its sophisticated and graceful architecture, which is distinguished by ornate decorations that include various traditional Hindu elements.

Notable instances of Mughal architectural design are the Agra fort (constructed between 1565-74) and the impressive city of Fatehpur Sikri (built from 1569-74). Additional significant instances include the Ajmer fort constructed between 1564 and 1573, the entrance of the Arab Sarai in Delhi built in 1560-61, the Lahore fort known for its remarkable ornamentation from 1586-1618, and the Allahabad fort, mostly dismantled, established in 1583-84. Mughal fortress palaces are especially known for their huge boundary walls, which can stretch for long distances [1]. For example, the fortress in Agra has a wall that is 2.5km (1.5 miles) long and covered with dressed stone. The stunning beauty of the main entrance is enhanced by the white marble inlay contrasting with the warm red sandstone, showcasing the exceptional skill of Mughal architectural craftsmanship.

4 Medieval era (before 1526)

Prayagraj is recognized for its varied architectural heritage, featuring various styles and structures from medieval to modern times. This development shows the city's important past and diverse culture. In the medieval period, temples in Prayagraj played a major role in shaping Indian temple architecture. The design of this era is characterized by temples carved out of rock, mandaps, and halls with pillars. These constructions are often solid shrines made from a single rock, displaying the skill of the craftsmen from that era. These temples were constructed with Square Base and Pyramidal Superstructure; Mandaps and Rathas; and Semicircular Roofs [7]. The ancient Ashok Pillar and Bharadwaj Ashram in Prayagraj, dating back to the third century B.C, features inscriptions showcasing Emperor Ashoka's edicts and commending King Samudragupta [1].

The historical writings on the pillar offer valuable information about the governance and societal norms of the time period. Every era has had an impact, adding to the city's distinct look and cultural legacy. Two main architectural styles emerged in ancient India: the Indo-Aryan style in North India and the Upper Deccan, and the Dravidian style during the Rajput period. The Nagara style, also known as Indo-Aryan style, is recognized for its specific elements in temple construction, such as Vimana, Garbha Griha, Shikhara, Amalaka, and Sabha Mandap. The craftsmanship and cultural expression showcased in Indian temples, forts, and palaces highlight a deep tradition in art and architecture. Indo-Aryan and Dravidian styles' unique characteristics and aesthetic principles have greatly influenced India's architectural heritage. From the majestic temples and carved shrines to the impressive forts and lavish palaces, these buildings still evoke wonder and respect for their artistic brilliance and historical importance. The medieval period in India was marked by significant advancements in art and architecture, reflecting the keen interest of the rulers in these fields. During the medieval era in India, there were notable progressions in art and architecture, showcasing the rulers' strong fascination with these domains.

5 Mughal era (1526-1857)

Two significant Mughal historical buildings are closely examined to analyze the harm and destruction caused by different environmental elements. Every type of structure has a specific function, requiring a thorough evaluation of the various structures, the materials utilized, and the resulting damages. This examination will assist in comprehending the particular effects on each building and offer an understanding into their conservation and repair. During the Mughal period, Khusro Bagh and Allahabad Fort were chosen to gain a thorough understanding of construction elements, structural materials, and techniques used in building [1]. *Khusro Mirza laid out Khusro Bagh (1622) gardens,* which are gorgeous views of the proportion of design and decorating. Stone platforms and water fountains enhance the

attractiveness of the lush green foliage in the Khusro Bagh gardens. The garden is covered by a massive (stone masonry) boundary wall, which has significantly weakened over time due to wear and tear.

Also, the slant of the stone walls in the boundary has increased by several inches. Allahabad Fort, built in 1583 by Akbar of the famous Mughal dynasty, is the oldest architectural marvel in Prayagraj. This popular tourist destination fort is controlled and used by the Indian Army. It stands majestically on the edging of the Yamuna River near Sangam, the confluence of the Saraswati, Ganga, and Yamuna rivers. The 16th-century fort features massive walls and three grand gateways, showcasing the grandeur of Mughal architecture. During the survey of the fort, the massive wall was built with a combination of thin and thick stone using fine mortar. brick masonry construction with rich plaster materials is visible on the top of the walls. Internal access is restricted to the public.

5.1 Khusro Bhag

It is a beautiful walled garden (four tombs designed) in the heart of Prayagraj, just a stone's throw from the railway station. It is covered by high stone masonry walls on all four sides, with a platform and a southern entrance gate, which is the grand construction. This gate, approximately 60 feet high, is similar to the Allahabad Fort's main gate. Khusro Bagh is named after Khusro, the eldest son of Jahangir, whose tomb is in the garden [8]. The lofty and attractive gate, situated north of the Khuldabad Sarai, stands a Persian inscription attributed to Jahangir, with Aqa Reza as the architect. The garden, entered by an 18m high archway, represents the typical Mughal enclosure. It houses the large and attractive tombs of Khusro mirza tomb, his mother “Nisar Begam tomb”, Tamolan bibi tombs and a tomb famously known as Shah Begam tomb, as shown in Fig. 2.

