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# A Conservation Study of the Naulakha Pavilion at Lahore Fort, Pakistan

Noor Jehan Sadiq  
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# A Conservation Study of the Naulakha Pavilion at Lahore Fort, Pakistan

## **Abstract**

This research is a conservation study of the marble elements of the Naulakha Pavilion at the Lahore Fort in Pakistan, built by the Mughal emperor Shah Jahan. The scope of work includes the two sets of adjoining jalis (lattice screens) on either side of the pavilion, that are self-supporting. The jalis along with the decorative veneer of the pavilion, both employ Makrana marble (from Rajasthan, India), more commonly known for its use in the Taj Mahal, India. Currently, the marble displays a wide array of deterioration including cracking, granular disintegration, and deformation that in several areas has led to dimensional loss. In particular, the thin, low strength jalis show signs of severe stress and destructive weathering due to thermal hysteresis in the presence of heat and moisture. So far, no comprehensive documentation of the monument's construction, previous interventions, or its current conditions exists. This work addresses the digital documentation of existing conditions and a synthesis of the prevalent deterioration mechanisms contributing to the behavior of the stone and the overall performance of the pavilion.

Investigations involved analyzing and characterizing the Makrana marble and its use in the pavilion along with conducting an in-depth conditions assessment for answering a range of research questions ultimately concerned with material, design, performance, alteration, treatment, and maintenance. The resulting digital documentation of conditions and synthesis of current deterioration mechanisms present on site, serves as a baseline for future conservation and interpretation of not just the pavilion but of the larger Lahore Fort complex as a whole.

## **Keywords**

Makrana, Jali, Marble, Hysteresis, Mughal

## **Disciplines**

Historic Preservation and Conservation

## **Comments**

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A CONSERVATION STUDY OF THE NAULAKHA PAVILION  
AT LAHORE FORT, PAKISTAN

Noor Jehan Sadiq

A THESIS

in

Historic Preservation

Presented to the Faculties of the University of Pennsylvania in  
Partial Fulfillment of the Requirements of the Degree of

MASTER OF SCIENCE IN HISTORIC PRESERVATION

2018

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Advisor & Program Chair  
Frank G. Matero  
Professor of Architecture, Historic Preservation

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## Abstract

This research is a conservation study of the marble elements of the Naulakha Pavilion at the Lahore Fort in Pakistan, built by the Mughal emperor Shah Jahan. The scope of work includes the two sets of adjoining *jalis* (lattice screens) on either side of the pavilion, that are self-supporting. The *jalis* along with the decorative veneer of the pavilion, both employ Makrana marble (from Rajasthan, India), more commonly known for its use in the Taj Mahal, India. Currently, the marble displays a wide array of deterioration including cracking, granular disintegration, and deformation that in several areas has led to dimensional loss. In particular, the thin, low strength *jalis* show signs of severe stress and destructive weathering due to thermal hysteresis in the presence of heat and moisture. So far, no comprehensive documentation of the monument's construction, previous interventions, or its current conditions exists. This work addresses the digital documentation of existing conditions and a synthesis of the prevalent deterioration mechanisms contributing to the behavior of the stone and the overall performance of the pavilion.

Investigations involved analyzing and characterizing the Makrana marble and its use in the pavilion along with conducting an in-depth conditions assessment for answering a range of research questions ultimately concerned with material, design, performance, alteration, treatment, and maintenance. The resulting digital documentation of conditions and synthesis of current deterioration mechanisms present on site, serves as a baseline for future conservation and interpretation of not just the pavilion but of the larger Lahore Fort complex as a whole.

## Glossary

<i>Aiena Kari</i>	Mirror mosaic work
<i>Badshah Namah</i>	Chronicle of the emperor (Shah Jahan)
<i>Bagh</i>	Garden
<i>Burj</i>	Tower
<i>Chajja</i>	Eave
<i>Dalan</i>	Loggia/verandah more or less open to the weather
<i>Jalis</i>	Carved lattice screens
<i>Jor Bangla</i>	Indigenous temple architectural style in Bengal
<i>Kanguras</i>	Antefixes, crowning Mughal forts with floral ornamentation at cornice level
<i>Kashi Kari</i>	Glazed ceramic tilework
<i>Lakh</i>	100,000
<i>Mahal</i>	Palace
<i>Mabtabi</i>	Platform
<i>Masjid</i>	Mosque
<i>Naqqashi</i>	Fresco work
<i>Parchin Kari</i>	Pietra dura inlay work
<i>Samadhi</i>	Tomb
<i>Shah</i>	King
<i>Shahjahan</i>	Belonging to the Shah Jahan era
<i>Shish</i>	Mirror or Glass
<i>Taza Kari</i>	Brick imitation work

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## 1.0 Introduction

The Picture Wall at the Lahore Fort, Pakistan is considered by most scholars of Islamic Art to be a crowning achievement of Mughal art and architecture of the 17<sup>th</sup> century. Measuring 1450 feet in length and 50 feet in height, it is one of the largest murals in the world. Since 2015, The Aga Khan Trust for Culture (AKTC) and the Aga Khan Culture Service Pakistan (AKCS-P) have been leading a conservation program for the Picture Wall. The focus of their project and analysis has been the decorative surface elements such as the *kashi kari* (glazed tilework), *naqqashi* (frescos), and *taza kari* (brick imitation) [Fig. 1]. This research contributes to the conservation of the marble elements of the Wall. These include the *jalis* (lattice screens), their supportive frameworks, and panels with *parchin kari* (pietra dura), located on the upper story, Naulakha Pavilion [Fig. 2].

While natural weathering of the marble pavilion is inevitable, there are several anthropogenic factors that have exacerbated the normal conditions of exposure. The stone has suffered damage from war, Sikh and later British interventions, neglect and deferred maintenance, and an ever increasingly polluted atmosphere of urban Lahore. Previous efforts at stabilizing the monument by disassembly, ferrous pinning, and reassembly has in fact added to the long-term displacement and material loss. In light of this, future conservation efforts must proceed with extreme caution. While AKCS-P determined a few prevailing conditions as part of its pilot study, no specialized investigations or treatment testing has yet been conducted for the Naulakha Pavilion; however, their long-term scope of work includes reconstruction of the missing portion of its western façade.

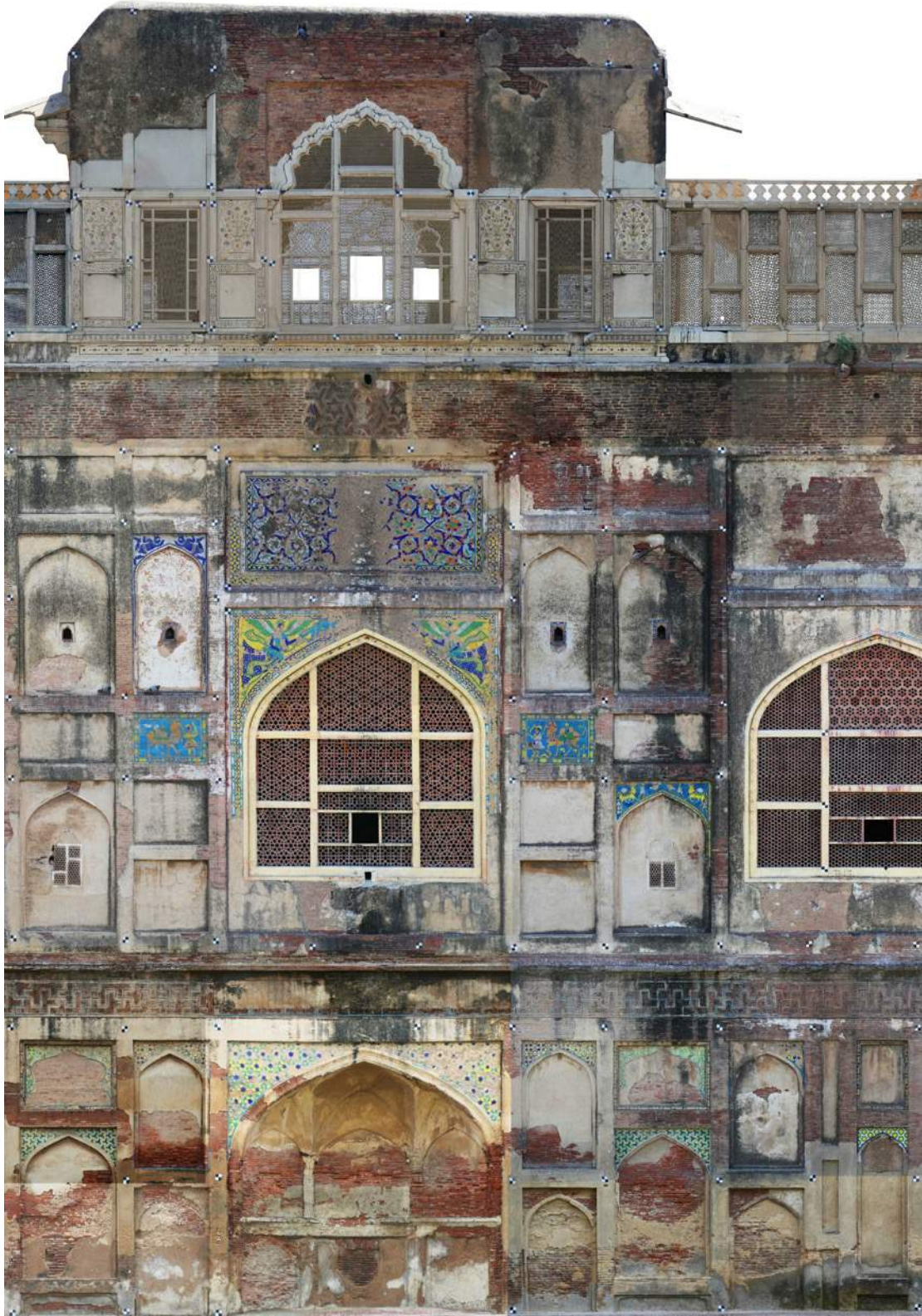


Figure 1: The decorative surfaces of the Picture Wall, Lahore Fort. These include, *kasbi kari* (glazed tilework), *naqqashi* (frescos), *taza kari* (brick imitation), and marble panels with *parbin kari* (*pietra dura*) that are part of the upper story Naulakha Pavilion.

## MARBLE ELEMENTS OF NAULAKHA PAVILION

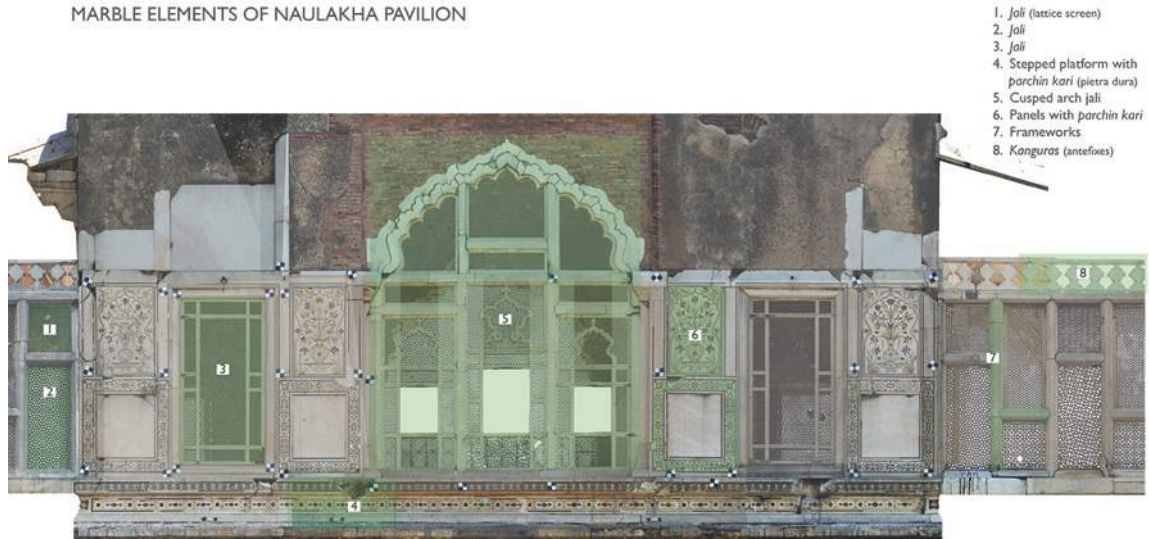


Figure 2: Marble elements of the Naulakha Pavilion. 1, 2, & 3- jalis (lattice screens); 4- stepped platform; 5- cusped arch jali; 6- panels with parchin kari (pietra dura); 7- frameworks; 8- kanguras (antefixes).

The following background research and current condition survey and assessment was completed in cooperation with the AKCS-P, under the supervision of Professor Frank Matero, Professor of Architecture and Historic Preservation in the School of Design at the University of Pennsylvania. It builds on recent investigations and historic restoration campaigns in order to contribute towards a more comprehensive understanding and consideration of past and current deterioration and treatment options for the entire Picture Wall, including its interpretation. The process involved analysis and characterization of the Makrana marble, its use and construction in the pavilion, including the identification of its physical properties in its current state. The performance and deterioration of the Pavilion's marble were diagnosed through a detailed treatment history and a condition survey conducted in December 2018. Other well-known monuments utilizing Makrana marble such



as the Shish Mahal, Lahore and the Taj Mahal, Delhi were studied as comparables.<sup>1</sup> Finally, the research proposes recommendations for further analysis, prioritized repairs, and other considerations for developing an appropriate course of action for treatment of stone friability and mechanical failure.

Although the in-situ survey included marble elements on all four sides of the pavilion, the study focuses on its western facade, looking at both its interior and exterior conditions. This area shows a lot more damage relative to the rest of the pavilion due to its high environmental exposure and inaccessibility that has left it largely unattended over the years. Additionally, it is also the area of direct concern and priority to the current AKCS-P project. It is hoped that the conclusions and diagnosis drawn from this research can be used as a representative study for treatment and analysis for the remainder of the pavilion.

## **2.0 Methodology**

Documentation and conditions assessment are crucial steps in developing a successful intervention program, as has been well emphasized within the field of architectural conservation.<sup>2</sup> It is an essential preliminary tool that not only aids in identifying existing conditions and ascribing causes but informs decisions for future actions such as preventive conservation. Although the pavilion has undergone several minor and some major treatment campaigns, it has generally lacked sufficient documentation describing those activities. Since

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<sup>1</sup> R. K. Dube, "Superiority of Makrana (Rajasthan) Marbles," *Indian Journal of History of Science* (2016).

<sup>2</sup> The importance of documentation and condition survey for conservation was first codified in international charters acknowledged by many countries' conservation communities worldwide such as the Venice Charter (1964). Documentation requirements were also incorporated in the International Council on Monuments and Sites (ICOMOS). See International Council on Monuments and Sites (ICOMOS), "International Charter for the Conservation and Restoration of Monuments and Sites (The Venice Charter 1964)" produced from *the II<sup>nd</sup> International Congress of Architects and Technicians of Historic Monuments*, (Venice, 1964), 4.

the pavilion has never been systematically documented, comprehensive recording and assessment of present conditions and a synthesis of previous studies are required before a treatment plan can be developed. Therefore, this research has been aimed towards historical documentation, survey, analysis, and diagnosis. Its purpose is not only in increasing the ability to make good, evidence-based decisions about current and future treatments and interpretation, but also to ensure that future generations are informed of the precise location and nature of previous interventions.<sup>3</sup> The conditions assessment includes details of current conditions, but also identifies features pertaining to the original construction and later alterations.

This research was a multi-step process comprising three phases: Phase 1- Reconnaissance, that included archival research, documentation, condition survey, and material sampling; Phase 2- Characterization and Analysis, including condition mapping, and material characterization; and Phase 3- Diagnosis and Recommendations involving identification of the causes of deterioration and recommendations for treatment.

## ***2.1 Archival Research***

Prior to beginning the conditions assessment, all previous documentation on the pavilion, relevant events in the history of the Fort, and previous interventions were studied to determine the corpus of known information about the pavilion's construction, its original appearance, and alterations made to it. Several sources were consulted including the Reports of the Curator of Ancient Monuments in India 1881-83 to 1883-84; Archaeological Survey of India Annual Reports from 1902-03 to 1937-38, pre-independence conservation notes;

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<sup>3</sup> Robin Letellier, *Recording, Documentation, and Information Management for the Conservation of Heritage Places: Guiding Principles* (Los Angeles: The Getty Conservation Institute, 2007), xiii.

annual progress reports and master plan for Lahore Fort by the Department of Archaeology, Ministry of Culture, Tourism and Sports, government of Pakistan from 1947 to 2004; and archival photographs. Research was mostly conducted at the Lahore Fort archives and the libraries of the University of Pennsylvania. This in-turn resulted in a comprehensive historical timeline that glosses over significant events as well as highlights the evolution of materials and techniques that led to the design and construction of the Naulakha Pavilion [Appendix A: Historical Timeline]. The timeline subsequently provided a good reference for case studies and comparables with similar material and construction that were analyzed in reference to the pavilion's deterioration and performance.

## ***2.2 Documentation and Condition Survey***

The documentation of the existing structure was done through in-situ investigation and data provided by AKCS-P. The AKCS-P team conducted documentation of the entire Fort in 2015 which was used as the basis of the research's investigation. The author built on the basic data provided to her and created finalized elevations of the western façade, with details of the construction; individual marble slabs and their decorative elements, whilst incorporating the anchoring system used in the pavilion. This task entailed identifying the location, approximate size and general shape of the embedded iron cramps with the use of a metal detector. As a result, this process created a baseline drawing on which the specific locations of deterioration within each slab could be mapped and identified separately. The drawings produced are essentially based off the rectified photo elevation of the west façade provided by AKCS-P. Additionally, the author hand-recorded present conditions of all sides of the pavilion and its adjacent *jalis* on a 30 ft high scaffolding over a period of three weeks, in 2017. The range of conditions present on site were examined that became the basis for

developing a preliminary conditions glossary and symbology for each condition that was later modified and characterized as per the individual conditions. The resultant glossary should be adaptable to other monuments in the Lahore Fort complex, in particular those that employ marble, such as the Shish Mahal [Appendix C: Conditions Drawings]. This would in turn allow for marble conditions and data to be compared across a wider spectrum of case studies present within the Fort.

Following the preparation of the conditions glossary, a systematic method of recording conditions with colored pens on transparent mylar film laid on top of the rectified photo elevations was carried out. For accuracy and clarity in survey, the high-resolution photo elevation was printed in three sections prior to hand recording. The importance of using the mylar film was that several sheets could be overlaid in-situ and the author could begin to understand patterns of deterioration and therefore focus in-situ investigations immediately. A total of 24 conditions were recorded at the monument, including surface accretions such as black crust and yellow surface discolorations, displacement and cracking, disaggregation, macroflora, repairs/restorations and locations of previous testing, and evidence of original construction (anchoring system). Additionally, photographs were taken of representative examples of each condition. At the end of Phase 1, three samples of friable stone and two that were previously taken by AKCS-P were used for material characterization and analysis at the University of Pennsylvania. Sample locations were marked on architectural drawings that can be seen in Appendix D: Material Analysis.

### ***2.3 Condition Mapping***

A thorough condition mapping records the type and extent of conditions, their relationship to each other, to the architectural elements, and to location. By mapping conditions in



combination with other physical aspects of a monument, such as construction, and by considering what such conditions mean throughout the pavilion, the condition assessment becomes a more powerful diagnostic tool for answering a range of research questions ultimately concerned with design, performance, alteration, treatment, and maintenance. The hand-recorded conditions were each digitally recorded in AutoCAD whilst expanding on the symbology previously created on site. Each condition was coded with its unique color and symbol, placed in a separate layer for ease of future analysis, but also to facilitate correlation of certain overlapping conditions. Locations of samples taken by the author and the ones provided by AKCS-P were notated onto the drawings. These condition drawings were divided into three sets for clarity in disseminating deterioration patterns: 1-Surface Accretions and Alterations; 2-Displacement and Cracking; and 3-Repairs and Replacements as well as an overlay of all conditions onto one drawing. These drawings serve as a visual aid for locating deterioration conditions within each marble slab as well as a tool for diagnosis.

## ***2.4 Material Analysis***

In order to understand and analyze the deterioration patterns and their impact on the pavilion, it is crucial to fully describe and characterize its building materials. This includes the identification of the stone's physical and mechanical properties in its current state. The marble type used in the Naulakha Pavilion had been previously identified by AKCS-P, as Makrana marble, procured from the Makrana quarry, in Rajasthan, India. This information was corroborated through scientific analysis conducted by the Geoscience Advance Research Laboratories, Pakistan in 2017.<sup>4</sup>

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<sup>4</sup> Asif Hanif and Muhammad Siddiq, *Makrana Marble: Comparison and Origin* (Geoscience Advance Research Laboratories, 2017).

Due to the constraints in sampling, the characterization of the stone was limited to its petrographic analysis, investigating its physical and chemical features and not its mechanical properties. Varying stages of analysis were conducted, including petrographic examination of the samples, beginning with the hand specimens. For the microstructural examination of the samples, thin sections were observed under a stereoscope using polarized light microscopy (PLM) at the Center for the Analysis of Archaeological Materials (CAAM) at the Penn Museum, University of Pennsylvania Museum of Archaeology and Anthropology under Dr. Marie Claude Boileau. Petrographic thin sections were prepared and optically analyzed by using a Leitz polarizing microscope. Additionally, further analysis included scanning electron microscopy/energy dispersive x-ray spectroscopy (SEM/EDS) carried out at the Singh Center for Nanotechnology, University of Pennsylvania, Philadelphia, under Jamie Ford to understand the microscale features and the elemental composition of the marble along with investigating the yellow accretion found on the stone surface. Marble samples were also tested against exposure to a diluted solution of hydrochloric acid in order to differentiate between calcitic and dolomitic mineral make-up of the stone. Alongside the author's analysis, previous studies on Makrana marble were also consulted to gain a better understanding of the stone's physical makeup and its means of deterioration. For a more comprehensive understanding of the behavior of the stone, the study will be recommending mechanical tests and other forms of analysis pending availability of adequate samples.

## ***2.5 Diagnosis and Recommendations***

Following the digitization of hand recorded visual survey, the conditions were summarized and described with regard to their prevalence and general locations. Thereafter, in

conjunction with the material analysis, the conditions were characterized within deterioration and performance failures posed by the pavilion's original design, material, construction, surrounding environment and previous interventions. Conditions posing the greatest risk to the pavilion and the adjacent *jalis* were posited as well as highlighting areas that need to be prioritized. Correlations between overlapping conditions were noted where they occurred, diagnosing them to their plausible causes.

Following the summary of conditions and their diagnosis, conclusions covering an overall assessment of the general condition of and greatest risks to the monument were presented. From these, recommendations were drawn that are best suited to Naulakha and its immediate and long-term conservation plan. These recommendations include prioritized areas, and suggestions for further analysis.

### **3.0 Significance**

#### ***3.1 Historical Background***

The Lahore Fort, locally referred to as Shahi Qila is situated in the northwest corner of the Walled City of Lahore, Pakistan. Although its origin is undocumented, the present fortifications were begun by Mughal emperor Akbar in the late 16<sup>th</sup> century. Akbar built this fort on the foundations of an abandoned 11<sup>th</sup> century mud brick fort, enclosing his new palace and the city with red fired brick.<sup>5</sup> The solid masonry complex was later destroyed, rebuilt, and extended several times by successive Mughal Emperors, as well as the Sikhs and the British throughout the 17th to the 20th centuries [Fig. 3].

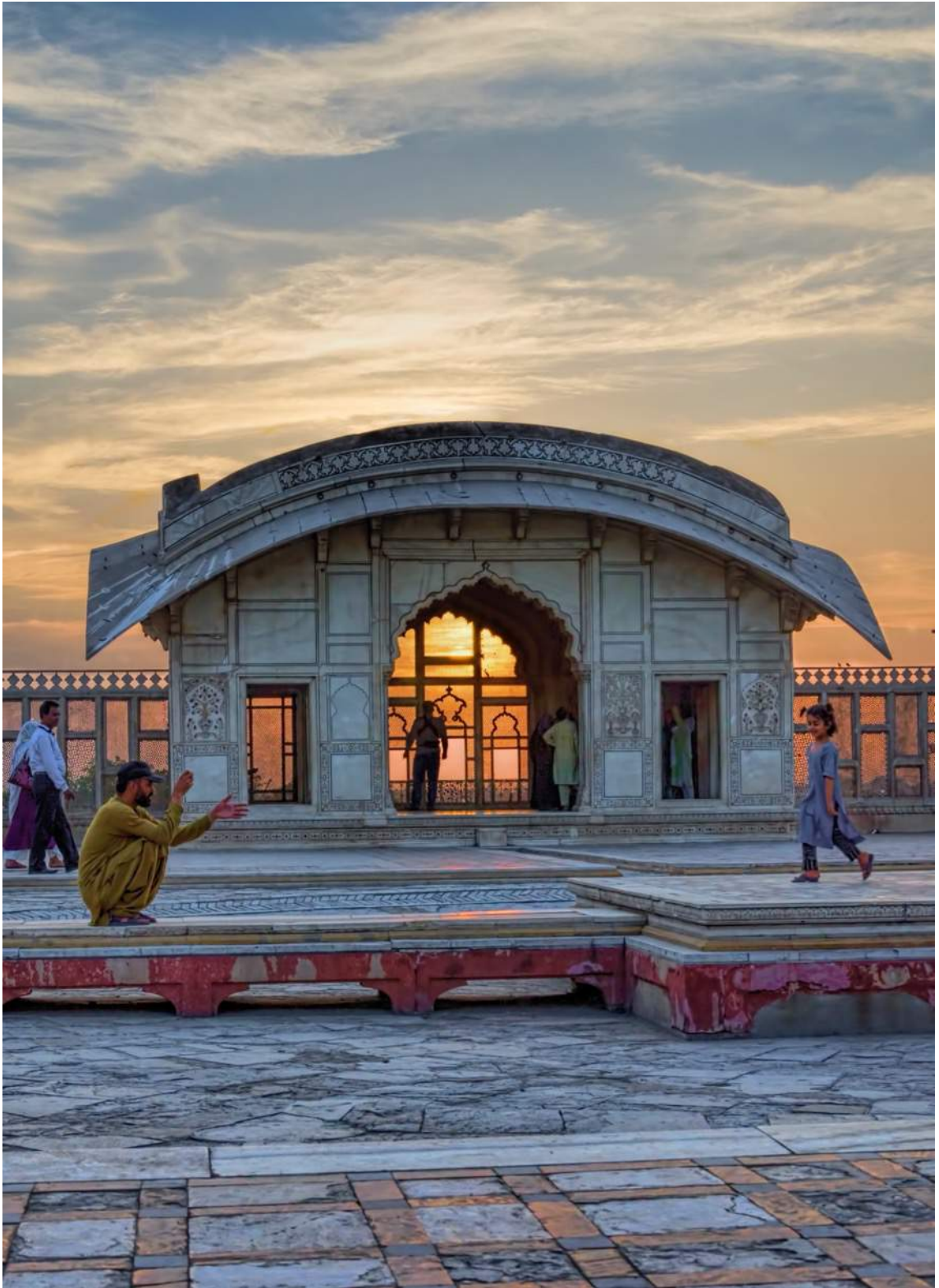
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<sup>5</sup> Syed M. Latif, *Lahore: Its History, Architectural Remains and Antiquities, with an account of its modern institutions, inhabitants, their trade, customs, &c.* (Lahore: New Imperial Press, 1892), 1–6.



Figure 3: Overview of the Lahore Fort complex. Showcasing the conglomeration of monuments and structures built during the successive periods.

The 21 monuments which survive within its boundaries compose an outstanding repository of the Fort's multifaceted history and the varied forms of Mughal architecture. While architecture during Akbar's reign (1542-1605) is known by its standardized masonry of fired brick and red sandstone courses adorned with Hindu motifs, Jahangir's reign (1569-1627) was characterized by complex vaulting systems and decorative surfaces such as *kashi kari* and *naqqashi* that included European-influenced mythological Solomonic and Christian iconography. Whereas, monuments commissioned by Shah Jahan (1627-58) are recognized by their geometric design and symmetry, extensive use of white marbles, intricate marble *jalis*, *parchin kari* and mosaic work, set within exuberant decorative motifs of Persian origins [Fig. 4]. Collectively, as part of the larger Lahore Fort complex, these monuments have been inscribed as a UNESCO world heritage site since 1981.



*Figure 4: The Naulakha Pavilion as an example of Shahjahan Architecture. It uses white marble, intricate jalis, and pietra dura among other architectural and decorative elements. (Data Source: Mubd. Zahid Ansari)*

The present configuration of the Fort includes a few remaining structures added during the later periods. When Lahore was conquered by the Sikh Empire, the Fort fell into the hands of Ranjit Singh in 1799. He altered many of its earlier monuments while adding some of his own. Additionally, due to the scarcity of building material, marble and semi-precious stones are believed to have been appropriated from many Mughal structures, reused in various Sikh funerary monuments.<sup>6</sup>

The Sikhs were defeated in the Anglo-Sikh Wars and, in the mid 19<sup>th</sup> century, Lahore fell into British hands. The British, following the invasion of Lahore, used the Fort as a military compound. Many earlier monuments were rehabilitated for military use, while newer structures such as barracks and storage depots were added to the Fort. At the turn of the 20<sup>th</sup> century, the British carried out extensive repair and restoration work at the Fort, including restoration of the Picture Wall and Shah Burj Quadrangle. Moreover, several modern structures were demolished in attempts to restore the Fort as per the Mughal period. Since the founding of the modern state of Pakistan, no new permanent structures have been added to the Fort complex, while conservation and repair work continues. Currently, the Department of Archaeology occupies some of the remaining British barracks as offices.

### ***3.2 Site Context***

Mughal structures pertinent to this research include the western facade of the Picture Wall and the Shah Burj Quadrangle that holds the Naulakha Pavilion, all belonging to the *Shahjahan* Architecture.<sup>7</sup> Although the construction of the northern side of the Wall was

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<sup>6</sup> *Scheme for the Preservation and Restoration of the Shish Mahal inside Lahore Fort* (Lahore: Department of Archaeology, Ministry of Culture, Tourism and Sports, Government of Pakistan, 1986).

<sup>7</sup> ed. Gulru Necipoglu, *Muqarnas: An annual on the Visual Culture of the Islamic World* (Leiden: Brill Academic Publishers, 2005), 138-141.



completed under Jahangir in 1624, Shah Jahan extended it westwards in 1632. Behind its western facade lies the Summer Palace and built on top is the Shah Burj Quadrangle [Fig.5].