The tombs within the large garden are surrounded by lush green patches constructed from red sandstone. These tombs are ornately imprinted and aesthetically decorated with marble carvings, exemplifying the exquisite craftsmanship of the Mughal era. The garden's main gate and the tombs inside have undergone major alterations over time due to changing weather patterns, crumbling building materials, and binding techniques. Even though the hue of these buildings has altered, it is still clear how magnificent Mughal architecture, craftsmanship, and construction methods were. Between 1599 and 1605, Jahangir utilized Prayagraj as a retreat and built the city's defences. Later on, the garden was dubbed Khusro Bagh in honour of Prince Khusro, who was interred there. Sultan Begum's three-tiered mausoleum, the surrounding gardens, and the main entrance gate have all been credited to Jahangir's chief court architect and artist, Aqa Reza.

A comprehensive field survey was undertaken to investigate Mughal architecture, focusing on selecting numerous Mughal mosques in Prayagraj renowned for their remarkable structures, decorations, and materials. The authors conducted several field visits to meticulously examine these mosques, evaluating their architectural features and materials [8]. They extensively documented their findings through photographs, capturing the actual conditions of the mosque structures. Aside from field research, the writers also utilized a range of additional resources like books, articles, encyclopedias, and images to enhance their research. This diverse strategy offered a thorough comprehension of Mughal architecture in Prayagraj, enhancing the research with various viewpoints and understandings.

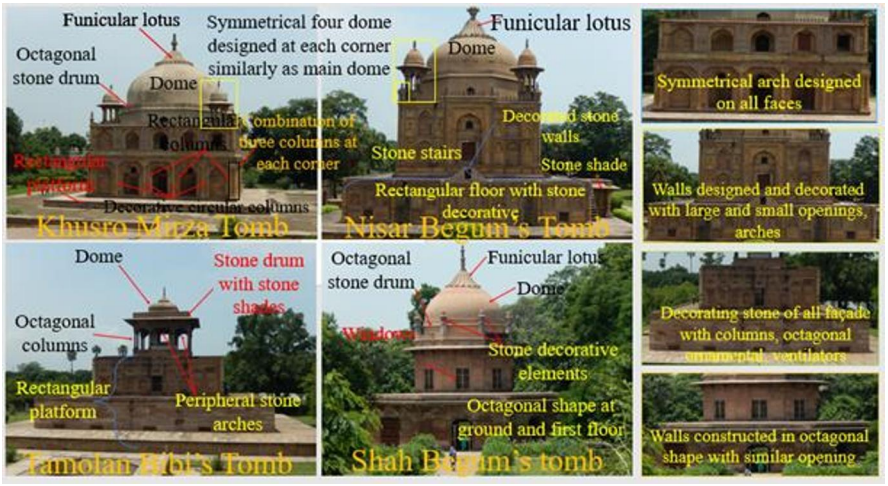

Fig. 2. Structural view of Khusro Bhag tombs

Mughal architecture is defined by its unique features that focus on practicality and beauty, carefully considering space and structural creativity. In Allahabad's mosques, traditional concepts are utilized in elements like the cornice, façade, and wall panels, seamlessly integrating form and function. The mosques' foundations are carefully designed using precise mathematical calculations. One of the distinctive characteristics is the range of dome styles, such as three-domed, five-domed, seven-domed, or multi-domed buildings, all adding to the mosque's charm. The ground plan and interior structure further differentiate these mosques, with the Mughal mosques of Khusro Bagh exhibiting characteristics akin to the Bengali architectural style. The open court, designed from short octagonal corner minarets, is emphasized in these mosques, and the typical features of square and rectangular shapes are shown in Fig. 2.

For instance, the Khusro Bagh tomb predominantly features a single-domed structure with four fluted shoulder stone domes resting on octagonal stone drums shown in Fig. 2. The central dome of Khusro tomb is the bigger dome, larger than the side ones, covering the mosque, with four mihrabs inside the stone wall corresponding to the one entrance. The rectangular plans with octagonal corner minarets are evident in transition phases, such as in the Allahabad Fort mosque, which also features a corner tower with flanking turrets. Its rows of recessed niches and cusped arches give it a sophisticated appearance that sets it apart from modern buildings.

The main entrance of Mughal-era constructions typically opens under a half-dome, adorned with intricately plastered net-work on the underside. Inside the mosque, the interior space is divided into three bays of varying measurements by two lateral arches. The bays on both sides are narrower, with smaller bays covered by intermediary half domes. Ground plans are carefully designed to achieve spatial perfection, featuring rectangular layouts with four regular octagonal corner minarets. At the qibla wall *(qibla wall is the wall in a mosque that faces Mecca),* three unequal rectangular doorways and three mihrabs project with half-octagonal shapes [9]. The central mihrab *(mihrab is a niche in the qibla wall indicating the direction of Mecca)* is larger than both the central doorways and the domes [9,10]. The prayer chamber is divided into three bays, with the central one being square-shaped and the northern and southern bays rectangular, following the typical layout of Mughal mosques. The ground plan of Khusro Bagh differs at ground level, as it stands on a platform more than 2.5 feet high above the ground, beneath which are vaulted rooms. Additionally, every mosque features northern and southern doorways with rectangular plans.

5.2 Mughal construction and architecture

Mughal architecture displays a wide range of building methods and materials. Load-bearing structural materials in the form of masonry walls support these structures. As seen in Figure 3, stone materials were used for various functions in various sizes and shapes, using thick mortar and random and ashlar masonry. Large foundations, broad verandahs, halls, magnificent domes, graceful arches, tall minarets, and vaulted roofs exhibit unmatched ornamentation, all essential elements of Mughal architecture. The Mughals are recognized as the leading producers of architectural splendour because of their massive structural designs and finely crafted ornamental artwork [8].

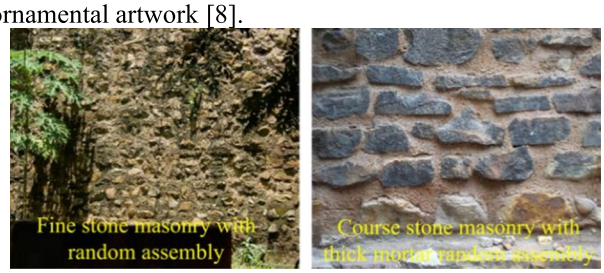

Fig. 3. Thick layer of lime mortar on the outer wall of Khusro Bagh

The Mughal era saw the height of bricklaying, cutting, and producing techniques. Using white marble, red sandstone, and glazed tiles as veneers over the brick core produced an opulent and sumptuous look by deftly combining colour and geometry shown in Fig. 4. The use of white marble adorned with priceless stones and mirrors displays the Mughals' excellent taste. Legendary tales of its golden past elude every monument built during this period. The following are some important characteristics that define the sustainability of Mughal architecture: Massiveness of the Structure: The overall constructions are enormous and imposing, even with their little 8 in. × 4 in. × 1 3/4 in. basic building unit. Rich Mortar: By applying layers of mortar nearly as thick as the building unit's height, rich mortar increases the sturdiness and strength of the structures. Nonporous Materials: Longevity and weather resistance are ensured by using nonporous materials as the foundation for platforms, cladding, and lining. These components preserve the Mughal era's architectural grandeur and long heritage [11,12].

The Mughal architectural constructions have suffered substantial damage from various climatic and environmental conditions, including: Discoloration: The structures' discoloration results from airborne pollutants such SO_3, NO_3, CO_2, and fluorides. Plaster chipping: Over time, the plaster has been worn down by pollutants and environmental exposure. Formation of Cracks: Environmental factors and structural forces have led to the development of cracks. Degradation of Structural Elements: There has been a great deal of degradation as a result of the structural materials' weakness, which is mostly caused by water penetration. Ornamental Ceiling Works Destroyed: Difficult ornamental ceiling works have been destroyed as a result of roof leaks. These elements work together to exacerbate these ancient buildings' continuous deterioration, endangering their historical significance and ability to be preserved.

5.3 Assessment of building materials

Field visits to specific places reveal the exact extent of the damages and the current state of the monuments. The strength of both decorative and structural cladding materials has been considerably reduced. These constructions serve as a showcase for the many local and imported materials used during the period. The typical Mughal brick measures 8 inches × 4 inches × 1 3/4 inches, and it has a coating of lime mortar that is nearly one inch thick. Rich

gypsum plaster, which offers a robust and smooth texture, was frequently utilized in Mughal construction. This plaster was superseded by cement-based plastering material following the Mughal era. The newer cement-based material and the previous gypsum plaster had a weaker bond due to compositional variations, which accelerated the chipping process.

During the Mughal era, lime, kankar, a kind of calcium carbonate, shattered marble or brick fragments, and additional ingredients to improve its qualities were mixed together to make mortar. This combination enhanced the strength and longevity of the constructions. The Khusro Bagh tomb and the Allahabad fort are examples of how different mortars were employed for different purposes throughout the Mughal era of construction. The following is a description of the ingredients used in Mughal mortar: Dahi (curd): Used to give a delicate finish, Urd pulse, or Dal: Serves as a plasticizer, San (Jute fiber): Promotes stronger bonds, Plant gum, or gond, acts as a retardant, Jaggery sugar, or gur, helps in hardening, Raw sugar, or batashe, serves as a bonding agent, Glue, or Sirish-i-Kahi: Strengthens bonds, Straw Bhus: lessens fractures. The mortar used in Mughal buildings was of higher quality, more resilient, and easier to work with, thanks to these conventional additions.