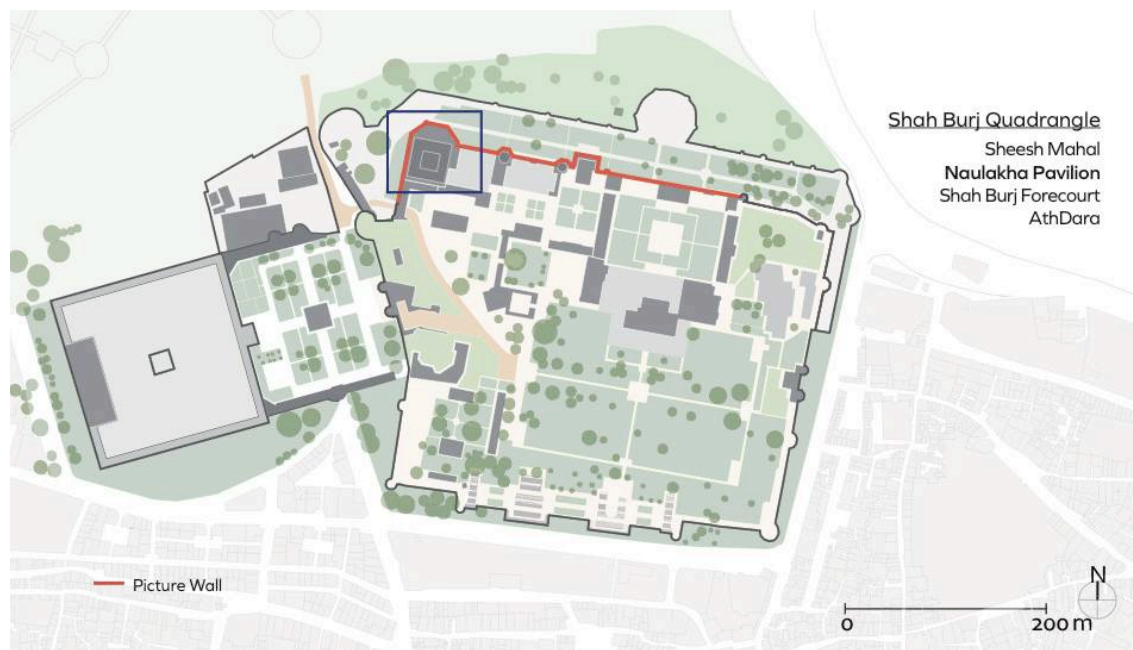


Figure 5: The Picture Wall and Shah Burj Quadrangle in relation to the rest of the Fort complex. (Data Source: AKCS-P)

The Shah Burj Quadrangle situated at the northwest corner of the Fort originally overlooked the river Ravi, whose course has now changed. Its white marble buildings, like their counterparts at Shah Jahan’s palaces in India had a similar style and setting and were reserved for the emperor and his family. Some records suggest the quadrangle was used as the empress’ harem when she visited Lahore.<sup>8</sup> Among these marble monuments is the famous Shish Mahal (mirror palace) to the north, and the Naulakha Pavilion with two adjoining *jalis* on the west end of the quadrangle [Fig. 6]. Additionally, there are three surrounding *dalans* (loggias) made in white marble and red sandstone. All of the

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<sup>8</sup> Muhammad W. Khan, *Lahore and its Important Monuments* (Karachi: Anjuman Press, 1973), 26.

aforementioned structures are built around a spacious forecourt laid in variety of variegated marbles. The courtyard boasts remnants of a sophisticated drainage system, comprised of water channels on each of the four sides and fountains that once ran into a shallow circular water basin in the middle. In the center of the water basin is a marble *mahtabi* (platform).

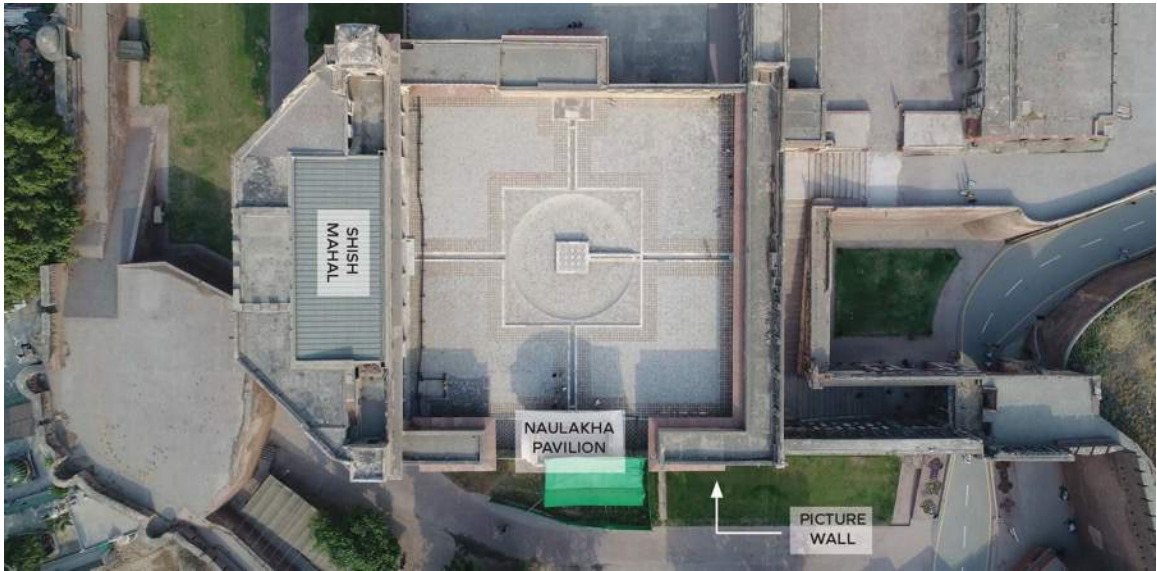


Figure 6: Overview of the Shah Burj Quadrangle. Showcasing the Naulakha Pavilion, Shish Mahal, and the surrounding dalans (loggias) among other structures. (Data Source: AKCS-P)



#### 4.0 Naulakha Pavilion

Built between 1631-33, the pavilion is one of Lahore's most recognizable sights, revered for its symmetry, use of chaste white marble, Mughal workmanship, and intricate *parchin kari*. Commonly known today as the Naulakha, the name refers to the monument's cost of nine lakh rupees, presumably a modern imprint to its history since neither the name nor the sum is mentioned in the *Badshah Namah* (memoir of Shah Jahan). Some historians have also referred to the monument as *Bangla* due to its curvilinear roof. Such roofs (*gor-bangla*) can be credited to the indigenous architectural style in Bengal, where Shah Jahan spent much time as a rebel prince.<sup>9</sup> The monument has influenced art and architecture in many forms, not just locally but also internationally. Along with have been previously featured on the Pakistani one rupee note and providing inspiration for the Pakistan Embassy building in Washington D.C., the monument was also a source of inspiration for Rudyard Kipling's novel about a precious jewel that he named "The Naulakha". In addition, Kipling also named his residence in Vermont after the monument.<sup>10</sup> Furthermore, a very similar pavilion in size and form, built around the same period is found in the Agra Fort, India that retains a gilded roof. Both these pavilions had a similar function, as the emperor used them for public viewing. It is therefore, believed by some, that Naulakha once too had its roof painted with gold leaf, although no such evidence was found through archival and in-situ investigation. The western facade of Naulakha overlooks the fortification walls, bearing a marble *jali* with a crown-like profile carved directly above its central opening through which Shah Jahan presented himself

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<sup>9</sup> Catherine B. Asher, *The New Cambridge History of India: Architecture of Mughal India* (Cambridge: Cambridge University Press, 1992), 180–81.

<sup>10</sup> Rudyard Kipling, *Something of Myself: for my friends known and unknown* (London: Macmillan and Co., 1951), 114-115.

to the public [Fig. 7]. This architectural device enhanced his royal presence so that whenever he appeared through the *jali*, he embodied the throne.<sup>11</sup>



Figure 7: The eastern facade of the Naulakha Pavilion and its adjoining *jalis*. Showcasing the central cusped arch *jali* through which Shah Jahan presented himself to the public.

#### 4.1 Physical Description

Naulakha is a four-walled, vaulted pavilion, 16 feet wide by 30 feet long and rises 18 feet in height, atop the Picture Wall, 30 feet above grade. It consists of a single rectangular room, and a vaulted ceiling clad with wood, *naqqashi* (frescos), and *aiena kari* (mirror work). One large cusped arch opening, flanked by two smaller openings, articulate its front facade on the east, and one opening each relieve both sides. The western facade bears three marble *jalis* – a central cusped arch *jali* with three small window openings flanked by two pietra dura panels

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<sup>11</sup> Mudassar Chaudhry (tour guide, Lahore fort) in discussion with the author, December 2017.

and two rectangular *jalis* [Fig. 8].<sup>12</sup> Additionally, the west facade is adjoined by two sets of interlocking *jalis* that are self-supporting and stand in perfect symmetry to one another. They boast five different lattice styles, with ornate floral *kanguras* and a solid cornice band on top [Fig. 9]. Each pair measures 8 feet in height and 18 feet in width. Moreover, the monument carries intricate *parchin kari* work wrought in precious and semi-precious stones such as coral, cornelian, agate, jade, and lapis-lazuli [Fig. 10].<sup>13</sup> The interior engaged columns supporting the two central arches, in particular have been acknowledged for their miniature niches adorned with 102 miniscule pieces of stones inlaid in a floral pattern.<sup>14</sup>



Figure 8: Partial view of the western facade of the Naulakha Pavilion. Displaying the central cusped arch jali and pietra dura panels.

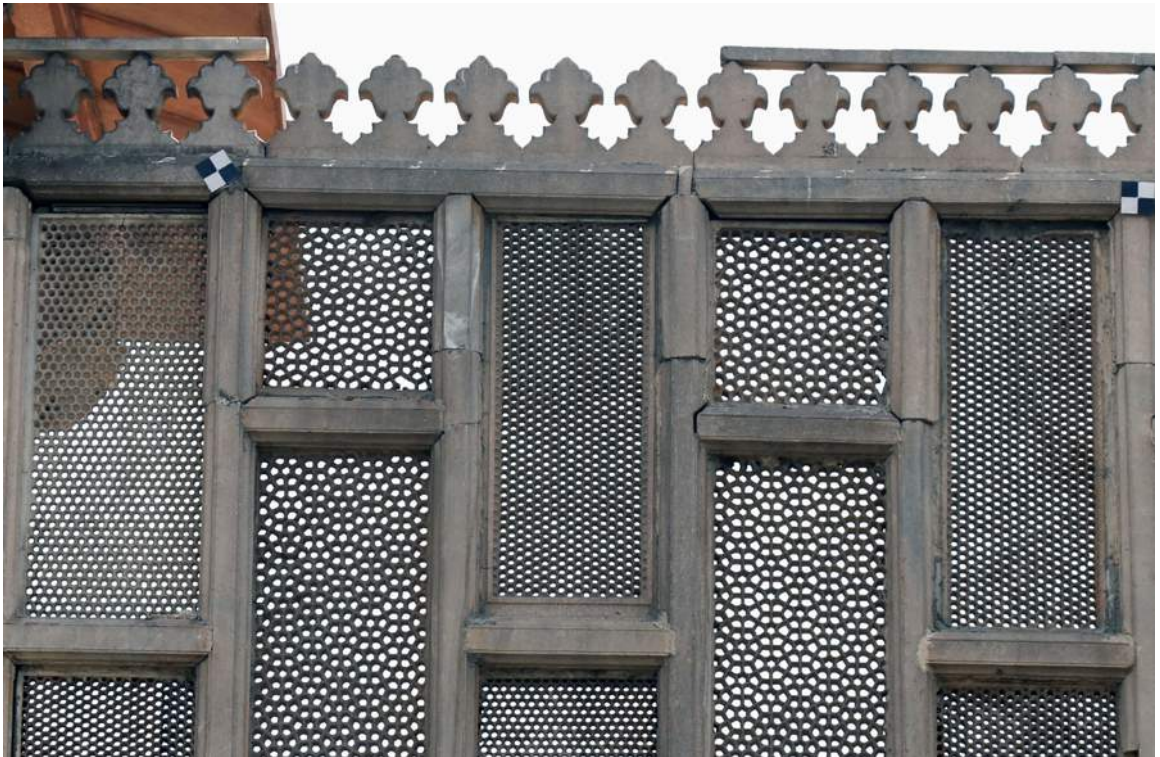
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<sup>12</sup> Muhammad I. Khan, *World Heritage Sites in Pakistan* (Islamabad: United Nations Educational, Scientific and Cultural Organization-Pakistan, 2000), 80.

<sup>13</sup> Jean P. Vogel, *Tile-Mosaics of the Lahore Fort* (Calcutta: Superintendent Government Printing, 1920), 26.

<sup>14</sup> Muhammad I. Khan, *Master Plan Lahore Fort* (Lahore: Department of Archaeology, Ministry of Education and Provincial Coordination, Government of Pakistan, 1973), 22.





*Figure 9: The self-supporting jalis flanking both sides of the pavilion. Showcasing the different lattice styles and the ornate kanguras (antefixes) on top.*



*Figure 10: Rectified parchin kari (pietra dura) panel.*



### **4.3 Construction**

The pavilion is a brick and mortar structure on top of a stepped platform with marble slabs used as a decorative veneer over the brickwork. These marble slabs do not contribute to the strength of the structure itself, and therefore, if they were to disintegrate or become detached, the basic structure would still stand.

The marble slabs are fixed to the brick structure with lime-based mortar and often with a ferrous anchorage for support. Iron cramps have been used in several places to join one slab to the other, along with an interlocking joint system. More intricate stone pieces such as the *jalis*, use frameworks with interlocking joints that allow the *jalis* to slide into their interior grooves, for these are not supported by a brick backing wall. Furthermore, as part of the curvilinear roof there are the downward sloping *chajjas* (eaves) made up of individual slabs joined together with iron cramps that rest on solid marble corbels.

The mortar used in construction appears to be of lime, still appropriately hard and strong, however mortar analysis should be conducted for confirmation.<sup>15</sup> The marble slabs are of varying sizes and thicknesses. Some are more than 3 feet in length and are 6 inches or wider. The thickness varies from place to place, but mostly they are about 2-5 inches thick.

### **4.4 Masonry Characterization**

Earlier investigations carried out by AKCS-P on the origins of the marble cladding used in the Naulakha Pavilion determined the stone as Makrana marble.<sup>16</sup> The widespread use of white marble in *Shahjahan* architecture during the 17<sup>th</sup> century often employed marble from

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<sup>15</sup> Although no documentation was found describing the precise mortar composition of the pavilion, however, historically most Mughal architecture employed lime mortars, including the Picture Wall.

<sup>16</sup> Asif Hanif and Muhammad Siddiq, *Makrana Marble: Comparison and Origin* (Geoscience Advance Research Laboratories, 2017).

the Makrana quarry in Rajasthan (now part of India), preferred for its pristine whiteness, coarse grain structure and low porosity.<sup>17</sup> Despite the large transporting distance of approximately 500 kilometers, the marble was extensively brought into Lahore during the construction of several Mughal monuments and gardens. Today buildings all over the Subcontinent, including the next door Shish Mahal in Lahore Fort, as well as Taj Mahal in Dehli are built with Makrana marble.<sup>18</sup>

Geologically marble has a saccharoidal or crystalline structure, formed by metamorphosed limestone consisting primarily of calcite ( $\text{CaCO}_3$ ), and dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ) minerals that greatly influence deterioration patterns in the stone.<sup>19</sup> Although marble is denser and resistant to weathering than most limestones, when subjected to polluted environments such as of Lahore's, it can experience severe loss from cracking, granular disintegration, and deformation. While all marbles are susceptible to decay, the mineralogical composition, texture, fabric, and secondary minerals of the stone dictate to a large degree its specific response to weathering. Therefore, the petrographic evaluation of Makrana marble, along with other supporting material analyses were crucial to diagnosing the stone's behavior and impact on the current deterioration of the pavilion and its adjoining marble *jalis*.

The hand specimen of marble sample PW12 (cleaned earlier), displays a white (Munsell color 5PB-9/1) matrix with no preferred grain orientation [Fig. 11]. Thus, no clearly developed foliation is observable. The marble is relatively soft with a hardness of 3 out of 10 on the Moh's scale.

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<sup>17</sup> Indira Bhavan, "Marble," *Indian Minerals Yearbook 2013 (Part-III: Mineral Reviews)* (2015).

<sup>18</sup> Judit Zoeldfoeldi, "Database of white marble from the Indian Subcontinent: a review," Research-Gate, 2009, [https://www.researchgate.net/publication/271906905\\_Database\\_of\\_white\\_marble\\_from\\_the\\_Indian\\_Subcontinent\\_a\\_review](https://www.researchgate.net/publication/271906905_Database_of_white_marble_from_the_Indian_Subcontinent_a_review).

<sup>19</sup> ed. Alison Henry, *Stone Conservation: Principles and Practice* (Florence: Taylor and Francis, 2015), 217–219.



*Figure 11: Hand specimen of Makrana marble (Munsell color 5PB-9/1). Sample no. PW8. Magnification: 50X. Showcasing a coarse grain structure with no preferred orientation.*

The examination of thin sections of the marble samples under polarized light microscopy, followed by an acid exposure test revealed that Makrana marble is predominantly calcitic ( $\text{CaCO}_3$ ) in nature which gives the stone its characteristic translucency due to calcite's low index of refraction. Along with few to rare muscovite and quartz inclusions, the stone demonstrates an overall strong anisotropic grain structure. Although there are variations in textural features between the samples, all samples exhibit a coarse, heteroblastic texture with predominantly sutured, less often embayed grain boundaries. The grain size is averaged 2 mm and ranges closely between 0.1 mm to 5.6 mm with a closely packed inter-grain relationship and frequent triple junctions. The sparite calcite grains are



sub-rounded with no relative orientation, displaying strong rhombohedral cleavage and lamellar twinning. Accessory muscovite and quartz appear between calcite grains in irregular clusters or as calcite inclusions (size: 0.02 mm to 0.9 mm) [Fig. 12].

The large tightly-grown calcite crystals and lack of voids in the stone indicate its high-grade metamorphism. Though the marble displays little-to-no void space, the presence of microcracks within thin sections do underline its somewhat increased porosity due to weathering. Samples PW8 and PW10 reveal a changing texture of the stone, with extremely sutured boundaries, and embayed calcite intergrowth displaying grain size as small as 0.08 mm. Specifically, sample PW10 shows a great amount of mineral alteration, with traces of a few larger calcite grains, possibly undergoing alteration due to the dissolution of calcite minerals [Fig. 13]. Moreover, sample PW12 contrary to the rest of the samples and previous petrographic investigations by AKCS-P, exhibits a microcrystalline quartz vein (approximately 18 mm in length) running diagonal to the surface of the stone [Fig. 14]. The presence of this vein challenges the relative frequency ratio of the quartz minerals to calcite grains maintained by the rest of the samples, however, is an important reminder of the possible variability in texture of stones even from the same quarry.

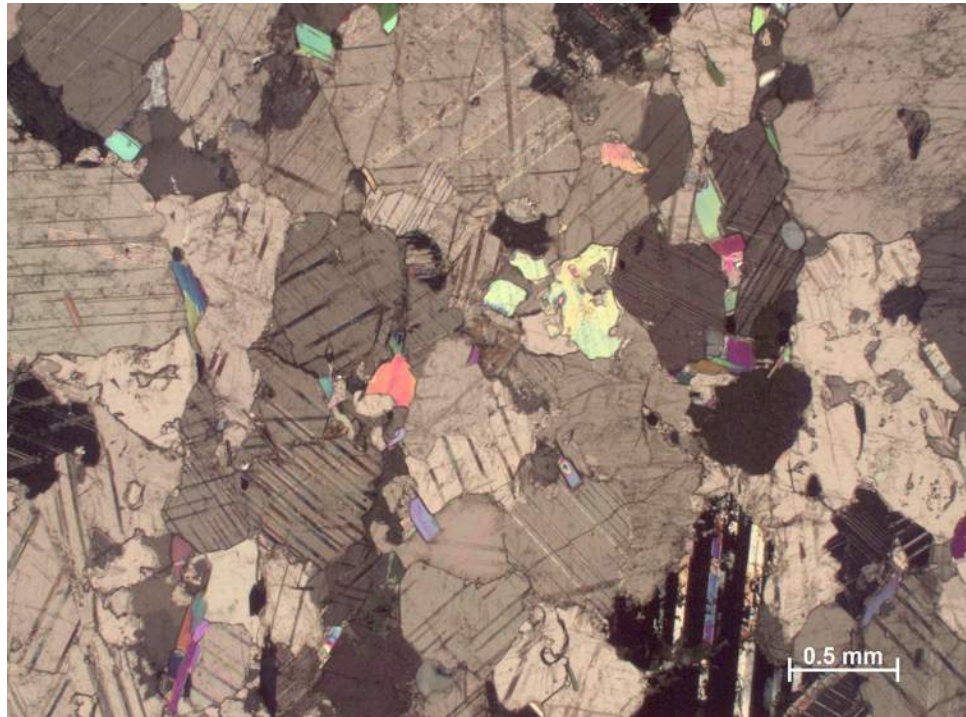
Additionally, deformation largely due to the anomalous thermal behavior of calcite minerals can be clearly seen in samples PW9 and PW11 [Fig. 15]. As the threshold of cohesive grain-to-grain strength of the stone exceeds its limit, large internal stresses lead to microcracking often occurring at triple junctions and along the grain boundaries.<sup>20</sup>

Therefore, grain boundary cracking is a common indication of marble deterioration that is

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<sup>20</sup> Tzy-Chung Wu et al., “Anisotropic Thermal Expansion of Calcite at High Pressures: an insitu X-Ray Diffraction Study in a Hydrothermal Diamond-Anvil Cell,” *American Mineralogist* 80, no. 9–10 (1995), 941–46.

largely dependent on the inter-grain relationship of its minerals. More evidence of plastic deformation is presented by undulose (zoned) extinction, polysynthetic twin deformation and fractures that are going through the grains, and sometimes along the cleavage planes [Fig. 16].



*Figure 12: Thin section micrograph under polarized light microscope for sample PW8. Magnification: 25X. Showing calcite grains with rhombohedral cleavage and lamellar twinning. Accessory muscovite can be seen in clusters and as calcite inclusions.*

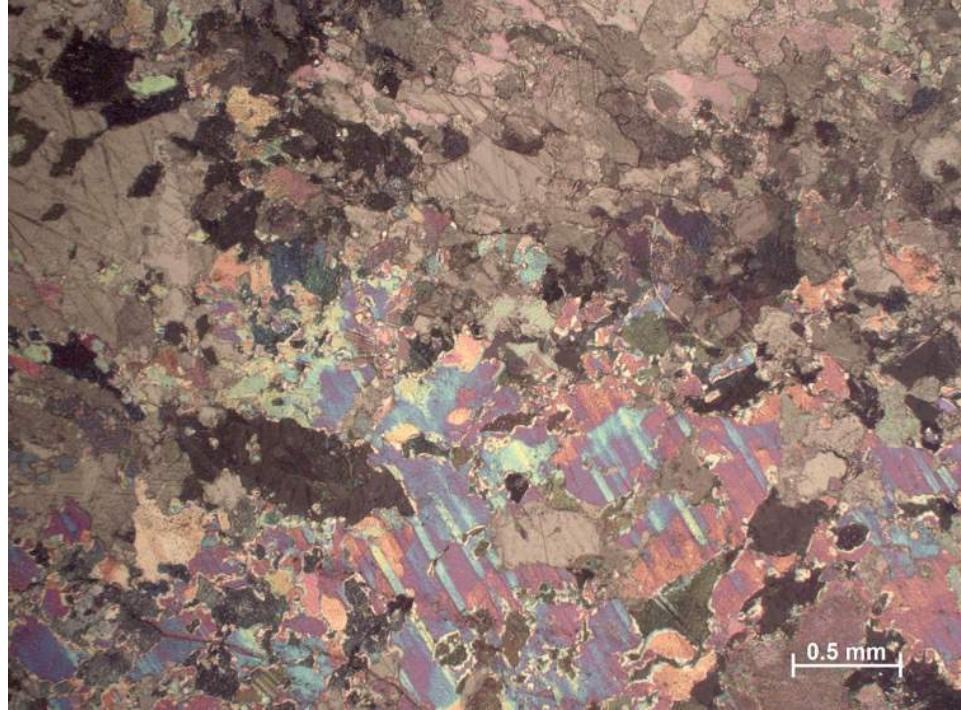


Figure 13: Thin section micrograph under polarized light microscope for sample PW10. Magnification: 25X. The texture of stone is seen changing as the large calcite grains undergo alteration, possibly due to their dissolution by acidic rain.

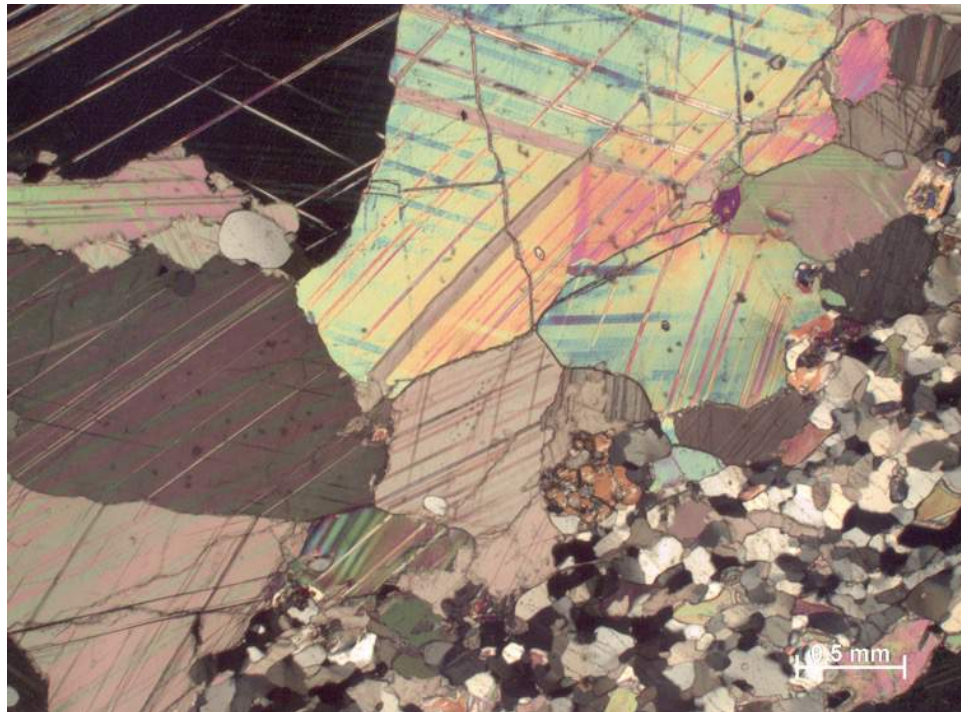
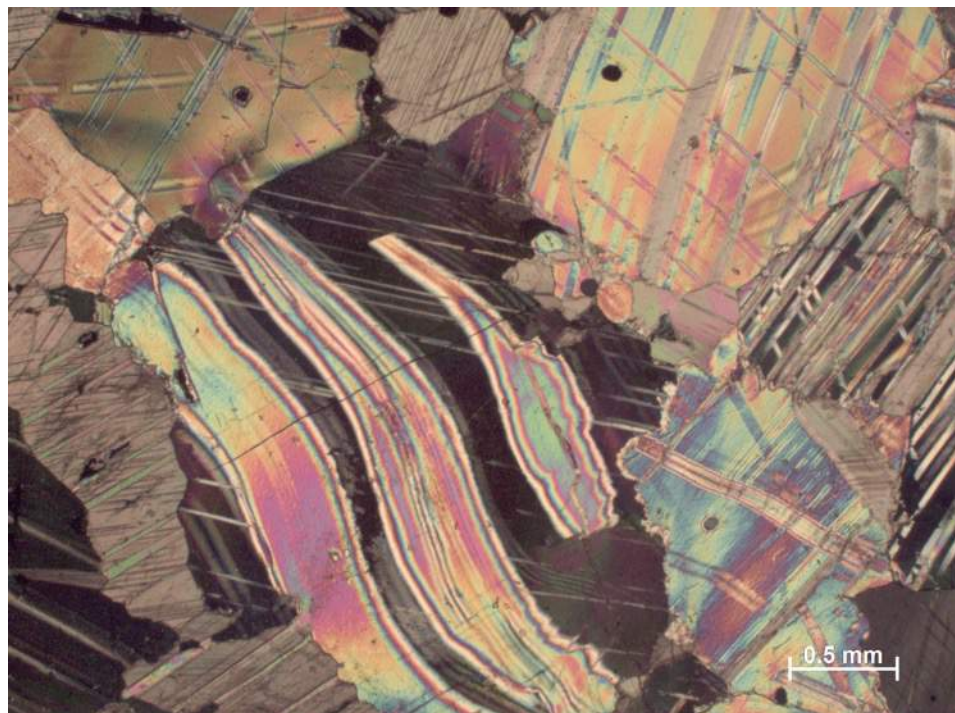
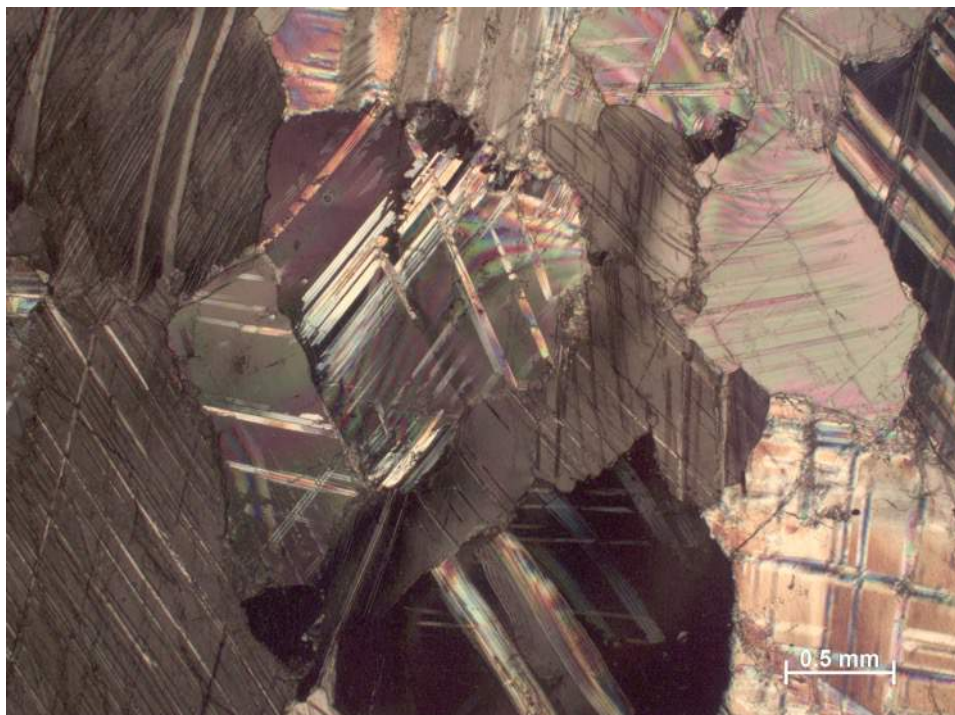


Figure 14: Thin section micrograph under polarized light microscope for sample PW12. Magnification: 25X. Displaying the microcrystalline quartz vein running through calcite grains.





*Figure 15: Thin section micrograph under polarized light microscope for sample PW9. Magnification: 25X. Displaying calcite grains under stress causing polysynthetic twin deformation.*



*Figure 16: Thin section micrograph under polarized light micrograph for sample PW9 with undulose extinction. Magnification: 25X.*

The scanning electron microscopy results confirm the presence of alterations such as microcracks, disintegration between calcite crystals, and a surface film covering the crystalline structure of the stone [Fig. 17]. Energy dispersive x-ray spectroscopy of samples PW8 and PW9 detected a pure carbonate composition, with low amounts of magnesium and aluminum [Fig. 18].

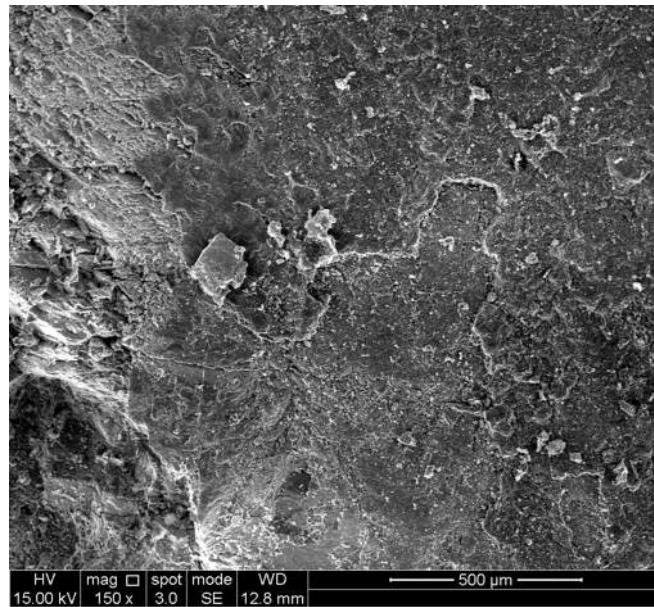


Figure 16: SEM micrograph of deteriorated marble sample PW9. Magnification: 150X. Showing a variety of cracking patterns, and the presence of a surface film covering the crystalline structure.