5.4 Decorative and binding materials

Red sandstone was the main cladding material used in Mughal architecture under the reigns of Akbar and Jehangir. Later, during Shah Jahan's reign, white marble replaced this. Red sandstone was used because of its strength and visual attractiveness. It is recognized for being nonporous and having minimal water absorption qualities. Red sandstone, according to Andrew Petersen (1996), is hard and powerful when compressed; despite this, it was finely carved in Mughal architecture. This demonstrates the extraordinary artistry and cutting-edge methods employed by Mughal designers and constructors [10]. The Mughal era made great use of red sandstone because of its advantageous qualities. It is now subject to the weathering process, nevertheless. The new sandstone utilized in restoration projects differs from the original, and variations in its inherent qualities are readily apparent. The disjointing of cladding material from the base surface is rather common, and the joints where the cladding materials intersect have opened. Pollution-induced decolourization is evident; the original red colours disappear, and the stone inlays break easily. Every cladding material's surface has turned black. Exquisite brackets and richly carved columns made of red sandstone have lost much of their charm and colour. The salt attack is common in practically all buildings, where gasses in the air and dissolved salts react to cause major damage to the facades. The presence of moisture on the surfaces fosters the growth of plants in a wet, suitable environment, which weakens the structures even more as roots spread. Due to the loss of binding strength with the base material, mirror pieces in the mosaic work have fallen, and dust particles in particular have had a major negative impact on their transparency.

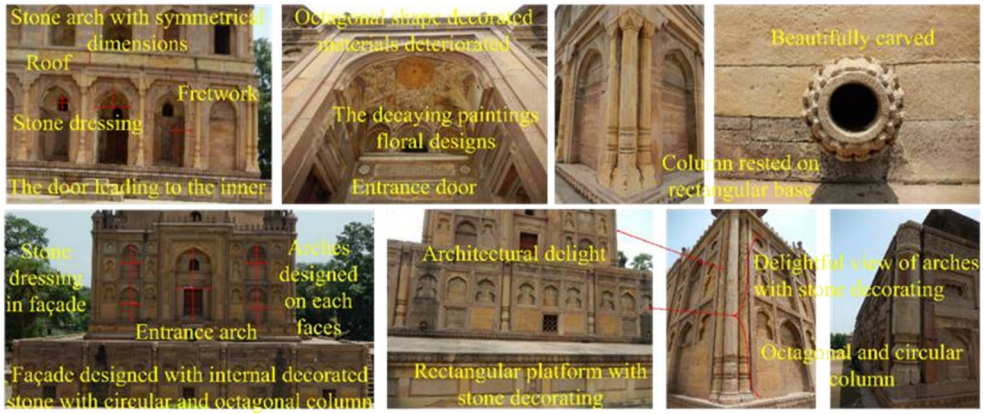

Fig. 4. Architectural decorating of Khurso Bagh tombs

5.5 Structural cracks and damages

As shown in Fig. 5 and Fig. 6, cracks have formed and spread into the surface materials in multiple places, presenting a severe risk to structural integrity. Rainwater, in particular, is a major environmental component responsible for these fissures. Plastered surfaces are rare; most surfaces have visible mortar. The walls' plaster components are now apparent due to degradation, exposing the thin mortar that held the stones and bricks together. Plaster structures have surface fractures due to drying and shrinking back and forth.

The external sandstone veneer and the stone at the base of the columns have chips or cracks in them. Rainwater collection on the roof surface has caused severe fractures in most houses. These cracks are noticeable at the ceiling level and spread quickly. These structural fissures, situated in the zone of highest bending force, have gotten considerably wider, up to one inch or more. These fissures are wide enough for tiny birds to build their nests inside the surfaces of the facade and roofs. Furthermore, the spaces between floor tiles have gotten wider, resulting in rougher surfaces from previously smooth finishes. This is most likely explained by the temperature gradient between the interior environment, which is kept colder by the massiveness of the structures, and the outside, warmer climate.

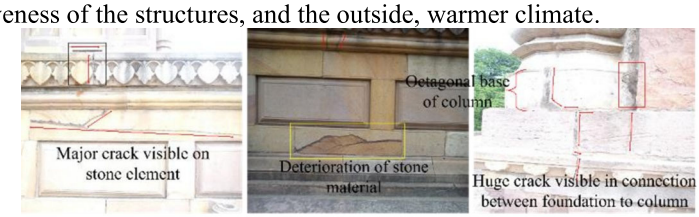

Fig. 5 Structural Crack at Khusro Bagh

Fig. 6 Crack and material deterioration in structural elements

5.6 Weakening due to deterioration of binding materials of structural elements

The mortar is currently slipping off the bricks and stones in places where the plastering material has entirely peeled off. Reduced cross-sections have caused the structural parts to lose strength in several locations. As seen in Figure 6, this has caused significant harm to the stability of the large structure supported by these pieces. As seen in Figure 6, there are some cases when the deterioration is so bad that the structure needs to be temporarily supported to stay in place. Mughal architecture is known for its massiveness, with several-foot-wide outer walls. However, as seen in Figure 6, these boundary walls are in poor condition, with lengthy, steep-sided depressions visible due to ongoing wear and tear and carelessness in repair work. The arches and domes also emphasize the buildings' diminished solidity; many of them now resemble hollow frameworks [13].

The well-decorated rectangular panels with multi-foiled arches that characterize Mughal architecture adorn the mosques. The side doorways are less noticeable than the central arched doorways. The dome and minaret, two crucial elements of these mosques, were built in accordance with centralized blueprints and conventional measurement procedures. The parapet wall of the Allahabad Fort Mosque is topped with octagonal corner minarets ornamented with plastered kiosks, which are little garden pavilions open on some or all sides. On the other hand, Khusro Bagh's corner minarets have an unusual design; they are covered in domes and hollow and constructed in two stages. Minarets in Mughal mosques are characterized by their round or polygonal outlines in terms of plan and decoration. A combination of circular and polygonal shapes is evident in certain cases, reflecting patterns witnessed in other Islamic architectural contexts. Mughal mosque minarets follow precise geometric shapes, reflecting the Northern Indian architectural style, even though they are not as tall as those in other places.

The domes have geometric decorations like triangles, diamonds, and basal leaves, which form towering finials placed in a step-by-step pattern. Significant research with three-dimensional applications of geometry is also evident in the transitional zones of the domes. In addition, Mughal architectural styles occasionally use smooth terracotta, multicoloured mosaics, and glazed tiles. Islamic architectural ideals stress the flexible application of geometric rules and formulas to achieve both utilitarian and aesthetic goals. Important architectural features, including the mihrab, member, domes, arches, and ornamental muqarnas, are made with expert craftsmanship utilizing regional methods, as illustrated in

Fig. 2. Plaster is used to decorate the façade, quibla wall, and mihrab; terracotta and stucco are employed sporadically to accentuate architectural elements. The intricately arranged decorative motifs of Mughal architecture, which are frequently influenced by the beauty of nature, are two-dimensional patterns made up of abstract geometric shapes and vegetal patterns. For example, the Khusro Tomb Mosque's mihrabs are decorated with elaborate geometric and floral clay ornamentation. As seen in Fig. 2, these include lotus motifs, rosettes, leaves, and vines. The elaborate beauty of the architecture is further enhanced by a frieze that is clearly shown in the areas between the stages and features diamond and triangular designs.

5.7 Architectural and construction materials

Architectural resources, including lime, sand, and bricks, were widely used in construction throughout the Mughal Empire. Bengali Mughal architecture became known for its plastered walls [14]. Because there was so little stone available locally, Mughal mosques were mostly built of brick, with surface decoration consisting of terracotta made from finely textured alluvial clay. The materials used in Mughal construction, such as bricks, sand, lime, and other elements, significantly impact the decorative patterns' aesthetic qualities. Lime was frequently used as plaster in conjunction with sand and brickwork to provide a smooth and waterproof finish on interior and external walls, roofs, and domes.

Plaster ornamentation in various styles, including rectangular and arched panels with flat, four-centred, or multi-foiled arches, was used to beautify Mughal mosques. While wood and stone were rarely employed in Mughal architecture for fundamental structural parts, they were prominent in ornamentation and practical aspects like mihrabs, doors, and windows, highlighting the opulence of the architectural style. As shown in Fig. 7, longitudinal and transverse iron plates and pins were used to reinforce connections between structural elements. The elaborate patterns and huge proportions of Mughal architecture could withstand the test of time because these reinforcements guaranteed the constructions' stability and durability.

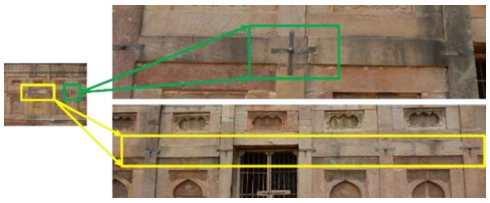

Fig. 7 Connection element used in Mughal tombs

6 British Era (1858-1947)

During the British era, most monumental structures were designed for numerous purposes and are currently used. Most of the important structures [1]: Ulta Qila (1855), Minto Park Allahabad (1858), Allahabad Railways station (1859), Allahabad High Court (1869), Alfred Park (1870), K. P. inter College main building (1872), Allahabad public library (1864 est. - 1878 comp.), Mayo memorial hall (1879), Muir college Allahabad (1886), Allahabad University (1887), Ewing Christian college (1902), Anand Bhawan (Indian government 1930), Allahabad museum (1931), etc. These structures have been designed from load-bearing masonry walls with numerous structural materials such as brick, stone, wood, iron, etc. In British construction, symmetrical construction techniques have been used in buildings, towers, churches, etc., [15–18]. The tower element has been added by British architecture. Tower elements have mostly been used in British constructions, showing buildings, churches,

cathedrals, and numerous structures [19–22]. It shows the beautiful views. During the survey, two monuments, Allahabad Public Library and all-saint cathedral church, were selected. The structures are publicly in use.