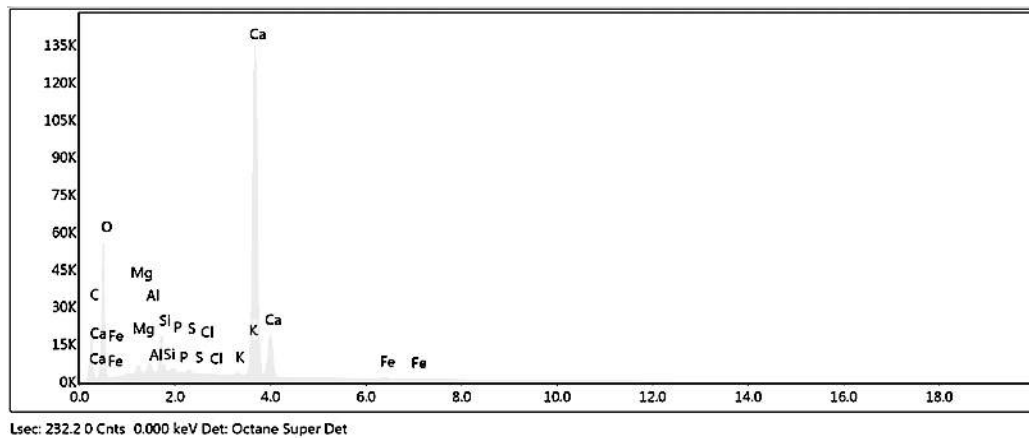


Figure 17: EDS chart of marble sample PW9. Revealing an almost pure carbonate composition, with low amounts of all elements but Ca.

#### 4.5 *Environmental Conditions*

Due to the significant impact of extrinsic factors that include, but are not limited to temperature, solar radiation, moisture, wind, human activity, and airborne pollution, the study of Lahore's environmental conditions specific to the pavilion were key in conducting a more conclusive conditions assessment and diagnostics for the monument. The city of Lahore lies 712 feet above sea level and falls under a semi-arid climate zone with low humidity, according to the Koppen-Geiger climate classification.<sup>21</sup> The temperature during the long, hot and dry summer periods remains high throughout the day, ranging closely between 80-130°F with an average high of 95°F. The winds are hot and full of dust during the day while nights are slightly cooler. On the other hand, the day temperature for the short, rainy winter periods can get as high as 90°F but drop as low as 41°F at night. The highest diurnal temperature variation in the city is experienced between March to May with temperature difference as extreme as 59°F.<sup>22</sup> Additionally, in summer the sun travels through east, crossing the meridian due south at noon, ultimately exposing western facing structures to high intensity solar radiation until it sets in the west. Therefore, the western face of the Naulakha Pavilion along with its adjacent monuments face a more extreme and longer exposure to direct solar radiation through most of the day.

Lahore has an average annual precipitation of 24.8 inches, with its wettest months being July and August that bring with them heavy monsoon rains with 8 inches of average rainfall. The wind direction and speed in the city experiences variation throughout the year,

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<sup>21</sup> Sardar Sarfaraz, et al., "Regionalizing the Climate of Pakistan using the Koppen Classification System" *Pakistan Geological Review*, Vol. 69, No. 2, (2014).

<sup>22</sup> "Average Weather in Lahore, Pakistan, Year-Round," Weather Spark, accessed February 22, 2018, <https://weatherspark.com/y/108021/Average-Weather-in-Lahore-Pakistan-Year-Round>.



however it broadly blows from northwest for most winter months and southeast in summer. The wind-driven precipitation, therefore, particularly in the monsoon seasons with heavy continuous downpour is possibly contributing to a considerable extent to the deterioration of the pavilion's west facade.<sup>23</sup>

The Fort shares close proximity with several other historic sites while being surrounded by urban sprawl, experiencing heavy traffic and congestion from all sides [Fig. 19]. Several factors such as Lahore's rapidly growing population and the heavy traffic flow exposes the monuments to automotive emissions and fly ash, a residual of coal combustion and burning trash from surrounding slums along with vehicular traffic.



*Figure 18: Lahore Fort complex in relation to the surrounding urban fabric. (Data Source: AKCS-P).*

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<sup>23</sup> "Wind and Weather Statistic Lahore Allama Iqbal Airport," WindFinder, accessed 22, 2018, [www.windfinder.com/windstatistics/lahore\\_allama\\_iqbal\\_airport](http://www.windfinder.com/windstatistics/lahore_allama_iqbal_airport).

Furthermore, the air in Lahore has an annual average of 68  $\mu\text{g}/\text{m}^3$  of fine particulate matter (PM2.5), that is 6.8 times above the World Health Organization (WHO) prescribed safe level.<sup>24</sup> PM2.5 often results from burning cow dung cakes and municipal solid waste, both known to be common practices around the city. In addition to this, Lahore experiences dense smog especially during the month of December, due to the cyclical crop burning periods [Fig. 20].<sup>25</sup> The reaction of air moisture with airborne pollutants of carbon, sulphur dioxide, nitrogen, PM2.5, and dust particulates is alarmingly threatening to historic masonry buildings, and especially those of carbonate stones such as marble.



*Figure 19: View of the Lahore city enveloped by a shroud of toxic smog. (Data Source: Yasir Naseer).*

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<sup>24</sup> “City Data Page,” BreatheLife 2030, accessed January 11, 2018, <http://breathelife2030.org/city-data-page/?city=1875#>.

<sup>25</sup> “What’s PM 2.5 and Why is New Delhi, Lahore Smog so Bad?” Al Jazeera News, November 8, 2017, accessed January 11, 2018, [www.aljazeera.com/news/2017/11/pm-25-delhi-lahore-smog-bad-171108124435564](http://www.aljazeera.com/news/2017/11/pm-25-delhi-lahore-smog-bad-171108124435564).



#### 4.6 Conservation and Alterations History

This section chronicles the restoration of the pavilion, focusing in more detail on its exterior, including past remedial interventions and maintenance. Archival photographs from the 1900s document the curvilinear roof and western *chajja* of the pavilion to be missing for over a century [Fig. 21]. What remains now of the roof structure is a solid masonry parapet wall that dips down into a flat plane, surrounded by *chajjas* on the other three elevations. Several of the precious and semi-precious stones are missing except those, which could not be removed, leaving the marble panels and interior niches empty and vulnerable to further damage. Most of the missing pieces of *parchin kari* are said to have been removed during the Sikh and British periods.<sup>26</sup>



Figure 20: Historical photograph of the western façade of Naulakha (ca. 1900). Showing the missing western *chajja* (eave) in relation to the rest of the roof.

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<sup>26</sup> Muhammad I. Khan, *Master Plan Lahore Fort* (Lahore: Department of Archaeology, Ministry of Education and Provincial Coordination, Government of Pakistan, 1973), 22.

This was corroborated in the 1882 Curators Report of the Ancient Monuments in India, which discusses Naulakha's missing inlay work, damage to the ceiling and lintel, and previous Dutchmen repairs to its southern *chajja* and corbels with wood.<sup>27</sup> No other detailed source was found identifying what materials were used to clean and repair the stone previously. Although many corbels are missing now, the remaining pieces retain good original detail.

The only major 'known' structural change to Naulakha occurred in 1907, when the British embedded iron beams into its masonry for additional support. Soon after an earthquake in 1905, the foundations of the pavilion were discovered to have subsided, causing its crepidoma to crack and allowing the superstructure to bend dangerously outwards over the fortification walls. In order to stabilize the structure and deter further movement, the weight of the western wall of the pavilion which was resting primarily on the *jalīs* underneath, was transferred to iron beams, that required the disassembly and resetting of those *jalīs*. This included minor repairs such as filling cracks and repointing joints wherever needed, as well as repainting of the spandrels on each side of the screen.<sup>28</sup> However, the Archaeological Survey of India does not go into any more detail, to identify specific tools and materials, and techniques used for such a repair.

Minor mortar composite repairs, repointing of joints, Dutchmen, and replacement of missing stone elements were performed at intermittent times in the 20<sup>th</sup> and 21<sup>st</sup> centuries, often after marble spalled. Not all the repairs and patches were recorded or monitored for quality control. The somewhat recent conservation history of Naulakha gathered through

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<sup>27</sup> Henry H. Cole, *Preservation of National Monuments: First Report of the Curator of Ancient Monuments in India for the year 1881-82* (Simla: Government Central Branch Press, 1882), clxxxix.

<sup>28</sup> *Archaeological Survey of India: Annual Report 1907-8* (Calcutta: Superintendent Government Printing, 1911), 5.

archival photographs, is the 1970s reconstruction of the southwest corner of the parapet wall and the cornice band of the adjacent, freestanding marble *jalis* along with the 1997 ‘restoration’ of Naulakha’s floor with tessellated flooring [Fig. 22].



Figure 21: Historical photograph showing restoration of Naulakha's parapet wall (ca. 1970).

Additionally, the *jalis* on the northern side of the pavilion were leaning outwards and therefore, were disassembled, repaired and reset in 2000 [Fig. 23].<sup>29</sup> Much of the repair work, though still inadequate visually is comparatively less obvious from within the quadrangle.

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<sup>29</sup> Talib Hussain, *History of Interventions on Prototype Area of Picture Wall, Lahore Fort* (Lahore: Aga Khan Culture Service-Pakistan, 2017), 10–11.

Whereas, repairs on the western facade that are perhaps not clearly visible to the visitor have been carried out with extreme negligence. This includes inconsistencies in repair mortar composition and application that sometimes involved the use of cement, incompatible replacement material such as mismatched marble and in one instance terracotta replacing marble elements, as well as inaccuracies in resetting of the *jalis*, placing wrong components together. Furthermore, some recent maintenance procedures may also be equally problematic to accurately document. For a complete chronology of known repairs and restoration campaigns over the years, please see Appendix A: Historical Timeline.



*Figure 22: Repair by disassembly of the marble jalis (2000).*

## 5.0 Existing Conditions

As a carbonate-based metamorphic stone, a series of factors influence the deterioration patterns of marble. These include the intrinsic characteristics of the stone such as its mineralogical composition, texture, grain shape and size, as well as pre-existing conditions like the presence of foliation and microcracks within its structure.<sup>30</sup> These intrinsic factors consequently determine the specific response and vulnerability of the marble veneer panels in response to their exposure to extrinsic factors that include but are not limited to, the quarrying process and dressing of stone, orientation and placement of individual slabs, their anchoring system, atmospheric conditions, and past treatments.

For the identification and analysis of existing conditions present on site, a detailed glossary of conditions was developed during the field survey and systematically modified as the understanding of the broader deterioration patterns of the pavilion became clearer and more specialized during condition mapping and diagnostics. The conditions recorded comprise general conditions that are prevalent throughout the pavilion; surface accretions and alterations; structural displacement and cracking of the panels; along with previous repairs and replacements. In this way, existing conditions were studied, and their causes were determined, through examining visible conditions present in-situ in conjunction with previous events and interventions that have influenced the pavilion's current state of deterioration. The conditions glossary and drawings can be seen in Appendix C: Conditions Drawings.

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<sup>30</sup> Annette Zeisig, et al., "Thermal Expansion and Its Control on the Durability of Marbles," *Geological Society, London* (London: Special Publication, 2002), 65–80.

## 5.1 *General Conditions*

The current state of damage to the Naulakha Pavilion is essentially a function of its material, original design and construction in response to the surrounding environment and previous repairs. In particular, the interaction of the monument with heat and moisture has significantly contributed to its decay which in turn has led to several other processes of deterioration. Some of the resultant deterioration mechanisms include accumulation of airborne pollutants (soiling), dissolution of calcite minerals (disaggregation), thermally induced microcracking and the subsequent deformation of several marble *jalis*.

A surface condition that is prevalent throughout the pavilion, although in varied concentrations (dependent on the exposure of individual elevations of the pavilion), is the atmospheric soiling of the stone. This condition refers to the accumulation of a thin layer of airborne pollutants such as carbonaceous soot and dust particles transported onto the marble panels by rain and water runoffs.<sup>31</sup> Such particulates are loosely adhered to the surface of the stone, giving the pavilion a dirty appearance. Although this process does not damage the structure of the stone, it does however, impact its visual appearance, taking away the pristine whiteness of Makrana marble. Such soiling is particularly dense in areas that cannot be easily washed away by rain and around *jalis* that allow atmospheric particulates to accumulate within crevices and carved details [Fig. 24]. In addition, due to the difficult-to-no access, the western façade of the pavilion appears to have been severely neglected during cleaning cycles and therefore, shows heavy soiling in comparison to the other sides.

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<sup>31</sup> Tamara Anson-Cartwright, *Illustrated Glossary on Stone Deterioration Patterns* (Paris: ICOMOS International Scientific Committee for Stone (ISCS), 2010), 116.





Figure 23: Atmospheric soiling on the central jali of the Naulakha Pavilion.

Another prevailing condition found on several of the panels and marble frameworks of the *jalis*, is open mortar joints, varying between partial to complete loss of mortar. Although there are several causes that can be credited to the failure of mortar, moisture is found to be the most predominant. Particularly, in the case of lime-based mortars, its soluble components, calcium hydroxide ( $\text{Ca}(\text{OH}_2)$ ) and calcium carbonate ( $\text{CaCO}_3$ ) can easily dissolve in water.<sup>32</sup> Once the mortar erodes, this allows for even more moisture penetration inside and outside the structure. This problem is more apparent in vertical joints of the

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<sup>32</sup> Phillip F.G. Banfill, et al., “Deterioration of Natural Hydraulic Lime Mortars, II: Effects of Chemically Accelerated Leaching on Physical and Mechanical Properties of Carbonated Materials,” *Construction and Building Materials* 111 (Edinburgh: 2016), 182–90.

pavilion that are inherently more susceptible to water run-offs. Moreover, this condition was largely recorded around the two adjoining sets of *jalīs* on either side of the pavilion, that are primarily assembled with an interlocking system of marble frameworks, comprising several joints [Fig. 25]. Most of their corresponding mortar joints have eroded over time, partly due to their sacrificial nature but also as their design creates inset areas that in turn provide a longer contact time with water.



*Figure 24: Open joints in the supporting frameworks of the jalīs. Mostly seen as a result of mortar deterioration and spalling.*



Historically, mortars have been seen as a sacrificial element used to seal the masonry envelope, where their eventual friability and deterioration were part of the building's systems. Deterioration of the mortar joints protects the individual stone units against other deterioration mechanisms such as salt crystallization and spalling by creating alternative routes for moisture movement. However, the deferred maintenance of the pavilion has led to advanced mortar deterioration which unfortunately is now facilitating greater exposure into the masonry system and a lack of connective support. As a result, open mortar joints are allowing water and air direct contact with the stone as well as its ferrous anchorage.

## ***5.2 Surface Accretions and Alterations***

Conditions such as surface deposits and alteration crusts are by-products of many factors affecting Naulakha, such as its aging, neglect and repair. However, the mineralogical composition of its marble, and the intricately carved *jalīs* are particularly susceptible to atmospheric weathering. Such surficial alteration layers affect both the aesthetics of the monument and in some cases, the integrity of the stone underneath. Surface condition typologies identified through this research include black crust; yellow surface film; staining; and graffiti.

### *Black Crust*

Current surface conditions include a well-adhered, black alteration crust presumably of gypsum plus other mineral particulates, however, scanning electron microscopy and x-ray diffraction analysis should be conducted for confirmation. Encrustation of gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) on carbonate stone surfaces is a common phenomenon, understood as the reaction between the calcite minerals ( $\text{CaCO}_3$ ) in the stone, moisture, and sulfur dioxide ( $\text{SO}_2$ ) in polluted air; although, since gypsum is more soluble than calcite in water, it

accumulates mostly on sheltered surfaces that are protected from rain and water run-offs.<sup>33</sup> Additionally, inappropriate acidic cleaning of marble surfaces are also known to result in gypsum encrustation, though this seems unlikely in this case.

This condition has been documented underneath the eaves, and on the underside of the head of the openings of the central cusped arch *jali* on the western façade [Fig. 26].



*Figure 25: Gypsum related black crust seen on the underside of the central jali.*

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<sup>33</sup> Siegfried Siegesmund and Rolf Snethlage, *Stone in Architecture: Properties, Durability* (New York: Springer, 2014), 255-260.

Although currently adhering to the surface as a thin layer, gypsum crusts can become considerably thick (ca. 1 mm to 20 mm), and not only distort surface details but can potentially alter the subsurface of the stone through dissolution of calcite minerals.<sup>34</sup> Over time, crusts can lead to cracking and spalling of the affected areas, exposing the vulnerable, often disaggregated stone surface underneath. Therefore, cleaning such alteration crusts often brings with it the added challenge of losing carved details that were preserved beneath the crust while exposing new vulnerable zones of the stone to further disaggregation.

#### *Yellow Surface Film*

One surface condition recorded consistently throughout the pavilion, but limited to its exterior surfaces, is the formation of a thin yellow-brown alteration layer. It is seen in deep inset areas protected from rainwater such as, the inside of the fretwork and within carved details of the *jalis*, the underside of the cornice and stepped platform, within corners, and between crevices [Fig. 27]. The film appears to be firmly adhering to the stone, although, is not enmeshed into its subsurface, as it comes off if scraped. In addition, it displays a homogenous texture, often discontinuous and deteriorated with microcracks.

Research suggests, the composition of such films is based on the presence of calcium oxalate ( $\text{CaC}_2\text{O}_4 \cdot n\text{H}_2\text{O}$ ), calcite ( $\text{CaCO}_3$ ), and varying combinations of gypsum and silicates with some accessory mineral inclusions.<sup>35</sup> Their origin has long been debated in association with atmospheric pollution, biodeterioration, or degradative oxidation of previous organic

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<sup>34</sup> Stephen J. Kelley, American Society for Testing Materials, and ASTM Subcommittee E06.24 on Building Preservation and Rehabilitation Technology, eds., *Standards for Preservation and Rehabilitation*, STP 1258 (West Conshohocken, PA: ASTM, 1996), 376.

<sup>35</sup> Laura Rampazzi, et al., "Analytical Investigation of Calcium Oxalate Films on Marble Monuments," *Talanta* 63 (2004), 967–77.

surface treatments. In all such cases, oxalate films essentially correspond to mineral dissolution reactions between oxalic acid and calcium compounds, present as either a constituent element of the stone (calcite), or as a calcium salt deposit.<sup>36</sup> This in turn forms monohydrate and dihydrate calcium oxalates i.e., whewellite ( $\text{CaC}_2\text{O}_4 \cdot \text{H}_2\text{O}$ ) and weddellite ( $\text{CaC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ ) depending on the thermodynamic conditions of the site. Since they are less soluble than calcite, this reaction leaves a thin crystalline film on the surface of the stone.<sup>37</sup>



*Figure 26: Silica-based yellow surface film on the stone. Accumulating primarily within the carved details.*

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<sup>36</sup> Alessandra Bonazza, et al., “Oxalate Patinas on Stone Monuments in the Venetian Lagoon: Characterization and Origin,” *International Journal of Architectural Heritage* 9, no. 5 (2015), 542–52.

<sup>37</sup> Alison Henry, *Stone Conservation: Principles and Practice* (Florence: Taylor and Francis, 2015), 224–226.

For some historic sites, their preservation philosophy allows for oxalate films to be left in-situ, as they pose no serious threat to the building, and instead protect the underlying stone against atmospheric pollution.

One hypothesis discussed with the AKCS-P team suggests that the film boasts remnants of gilding carried out during the Sikh era.<sup>38</sup> This would mean that the yellow film is a residue of perhaps an oil size used as part of the gilding process. Although true for several other Mughal elements found in the Fort, no historic documentation, in-situ investigation or material analysis conducted by the author were able to corroborate this assumption.

For scientific investigation, film samples were taken together with the marble substrate with the help of a scalpel and were later used to prepare cross sections. Optical microscopy, scanning electron microscopy and energy dispersive x-ray spectroscopy analysis were systematically carried out in order to investigate the composition of the film. During visual examination and sampling on site no macroscopic evidence of any form of biological growth was found on the film. This was confirmed by microscopic observations that similarly indicated no such signs. Additionally, SEM of collected samples from protected areas displayed a hazy textured film on the surface of the marble [Fig. 28]. Further selective examination on samples PW8 and PW9 included x-ray EDS analysis to confirm visual observations and identify the elemental breakdown of the film. A central target at the interface between the yellow surface film and an area of the stone without any film was selected and an elemental spectrum was recorded.

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<sup>38</sup> Rashid Makhdum (AKCS-P conservation consultant) in discussion with the author, December 2017.

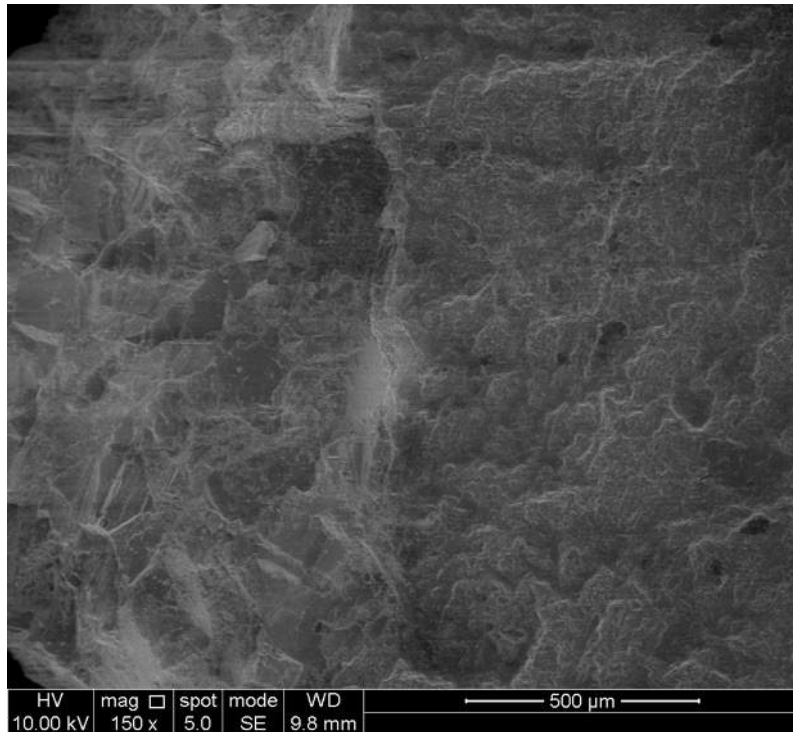


Figure 27: SEM micrograph of sample PW8. Magnification: 150X. Showing the interface between part of the stone without any film (left) and an area covered with the yellow surface film (right).

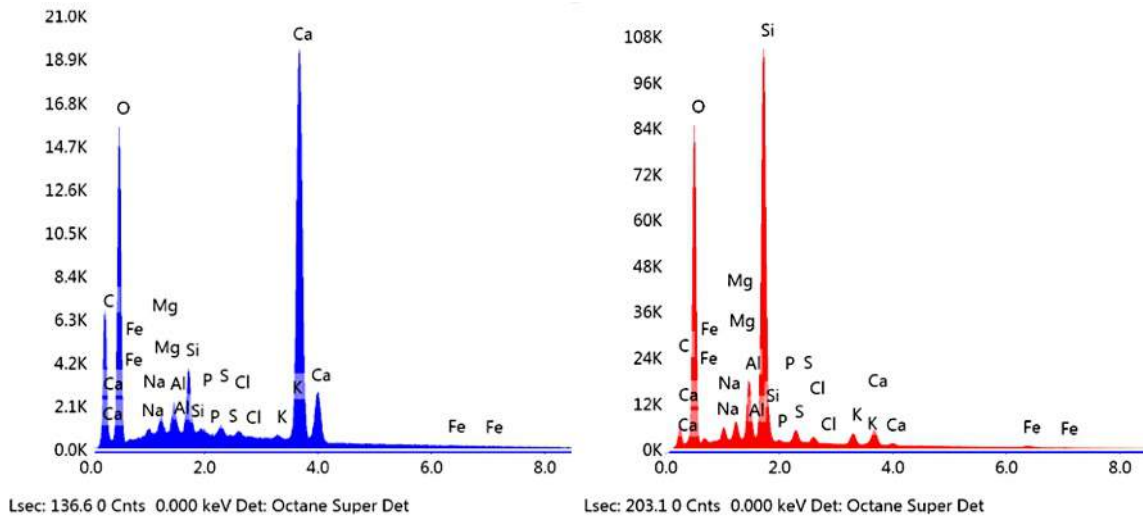


Figure 28: EDS chart of sample PW8. Revealing the predominant Si composition of the yellow surface film (right) in relation to the stone (left).

The spectra above on the left shows the marble surface without the film. It exhibits a high calcite (Ca) peak which is the dominant mineral of Makrana marble, with minimal readings



of silicon (Si), sulphur (S), and iron (Fe). Whereas the spectra on the right, taken from the film area, shows a substantially high silicon level with a significant increase in sulphur and the iron peaks as well [Fig. 29]. Therefore, the presence of a thin veil of gypsum, iron and predominantly silica particulates can be attributed to pollution related soiling. However, in order to reach a more conclusive understanding of the film's composition, x-ray diffraction analysis is recommended.

#### *Mechanical Staining*

In certain areas around the pavilion, especially marble slabs that employ ferrous pinning, evidence of slight orange-brown staining was found. This localized change of the stone color due to mechanical staining results from the oxidation of iron cramps used to anchor the marble slabs. It was mostly observed close to joints on internal stone surfaces, only discernable due to spalling. This condition was recorded primarily on the western façade and on top of the eaves that receive direct rain which in turn causes corrosion.

#### *Graffiti*

Graffiti involves the engraving, scratching or using of ink on stone surfaces as an act of vandalism. Unfortunately, many of the monuments within the Fort complex have been victims of visitor indiscretion. Although it does not harm the structure of the building or of the stone, it does however, compromise its aesthetic appeal. This condition was primarily recorded inside the pavilion, and in areas easily accessible to the visitors.

### ***5.3 Displacement and Cracking***

Thin-veneer marble is significantly more vulnerable to environmental conditions related to temperature and moisture than bulky stone monuments. Although all stone facades face surficial weathering and thermal expansion, undersized marble panels and *jalis* such as those

used in Naulakha, are especially prone to severe stress and destructive weathering due to thermal-hysteresis.

Hysteresis refers to the permanent deformation of marble when exposed to several thermal cycles in the presence of moisture.<sup>39</sup> This occurs when marble panels attached to a building face differential thermal expansion as their external face is heated and cooled at a significantly different rate than the internal face. Often times the displaced (calcite) grains become interlocked, deterring the panel from contracting back into its original shape and therefore cause deformation. This phenomenon is a direct consequence of the anisotropic behavior of calcite minerals that tend to expand along two crystallographic directions while contract along the third as the temperature changes.<sup>40</sup> In addition, this cyclical process of expansion and contraction leads to considerable displacement which in turn causes an increase in porosity of the stone. Although the samples tested show little-to-no porosity, under such circumstances the presence of moisture can enhance the expansion of the stone, causing irreversible deformation and cracking.<sup>41</sup> Such thermo-hydric fluxes initiate other deterioration mechanisms such as freeze-thaw cycles, salt crystallization, and granular disintegration creating a reinforcing loop that distresses the internal structure of the marble, causing its failure through the loss of its flexural strength.<sup>42</sup> In-situ conditions found to be

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<sup>39</sup> Victoria Shushakova, et al., “Marble Decay Induced by Thermal Strains: Simulations and Experiments,” *Environmental Earth Sciences* 69 (2013), 1281–97.

<sup>40</sup> Siegfried Siegesmund, et al., “Physical Weathering of Marbles Caused by Anisotropic Thermal Expansion,” *International Journal of Earth Sciences* 89 (2000), 170–82.

<sup>41</sup> Siegfried Siegesmund, et al., “The Combined Effect of Moisture and Temperature on the Anomalous Expansion Behaviour of Marble,” *Environmental Geology* 46 (2004).

<sup>42</sup> Reinforcing loop refers to a series of processes that correspond to an action producing a result which influences more of the same action thus resulting in gradual (growth or) decay. It is one of the two fundamental structures of systems thinking introduced by Donella Meadows, *Thinking in Systems* (Hartford: Chelsea Green Publishing, 2008).



affecting the structural integrity of the Makrana marble include, cracking; spalling; deformation; displacement; sugaring; macroflora; and dimensional loss.

### *Cracking*

Cracking in buildings can occur for various reasons that consequently lead to spalling, displacement, and dimensional loss. For load-bearing components, cracking often results from mechanical damage, caused by tensile, compression or shear forces, whereas, smaller intricate architectural elements develop microcracks through traffic, construction vibrations, and thermal expansion. In both cases, once the forces exceed the cohesive grain-to-grain strength of the marble, and the internal stresses are released during phases such as, the quarrying, preparation and placement, and thermo-hydric fluctuation of the stone, cracks of varied nature start to develop at the grain boundaries.<sup>43</sup>

As the marble samples display a polycrystalline structure with a random grain orientation, this allows the thermal expansion anisotropy of calcite minerals to produce stochastic strains which consequently cause internal stress. Previous studies on marble show that when the threshold for cohesion between the grains is exceeded, large internal stresses develop primarily at triple junctions and along the grain boundaries. These stresses, independently, or in combination with other moisture-assisted factors, then lead to microcracking and disintegration.<sup>44</sup> A similar behavior was observed during the petrographic analysis of Makrana marble, that showed calcite grains with microcracking and polysynthetic twin deformation under stress, often around grain boundaries [Fig. 30].

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<sup>43</sup> Alison Henry, *Stone Conservation: Principles and Practice* (Florence: Taylor and Francis, 2015), 222.

<sup>44</sup> Victoria Shushakova, et al., "Microcracking in Calcite and Dolomite Marble: Microstructural Influences and Effects on Properties," *Environmental Earth Sciences* 69, no. 4 (2013), 1263–79.



*Figure 29: Thin section micrograph under polarized light microscope for sample PW8 with grains under stress. Magnification: 50X. Displaying the polysynthetic twin deformation and microcracking of calcite minerals around grain boundaries.*

It is however, important to point out that the inequigranular grain size distribution, sutured boundaries, and the presence of mica should be able to counteract at least some amount of thermally induced stress. Therefore, in order to quantify the precise level of deterioration of the stone based on its grain texture, distribution, and inter-grain relationship, further analysis of its microscopic deformation patterns should be studied.

During the conditions survey, fissures of varying length, depth, and orientation were recorded and grouped accordingly. These include, fractures ranging 3.2 mm or greater in width; moderate cracks that are 1.6 to 3.2 mm wide; and finer cracks such as hairline and star

cracks less than 0.1 mm wide. In addition to these, areas with networks of fine intersecting cracks occurring on the surface of the stone were also recorded. While a considerable amount of microcracking from deformation due to marble hysteresis exists on the intricate *jali* work, fractures were mostly found occurring in longer panels and vertical frameworks that are splitting largely due to their corroded pinning system [Fig. 31].



*Figure 30: The varied forms of cracking within the marble elements. Showcasing a fractured part of the jali in relation to the surrounding microcracking.*

Numerous cement and mortar composite fills along with other incompatible materials used for repairs and replacement too have led to additional cracking in the pavilion. A more detailed discussion on the causes of failure of incompatible repairs is presented in the next section. Additionally, an extensive amount of cracking is concentrated on the load-bearing central cusped arch *jali* and the stepped platform underneath. It is likely that the compression forces from the added load of the corroding iron beam repair are a major cause of deformation and cracking of the central archway. In-situ investigation and condition mapping confirmed that several of the fractures in the upper stone border of the archway and the supporting vertical panels, are splitting the stone all the way through, and can be observed from the interior of the pavilion. This renders the central *jali* highly susceptible to collapse, therefore requires immediate attention.

While the central archway necessitates immediate consideration, non-structural cracks too bring with them the assertion of systems failure. As new cracks develop while already existing ones expand, this increases porosity which in turn provides moisture and salt entry into the stone causing greater damage. Water that is currently being absorbed by the marble panels has led to the corrosion of the ferrous pinning system, whereas moisture retained by the stone is possibly being subjected to freeze-thaw cycles, although this requires free-thaw testing for verification.

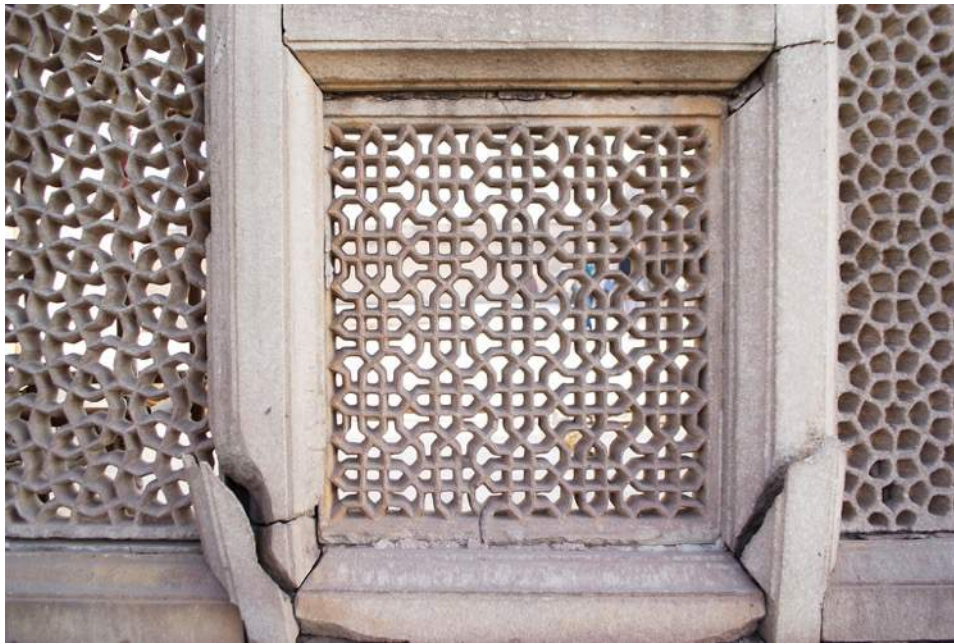
### *Spalling*

The current spalling of marble occurring on site is due to pressure being exerted on the stone from the corroded pinning system, freeze-thaw cycles and presumably salts in the presence of moisture trapped under the surface of the stone. The continuous internal stresses produced through this process result in localized loss that is typically preceded by



star-shaped cracking. Spalling can also result from the lack of or inadequate provision for expansion joints and poor anchorage that do not permit movement between panels. Additionally, improper laying of marble slabs, and repointing techniques that utilize incompatible materials that do not account for expansion and contraction of the stone can also contribute to this condition.<sup>45</sup>

This localized loss in stone can be seen primarily on panels that are spalling as a direct response to their corresponding corroded ferrous pins. It is a relatively constant condition scattered around the pavilion especially in areas employing iron cramps for pinning of the marble panels. This is predominantly occurring in pairs, wherever two elements of stone are pinned together, most common in marble frameworks that are holding the *jalis* in place [Fig. 32].



*Figure 31: Spalling of the marble frameworks as a response to their corroded pinning system.*

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<sup>45</sup> *A Glossary of Historic Masonry Deterioration Problems and Preservation Treatments* (Washington DC: Department of the Interior National Park Service Preservation Assistance Division, 1984), 20.

### *Deformation*

Deformation refers to the change in shape of marble slabs largely due to thermal hysteresis that leads to their bending and warping. This condition is most apparent, but not limited to, the central cusped arch *jali* which appears to have exceeded its elastic limit, and therefore, is bowing outwards to the western fortification wall.<sup>46</sup> The primary reason for this condition is the build-up of internal stresses brought on the *jali* by thermo-hydric fluctuations, as discussed in detail previously, in combination with the additional load of the structure sitting atop the archway. Though most of the weight of the pavilion lies on the brick walls, its design however, does not adequately take into consideration the central *jali* that has no back support of a masonry wall like the rest of the veneer panels [Fig. 33].



*Figure 32: Convex deformation of the central cusped arch jali.*

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<sup>46</sup> Urban J. Akesson, et al., "Relationship between Microstructure and Bowing Properties of Calcite Marble Claddings," *Bull Eng. Geology Environment*, 65 (2006), 73–79.



Additionally, the iron beams that were added during the British repair campaign to redistribute the deadload, have significantly increased the load on the *jali*. Since thin marble slabs are not structurally capable to be load-bearing and are extremely vulnerable to thermal flexing, this has led to the irreversible plastic deformation of the central archway. Moreover, other individual *jalis* too display warping in conjunction with granular disintegration [Fig 36].

### *Displacement*

Displacement of the marble panels occurs as a result of an already existing condition, and sometimes as a confluence of several overlapping deterioration mechanisms that can be linked back to hysteresis.<sup>47</sup> Current conditions present on site such as open joints, cracking, and deformation are all facilitating the movement in the stone that in turn has resulted in a shift in surface of several panels more than half an inch out of plane. There are two predominant types of displacement of panels that were recorded during the conditions survey. These include tilting of the marble panels and *jalis* to varying degrees, across as well as along the western facade of the pavilion [Fig. 34].

The displacement of individual *jalis* that can be attributed to their thermal flexing, conforms to the same movement, i.e. tilting along the façade, restricted within the grooves of their frameworks. Some of these *jalis* were recorded to be as much as two inches out of plane. On the other hand, most of the marble frameworks with open joints and fractures tend to be tilting outwards, across the façade [Fig. 35]. Additionally, while some panels respond to the internal stresses by tilting across the facade, the two pietra dura panels flanking the central cusped arch *jali* show displacement in correspondence to the bowing

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<sup>47</sup> Victoria Shushakova, et al., “Marble Decay Induced by Thermal Strains: Simulations and Experiments,” *Environmental Earth Sciences* 69 (2013), 1281–97.

movement of the *jali* itself. As the archway bows outwards, the panels to its south tilt along the facade, panning leftwards, while the panels on its north pan rightwards. Together with the central *jali*, these elements create a synchronized convex displacement.



*Figure 33: Displacement of the marble jali as it tilts along the façade due to thermal movement.*



Figure 34: Displacement of the parchin kari (pietra dura) panel as it tilts across the façade.

### *Sugaring*

The extensive granular disintegration of carbonate stones that creates a sugar-like texture of isolated calcite grains is referred to as sugaring. Several deterioration mechanisms such as thermally induced microcracking, salt crystallization, and acid dissolution have been commonly associated with the disintegration of marble.<sup>48</sup> Indicative of gradual loss of material, sugaring enables H<sup>+</sup> -ion to react with carbonate minerals causing their dissolution and formation of magnesium and calcium salts. The major source of acidity triggering the

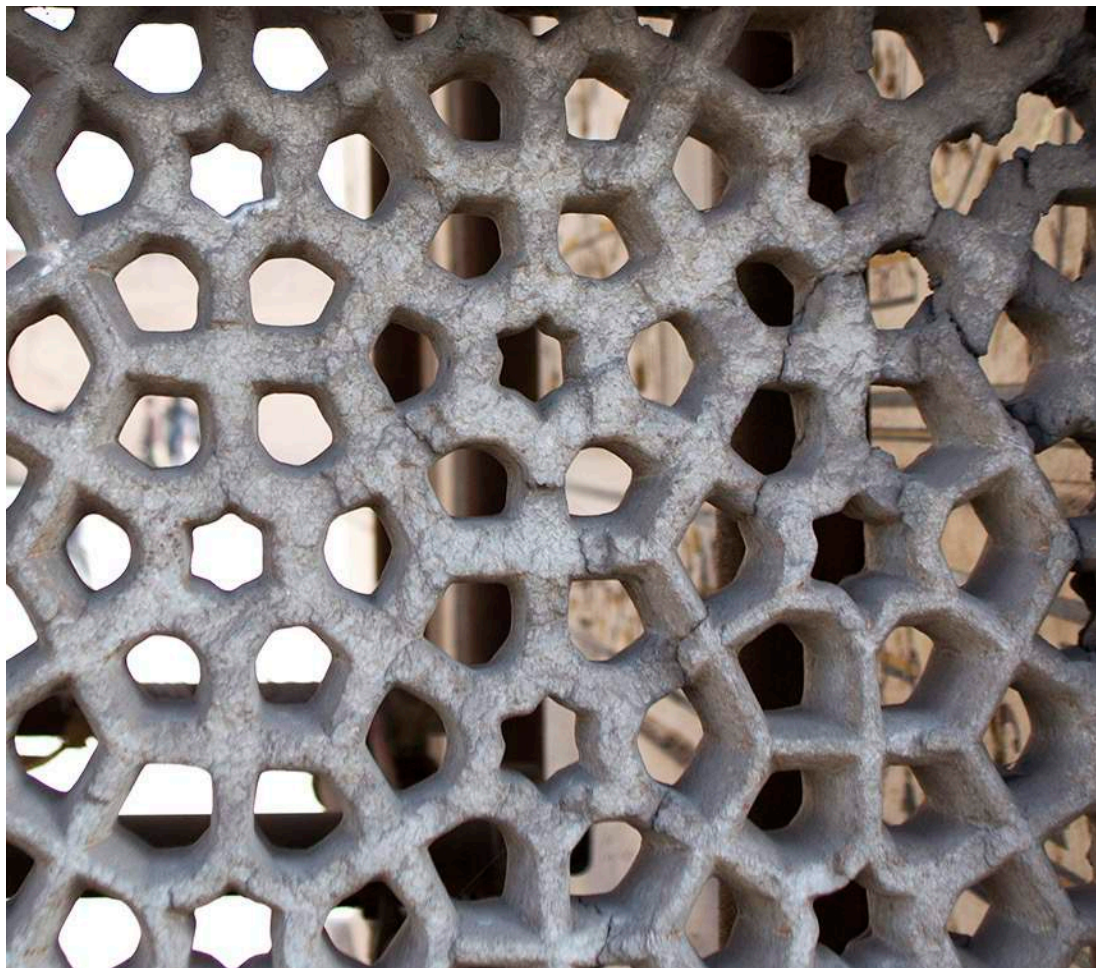
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<sup>48</sup> Enrico Sassoni and Elisa Franzoni, “Sugaring Marble in the Monumental Cemetery in Bologna (Italy): Characterization of Naturally and Artificially Weathered Samples and First Results of Consolidation by Hydroxyapatite,” *Applied Physics A* 117, no. 4 (2014), 1893–1906.



dissolution in this case, is coming through rainwater. Since calcite minerals exhibit a high solubility in water, when exposed to acidic rain, they can dissolve rather drastically.<sup>49</sup>

Although some amount of sugaring can be seen throughout the pavilion, exposed areas, particularly the *jalis* and some pietra dura panels on the west façade show moderate to high disaggregation that in some cases has also led to warping and dimensional loss [Fig. 36].



*Figure 35: High disintegration of the marble jali resulting in softening of its fretwork detail and warping.*

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<sup>49</sup> Siegfried Siegesmund and Rolf Snethlage, *Stone in Architecture: Properties, Durability* (New York: Springer, 2014), 255–260.

The extent of this condition is considerably different around the rest of the pavilion, that is sheltered by the eaves, relative to the western façade that faces direct exposure to rain. Moreover, the intricate marble *jalis* and their *kanguras* that are exposed to rainwater from all directions, have significantly suffered from dissolution that has led to the softening of their sharp edges and fretwork details. The severity of disaggregation however, differs between individual *jalis* and panels. Although all of the original stone was quarried from the same area, polarized light microscopy showed important nuances in the petrography of the five samples. Therefore, one hypothesis for the disparity in the extent of decay between similar components is the subtle differences in the stone's microstructure, level of metamorphism, and mineral inclusions which have likely resulted in varied levels of susceptibility and resistance to weathering within the quarried stone blocks.

Some other parts of the pavilion that show a moderate concentration of sugaring are areas bounded with grooves and/or are inset areas that allow a longer contact time with water. Moreover, this condition was also observed in spalled areas which provide exposure to newer, more vulnerable surfaces of the stone. In several of these spalled areas, their sugaring through direct contact with acidic rain has caused further dimensional loss.

#### *Macroflora*

The direct vegetal growth of high grade plants in stone work is known as macroflora. It is indicative of trapped moisture and is frequently linked with open joints and other areas boasting a sustainable environment for plant life.<sup>50</sup> While plant growth is commonly known to compromise the aesthetics of the monument, thus making it look unkept, it also brings

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<sup>50</sup> John Ashurst and Nicola Ashurst, *Practical Building Conservation English Heritage Technical Handbook: Stone Masonry* (London: Gower Technical Press, 1988).

with its connotations of chemical and mechanical damage to the building. Since most plants produce acids, these can result in the dissolution of carbonate minerals causing disaggregation of the stone's surface. Oftentimes, this chemical reaction softens the underlying stone and allows roots to establish into the structure of the building. As the plant grows, its roots become larger, widening gaps between adjoining marble slabs, expanding already existing cracks in the surface, as well as potentially causing new cracks within the structure.<sup>51</sup> Currently this condition is limited to the far north corner of the pavilion, impacting one of the pietra dura panels. The plant appears to be vigorous, showing tough basal growth capable of causing spalling and displacement of the adjacent panels [Fig. 37]. This type of mechanical damage when allowed to advance unmonitored not only affects the stone in direct contact with the growth but also threatens the stability of the entire structure.



Figure 36: The growth of macroflora around the parchin kari (pietra dura) panel. Displaying resultant fracturing of the stone.

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<sup>51</sup> A.K. Mishra, et al., "Role of Higher Plants in the Deterioration of Historic Buildings," *Science of The Total Environment* 167, no. 1-3 (1995), 375-92.



### *Dimensional Loss*

For this study dimensional loss has been characterized as the localized loss in stone greater than two square inches in area. While most of the aforementioned conditions contribute to dimensional loss, major conditions found to be directly causing loss on site include cracking, spalling, and high disaggregation. Other causes pertain to the overtime theft as well as removal of marble and semi-precious pietra dura stones, in later periods for use in other monuments.<sup>52</sup> The recorded dimensional loss of the Naulakha Pavilion varies drastically in scale. It comprises loss as small as individual fretwork detail in the *jalis* to much more large-scale losses such as the entire missing western *chajja*, measuring approximately 150 feet of surface area lost in damage. Additionally, marble veneer panels for the upper half of the western façade can also be accounted as dimensional loss, that has exposed the underneath brick masonry structure of the pavilion.

### **5.4 Repairs and Replacements**

Inappropriate repairs and replacements in buildings, whether structural or superficial often contribute to their ongoing deterioration. Such work not only impairs the aesthetic harmony of the monument but can potentially be structurally damaging as well. Repointing and composite repairs carried out with hard impervious materials (typically cementitious in nature) along with incompatible replacements that are denser than the original stone lead to preferential deterioration of the weaker material which is oftentimes the host stone undergoing continuous weathering.<sup>53</sup> The higher density and lower permeability of such

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<sup>52</sup> Muhammad I. Khan, *Master Plan Lahore Fort* (Lahore: Department of Archaeology, Ministry of Education and Provincial Coordination, Government of Pakistan, 1973), 22.

<sup>53</sup> David Odgers and Alison Henry, *Practical Building Conservation: Stone* (Burlington: Ashgate Publishing Company, 2012), 57–84.

repairs relative to the original material renders it susceptible to thermo-hydric fluxes resulting in salt crystallization, cracking, and granular disintegration on the surface of the original stone.

Current repairs of the pavilion were documented with the help of previous reports, historical images and in-situ investigation. These include, lime plaster on the exposed brick structure and the addition of iron beams, both under the 1907 British repair campaign; cementitious resetting mortar primarily used in the adjoining *jalis* corresponding to the disassembly and repair of the northern *jalis* in 2000; composite mortar and marble dust fills; and a recent resin-based surface treatment with Paraloid B-72 carried out by AKCS-P in 2017. Additionally, partial replacement of original stone work with Dutchman repairs and full unit replacements of unsalvageable stone with new marble pieces and in some instances other materials like terracotta were also recorded [Fig. 38].



Figure 37: Dutchman repair of the marble jali with terracotta.

The iron beams that were embedded into the masonry of the pavilion appear to be the most structurally damaging repair. Due to their corrosive environment, the ferrous beams are now failing which as a result is exacerbating the internal stresses of the structure, putting severe load onto the underneath cusped arch *jali*. In addition, during their installation, the central *jali* was taken out of its place using an impact tool that has left minute punctures (less than ½ inch in diameter) in the stone. This condition has been recorded as impact damage, though is currently not contributing to any further deterioration. Most of the cementitious repairs concentrate on the northern *jalis*, associated largely with a singular repair campaign. These have been crudely applied as resetting mortar between the *jalis* and frameworks, often carrying out of the joints and grooves onto the rest of the stone surface [Fig. 39].



Figure 38: Incompatible cementitious mortar used for resetting the *jalis* and their frameworks (2000).

On the other hand, some composite repairs such as the marble dust fills are almost indistinguishable, however what gives them away is the extensive network of fine cracks on their surface. These cracks are indicative of the inappropriate hardness of the repair materials as well as the on-going movement and displacement of the marble slabs [Fig. 40].

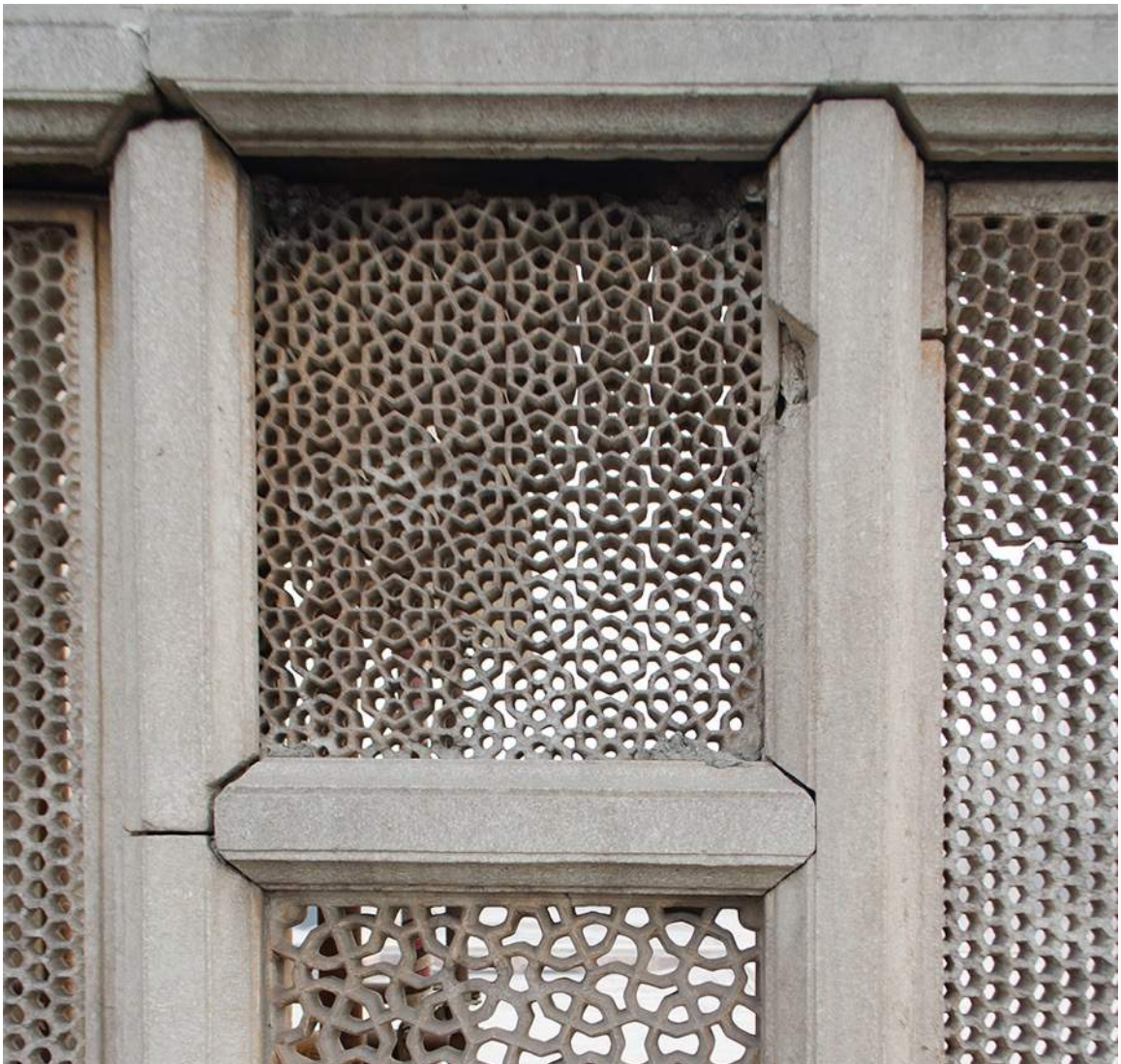


*Figure 39: Incompatible marble-dust fill repairs showing extensive network cracking.*

Although the repair work all around the pavilion does not match up to the original craftsmanship, there is however, a clear hierarchy in the quality of work found amongst the recent repairs. While the main entrance of the pavilion which is its eastern façade exhibits



more subtle repairs, the western façade on the contrary, boasts inconsiderate and sloppy repairs including inaccurate placement of marble elements during reassembly [Fig. 41]. This approach seems to be rooted in the idea that the western façade cannot be viewed from eye level which allows room for inconsistencies, however, fails to take into consideration what this means to the authenticity of the pavilion.



*Figure 40: Inaccurate placement of the marble elements during reassembly. The interlocking joint of the framework on the upper right side does not cohere with the rest of the elements, and therefore is seen without any counterpart which consequently skews the interpretation of the original design.*



## 5.5 *Structural Conditions*

The structural conditions of the pavilion essentially relate to the stability of the brick masonry substructure behind the marble veneer and the two sets of adjoining *jalis* that are self-supporting. The marble panels attached to the brick masonry do not contribute to the strength of the structure, therefore, their present disintegration and displacement does not directly impact the structural integrity of Naulakha. Currently, the pavilion shows a few structural cracks and an overall outwards tilt that is being monitored by AKCS-P.<sup>54</sup> Some of these cracks begin at ground level, ascending diagonally through the Picture Wall towards the pavilion in a discontinuous pattern [Fig. 42].



*Figure 41: Structural cracks beginning at ground level as seen on the Picture Wall.*

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<sup>54</sup> Werner Schmid, *Mission Report, Pakistan: The Picture Wall of the Lahore Fort* (Aga Khan Culture Service-Pakistan, 2017), 15–16.

While such structural damage can appear alarming, it is likely that the historic lime mortar used in the construction of the Picture Wall, has played a significant role in maintaining its stability, as lime-based mortars are known to carry a sufficient amount of elasticity that can adapt under extreme stresses.<sup>55</sup>

In 2016, AKCS-P conducted visual investigations and installed crack movement monitoring tools such as tell-tales and studs to analyze the behavior and severity of these cracks. Although the crack monitoring is an ongoing endeavor, the results so far show a static movement within the existing cracks, whereas a few of the deeper cracks demonstrate shrinkage.<sup>56</sup> Based on these preliminary investigations and historical documentation, the team determined the chief cause to be differential settlement of the foundations of the Picture Wall, that created uneven stresses, causing the structure to crack.<sup>57</sup> Though no direct reason behind the settlement has yet been verified, this research postulates its possible correlation with the 1905 earthquake in Lahore. The earthquake reportedly damaged many historic buildings around the city including Shish Mahal and *other delicate marble fabrics*.<sup>58</sup> Suffice to say the damage was significant enough to have been featured in news in England [Fig. 43] and later led to several British repair campaigns. One of these repairs was the 1907 structural stabilization of the Naulakha Pavilion with iron beams as its *foundations had* (previously) *subsided*.<sup>59</sup>

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<sup>55</sup> David Odgers and Alison Henry, *Practical Building Conservation: Stone* (Burlington: Ashgate Publishing Company, 2012), 57–128.

<sup>56</sup> Tanveer Johar (AKCS-P project engineer) in discussion with the author, December 2017.

<sup>57</sup> *Conservation of the Picture Wall, Lahore Fort: Preview of the Prototype Area, Western Facade* (Aga Khan Culture Service-Pakistan, 2017), 20.

<sup>58</sup> *Archaeological Survey of India: Annual Report 1906-7* (Calcutta: Superintendent Government Printing, 1909).

<sup>59</sup> *Archaeological Survey of India: Annual Report 1907-8* (Calcutta: Superintendent Government Printing, 1911), 5.



Figure 42: Illustrations of the Earthquake that hit Lahore in April 1905. Published in *The London News*, England.

While the structure of the pavilion may appear to be stable, the adjoining *jalis* on the contrary, show an alarmingly high structural decay and displacement. The various deterioration mechanisms discussed previously are collectively threatening the structural integrity of the *jalis* that could lead to potential collapse. Therefore, in order to plan for their preventative stabilization, a more conclusive understanding of the on-going movement within the pavilion and the *jalis* is required. For this reason, AKCS-P has hired ATAC Engineering Consultants, an engineering firm well-versed in historic buildings, that is currently performing the structural assessment of the entire Picture Wall and its associated monuments.

## 5.6 *Summary of Analysis*

Several of the conditions recorded revealed inherent compositional weaknesses within the stone, oversights in the original design and construction, the influence of weathering conditions in the surrounding environment (airborne pollutants, temperature, moisture), orientation of the façade, seismic events, and previous interventions. The local microclimate, specifically, wind-driven acid precipitation and prolonged exposure to direct sunlight (particularly due to the missing eave), has resulted in far worse conditions on the western façade than on the east, displaying varying degrees of soiling, cracking, displacement, disaggregation, and dimensional loss. While some of these conditions correlate to individual causes and locations within the pavilion, oftentimes dominant deterioration mechanisms have resulted in a chain reaction of events leading to several distinct yet overlapping conditions.

At the forefront of the identified deterioration patterns lies the impact of thermal hysteresis to the monument in the presence of moisture. Thermal cycling and its associated cracking along with acid precipitation have turned out to be particularly damaging to the undersized marble *jalis*. Since the pierced high surface area of these thin, low strength *jalis* provide greater exposure to weathering, this has led to their extreme disintegration and deformation, putting the structural integrity of the *jalis* at risk. Another condition that presents great risk is the corrosion of the ferrous anchoring system. Some 95%, if not all ferrous reinforcement in the pavilion and the frameworks of the adjoining *jalis*, is already extremely corroded due to consistent presence of moisture, and possible salts. These elements may still be corroding as their exposure to air increases, and as this happens, their volumetric expansion brings about additional stress and displacement within the pavilion.

Not all of these conditions, however, present serious threats to the longevity of the remaining structure. For instance, the biological activity appears to be limited to one location, and therefore does not likely pose significant future threat, if controlled timely. Based on the hierarchy of deterioration mechanisms affecting the monument, the following section will be addressing the present conditions with recommendations for further analysis and prioritized repairs.

## **6.0 Recommendations**

The information produced through this research serves as the first step towards formalizing and implementing a strategic and well-informed treatment and maintenance plan for the Naulakha Pavilion and its adjoining *jalis*. The key aspects of this report are the material analyses and conditions graphics that follow in Appendix C: Conditions Drawings. These drawings indicate the locations and extent of conditions and serve as the basis for future repair specifications. Based on the findings of this research and to fill in necessary gaps, this section puts forward suggestions for further scientific analysis; an outline for prioritized repairs; and future considerations for the development of a successful conservation plan for the pavilion.

### **6.1 *Further Scientific Analysis***

Having identified the conditions and their corresponding areas of damage, it then becomes crucial to develop a thorough understanding of each condition type before specific treatments can be prescribed to them. For instance, knowing the precise composition and morphology of the identified surface layers and understanding the physico-mechanical behavior of the marble in the presence of moisture and under stress are useful tools when



finalizing the priorities and their level of intervention in a project. In order to further develop the research carried out so far, it is recommended to conduct the following material analyses:

1. Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM/EDS) – *black crust*
2. X-ray Diffraction (XRD) – *yellow surface film*
3. Petrographic Analysis – *historic mortar*
4. Salt Analysis – *if salt presence is identified*
5. Water Absorption/Desorption – *marble*
6. Strength-Drilling Resistance – *marble*
7. Freeze-Thaw – *marble*

The scanning electron microscopy with energy dispersive x-ray spectroscopy (SEM/EDS) is a straightforward procedure, necessary to verify if the black crust is indeed atmospheric pollution related, gypsum encrustation. Thin section petrography of a representative sample can also be useful in determining the depth and morphology of the aforementioned alteration layer. In addition to the scientific analysis performed on the yellow surface film and to conclude its mineral composition, x-ray diffraction (XRD) analysis is required. While the historic mortar is believed to be lime-based, original mortar still needs to be identified and analyzed before new formulations for repair can be developed. Mortar analysis therefore, is a crucial tool in developing suitable mortar composition that addresses compatible performance and visual match to the cleaned historic mortar. Although no salt component was identified on the stone surface during the condition survey, a more thorough assessment is required to determine the presence of salts, if any at all. In case salts

are detected, a quantitative analysis of salt ions with XRD can be used to identify the salts and subsequently their source. This process will allow to recognize whether salts may be a risk to the stone or not and prepare for adequate treatments. Alongside these material analysis, it is imperative to conduct physical and mechanical testing on the marble substrate itself. These investigations include, Water Absorption/Desorption, Strength-Drilling Resistance, and Freeze-Thaw tests in order to better understand the resistance and behavior of the stone to deterioration mechanisms particularly related to moisture.

## **6.2 *Prioritized Repairs***

This section follows the ASTM standards for Repair and Restoration of Dimension Stone (C1722-11). The following recommendations are characterized under two phases of prioritized repairs based on the severity of deterioration and the level of threat to the monument.

### *Priority I*

Addressing more immediate conditions that put the monument's structural stability and integrity at risk along with testing experimental treatment methods for the next phase.

Recommended to be carried out within 1-2 years.

1. The need for structural repairs and emergency measures will be identified by ATAC Engineering Consultants. If an on-going tilt in the structure is detected, the monument will need to be secured in place.
2. Stabilization considerations for the central cusped arch *jali*.
3. Preventative interventions for the corroding ferrous anchorage system.
4. Injection grouting for moderate to large cracks and spall detachments.

5. Removal of deteriorating mortar, followed by repointing of all open mortar joints with a compatible lime-based mortar.
6. Pre-consolidation of severely deteriorated marble elements such as the *jalis*.
7. Experimentation of consolidation methods with nano-lime.
8. Test pinning, patching and grouting methods to stabilize areas of deteriorated stone, especially the *jalis*. Install a range of test panels to assess the performance of consolidants and mechanical repairs.
9. Temporary/ limited experimental Dutchman repairs to all spalls and areas of dimension loss greater than 3 inches in diameter or as required. Practice on mock ups before in-situ repair can take place.

*Priority II*

Focused on conditions that are not an immediate threat, however can exacerbate the deterioration occurring on the monument and its visual appearance. Additionally, this includes carrying out treatment methods that were previously finalized in Phase I.

Recommended to be addressed within 2-3 years, however methods focusing on the aesthetic appearance of the monument should ideally be carried out regularly as part of its maintenance plan.

1. Surface Cleaning:

Soiling	Nebulized low-pressure water misting
Pollutant Crusts	Nebulized low-pressure water misting
	Water and non-ionic detergent
	Alkaline cleaner ( <i>ammonia/potassium hydroxide</i> )

Metallic Stains	Poultice with ammonium citrate in water and glycerin/ammonium oxalate
Graffiti	Micro-abrasion

2. Removal of inadequate composite repairs and replacements.
3. Mechanical removal of macroflora.
4. Finalized consolidation and mechanical repair with inert reversible pinning systems.

### **6.3 Future Considerations**

The recommendations for prioritization and treatments presented through this research are essentially guidelines to explore and develop a more in-depth conservation plan and schedule for the pavilion. Before more aggressive remedial treatments can take place, it is imperative to stabilize the *jalis* as their disintegration and deformation is rapidly progressing.

Preventative measures can be tested with pre-consolidation, however, given the state of friability, the *jalis* may have to be disassembled and treated separately in a controlled environment. Repair by disassembly is not new to the Naulakha's conservation intervention history, especially in reference to the marble *jalis*, including the central cusped arch, and therefore, is foreseen as part of its future conservation as well. However, the lack of a strategic plan for dismantling and reassembly, as mentioned previously, allows room for inaccuracies. This has resulted in incorrect placement of certain marble frameworks and their corresponding *jalis* that not only affects the authenticity of the monument but also skews its future interpretation. It is therefore, crucial to develop a systematic protocol for the disassembly of the various elements of the pavilion before its in-situ implementation can begin. This includes numbering each component separately and preparing a digital catalogue

for individual elements and their associated fractured units. This program has already been initiated in this research through delineating each marble slab unit separately in the conditions drawings [Appendix C: Conditions Drawings]. What needs to follow is a numbering system that could be used for the entire pavilion throughout the project.