Fig. 8 shows the location of the Allahabad Public Library (1864), also called the Thornhill Mayne Memorial, in Chandrashekhar Azad Park. This library, created by Richard Roskell Bayne, is a prime example of Scottish Baronial Revival building design. It is among Uttar Pradesh's largest libraries in terms of size. The building's architecture, with its tall towers and arcaded cloisters, showcases structural polychromy with its pointed granite and sandstone pillars and turrets. The entrance gate is especially noteworthy since it combines triangular stones with arch connections to the building's architectural grandeur. A high stone tower has been constructed on the right side of the main gate. Most decorated stone materials are designed from the ground floor to the top. The rectangular shape is visible on the ground floor and first floor, and many openings are designed with lofty shapes. The main building has been designed with huge columns and arches. Rectangular and circular columns are provided in main load-bearing elements, and walls are assembled with stone materials. All structural elements of the building are constructed from the stone materials. The main roof has been designed triangularly, supported by wood and iron elements.

A building survey reveals that stone has been used in various forms for numerous purposes. Dressed stone is employed for columns, arches, walls, and facades [23–25]. Symmetrical construction techniques are evident in the verandah arches, rectangular load-bearing columns, and stone facades. The stone assembly predominantly utilized thin mortar. The entire building features yellow stone, which enhances its aesthetic appeal. Highly decorated stones are placed on the outer roof connections and columns. Minor and negligible cracks are visible on the surfaces of the load-bearing stone elements, while major cracks are noticeable on the outer structural and decorative elements, as shown in Fig. 9. In most elements, there is a significant gap between the columns and the stone façade wall.

Fig. 8 Architectural views of Allahabad Public Library

Fig. 9 Decorative element use in Allahabad Public Library

Constructed in 1887, the All Saints Cathedral Church is a notable example of Anglican architecture in Asia [1]. It perfectly captures the Gothic style of the thirteenth century and represents India's imperial architectural history. Only the tower over the crossing was finished, unlike the two towers originally intended for the main entrance front. The Cathedral, which was dedicated in 1887, has a nave that is roughly 40 feet broad and 130 feet long, as seen in Fig. 10. The building's internal width is approximately 56 feet overall because of its narrow nave. Its architectural magnificence is attributed to several elements, including transepts on both the north and south sides, an ambulatory chancel, a central tower at the intersection of the nave and transepts, and a west porch. Despite its antiquity, the Cathedral has a superb marble altar, and its original stained glass remains intact. Originally intended to serve as the North-West Provinces Cathedral, this church's open verandah and ambulatory were intended to hold 300–400 people. The church is currently undergoing development, adding a nave and western towers, bringing its overall length to 240 feet, as seen in Figure 10.

The choir will probably finally find a home beneath the central tower. The extreme heat in the area has influenced architectural choices, which include low-set windows that may be covered with wet cuscus mats in the summer and two carriage porches beneath the towers. Arches support the roof because white ants are a menace, and the lack of detail represents the labour force accessible in this part of India. The Cathedral's roof is decorated with red native tiles and is built of cream-coloured stone with exquisite red sandstone dressings. The corresponding drawings present a cross-section that emphasizes the western towers and the end of the nave, and a longitudinal section that shows the major plan [24,26].

Fig. 10 Internal and external views of All saint cathedral church

Fig. 11 Cracks and material deterioration of All saint cathedral church

The complete framework is assembled during the visual examination, utilizing load-bearing structural components. Large pillars and surrounding arches were created on both the interior and exterior of the Cathedral. Arches are used in a combination for construction on either side of the outer nave. Internal side arches run continuously from bottom to top, while outer side arches vary in size. The peripheral walls and columns on the outer arches are intended to form a broad verandah on the ground floor, first floor, and second floor. The Nave roof is made of a small portion of stone masonry and a thin layer of mortar. Mortar has been precisely employed in this structure for binding and ornamenting the walls, arches, columns, etc., as depicted in Fig. 11. The large and small fissures can be seen in the stone walls on the inside. Small and insignificant cracks have been noticed on all buildings' stone columns, arches, and façade walls. The external colour has lost its brightness because of weather conditions, showing a dark hue on everything from the building to the decorations. Building and design materials have consistently degraded and warped structural and decorative parts. Significant ornamental features have fallen on the structure's roof, as depicted in Figure 11.

6.1 Structural materials

Clay and brick materials play essential roles in construction and manufacturing, especially in the British era. Clay bricks and bricklaying were prevalent construction methods extensively employed in various structures. Clay also served as a vital component in daub and cob construction techniques and found widespread use in pottery manufacturing. However, the technique for creating fired bricks, a method practised since ancient times, was not widely adopted in Britain until later. Slate became a favoured roofing choice for luxury homes due to its impressive ability to resist absorbing water. The usual installation process included using double nails to fasten the slates onto either timber battens or timber sarking boards. Historically, copper nails were the preferred choice for this job. When properly done, these installation techniques guarantee a long-lasting roof that can withstand various weather conditions and last 80 to 100 years.