Since previous repairs and replacements play an integral role in the conditions assessment and diagnostics of a building, it is necessary that all future investigations and interventions are thoroughly recorded to avoid later misinterpretations. Experimental failures and hypotheses proved wrong are as important to the process and the future interpretation of the monument as the final deliberations. Therefore, beginning from the preliminary investigations to planning, until the final treatment implementation, every step should be recorded as part of the documentation process. There are already several missing gaps in the conservation history of the site, as not every repair campaign has been documented, which makes it ever more crucial today to ensure consistent documentation. Its purpose resides not only in increasing the ability to make good, evidence-based decisions about the future treatment or interpretation, but also to ensure that future generations are informed of the precise location and nature of previous interventions.<sup>60</sup> Furthermore, opportunities to improve survey methodology and the potential additional deterioration mapping for identifying precise patterns and rates with the analytical capabilities of Geographic Information System (GIS) software should also be explored.

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<sup>60</sup> Robin Letellier, *Recording, Documentation, and Information Management for the Conservation of Heritage Places: Guiding Principles* (Los Angeles: The Getty Conservation Institute, 2007), xiii.



## 7.0 Conclusion

The intrinsic characteristics of the Makrana marble in response to its exposure to the immediate environment of Lahore has resulted in the Naulakha Pavilion and its adjacent *jalis* in a considerably compromised state compared to its original appearance. While decay through temperature variation, monsoon rains, flooding, ground movement, and earthquakes have had a severe impact on the monument, several anthropogenic factors too have contributed to its ongoing deterioration. These include the demographic growth and the movement of population into Lahore, increasing dominance of motorized vehicular traffic, the failure of planners to control new development that is insensitive to the traditional urban fabric of the Walled City of Lahore, disregard for national policies for the protection and conservation of historic buildings, along with incompatible repair campaigns and a general lack of planned maintenance around the Fort.

For political and social reasons, both the national (Antiquities Act 1975) and state policies are inadequately applied when it comes to the preservation of the historic fabric of Lahore. The Metropolitan Corporation of Lahore (MCL), the Lahore Development Authority (LDA), and private individuals are not subject to a formal review for rehabilitation or even demolition of and around historic properties, which has resulted in the long-term displacement and loss of sites with cultural and historical significance. In addition, there is not a very strong presence of conservation authorities, partly due to the lack of funding and expertise needed to exercise the statutory requirements of control seen globally. This necessitates international organizations such as the Aga Khan Trust for Culture to bring the several stakeholders together into devising and successfully implementing a more coherent preservation approach for the historic built environment. So far, AKCS-P's efforts at the

Lahore Fort have focused on the preservation of the Picture Wall, however their long-term plan for the restoration of the larger Lahore Fort complex includes the Naulakha Pavilion. Their present proposal for the pavilion recommends restoration of its western façade which entails reconstruction of its missing *chajja* and veneer panels. Contrary to the approach for the Picture Wall, i.e., minimal intervention through conservation, reconstruction on the other hand, brings with it many ethical and practical implications that must be considered before any such decision is made. More importantly, international charters such as the International Charter for the Conservation and Restoration of Monuments and Sites (Venice Charter) of 1964, revised in 1978, and the Australia ICOMOS Charter for the Conservation of Places and Cultural Significance (Burra Charter) of 1981, revised in 2013, for the conservation of historic monuments and places of cultural significance should be consulted. Despite their differences, all these documents identify the conservation process as one focused on the respect for aesthetic, historic, and physical integrity of the monuments by a high sense of moral responsibility.<sup>61</sup>

Additionally, the pavilion is inadequately protected from threats and more importantly has not yet benefited from a formalized conservation plan that includes its interpretation and presentation to the public. In developing a conservation plan, factors such as the age and history of the pavilion, the material used, the nature of decay mechanisms present in-situ, and the rate of deterioration should be considered. Moreover, to retain the cultural significance of Naulakha, in-situ conservation must include provision for its security and maintenance for its future. What is needed is a cyclical maintenance schedule which is

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<sup>61</sup> Frank G. Matero, "The Conservation of Immovable Cultural Property: Ethical and Practical Dilemmas," *Journal of the American Institute for Conservation* 32 (1993). 15-21.

essentially a cost-effective form of preventative conservation, with reversible repairs to protect the integrity of the original fabric and ensure its longevity.

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## Appendix A: Historical Timeline

c. 11 <sup>th</sup> cent.	Laying of the initial foundations of a Hindu mud-brick fort that was later abandoned due to several successive invasions of Lahore. <sup>62</sup>
1241-1421	A long period of repeated destruction and reconstruction by foreign invaders until the fort was rebuilt under Mubarak Shah of Sayyid dynasty in 1421.
1585-1605	Construction of the existing Lahore Fort under Mughal Emperor, Akbar. He spent the last 12 years of his reign in Lahore; using remnants of the earlier mud-brick structure to extensively upgrade and expand the Fort into a fired brick masonry complex, enclosing the city within a red brick wall with 12 gates.
1605-1627	Mughal Emperor, Jahangir's additions to the Fort that include the Shah Burj, Jahangir Quadrangle, and the northern side of the Picture Wall built between 1624-25.
1628-1658	Expansion of the Fort complex under Mughal Emperor, Shah Jahan. Includes reconstruction of Shah Burj and construction of Kala Burj, Summer Palace, Shah Burj Quadrangle (comprising Shish Mahal and Naulakha Pavilion built between 1628-33), Dewan-e-Khas, Moti Masjid, and extension of the Picture Wall to the western side, completed in 1632.
1658-1797	Besides the construction of Alamgiri Gate and Badshahi Masjid under Mughal Emperor, Aurangzeb from 1671-73, the Fort remained largely

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<sup>62</sup> Syed M. Latif, *Lahore: Its History, Architectural Remains and Antiquities, with an account of its modern institutions, inhabitants, their trade, customs, &c.* (Lahore: New Imperial Press, 1892), 1–6.

unused, followed by a century of neglect after Aurangzeb's death in 1707.

- 1799-1839 Ranjit Singh, founder of the Sikh empire takes over Lahore using the Shish Mahal as his private quarters. He builds a double story structure on top of Shish Mahal, whilst adding another structure, Ath Dara to its back.<sup>63</sup> The openings of the two western *dalans* (loggias) in Shah Burj Quadrangle were enclosed with brick masonry and lime plaster. Additionally, other structures such as Sikh funerary monuments were added to the Fort, using marble and other semiprecious stones from the existing Mughal structures.
- 1841 Damage caused to the Picture Wall during Sikh accession wars through bullet holes.
- 1849 British annexation of Punjab resulting in the use of the Fort as a military compound. Many structures were altered, and some added including barracks built against the lowest story of the western facade of the Picture Wall.
- 1882 The Curators Report mentions the missing *pietra dura* work of Naulakha Pavilion on its southern facade, fracture in the stone lintel at its eastern entrance, and ceiling cracks. Naulakha's southern *chajja* (eave) and brackets, and part of the northwest corner *chajja* are documented to have been previously replaced with wood.<sup>64</sup>

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<sup>63</sup> The additional weight of these structures has potentially caused further damage to Shish Mahal and underneath structures such as the Picture Wall.

<sup>64</sup> Henry H. Cole, *Preservation of National Monuments: First Report of the Curator of Ancient Monuments in India for the year 1881-82* (Simla: Government Central Branch Press, 1882), clxxxix.

early

20<sup>th</sup> cent.

Extensive British period restoration: In 1905 an earthquake hit Punjab that severely damaged many Mughal monuments including Shish Mahal.<sup>65</sup> An emergency stabilization of its ceiling was carried out in 1906. Between 1907-8 iron rails were embedded into the upper structure of Naulakha that required the disassembly and resetting of the marble *jalis*. This included minor repairs such as filling cracks and repointing joints.<sup>66</sup> The barracks along the base of the Picture Wall's western facade are demolished and the damaged lower part of the wall is repaired with brownish *kankar* lime plaster. In 1911 the corroded iron rainwater spouts on the Picture Wall's western facade are replaced by red sandstone. Archival photographs document that some of the decorative surfaces of Shah Burj Gate and the Picture Wall were reconstructed while the western *chajja* of Naulakha is seen missing. In 1915 repair work on Shish Mahal and the *dalans* (loggias) along with the replacement of missing curved portion of Naulakha's parapet wall, and pietra dura work on its southern facade is carried out.<sup>67</sup>

1920

Dutch sanskritist and epigraphist Jean Philippe Vogel (Superintendent, Archaeological Survey of India) publishes a comprehensive research on the tile mosaics of the Picture Wall.

1927

The British military evacuates the Fort in 1924. Subsequently, the Department of Archaeology of British India assumes control in 1927. Most modern structures built by the British were dismantled in attempts to restore the Mughal period configuration of the Fort.

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<sup>65</sup> Due to its close proximity to Shish Mahal, it's likely that the earthquake also impacted Naulakha Pavilion which resulted in its 1907 repair campaign.

<sup>66</sup> *Archaeological Survey of India: Annual Report 1907-8* (Calcutta: Superintendent Government Printing, 1911), 5.

<sup>67</sup> *Annual Progress Report of the Superintendent, Muhammadan and British Monuments, Northern Circle, for the year ending 31<sup>st</sup> March 1915* (Allahabad: Government Press, 1916), 17.



1935-36	The southeast corner of Naulakha and some ceiling cracks are repaired. <sup>68</sup>
1947	End of British Raj: Founding of Pakistan.
1950	Program for repairs of Lahore Fort conceptualized in view of the visit of his Imperial Majesty Shahenshah of Iran.
1960s	Part of the Picture Wall's western facade affected by rising damp and efflorescence restored with dressed brick and <i>kankar</i> lime plaster.
1970s	Naulakha Pavilion is listed as a protected monument under the 1976 Antiquities Act by Pakistan's Department of Archaeology. Southwest corner of Naulakha's parapet is reconstructed, several other marble panels are replaced, and the top horizontal member of the freestanding marble <i>jalis</i> to the south of the pavilion are reconstructed. Additional works in Shah Burj Quadrangle include <i>kankar</i> lime plaster wash and replacement of sections of the eaves and one rainwater spout of the <i>dalans</i> with red sandstone.
1980s	Structures built on top of the Shish Mahal during the Sikh periods are demolished. The Lahore Fort Complex inscribed as a UNESCO world heritage site. In 1986 a scheme for repairs and restoration of Shah Burj Quadrangle is devised by the Department of Archaeology. Focus is set on restoring the original flooring, wooden ceiling and roofing of Naulakha. Additional restoration work to include the forecourt, <i>dalans</i> , and Ath Dara.

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<sup>68</sup> *Archaeological Survey of India: Annual Report 1935-36* (Calcutta: Superintendent Government Printing, 1938), 10.

- 1990s                      The masonry fill of the southern *dalan* is removed and a balustrade made of marble *jalis* is constructed in its place. The damaged floor of the forecourt and its water channels are dismantled, and the floor is re-laid with Sang-e-Badal, Sang-e-Abri, and other stones. Archival photographs document the restoration of Naulakha's floor with tessellated flooring in 1997.
- 2000-06                    The freestanding marble *jalis* to the north of Naulakha were leaning outwards. These were disassembled, repaired and reset in 2000.<sup>69</sup> Repairs for Shish Mahal in collaboration with the Norwegian Government and UNESCO were carried out between 2002-6. In 2005, the Lahore Fort Master Plan was created.
- 2013-14                    Restoration attempts of the Picture Wall's western facade were carried out by the Directorate General of Archaeology, Government of Punjab. In 2014, the managerial custodianship of the Fort was given to the Walled City Lahore Authority (WCLA).
- 2015-18                    Aga Khan Trust for Culture (AKTC) becomes involved in the documentation and conservation of several monuments within the Fort, including the Picture Wall. Documentation of Picture Wall is completed in 2017. Currently ongoing conservation work is being carried out on the western facade of the Picture Wall.

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<sup>69</sup> Talib Hussain, *History of Interventions on Prototype Area of Picture Wall, Lahore Fort* (Lahore: Aga Khan Culture Service-Pakistan, 2017), 10-11.



*Figure 43: The original configuration of the Fort built by Akbar the Great (r. 1556-1605).*



*Figure 44: Emperor Jahangir's additions to the Fort (r. 1605-1627). This includes structures such as the northern side of the Picture Wall and the Jahangir Quadrangle.*



*Figure 45: Emperor Shah Jahan's additions to the Fort. (r. 1628-1658). This includes the western side of the Picture Wall and Shah Burj Quadrangle that comprises the Naulakha Pavilion and Shish Mahal, among others.*



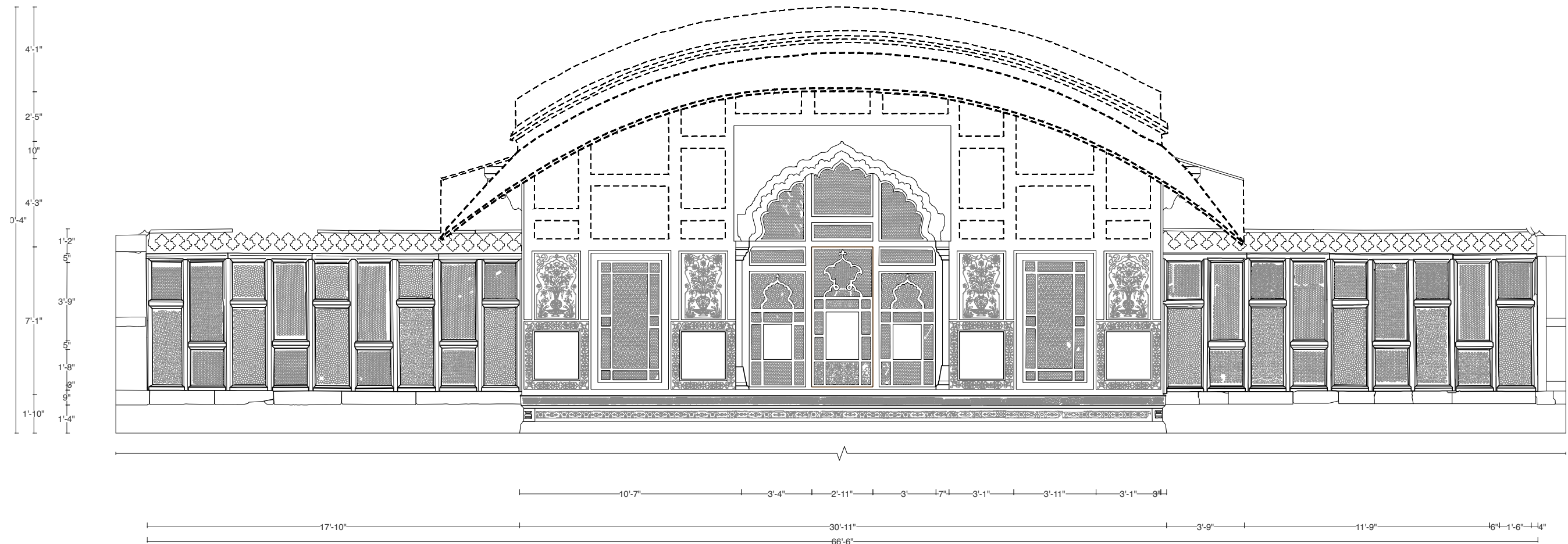
*Figure 46: The Fort at the end of the reign of Emperor Aurangzeb (r. 1658-1707). Among the additions, the most significant contribution is the Badshahi Masjid (mosque) and its adjacent gardens.*





*Figure 47: The Fort after the Sikh period (1789-1849). The additions include the Hazuri Bagh (garden), Ranjit Singh's Samadhi (tomb), and smaller structures such as the Athdara next to the Shish Mahal.*

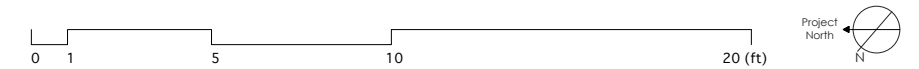
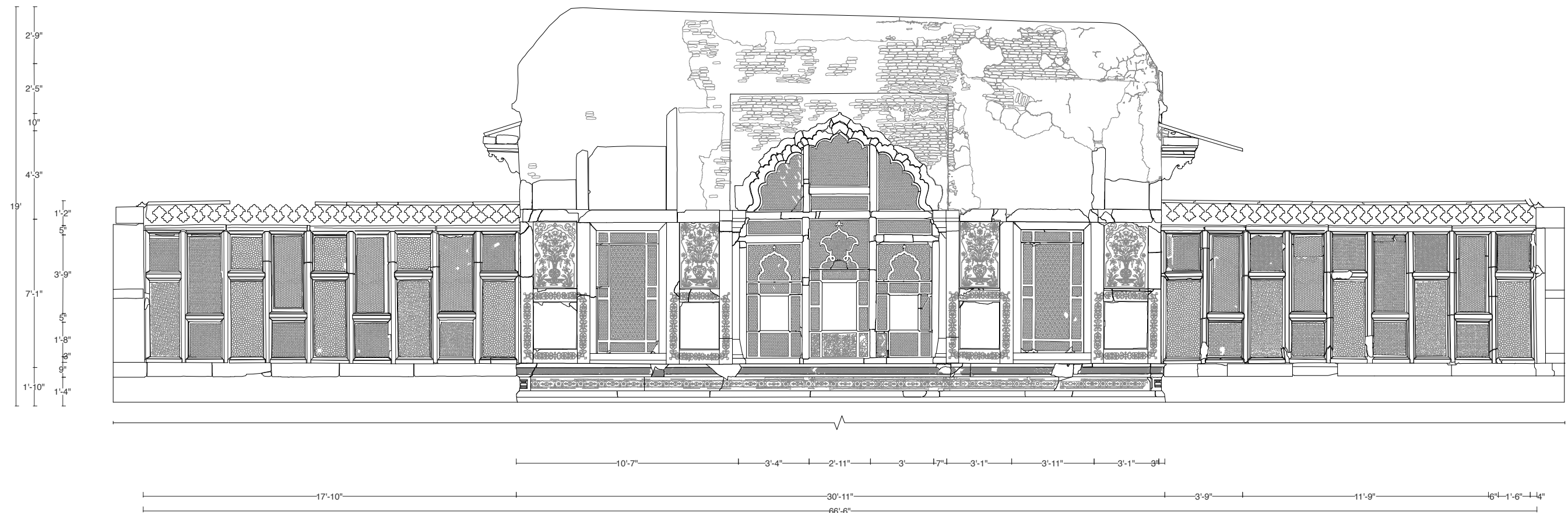
Appendix B: Architectural Drawings



UNIVERSITY OF PENNSYLVANIA School of Design	NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	ARCHITECTURAL DRAWING Western Elevation	DATA SOURCE: Aga Khan Trust for Culture	DRAWN BY: Noor J. Sadiq	SCALE: 3/32" = 1'-0"	SHEET NO: A1	DATE: May 3, 2018
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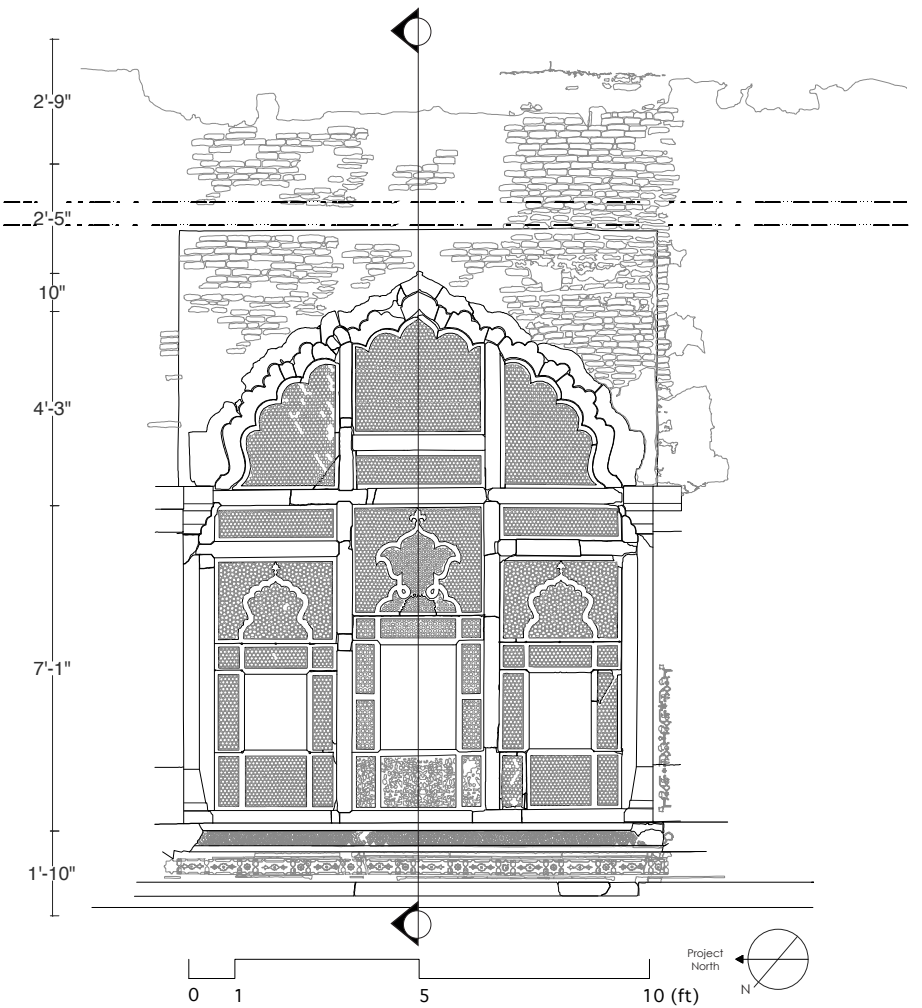
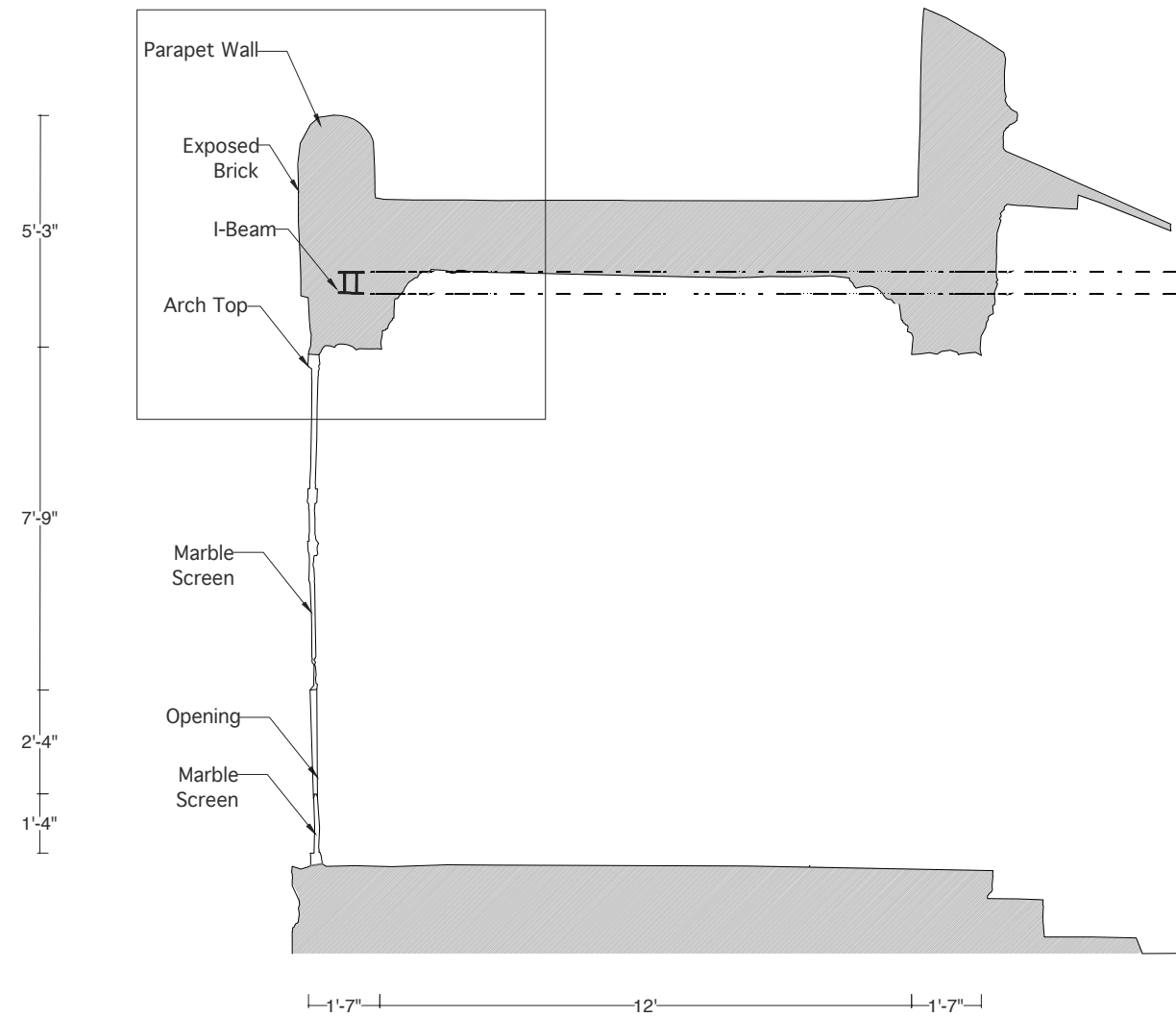
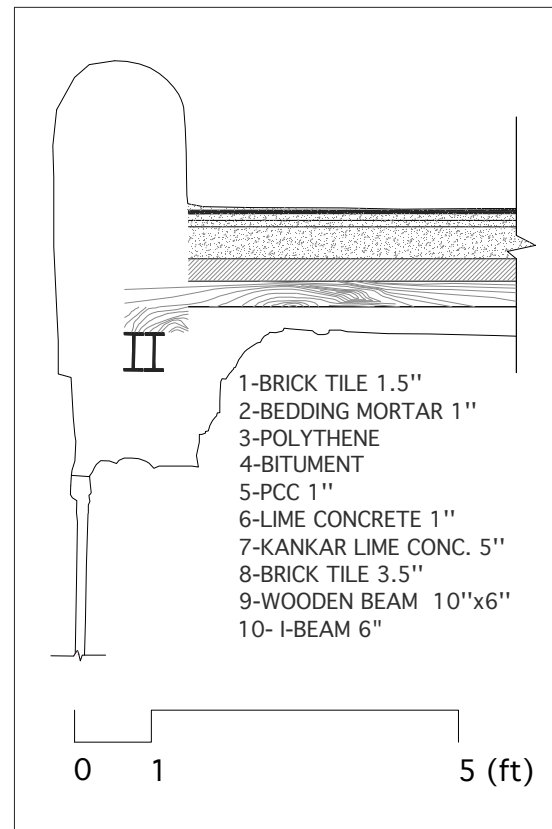


Appendix B: Architectural Drawings



UNIVERSITY OF PENNSYLVANIA School of Design	NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	ARCHITECTURAL DRAWING Western Elevation	DATA SOURCE: Aga Khan Trust for Culture	DRAWN BY: Noor J. Sadiq	SCALE: 3/32" = 1'-0"	SHEET NO: A2	DATE: May 3, 2018
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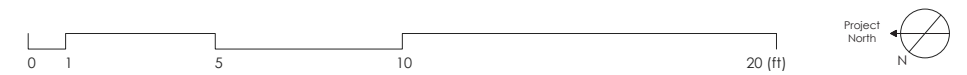
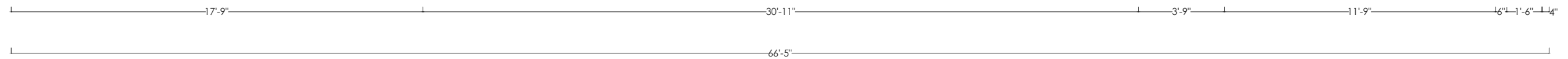
Appendix B: Architectural Drawings



UNIVERSITY OF PENNSYLVANIA School of Design	NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	ARCHITECTURAL DRAWING Section	DATA SOURCE: Aga Khan Trust for Culture	DRAWN BY: Noor J. Sadiq	SCALE: 1/4" = 1'-0"	SHEET NO: A3	DATE: May 3, 2018
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Appendix B: Architectural Drawings



UNIVERSITY OF PENNSYLVANIA School of Design	NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	BUILDING COMPONENTS Western Elevation	DATA SOURCE: Aga Khan Trust for Culture	DRAWN BY: Noor J. Sadiq	SCALE: 3/16" = 1'-0"	SHEET NO: A4	DATE: May 3, 2018
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Appendix B: Architectural Drawings



1. *Jali* (lattice screen)
2. *Jali*
3. *Jali*
4. Stepped platform with *parchin kari* (pietra dura)
5. Cusped arch jali
6. Panels with *parchin kari*
7. Frameworks
8. *Kanguras* (antefixes)

UNIVERSITY OF PENNSYLVANIA School of Design	NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	MARBLE ELEMENTS Partial Photo Elevation	DATA SOURCE: Aga Khan Trust for Culture	DRAWN BY: Noor J. Sadiq	SCALE: not to scale	SHEET NO: A5	DATE: May 3, 2018
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## Appendix C: Conditions Drawings

### SOILING

Darkening of the stone by a thin layer of atmospheric pollutants and/or particles transported by rain and runoff water. Found in areas that cannot be easily washed away by rain.



### BLACK CRUST

Encrustation of calcium sulphate (gypsum) as rainwater combines with atmospheric particulates such as carbon, giving the surface its black color. Usually adheres firmly to the substrate.



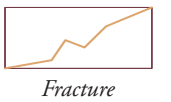
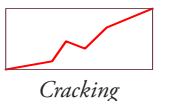
### GRAFFITI

Engraving, scratching or using ink on stone surfaces as an act of vandalism. Found mostly in more easily accessible interior spaces of the pavilion.



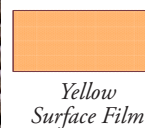
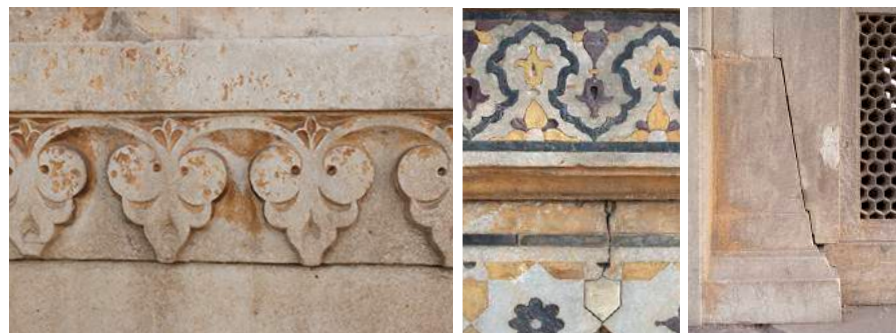
### CRACKING

Fissures of varying length, depth and orientation likely associated with displacement, spalling, and dimensional loss. Includes fractures (> 3.2 mm), moderate cracks (1.6 to 3.2 mm), hairline and star cracks (< 0.1 mm) caused by corroding iron.



### SURFACE FILM

Formation of a thin ochre-to-brown surface alteration layer enriched with silicates, gypsum, and other accessory minerals. Found in areas protected from rain water intrusion.



### SPALLING

Localized loss of marble due to internal pressure through volumetric expansion induced by the corrosion of the ferrous anchorage. Typically preceded by star-shaped fractures.



### STAINING

Localized change of the stone color due to metallic staining resulting from the oxidation of ferrous anchorage embedded in the marble slabs.



### DEFORMATION

Plastic deformation of marble *jalis* (screens) resulting in their convex/concave bowing out of plane, likely to be caused due to thermal stresses.

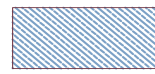
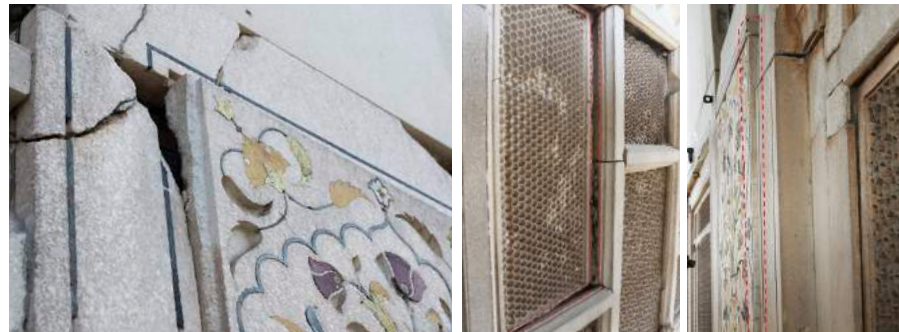




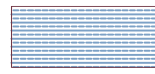
## Appendix C: Conditions Drawings

### DISPLACEMENT

Movement in the stone resulting in a shift in surface more than 1/2 inch out of plane. Includes primarily tilting of marble slabs across and along the western facade of the structure to varying degrees.



Tilt across the facade



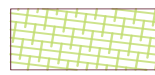
Tilt along the facade

### SUGARING

Sugaring is the dissolution of calcite crystals as they react with acidic rain. Extensive granular disintegration of *jalis* have resulted in areas with warping and dimensional loss.



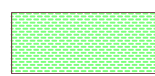
Sugaring (high)



Sugaring (moderate)

### MACROFLORA

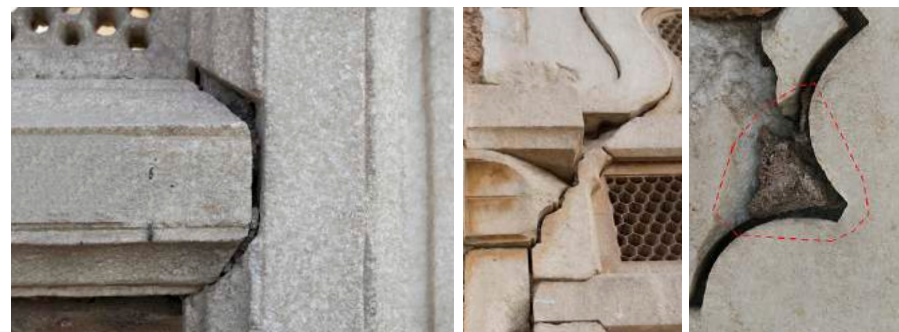
Direct vegetal growth on and in stone work, showing roots and leaves. Usually associated with open joints and areas containing sufficient moisture to sustain plant life.



Macroflora

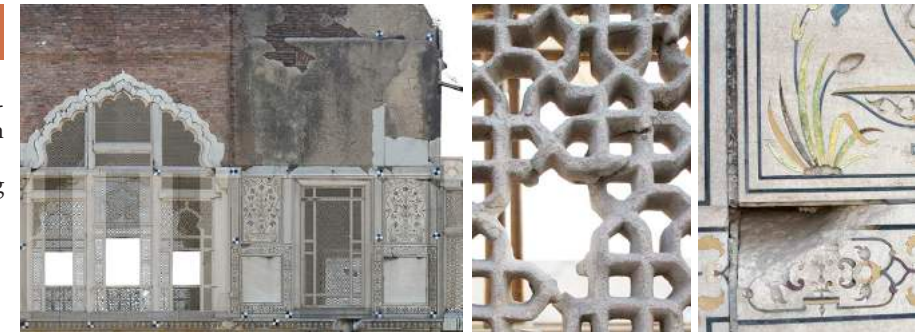
### OPEN JOINTS

Stone joints that show partial or complete loss of mortar, typically associated with erosion and moisture penetration inside and outside of the structure.



### LOSS

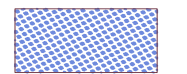
Localized loss in stone > 2 square inches in area. Typically caused in association with excessive disaggregation, spalling and cracking of stone.



Dimensional Loss

### REPAIRS

Repair work including composite repairs and cement fills primarily visible around the *jalis*. Along with recent resin based treatments (*Paraloid B-72*) used as a surface repair of cracks and losses.



Cement Fills



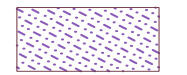
Composite Repair



Marble Dust



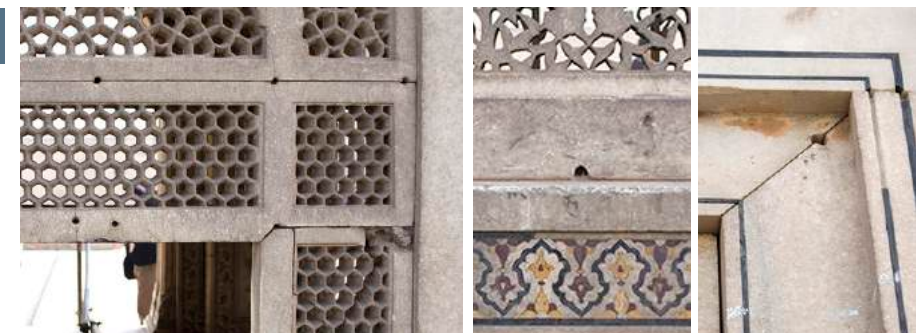
Plaster



Paraloid B-72

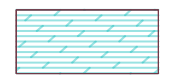
### IMPACT DAMAGE

Loss of stone material due to impact damage during disassembly of the structure for repair work. There are clear signs of an impact tool used to pull out the marble slabs.



### REPLACEMENTS

Previous repairs using an entirely new and different type of white marble and in some cases includes partial replacement of marble *jalis* with terra cotta.



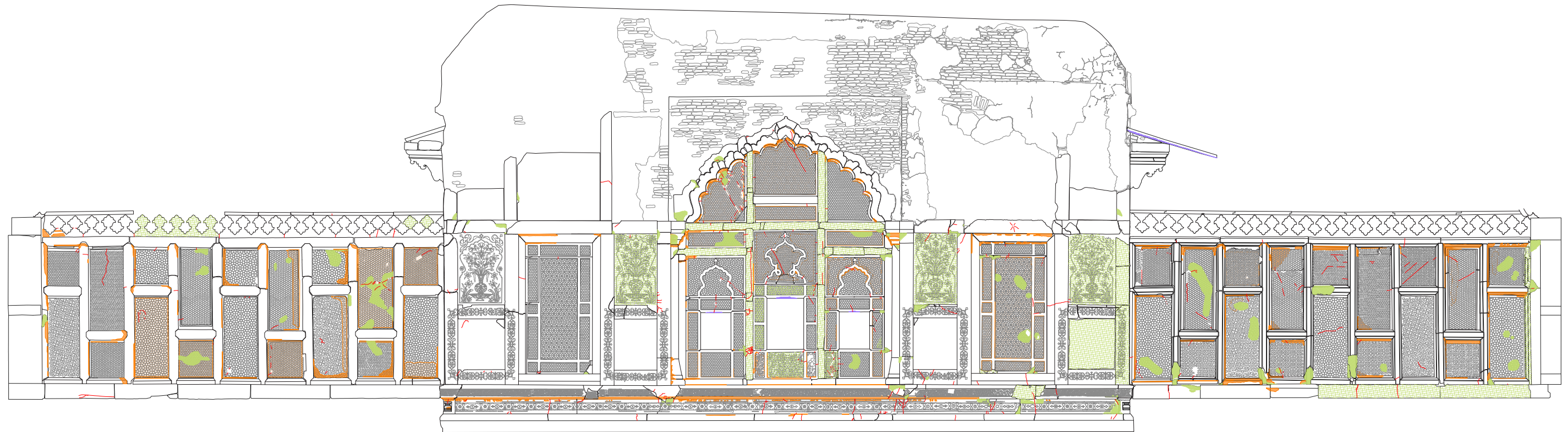
Replaced (marble)



Replaced (other)



Appendix C: Conditions Drawings



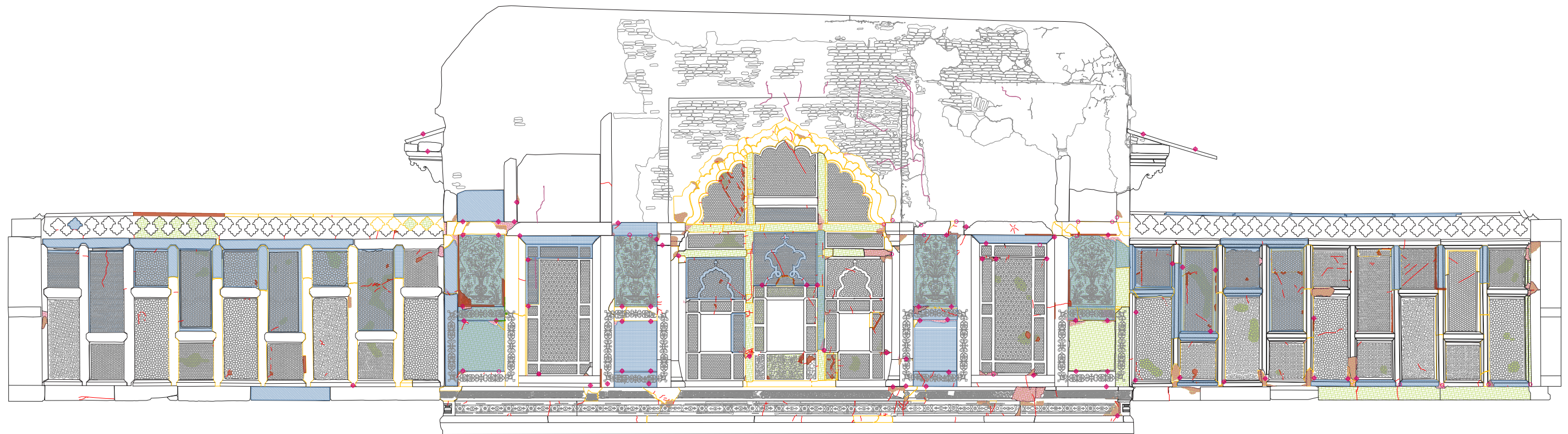
66'-5"

-   
Cracking
-   
Sugaring  
(high)
-   
Sugaring  
(moderate)
-   
Black  
Crust
-   
Yellow  
surface film



UNIVERSITY OF PENNSYLVANIA School of Design	NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SURFACE ALTERATIONS Western Elevation	DATA SOURCE: Aga Khan Trust for Culture	DRAWN BY: Noor J. Sadiq	SCALE: 3/16" = 1'-0"	SHEET NO: C1	DATE: May 3, 2018
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Appendix C: Conditions Drawings



66'-5"



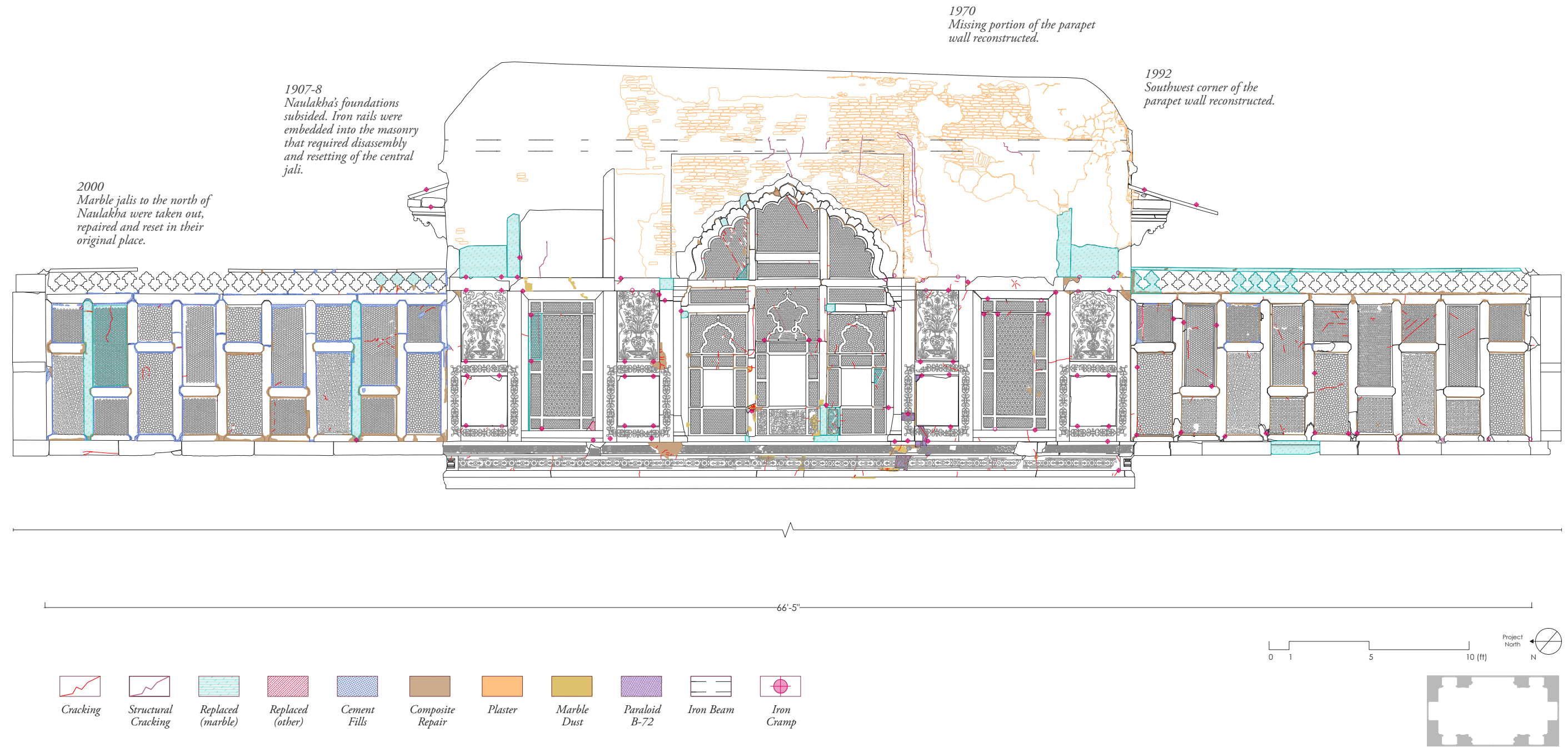
-  Cracking
-  Fracture
-  Structural Cracking
-  Spalling
-  Tilt across the facade
-  Tilt along the facade
-  Sugaring (high)
-  Sugaring (moderate)
-  Macroflora
-  Dimensional Loss
-  Iron Cramp



UNIVERSITY OF PENNSYLVANIA School of Design	NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	DISPLACEMENT & CRACKING Western Elevation	DATA SOURCE: Aga Khan Trust for Culture	DRAWN BY: Noor J. Sadiq	SCALE: 3/16" = 1'-0"	SHEET NO: C2	DATE: May 3, 2018
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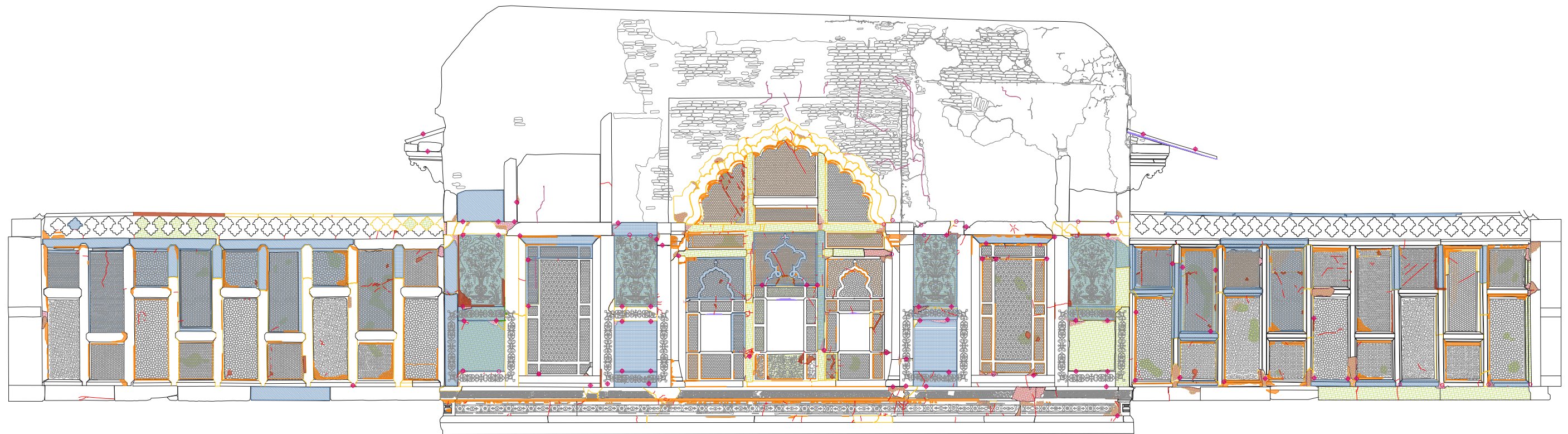


# Appendix C: Conditions Drawings
















UNIVERSITY OF PENNSYLVANIA School of Design	NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	REPAIRS & REPLACEMENTS Western Elevation	DATA SOURCE: Aga Khan Trust for Culture	DRAWN BY: Noor J. Sadiq	SCALE: 3/16" = 1'-0"	SHEET NO: C3	DATE: May 3, 2018
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Appendix C: Conditions Drawings



66'-5"



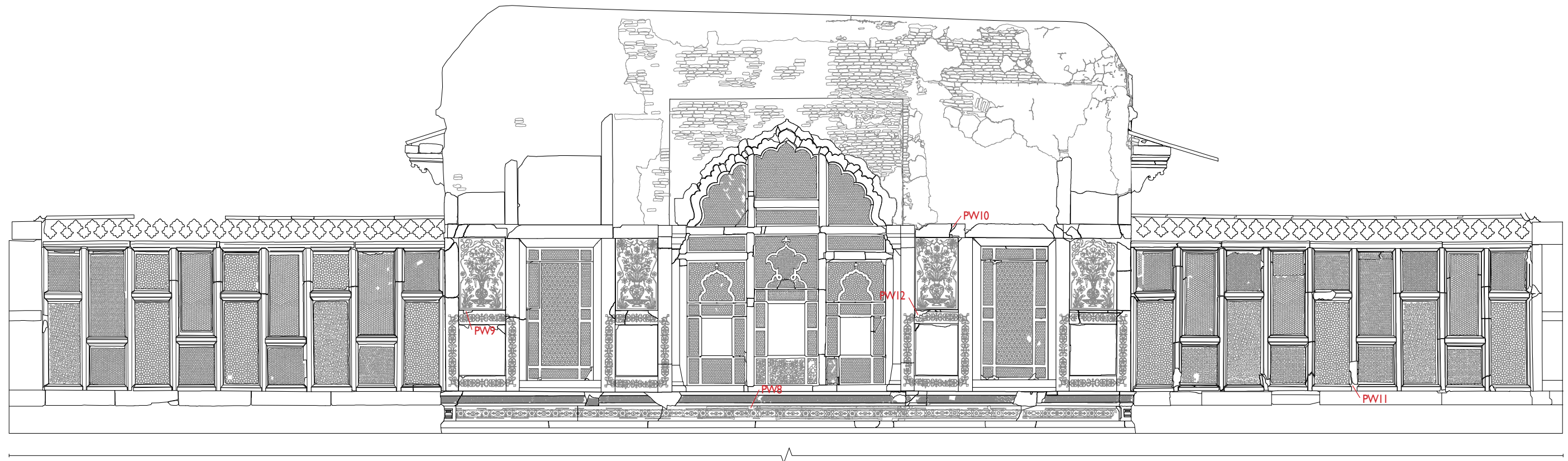
-  Cracking
-  Fracture
-  Structural Cracking
-  Spalling
-  Tilt across the facade
-  Tilt along the facade
-  Sugaring (high)
-  Sugaring (moderate)
-  Macroflora
-  Dimensional Loss
-  Black Crust
-  Yellow Surface Film
-  Iron Cramp



UNIVERSITY OF PENNSYLVANIA School of Design	NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	CONDITIONS OVELAY Western Elevation	DATA SOURCE: Aga Khan Trust for Culture	DRAWN BY: Noor J. Sadiq	SCALE: 3/16" = 1'-0"	SHEET NO: C4	DATE: May 3, 2018
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Appendix D: Material Analysis



*\*Locations and identification numbers of samples taken from the western facade in 2017.*



UNIVERSITY OF PENNSYLVANIA School of Design	NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SAMPLE LOCATION Western Elevation	DATA SOURCE: Aga Khan Trust for Culture	DRAWN BY: Noor J. Sadiq	SCALE: 3/16" = 1'-0"	SHEET NO: S1	DATE: May 3, 2018
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## Appendix D: Material Analysis

Sample no.: PW8

*Texture:* Heteroblastic texture with no preferred orientation of the minerals.

*Grain shape and inter-grain relationship:* Coarse grain structure with sub-rounded minerals. The grain size is averaged 1.5 mm and ranges closely between 0.08 mm to 3 mm with a closely packed inter-grain relationship and frequent triple junctions. Displays predominant sutured boundaries.

*Mineralogy:*

Predominant

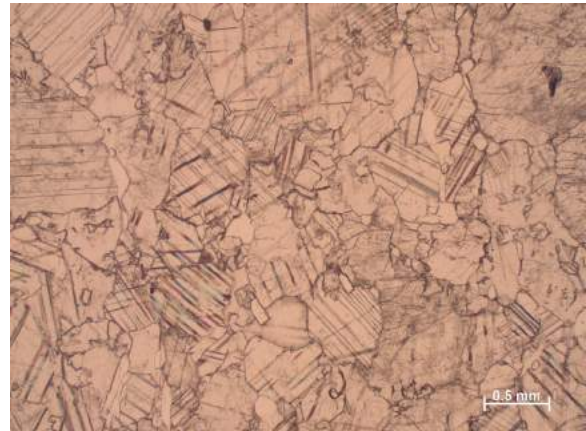
Calcite: sr, > 0.1 mm, mode 1.7 mm. Some grains have minor microcrystalline quartz inclusions.

Rare

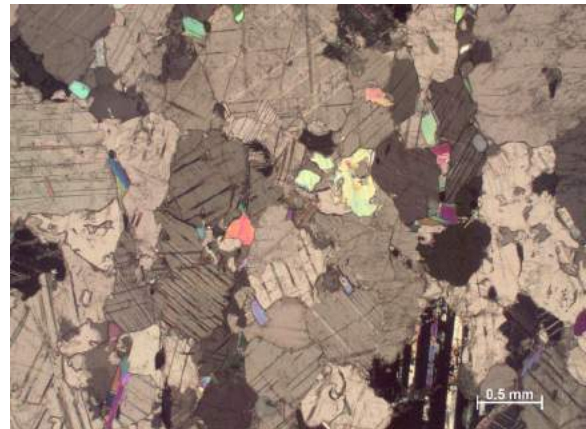
Microcrystalline Quartz: sr, < 0.2 mm, mode 0.12 mm.

Muscovite: a-sa, < 0.7 mm, mode 0.4 mm. Flake-like cluster inclusions within calcite crystals. *\*seen in a high frequency in relation to other samples*

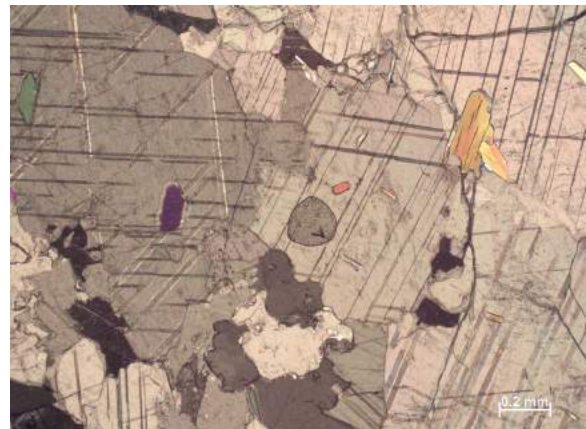
*Alteration:* Texture appears to be changing. Displays mineral intergrowth and polysynthetic twin deformation of calcite grains under stress.



Magnification: 25X | under plane polarized light (PPL)



Magnification: 25X | under cross polarized light (XPL)



Magnification: 50X | under cross polarized light (XPL)

NAULAKHA PAVILION  
& Adjacent Marble Screens

LAHORE FORT  
Lahore, Pakistan

PETROGRAPHIC ANALYSIS  
Makrana Marble

## Appendix D: Material Analysis

*Sample no.:* PW9

*Texture:* Heteroblastic texture with no preferred orientation of the minerals.

*Grain shape and inter-grain relationship:* Coarse grain structure with sub-rounded minerals. The grain size is averaged 2 mm and ranges closely between 0.1 mm to 3.6 mm with a closely packed inter-grain relationship and frequent triple junctions. Displays predominant sutured boundaries.

*Mineralogy:*

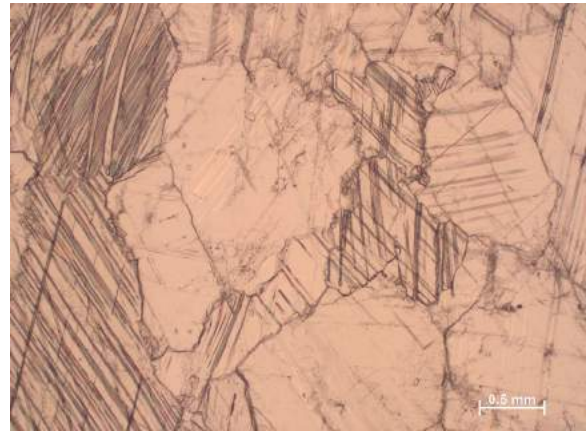
Predominant

Calcite: sa-sr, > 0.6 mm, mode 2.6 mm. Some grains have minor microcrystalline quartz inclusions.

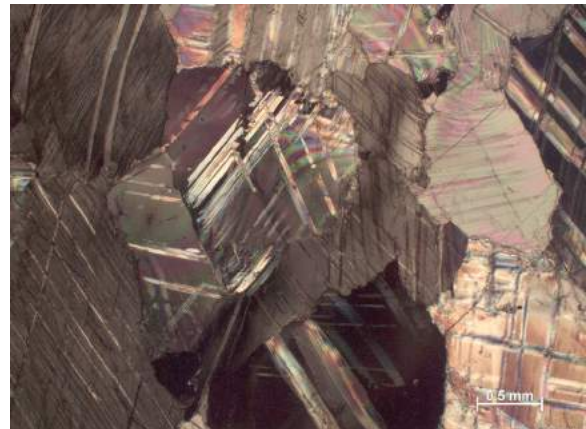
Rare

Microcrystalline Quartz: r, < 0.2 mm, mode 0.1 mm.

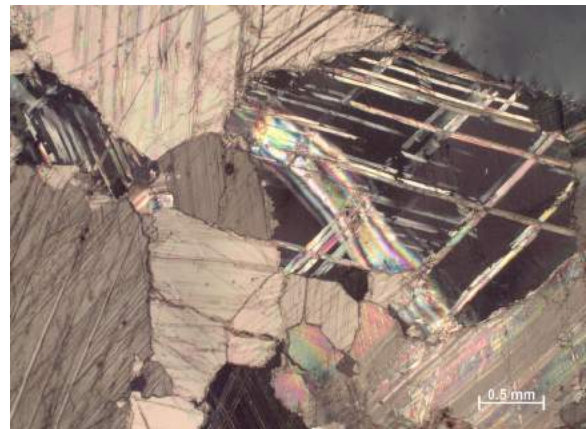
*Alteration:* Undulose extinction and poly-synthetic twin deformation of calcite grains under stress.



*Magnification: 25X | under plane polarized light (PPL)*



*Magnification: 25X | under cross polarized light (XPL)*



*Magnification: 25X | under cross polarized light (XPL)*

NAULAKHA PAVILION  
& Adjacent Marble Screens

LAHORE FORT  
Lahore, Pakistan

PETROGRAPHIC ANALYSIS  
Makrana Marble



## Appendix D: Material Analysis

Sample no.: PW10

*Texture:* Heteroblastic texture with no preferred orientation of the minerals.

*Grain shape and inter-grain relationship:* Medium to coarse grain structure with sub-angular to sub-rounded minerals. The grain size is averaged 2 mm and ranges closely between 0.08 mm to 5.6 mm with a closely packed inter-grain relationship and frequent triple junctions. Displays predominant embayed and less often sutured boundaries.

*Mineralogy:*

Predominant

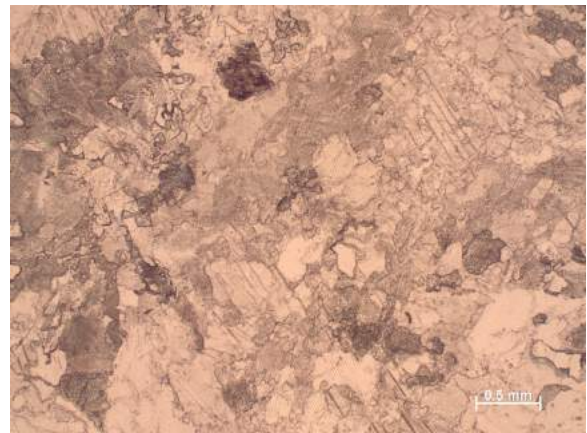
Calcite: sr, > 0.08 mm, mode 2.4 mm. Some grains have minor microcrystalline quartz inclusions.

Rare

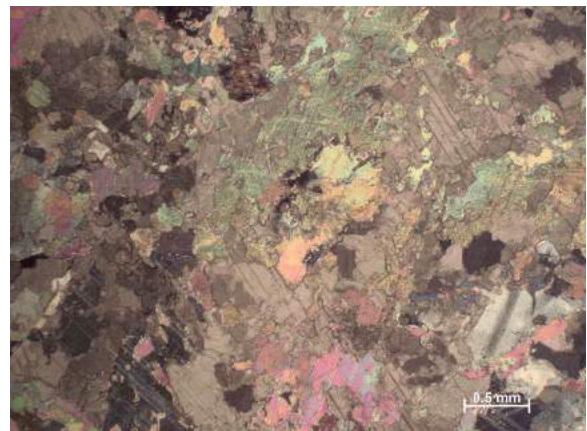
Microcrystalline Quartz: sr, < 0.3 mm, mode 0.08 mm. Very rare inclusions.

Muscovite: a-sa, < 1 mm, mode 0.4 mm. Individual laths and some clusters seen as inclusions within calcite crystals. *\*seen in a high frequency in relation to other samples*

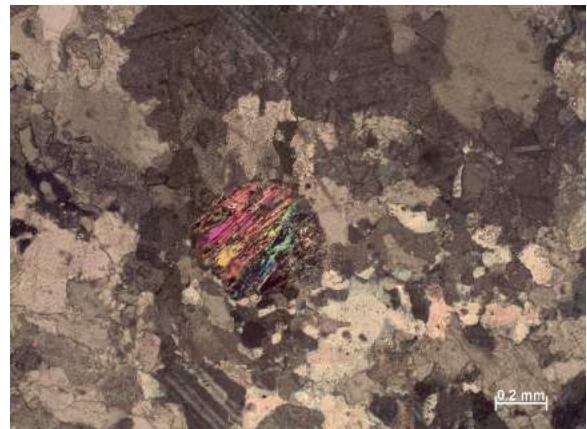
*Alteration:* Texture appears to be changing. Displays extensive mineral intergrowth along with undulose extinction of minerals under stress.



Magnification: 25X | under plane polarized light (PPL)



Magnification: 25X | under cross polarized light (XPL)



Magnification: 50X | under cross polarized light (XPL)

NAULAKHA PAVILION  
& Adjacent Marble Screens

LAHORE FORT  
Lahore, Pakistan

PETROGRAPHIC ANALYSIS  
Makrana Marble

## Appendix D: Material Analysis

*Sample no.:* PW11

*Texture:* Heteroblastic texture with no preferred orientation of the minerals.

*Grain shape and inter-grain relationship:* Medium to coarse grain structure with sub-rounded minerals. The grain size is averaged 1.6 mm and ranges closely between 0.08 mm to 3.4 mm with a closely packed inter-grain relationship and frequent triple junctions. Displays predominant embayed and less often sutured boundaries.

*Mineralogy:*

Predominant

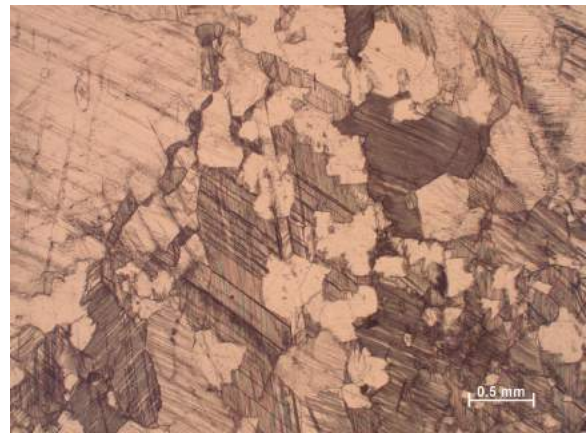
Calcite: sa-sr, > 0.2 mm, mode 2.4 mm.