During the British era, lime mortar or plaster was essential in construction. Stone was extracted from limestone quarries and transformed into quicklime in lime kilns during manufacturing. This pliable quicklime was used for construction, rendering, plastering, and lime washing. The lime powder was also a successful binding material for stone slabs, providing great thermal protection for structures. In regions lacking limestone, oyster shells were used in kilns to create a comparable substance, as they contain calcium carbonate. Limewash, made of a combination of lime and water, was commonly used to cover the outer walls of numerous wattle and daub houses. This plaster could absorb the colours of the earth it was mixed with, creating bright shades like red, yellow, or white plasters. British construction frequently displays this tradition, with structures showing white and yellow plastered masonry alongside white plaster covering wattle and daub within timber frames. Stone was important in medieval construction because of its strong and long-lasting qualities. It functioned as a superb construction material designed to evoke admiration and last for a long period of time. The durability of stone made it a valuable material for building long-lasting structures that could withstand powerful forces and stand the test of time. Stone was crucial in building medieval infrastructure, being a prominent material in bridges, cathedrals, castles, and manors. While timber was commonly utilized, many of these buildings featured stone frames, highlighting the strength and endurance of the material. The careful coordination of obtaining and using stone required a detailed logistical procedure, covering everything from extracting it from quarries to transporting it to skilled stonecutters, highlighting the challenges of working with this substance. This complex procedure resulted in the establishment of stonemason guilds, which protected the techniques and expertise of their trade. Stone's strength allowed it to withstand various weather conditions and provide excellent defence against outside dangers. Stone buildings can reach taller heights and bear heavier weights due to the material's natural strength.

Furthermore, the stiffness of the stone made the true modular design easier by removing the necessity for extra support, as its heaviness guaranteed the stability of the structure. Marble and granite were not commonly used for construction in the Middle Ages, except for limestone (such as Purbeck marble) utilized in certain cathedrals. However, in later periods, such as the Renaissance, marble became more common, particularly in the construction of civic buildings. Other secondary materials, such as iron, copper, and lead, played significant roles in medieval architecture. Iron was utilized for manufacturing nails, which are integral to nearly every type of building. Copper and lead were employed for various purposes, including piping and sheathing for cathedrals' domes and drainage systems. These materials were chosen for their durability and ability to withstand the test of time, which is particularly crucial for structures like cathedrals that require long-lasting materials for structural integrity. Iron rods also provided additional structural support in many military and religious buildings. Flint was primarily utilized for decorative purposes where it was abundant, but occasionally, entire buildings were constructed using flint. In certain northern regions, soil and turf were

employed, particularly for roofing, where a layer of soil was applied beneath a layer of turf to keep out moisture and water. Glass, primarily stained glass, was commonly used to adorn religious, civic, and military structures. Stained glass not only allowed sufficient light into stone buildings but also decorated them to evoke awe among visitors.

7 Discussion and Recommendation

In Prayagraj, a new aesthetic reflecting the shift during the colonial period was imposed, starting in the eighteenth century. Following the establishment of colonial architectural patterns in the city, this transition resulted in notable modifications to structural works and architectural styles. Prayagraj's graves were praised in 1908 for their magnificence, described as “plain but massive” with painted flowers and birds adorning the interior of the main mausoleum. Emerson's Cathedral, “Patthar ka Girjaghar”, built between 1871 and 1887 and modelled after the choir of Canterbury Cathedral from the twelfth century, is one noteworthy example from this era. Various public structures, including government offices, high court, Roman Catholic Cathedral, many churches, Muir Central College, and Mayo Memorial Hall, which housed the public library, are examples of Prayagraj's colonial-era architecture. These buildings were prime examples of the “Indo-Saracenic” architectural style, which combined Indian and European design features. Muir College: Architect William Emerson created this structure, which was finished in 1873 and has big bell towers that follow the “Saracenic” style. During this time, the European structures in Prayagraj were distinguished by big and frequent openings, and windows and doors were the main architectural elements.

Balconies and Corbelled Projections: these details heightened the opulence of the structures. Roof Designs: domed and flat roofs were both widely used. The structures' ample surrounding spaces gave the impression that they were spacious. In particular, the Indo-Saracenic architecture is distinguished by: Round Arches, which emerge from piers or columns. Dome on Pendentine: one important element was the supported domes. Detailed Capitals: intricate features were created by sculptured capitals. Encrustations and mosaics: the buildings were embellished with decorative features. Though the native Hindu architectural styles were mainly eclipsed during this period, these characteristics show how European art standards and Indian architectural traditions were blended. The eighteenth-century architectural development in Prayagraj shows a notable change brought about by colonial influences. The city's public buildings, representing a particular era in the region's architectural history, are examples of the Indo-Saracenic style and testify to the fusion of European and Indian architectural features.