Rare

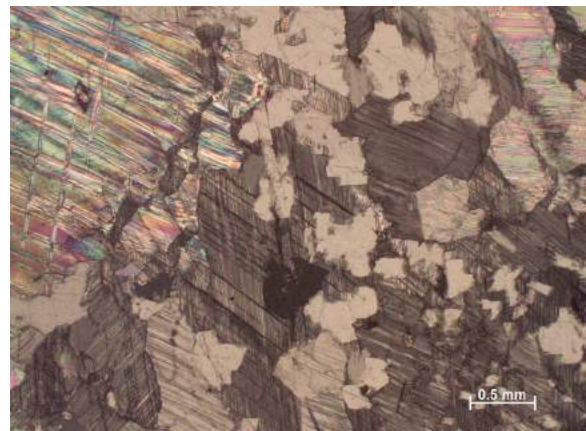
Microcrystalline Quartz: sa-sr, < 0.6 mm, mode 0.3 mm. Irregular clusters as calcite inclusions.

Muscovite: a-sr, < 0.3 mm, mode 0.12 mm. Seen as very rare inclusions within calcite grains.

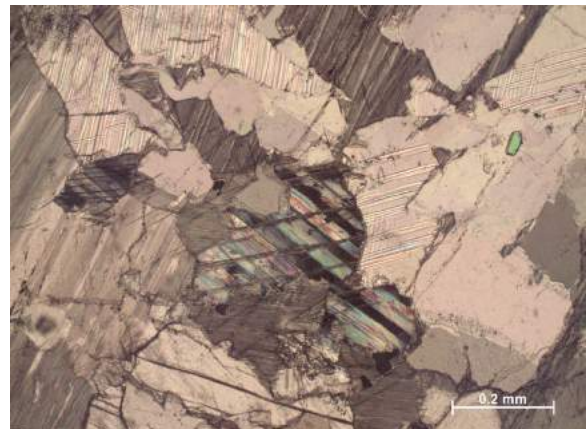
*Alteration:* Texture appears to be changing. Displays mineral intergrowth, polysynthetic twin deformation along with undulose extinction of calcite minerals under stress.



*Magnification: 25X | under plane polarized light (PPL)*



*Magnification: 25X | under cross polarized light (XPL)*



*Magnification: 50X | under cross polarized light (XPL)*

NAULAKHA PAVILION  
& Adjacent Marble Screens

LAHORE FORT  
Lahore, Pakistan

PETROGRAPHIC ANALYSIS  
Makrana Marble



## Appendix D: Material Analysis

*Sample no.:* PW12

*Texture:* Heteroblastic texture with no preferred orientation of the minerals.

*Grain shape and inter-grain relationship:* Coarse grain structure with sub-rounded minerals. The grain size is averaged 1.7 mm and ranges closely between 0.12 mm to 4 mm with a closely packed inter-grain relationship and frequent triple junctions. Displays predominant sutured boundaries.

*Mineralogy:*

Predominant

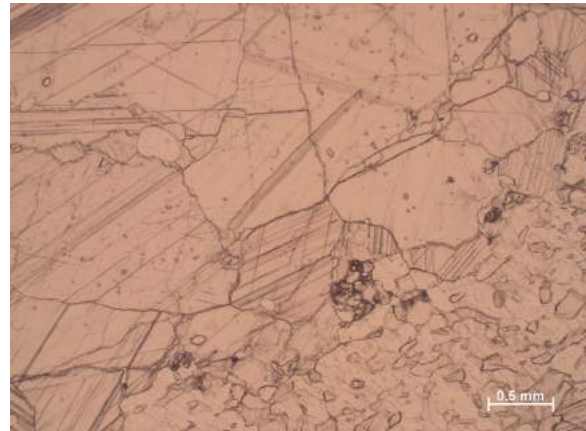
Calcite: sa-sr, > 0.2 mm, mode 2.4 mm.

Rare

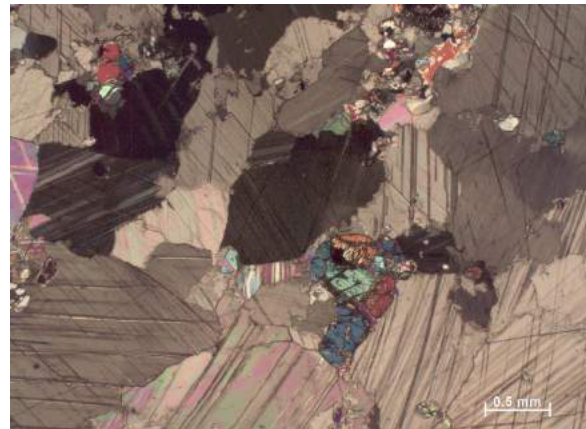
Microcrystalline Quartz: sr, < 0.3 mm, mode 0.2 mm. A quartz vein (approx. 18 mm in length) runs diagonal to the surface of the stone. *\*seen in a high frequency in relation to other samples*

Muscovite: a-sr, > 0.02 mm < 0.9 mm, mode 0.4 mm. Seen as accessory minerals as well as calcite inclusions.

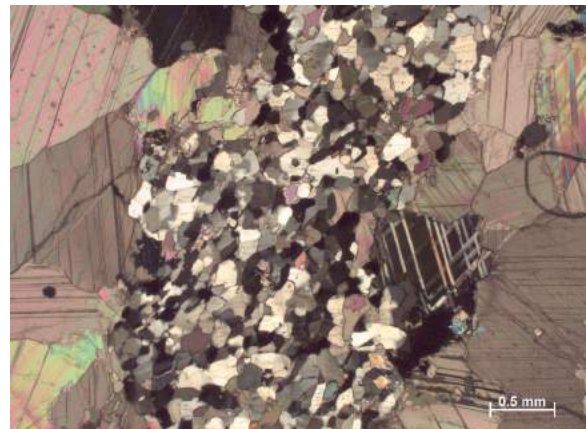
*Alteration:* Texture appears to be changing. Undulose extinction and extensive inter-growth within the mica clusters.



*Magnification: 25X | under plane polarized light (PPL)*



*Magnification: 25X | under cross polarized light (XPL)*



*Magnification: 25X | under cross polarized light (XPL)*

NAULAKHA PAVILION  
& Adjacent Marble Screens

LAHORE FORT  
Lahore, Pakistan

PETROGRAPHIC ANALYSIS  
Makrana Marble



## Appendix D: Material Analysis

### EDAX TEAM

Makrana Marble | Naulakha Pavilion

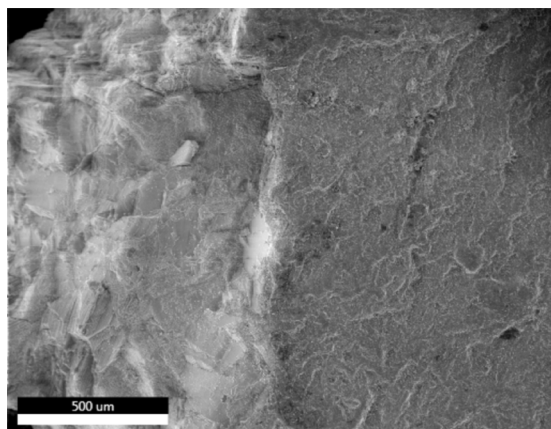
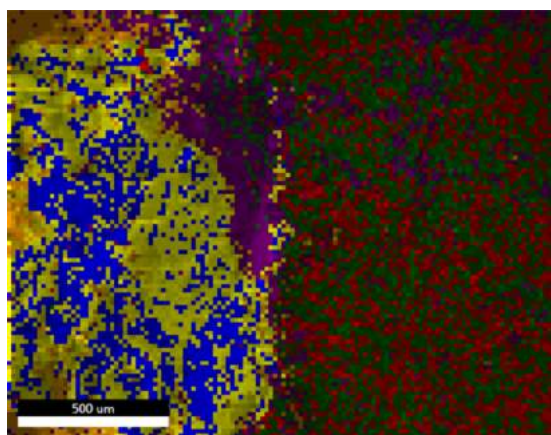
Author: Jamie Fort & Noor J. Sadiq

Creation: 4/3/2018

Sample Name: PW8

Area 1

#### Live Map 1



Image

NAULAKHA PAVILION  
& Adjacent Marble Screens

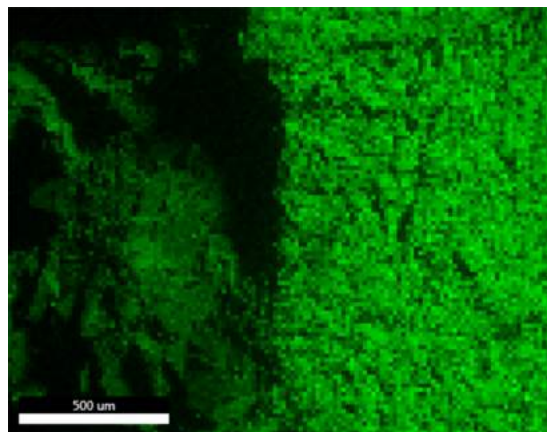
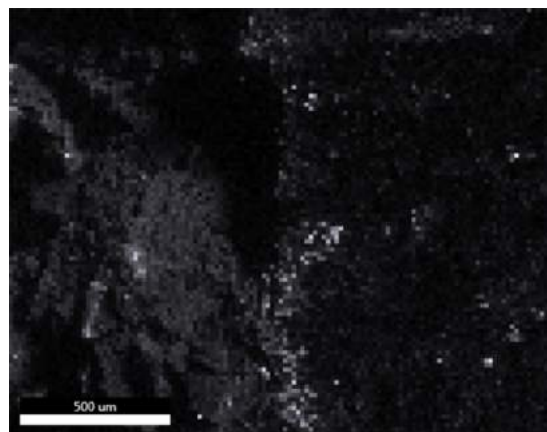
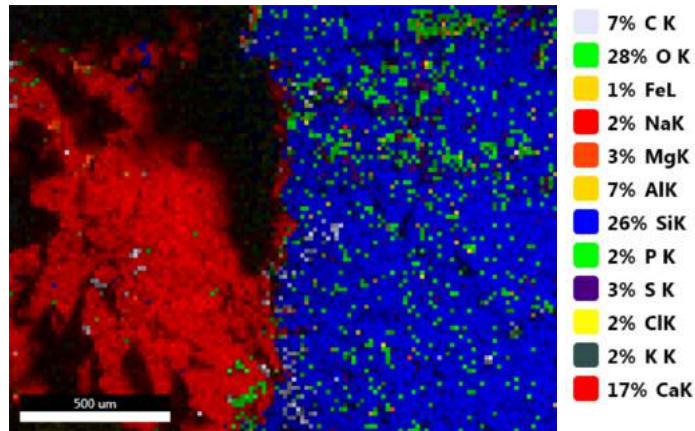
LAHORE FORT  
Lahore, Pakistan

SEM/EDS ANALYSIS  
Makrana Marble

# Appendix D: Material Analysis

## EDAX TEAM

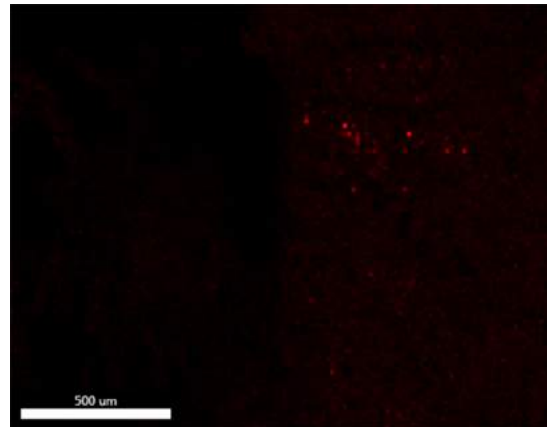
ElementOverlay



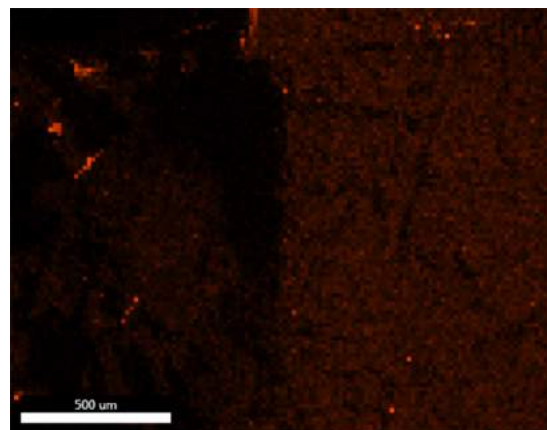
NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SEM/EDS ANALYSIS Makrana Marble
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## Appendix D: Material Analysis

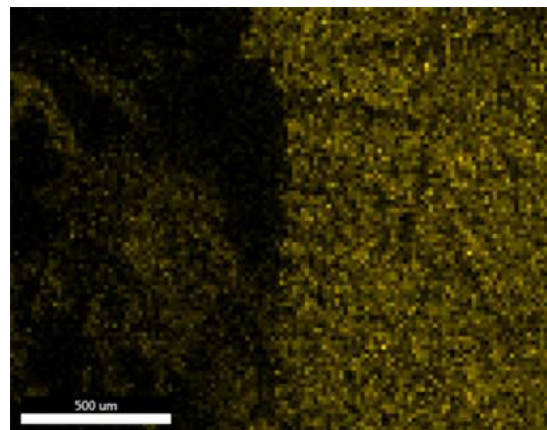
### EDAX TEAM



NaK\_ROI (278)



MgK\_ROI (140)

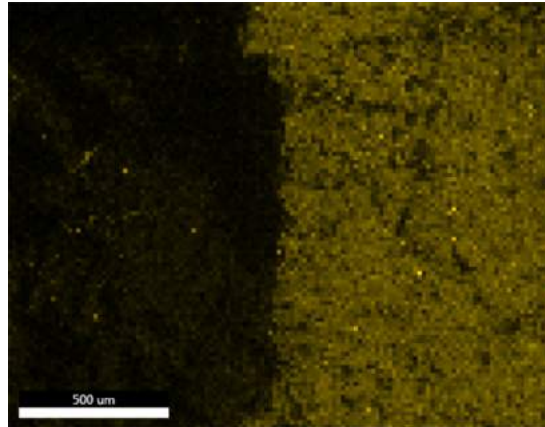


FeL\_ROI (43)

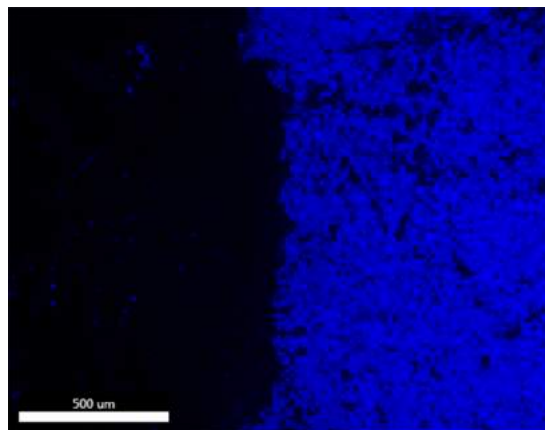
NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SEM/EDS ANALYSIS Makrana Marble
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## Appendix D: Material Analysis

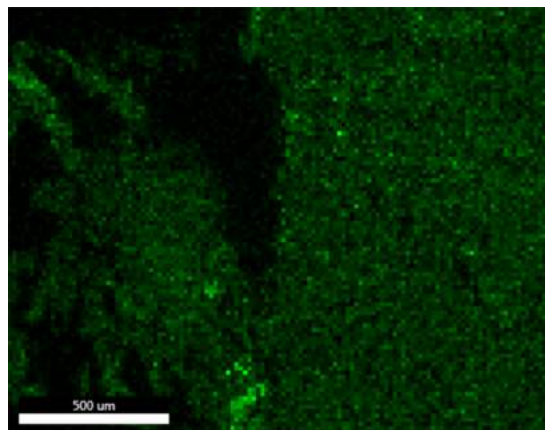
### EDAX TEAM



AlK\_ROI (181)



SiK\_ROI (477)



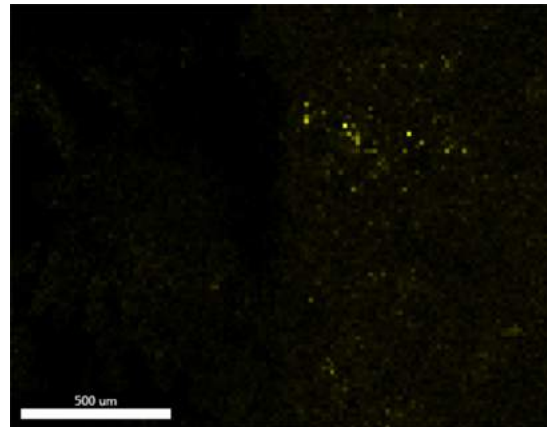
PK\_ROI (56)

NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SEM/EDS ANALYSIS Makrana Marble
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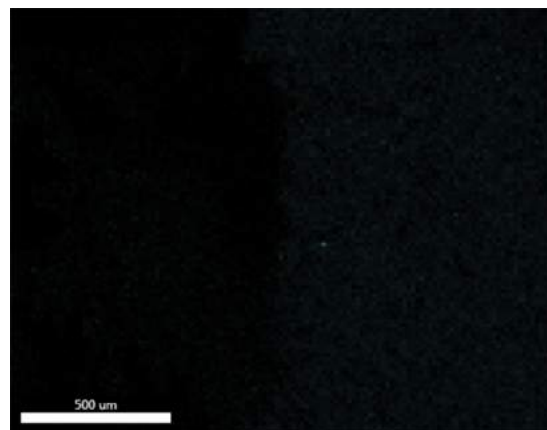


## Appendix D: Material Analysis

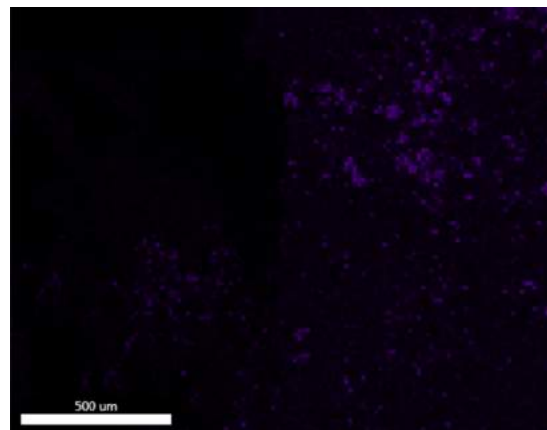
### EDAX TEAM



Cl K\_ROI (257)



K K\_ROI (99)

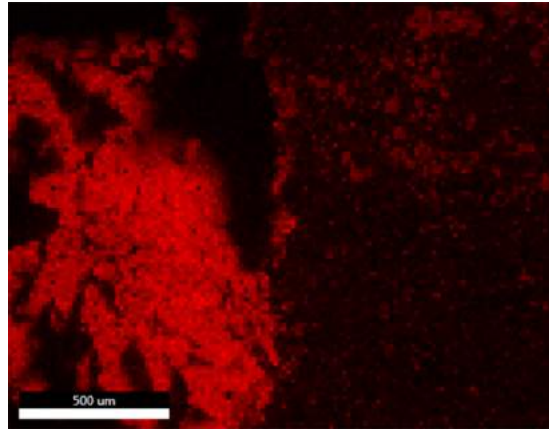


S K\_ROI (155)

NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SEM/EDS ANALYSIS Makrana Marble
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## Appendix D: Material Analysis

### EDAX TEAM



CaK\_ROI (216)

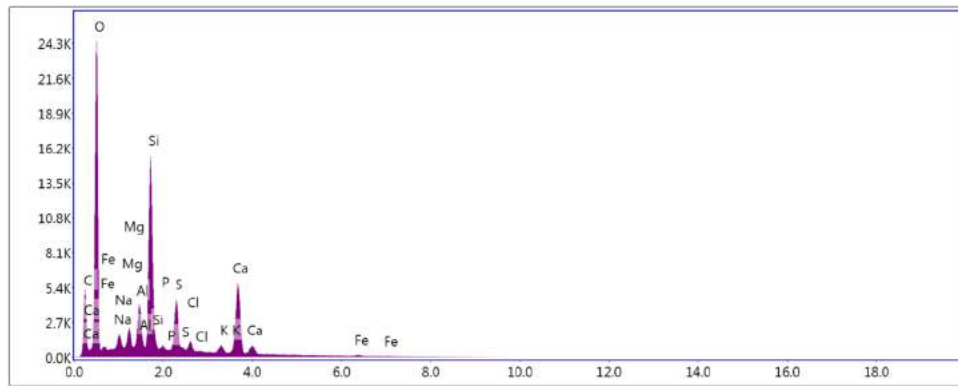
NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SEM/EDS ANALYSIS Makrana Marble
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# Appendix D: Material Analysis

## EDAX TEAM

kV: 10      Mag: 150      Takeoff: 54.1      Live Time(s): 123      Amp Time(μs): 1.92      Resolution:(eV)134.4

Phase:      O K/SiK/CaK/C K/AlK/S K



Lsec: 123.0 Cnts: 0.000 keV Det: Octane Super Det

### eZAF Smart Quant Results

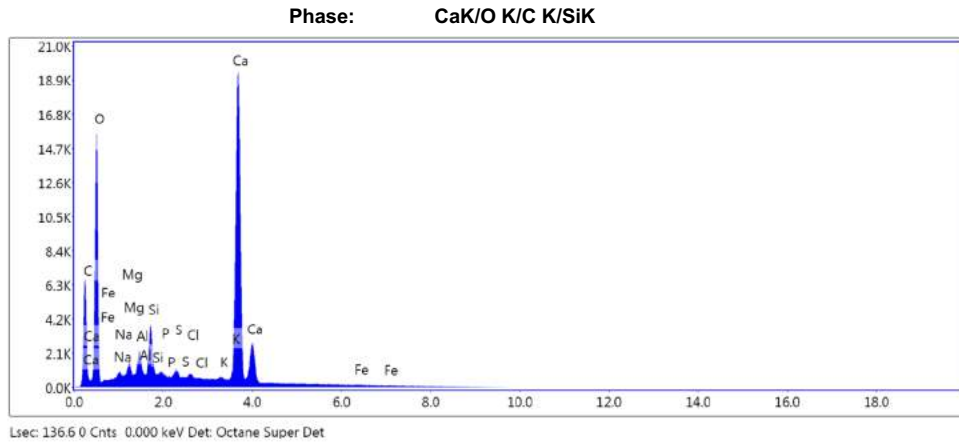
Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	20.88	31.45	233.80	8.12	0.1020	1.1000	0.9599	0.4439	1.0000
O K	43.32	48.98	1493.90	7.13	0.2218	1.0400	0.9803	0.4923	1.0000
FeL	0.00	0.00	0.00	99.99	0.0000	0.7748	1.1257	0.6142	0.9978
NaK	0.40	0.32	32.70	10.83	0.0028	0.9321	1.0039	0.7481	1.0040
MgK	0.68	0.50	77.90	6.03	0.0054	0.9446	1.0105	0.8479	1.0073
AlK	1.97	1.32	225.70	4.08	0.0164	0.9065	1.0165	0.9097	1.0120
SiK	10.58	6.82	1130.40	3.03	0.0931	0.9235	1.0220	0.9440	1.0097
P K	0.28	0.16	21.30	11.76	0.0024	0.8842	1.0269	0.9432	1.0161
S K	4.41	2.49	326.20	3.41	0.0389	0.8988	1.0313	0.9653	1.0183
ClK	1.00	0.51	63.00	8.16	0.0086	0.8525	1.0352	0.9735	1.0275
K K	1.19	0.55	54.80	9.84	0.0105	0.8428	1.0410	0.9913	1.0617
CaK	15.28	6.90	519.60	3.55	0.1320	0.8549	1.0427	0.9951	1.0153

NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SEM/EDS ANALYSIS Makrana Marble
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# Appendix D: Material Analysis

## EDAX TEAM

kV: 10      Mag: 150      Takeoff: 54.1      Live Time(s): 136.6      Amp Time(μs): 1.92      Resolution:(eV)134.4



### eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	17.05	30.03	299.70	5.68	0.1300	1.1401	0.9379	0.6685	1.0000
O K	32.17	42.52	814.20	8.71	0.1202	1.0795	0.9601	0.3463	1.0000
FeL	0.00	0.00	0.00	99.99	0.0000	0.8047	1.1037	0.5581	0.9978
NaK	0.00	0.00	0.00	99.99	0.0000	0.9689	0.9860	0.7082	1.0033
MgK	0.11	0.09	12.40	19.01	0.0009	0.9822	0.9933	0.8186	1.0061
AlK	0.52	0.41	60.90	6.25	0.0044	0.9430	1.0000	0.8902	1.0109
SiK	1.70	1.28	189.80	4.21	0.0156	0.9609	1.0063	0.9343	1.0173
P K	0.09	0.06	7.60	32.94	0.0008	0.9204	1.0120	0.9586	1.0298
S K	0.43	0.28	34.70	10.70	0.0041	0.9359	1.0172	0.9771	1.0484
ClK	0.35	0.21	24.30	11.61	0.0033	0.8879	1.0219	0.9878	1.0792
K K	0.50	0.27	27.40	13.87	0.0052	0.8785	1.0294	0.9991	1.2032
CaK	47.08	24.84	1680.00	3.13	0.4245	0.8916	1.0320	1.0012	1.0101

NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SEM/EDS ANALYSIS Makrana Marble
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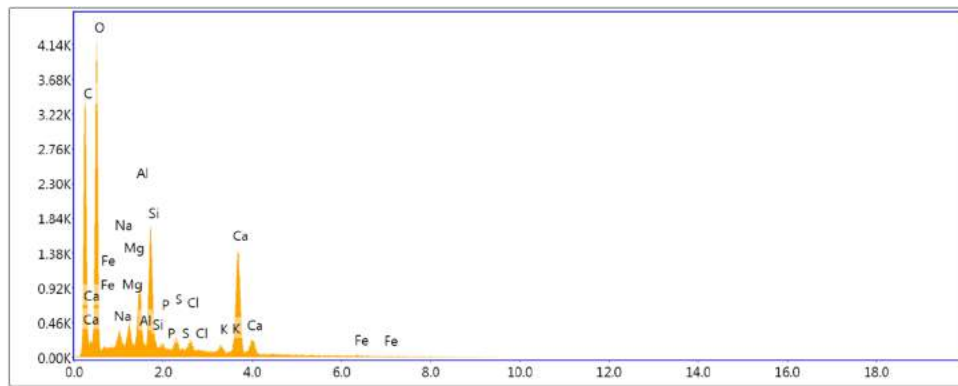


# Appendix D: Material Analysis

## EDAX TEAM

kV: 10      Mag: 150      Takeoff: 54.1      Live Time(s): 56.2      Amp Time(μs): 1.92      Resolution:(eV)134.4

Phase: O K/C K/CaK/SiK/AlK



Lsec: 56.20 Cnts: 0.000 keV Det: Octane Super Det

### eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	44.73	58.51	409.20	6.35	0.3006	1.0686	0.9715	0.6288	1.0000
O K	31.03	30.47	538.70	8.17	0.1347	1.0096	0.9909	0.4300	1.0000
FeL	0.00	0.00	0.00	99.99	0.0000	0.7519	1.1372	0.6429	0.9978
NaK	0.38	0.26	18.20	16.21	0.0026	0.9043	1.0132	0.7690	1.0034
MgK	0.61	0.39	41.10	8.42	0.0048	0.9163	1.0193	0.8640	1.0059
AlK	2.01	1.17	134.10	4.80	0.0164	0.8792	1.0248	0.9217	1.0092
SiK	4.27	2.39	265.50	3.80	0.0368	0.8955	1.0299	0.9523	1.0103
P K	0.28	0.14	12.40	20.54	0.0023	0.8574	1.0344	0.9648	1.0170
S K	0.72	0.35	31.40	12.30	0.0063	0.8715	1.0384	0.9811	1.0254
ClK	0.81	0.36	30.10	12.37	0.0069	0.8265	1.0418	0.9904	1.0382
K K	0.70	0.28	19.30	15.16	0.0063	0.8169	1.0467	1.0003	1.0882
CaK	14.46	5.67	285.20	4.06	0.1221	0.8286	1.0479	1.0021	1.0169

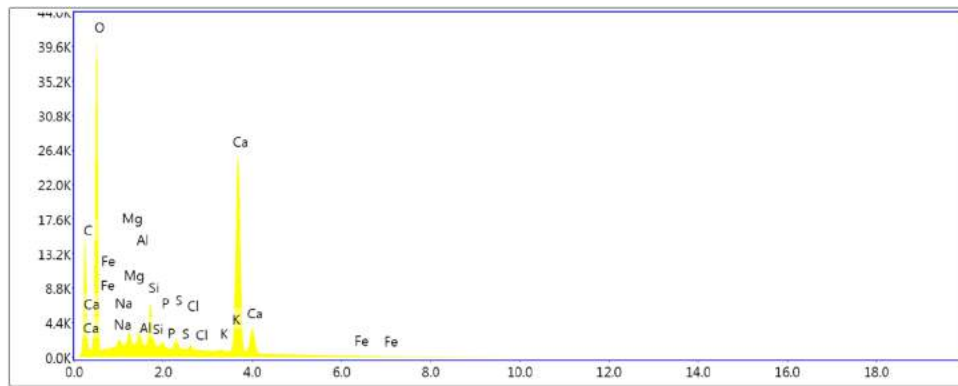
NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SEM/EDS ANALYSIS Makrana Marble
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# Appendix D: Material Analysis

## EDAX TEAM

kV: 10      Mag: 150      Takeoff: 54.1      Live Time(s): 195      Amp Time(μs): 1.92      Resolution:(eV)134.4

Phase:      CaK/O K/C K/SiK



Lsec: 195.0 Cnts: 0.000 keV Det: Octane Super Det

### eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	20.66	32.73	451.70	5.64	0.1500	1.1141	0.9506	0.6517	1.0000
O K	40.32	47.94	1507.80	7.99	0.1705	1.0541	0.9718	0.4012	1.0000
FeL	0.00	0.00	0.00	99.99	0.0000	0.7855	1.1165	0.5668	0.9978
NaK	0.04	0.03	3.90	61.52	0.0003	0.9453	0.9964	0.7168	1.0031
MgK	0.39	0.30	57.80	6.71	0.0031	0.9582	1.0033	0.8256	1.0056
AlK	0.59	0.41	88.20	4.94	0.0049	0.9197	1.0097	0.8949	1.0099
SiK	1.85	1.26	263.50	3.60	0.0165	0.9370	1.0154	0.9376	1.0152
P K	0.37	0.23	38.80	7.87	0.0033	0.8974	1.0207	0.9608	1.0255
S K	0.78	0.47	80.10	4.66	0.0073	0.9123	1.0255	0.9782	1.0400
ClK	0.41	0.22	36.30	7.97	0.0038	0.8654	1.0297	0.9882	1.0646
K K	0.34	0.17	23.10	13.40	0.0034	0.8558	1.0362	0.9993	1.1642
CaK	34.25	16.25	1557.50	3.12	0.3014	0.8684	1.0383	1.0016	1.0117

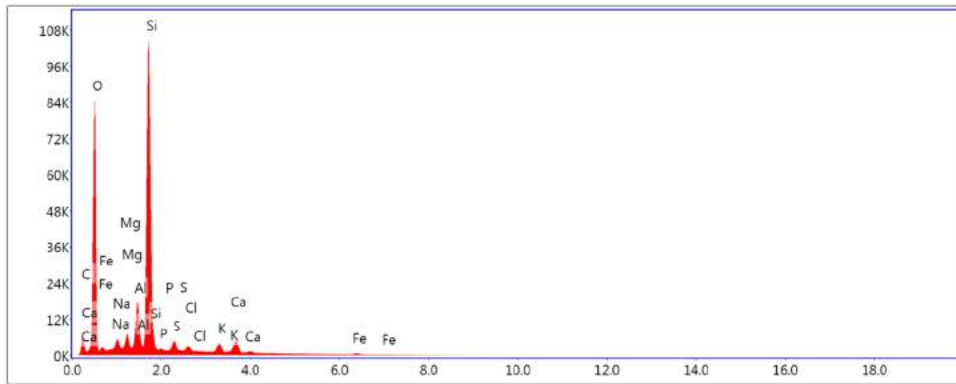
NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SEM/EDS ANALYSIS Makrana Marble
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# Appendix D: Material Analysis

## EDAX TEAM

kV: 10      Mag: 150      Takeoff: 54.1      Live Time(s): 203.1      Amp Time(μs): 1.92      Resolution:(eV)134.4

Phase:      SiK/O K/AIK



Lsec: 203.10 Cnts: 0.000 keV Det: Octane Super Det

### eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	13.16	20.50	182.80	9.12	0.0490	1.1054	0.9605	0.3366	1.0000
O K	45.67	53.41	3089.30	6.05	0.2817	1.0450	0.9809	0.5904	1.0000
FeL	0.00	0.00	0.00	99.99	0.0000	0.7784	1.1264	0.6557	0.9978
NaK	0.42	0.35	58.20	7.53	0.0031	0.9364	1.0045	0.7721	1.0061
MgK	0.74	0.57	143.80	4.89	0.0062	0.9489	1.0110	0.8649	1.0114
AlK	3.45	2.39	659.10	3.34	0.0295	0.9106	1.0170	0.9211	1.0186
SiK	27.33	18.21	4767.90	2.75	0.2412	0.9275	1.0224	0.9473	1.0047
P K	0.11	0.07	12.90	15.37	0.0009	0.8881	1.0273	0.9048	1.0077
S K	1.42	0.83	165.70	4.14	0.0121	0.9027	1.0317	0.9368	1.0104
ClK	0.88	0.46	87.40	6.13	0.0073	0.8561	1.0356	0.9582	1.0149
K K	2.33	1.12	168.90	4.36	0.0199	0.8463	1.0413	0.9841	1.0259
CaK	4.48	2.09	248.20	3.95	0.0387	0.8584	1.0430	0.9889	1.0187

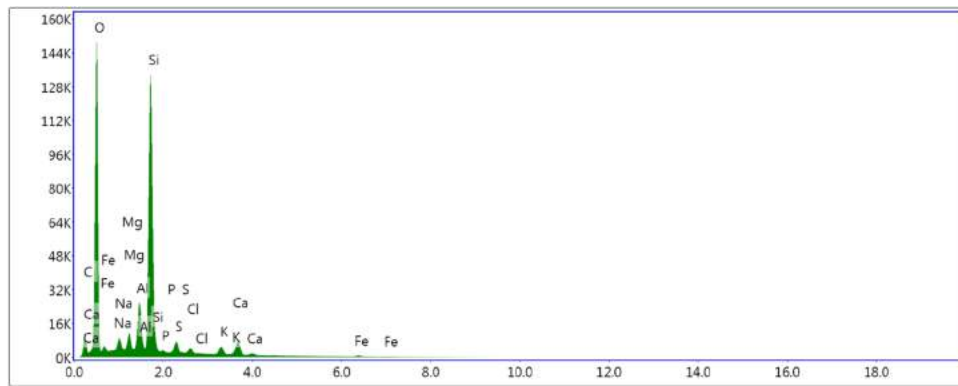
NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SEM/EDS ANALYSIS Makrana Marble
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# Appendix D: Material Analysis

## EDAX TEAM

kV: 10      Mag: 150      Takeoff: 54.1      Live Time(s): 261.1      Amp Time(μs): 1.92      Resolution:(eV)134.4

Phase:      SiK/O K/AIK



Lsec: 261.1 0 Cnts: 0.000 keV Det: Octane Super Det

### eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	R	A	F
C K	13.66	20.82	254.00	8.75	0.0548	1.1005	0.9626	0.3646	1.0000
O K	49.36	56.45	4246.00	5.85	0.3120	1.0402	0.9828	0.6077	1.0000
FeL	0.58	0.19	22.50	10.40	0.0029	0.7748	1.1284	0.6416	0.9978
NaK	0.78	0.62	130.30	5.61	0.0056	0.9320	1.0061	0.7614	1.0053
MgK	1.00	0.75	236.00	4.24	0.0082	0.9444	1.0126	0.8559	1.0097
AlK	3.41	2.31	795.70	3.25	0.0287	0.9063	1.0185	0.9140	1.0155
SiK	22.21	14.47	4764.70	2.79	0.1943	0.9231	1.0238	0.9427	1.0050
P K	0.25	0.15	36.60	7.94	0.0020	0.8838	1.0287	0.9140	1.0082
S K	1.56	0.89	226.70	3.60	0.0134	0.8984	1.0330	0.9437	1.0108
ClK	0.89	0.46	110.10	4.27	0.0074	0.8520	1.0368	0.9628	1.0154
K K	1.94	0.91	174.00	4.25	0.0165	0.8422	1.0424	0.9865	1.0275
CaK	4.36	1.99	299.10	3.77	0.0376	0.8542	1.0440	0.9910	1.0197

NAULAKHA PAVILION & Adjacent Marble Screens	LAHORE FORT Lahore, Pakistan	SEM/EDS ANALYSIS Makrana Marble
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**GOVERNMENT OF PAKISTAN  
GEOLOGY SURVEY OF PAKISTAN  
GEOSCIENCE ADVANCE RESEARCH LABORATORIES**

**Historical Materials Testing  
Picture wall Lahore Fort**

**Laboratory Test Reports**

**for Naulakha Pavilion**

**5<sup>th</sup> May 2017**

**Aga Khan Cultural Service Pakistan**

AKCS-P Report



**Government of Pakistan**  
**Geological Survey of Pakistan**  
**Geoscience Advance Research Laboratories**

\*\*\*\*\*

YOUR REFERENCE	Agha Khan Cultural Services Pakistan
MATERIAL	Marble
LOCATION	Lahore Fort (G-1121) & Rajistan (India) (G-1122)
WORK REQUIRED	Comparison and Origin
<b>Investigation By:</b>	Asif Hanif, Muhammad Nasir Siddiq
<b>Sample No.:</b>	<b>G-1121, G1122</b>

**Description:**

Samples were received in the form of hard rock specimens. Both the samples were tested chemically and mineralogically by the same procedures under the same conditions on state of the art instruments in Geoscience Advance Research Laboratories. Optical and mineralogical analysis indicated the samples processes the same paragenesis, degree of metamorphism, texture, minerals, cementing material and inclusions. Elemental analysis through XRF also indicates the same origin and source of these two samples a slight difference in the percentage of P<sub>2</sub> O<sub>5</sub> and SiO<sub>2</sub> in G-1121 is because of the mortar or the cementing material used for the binding of the stone.

**Conclusion:** Both samples of marble belong to the same source and origin

**Optical Laboratory**

(Muhammad Nasir Siddiq)

Assistant director

Geoscience Advance Research Laboratories

Geological Survey of Pakistan

Islamabad

AKCS-P Report

**Government of Pakistan  
Geological Survey of Pakistan  
Geoscience Advance Research Laboratories  
\*\*\*\*\***

**Sample No: Sand**

YOUR REFERENCE MATERIAL Source WORK REQUIRED <b>Investigation By:</b> <b>Sample No.:</b> <b>Investigations By:</b>	Agha Khan Cultural Services Pakistan Marble Lahore Fort Petrography Muhammad Nasir Siddiq <b>G-1121, G1122</b> Muhammad Nasir Siddiq
---	--

**Description:**

The samples were provided in the form of solid rock and were studied through optical microscope for the petrography  
Following is a brief description of the mineralogy.

G-1121

Rock Type: Marble

<b>Minerals</b>	<b>Percentage (%)</b>
Calcite (CaCO <sub>3</sub> )	99
Quartz	>1
Opaque minerals	>1

G-1122

Rock Type: Marble

<b>Minerals</b>	<b>Percentage (%)</b>
Calcite (CaCO <sub>3</sub> )	99
Quartz	>1
Opaque minerals	>1

AKCS-P Report

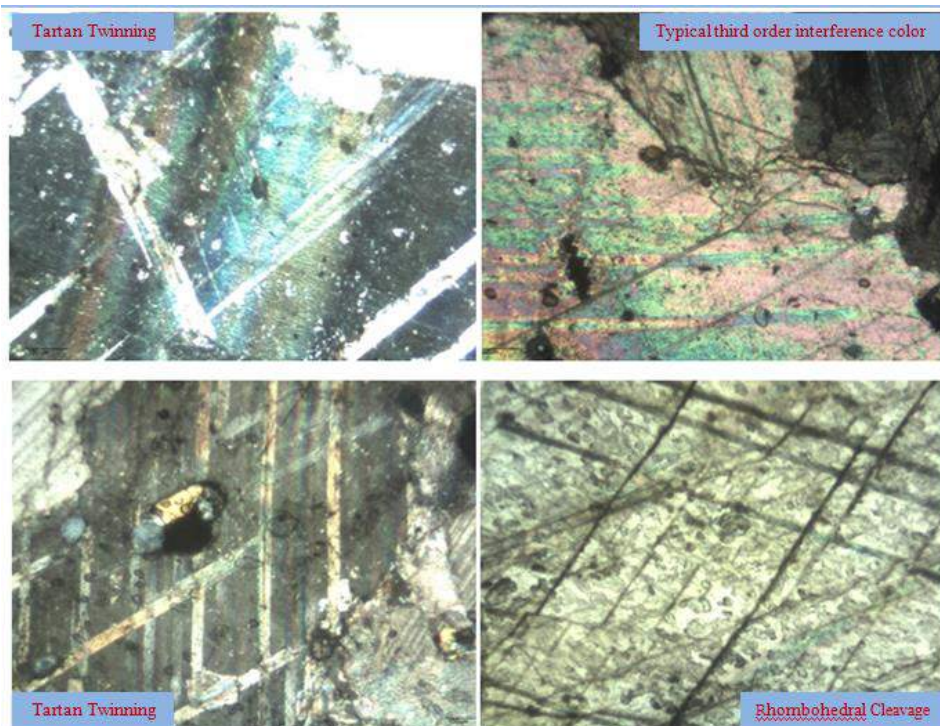
### Megascopic Features

Hand specimen is sugar textured white colored marble.

### Microscopic Features

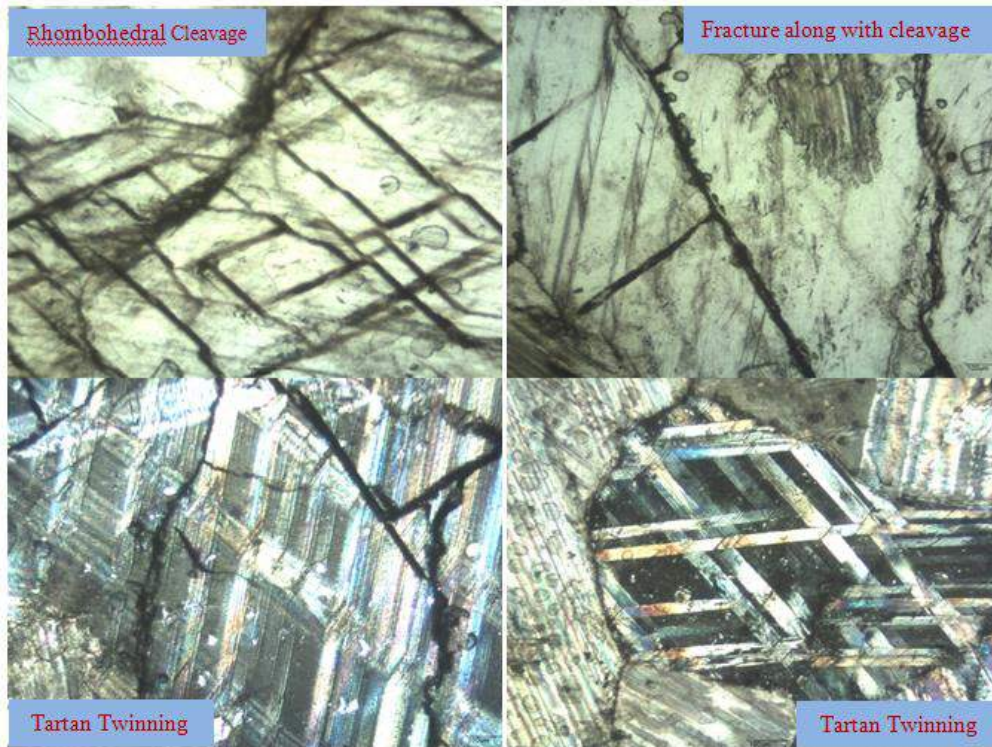
The provided samples are coarse grained marble pieces with very low impurities, containing 99 % calcite ( $\text{CaCO}_3$ ). Tightly packed grains along with twinning and cleavage indicate proper metamorphism of source. Rhombohedral cleavage and stress twinning are indicative of it along with very tight packing of grain in both of the samples. Fractures can also be seen in along with cleavage in calcite grains. Typical third order interference color of the calcite is show in the pictures given below. Other minerals present are very low amount of quart and few opaque minerals.

G-1121



AKCS-P Report

G -1122



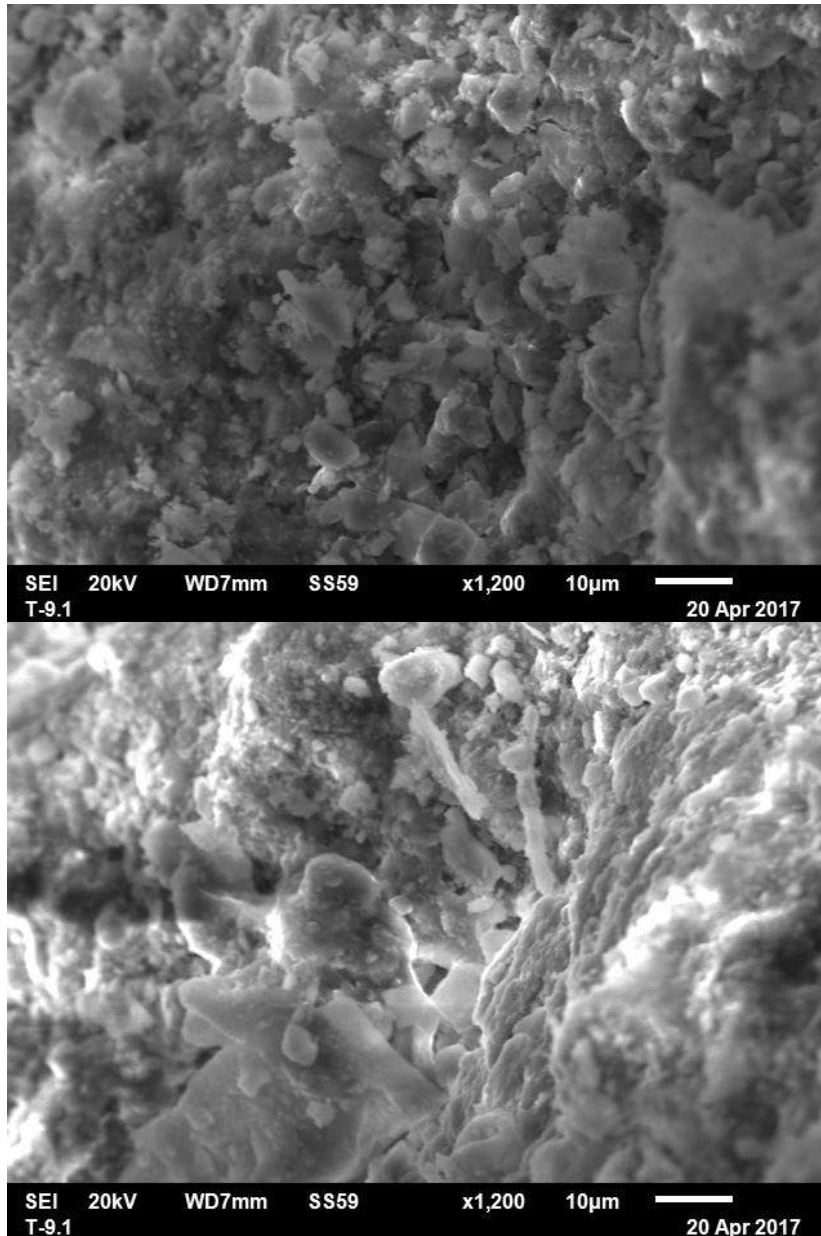
Note: We are only responsible for the samples provided

### Optical Laboratory

(Muhammad Nasir Siddiq)  
Assistant director  
Geoscience Advance Research Laboratories  
Geological Survey of Pakistan  
Islamabad

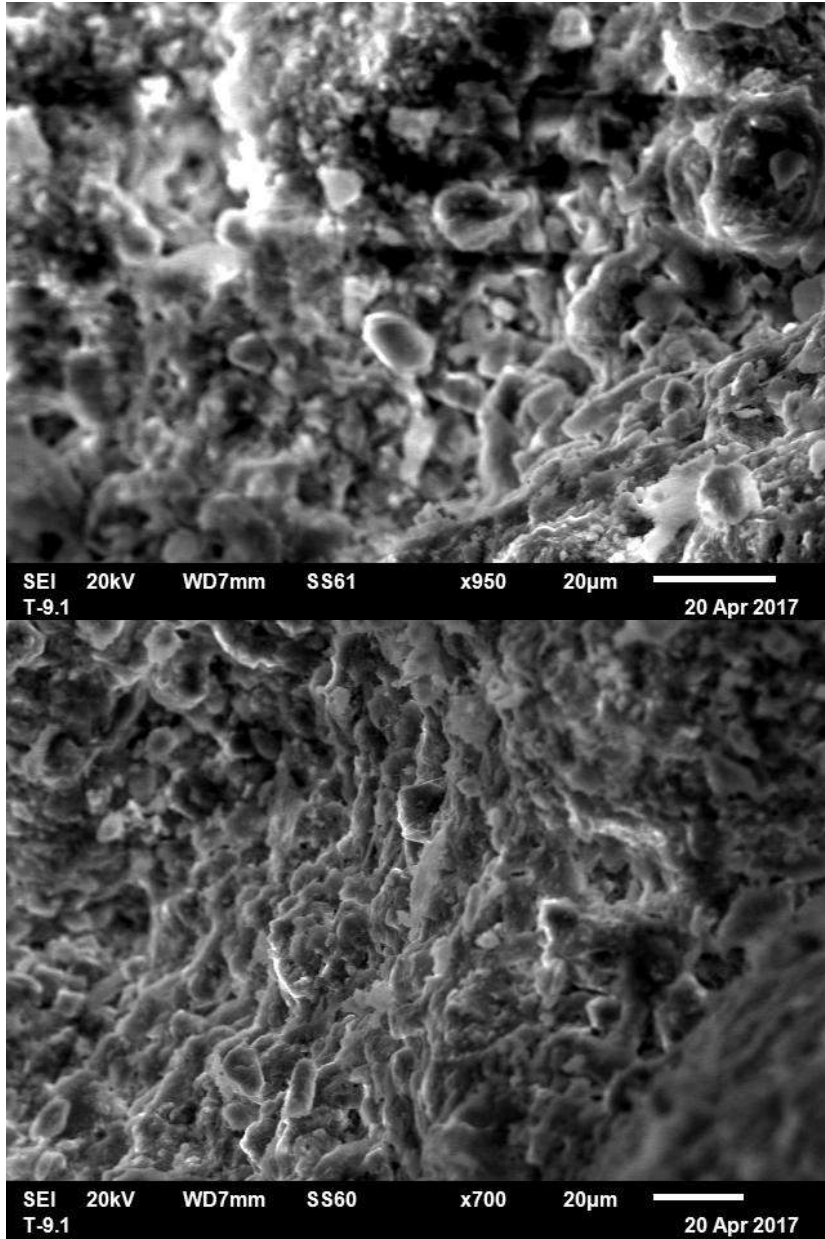
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### 3. Sample Inlay mortar: T-9.1

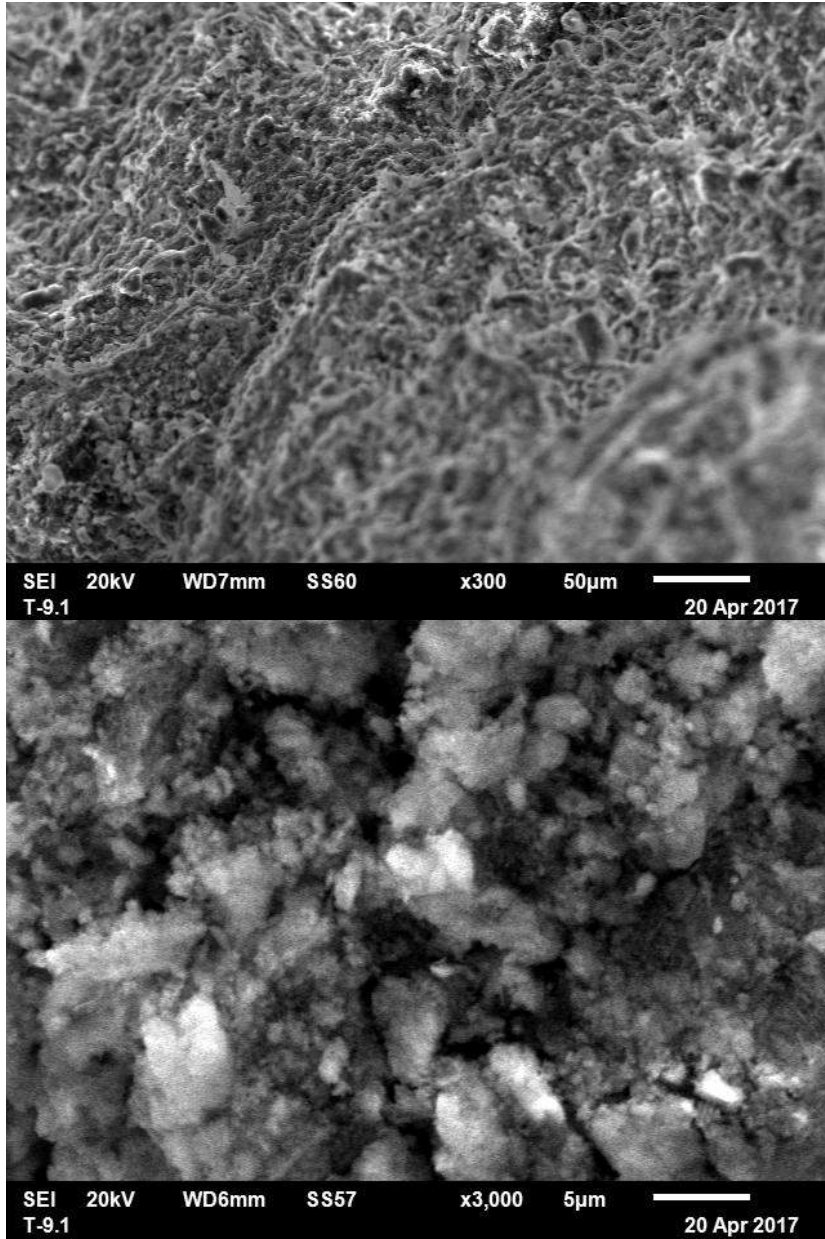


AKCS-P Report

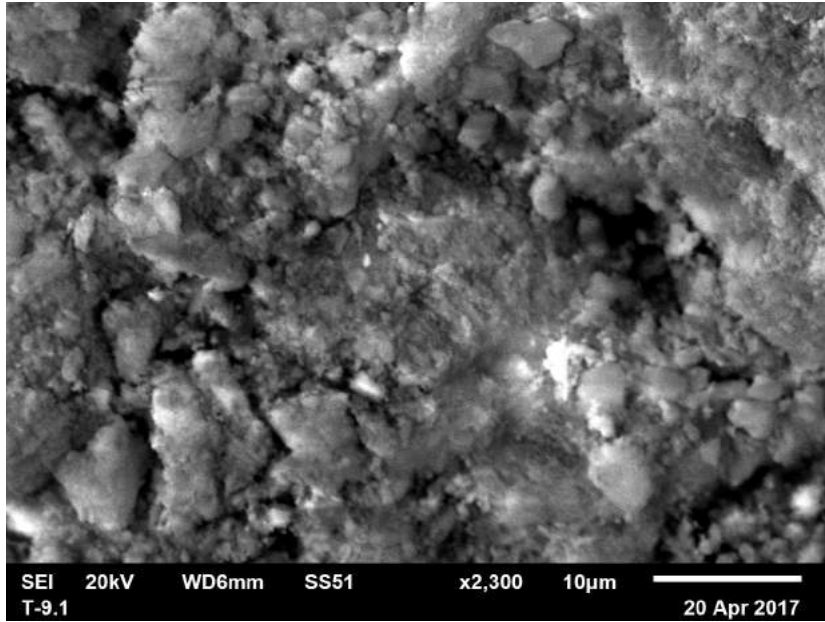




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## Mortar from Stone Inlay

Project: mortar from stone in lay  
 Owner: nic  
 Site: Site of Interest 1

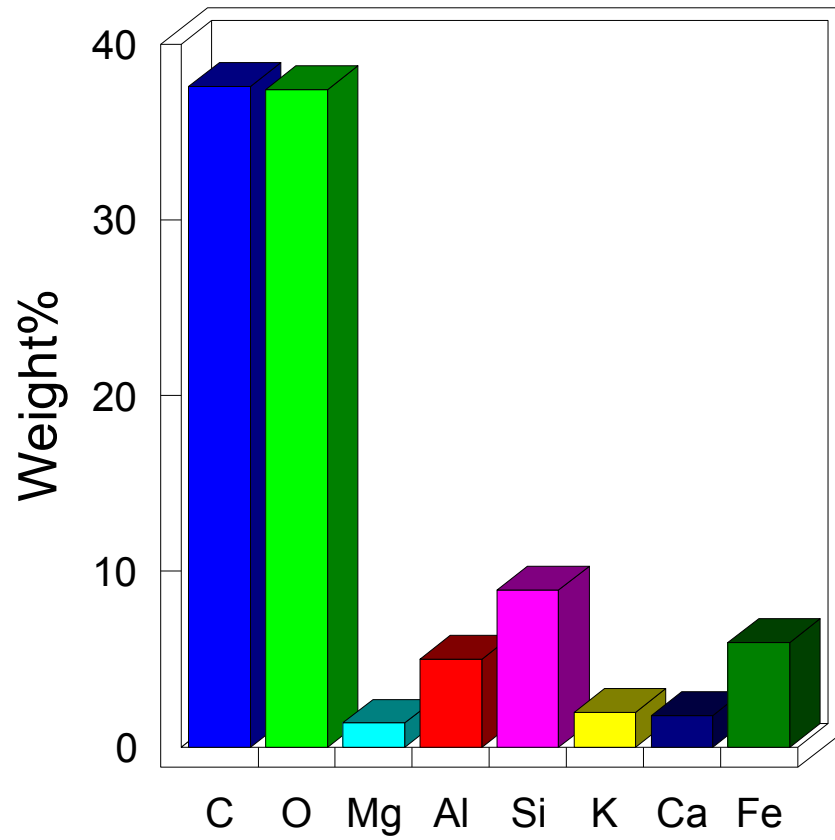
Sample: T-9.1  
 Type: Default  
 ID: T-9.1

Processing option: All elements analyzed (Normalized)

Spectrum	In stats.	C	O	Mg	Al	Si	P	K	Ca	Fe	Total
Spectrum 1	Yes	31.06	50.46	2.47	2.97	6.74		0.77	3.65	1.89	100.00
Spectrum 2	Yes	32.92	49.52	2.18	2.82	6.50		0.85	3.48	1.73	100.00
Spectrum 3	Yes	34.29	44.28	1.72	2.86	8.71		1.01	2.59	4.54	100.00
Spectrum 4	Yes	56.67	38.19	0.63	0.74	1.50			1.11	1.16	100.00
Spectrum 5	Yes	18.34	47.22	2.69	3.64	13.52	0.35	1.88	8.26	4.10	100.00
Max.		56.67	50.46	2.69	3.64	13.52	0.35	1.88	8.26	4.54	
Min.		18.34	38.19	0.63	0.74	1.50	0.35	0.77	1.11	1.16	

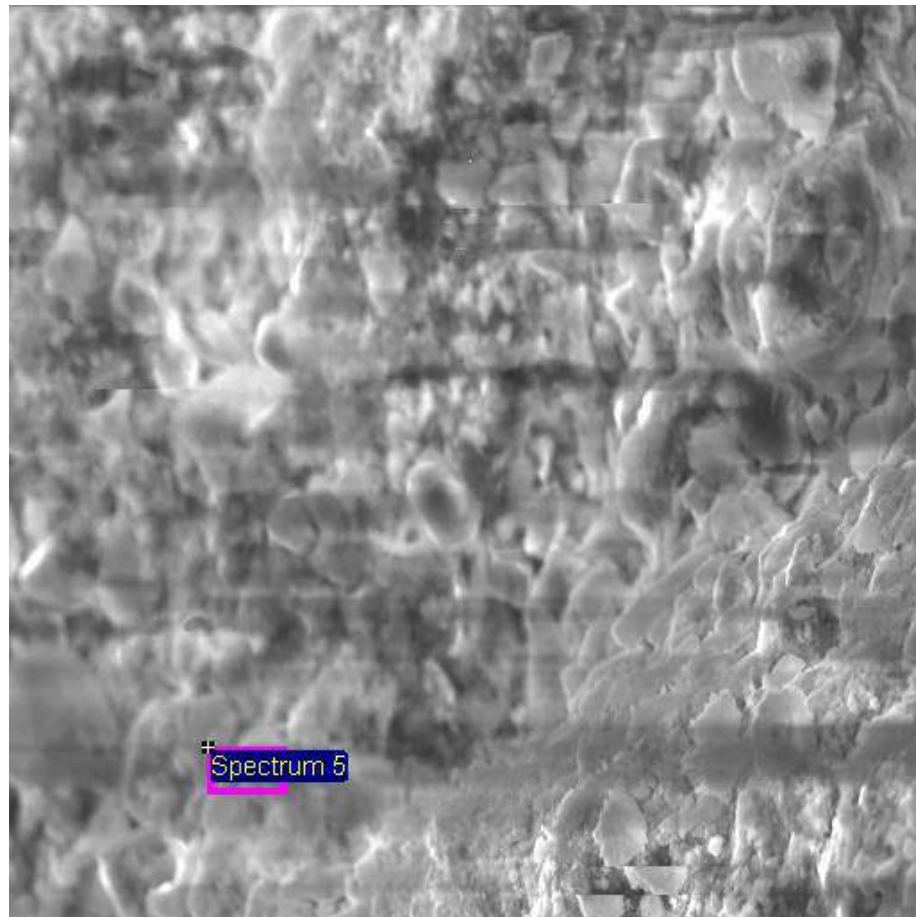
All results in weight%

## Quantitative results



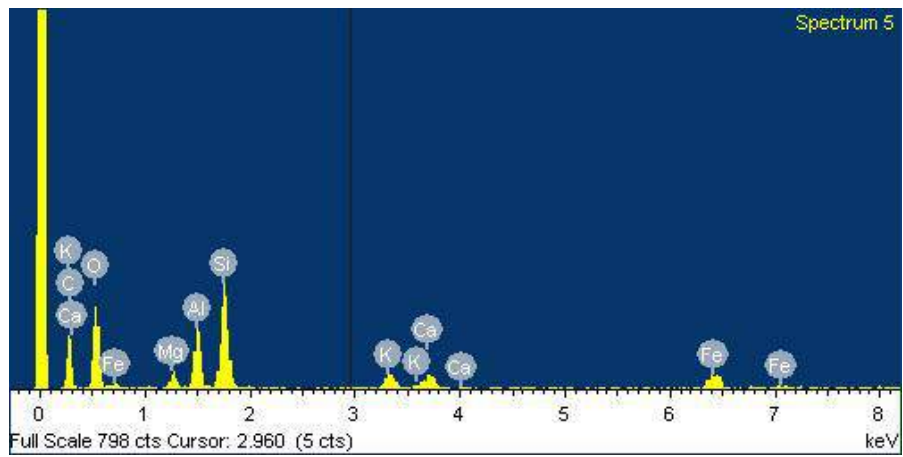
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1mm

Electron Image 1



AKCS-P Report

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