This study examined four distinct Prayagraj structures, each reflecting various construction techniques and architectural styles. Mughal architecture utilized load-bearing structural elements in massive walls, columns, and ornate features. The walls were constructed with brick and stone masonry, employing mortar layers between 25mm to 75mm thick. The outer walls were completed using luxurious plaster materials about 25mm thick. Khusro bhag showcases the use of random and ashlar forms of stone masonry in its structures. Khusro Bagh and Allahabad Fort utilized stone chips and dressed stones to achieve an elegant appearance. Domes were structures that were often seen in ancient architecture. An important component of Mughal architecture for structural and ornamental functions. These places' insides Various materials, such as paintings and glasswork, decorated the domes. Fine and enormous techniques were used in Mughal construction, exhibiting remarkable structural stability and craftsmanship. The binding and linkages of many structural elements, including walls, columns, arches, domes, and apertures, are clearly the result of these procedures. Thick materials were used to accentuate the grandeur of meticulously fashioned decorative and ornamental works on both tiny and major structural parts. In order to ensure the longevity and stability of the structures, the foundations were created with a thick and huge assemblage

of stone and brick elements bound together by significant mortar. This blend of sturdy construction and intricate decoration perfectly captures the splendour of Mughal architecture.

British architectural methods in Prayagraj also involved large-scale construction techniques similar to those used. During the Mughals period, architecture focused on taller structures by incorporating tower elements. Elements of the tower were familiar. They were affixed to numerous buildings from the British colonial period, including towers, churches, and cathedrals. Masonry was made of stone and brick; thin layers of mortar were frequently used, and thick protection was applied to the internal brick walls. A lime and surkhi mixture creating a 25mm thick coating of plaster. Mughal and British architectural styles included spacious designs and open layouts with large rooms, broad porches, terraces, sturdy bases, and partitions.

Prayagraj, known for its historical landmarks and tourist spots, contains important structures from the Mughal and British eras. Important locations such as Khusro Bagh and Allahabad Fort from the Mughal period, along with many British-era buildings and churches, continue to be utilized for different purposes today like education, administration, and cultural events. While certain buildings are kept in good shape through regular maintenance, others experience significant deterioration in their structural and binding components. Certain buildings have been closed because of severe deterioration, as seen in visual inspections that identified damage in walls, arches, roofs, and decorative elements. Factors such as rain, moisture, seepage, and temperature changes have played a role in causing this deterioration.

This research suggests thoroughly inspecting all monuments to detect and fix any cracks, damages, or structural issues by utilizing contemporary materials and methods. Maintaining these historic buildings is essential for comprehending previous architectural designs and techniques. Following correct restoration methods is essential to guarantee these historical landmarks' extended lifespan and ongoing admiration.

8 Conclusion

This research investigates the architectural details, building materials, methods, fissures, and destruction of ancient monument structures constructed in Prayagraj. Prayagraj, recognized as an ancient and sacred city in India, showcases numerous structures built during the Mughal and British periods, making it one of the city's most appealing attractions. These structures act as doorways to history and have multiple functions, such as hosting big crowds of individuals (approximately 100 to 600) units at once. In the Mughal era, structures were planned to be vast and airy, using large-scale construction methods and resources. High-quality mortar composed of lime and surkhi (approximately 25mm to 75mm thick) was utilized for connections, securing, and plaster (approximately 25mm thick) to construct brick walls, stone walls, domes, arches, columns, and decorative details. During British rule, construction methods changed to include balanced layouts and improved tower structures, showing a more contemporary approach to architecture. These developments improved the structure's strength and made it more visually attractive. Light mortar (approximately 10mm to 25mm) was utilized to construct various structural components, including walls (brick and stone masonry), arches, towers, domes, façades, and multiple decorative elements. Visual inspections have revealed that major cracks and deterioration are prevalent in the thick mortar used in Mughal construction.

In contrast, minor and negligible cracks have been found in the structures from the British period, which utilized fine mortar and more robust construction techniques. These monuments are invaluable for understanding history, architecture, construction techniques, and craftsmanship. Finally, during their visual investigation, the authors noticed that mortar is essential to the structural integrity of the old buildings in Prayagraj. Because of its thick

binding qualities, fine mortar utilized in construction elements has demonstrated strong performance. Structures with fine-binding mortar may exhibit slight and insignificant cracks, but structures built with thick mortar exhibit substantial and noticeable flaws. The main locations of material breakdown and degeneration are where the many constituents bond and join. This suggests that although thick mortar was used in some areas, it eventually caused more noticeable structural problems since thick mortar is resilient and long-lasting. One key aim is to preserve and protect these structures using new techniques and materials for strengthening and retrofitting.

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