The impacts of climate change on traditional brick masonry construction: A case study of The Sheesh Mahal Complex, Lahore Fort, Pakistan

Ifrah Asif

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The impacts of climate change on traditional brick masonry construction: A case study of The Sheesh Mahal Complex, Lahore Fort, Pakistan

Abstract
Pakistan is among the 10 countries that will be most affected by climate change. While the country contributes less than 1 percent of the world's greenhouse gases responsible for causing global warming, its 200 million people are among the world's most vulnerable victims of the growing consequences of climate change. The nation is facing ever-rising temperatures, drought, and flooding that present serious threats to the country's rich built heritage. This research explores the traditional passive climate-control strategies that have been used in Pakistan's traditional brick masonry buildings to mitigate its hot arid climate and considers how these design solutions can be preserved and adapted in the rehabilitation of these historic masonry structures. The research further investigates the capacity and resiliency of these age-old strategies to perform under changing climate conditions and recommends methods to improve their performance. The Sheesh Mahal Complex in Lahore Fort provides an excellent case study to analyze this traditional regional form of passive cooling and the impacts of climate change on its performance efficacy. The Complex was built as a royal residence during the Mughal Period in the 16th century and incorporates hydraulic engineering, architectural design, and urban planning all together as an integrated whole. The research further examines how its current restoration can incorporate the existing passive environmental systems as part of a more sustainable conservation and management plan.

Keywords
historic brick masonry, sustainable, passive design, hot arid climate, passive cooling

Disciplines
Historic Preservation and Conservation

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THE IMPACTS OF CLIMATE CHANGE ON TRADITIONAL BRICK MASONRY
CONSTRUCTION: A CASE STUDY OF THE SHEESH MAHAL COMPLEX,
LAHORE FORT, PAKISTAN

Ifrah Asif
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

2021

____________________
Advisor & Program Chair
Frank G. Matero
Professor of Architecture, Historic Preservation
For my parents, without their unconditional love and support this would not have been possible
ACKNOWLEDGMENTS

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TABLE OF CONTENTS

Acknowledgments iii

List of Figures vi

List of Abbreviations x

Definitions xi

1. Introduction 1
   1.1. Thesis Statement 1
   1.2. Significance of the Study 2
   1.3. Research Methodology 3
   1.4. Research Diagram 4

2. Climate Change in Pakistan 5
   2.1. Climate of Pakistan 5
   2.2. Climate of Lahore 7
   2.3. Climate and Comfort 9
   2.4. Thermal Comfort in Traditional Buildings 11
   2.5. Climate Change in Pakistan 11

3. Case Study: The Sheesh Mahal Complex, Lahore Fort 15
   3.1. Historical Background 15
   3.2. Site Context 18
   3.3. Physical Description 21
   3.4. Construction 30
   3.5. Masonry Characterization 31
      3.5.1. Mortar Analysis 35
   3.6. Passive Design in the Sheesh Mahal 38
      3.6.1. Courtyard 38
      3.6.2. Water Bodies 41
      3.6.3. Wind Channels 45
      3.6.4. Mashrabiya 46
      3.6.5. Thermal Mass 47
      3.6.6. Evaporative Cooling in the Basement 49
   3.7. History of Conservation of Sheesh Mahal 54
4. The Impacts of Climate Change on Traditional Brick Masonry Construction 61
   4.1. Potential impacts of climate change on traditional brick masonry construction 61
      4.1.1. Higher temperatures/ Increase in Annual Temperatures 61
      4.1.2. Increase in Cooling Degree Days 66
      4.1.3. Higher precipitation/ Increase in Annual Precipitation 67
      4.1.4. Pollution 72
      4.1.5. Wind 74
      4.1.6. Desertification 75
      4.1.7. Biological effects 77
      4.1.8. Earthquake 79
   4.2. Potential Impacts of Climate Change on Sheesh Mahal Complex 81
   4.3. Risk Scenario Planning for Sheesh Mahal Complex 89
      4.3.1. Flood and earthquake risk scenario 89
      4.3.2. Extreme precipitation and acid rain risk scenario 91
      4.3.3. High temperature and extreme precipitation risk scenario 92
      4.3.4. Higher temperature and less rainfall risk scenario 93

5. Recommendations to Mitigate The Impacts of Climate Change on Traditional Masonry at The Sheesh Mahal Complex 95
   5.1. Preventive Conservation 95
   5.2. Corrective Actions: Adaptation, Mitigation, and Preservation 95
   5.3. Collaboration and Cooperation 96
   5.4. Risk Preparedness 96
   5.5. Disaster Risk Management 97
   5.6. Climate Change Adaptation Strategies 99
   5.7. Scenario Planning 99
   5.8. Building Resilience 100

6. Conclusion 102

References 104

Bibliography 106

Index 116
LIST OF FIGURES

Figure 1: Annual Temperature of Pakistan for 1901-2016 (Source: World Bank) ........ 6
Figure 2: Annual Rainfall of Pakistan for 1960-2016 (Source: World Bank) .................. 6
Figure 3: Average Monthly Temperature and Rainfall of Pakistan for 1991-2016 (Source: World Bank) ............................................................................................................. 8
Figure 4: Average Monthly Temperature and Rainfall of Lahore for 1991-2016 (Source: World Bank) ............................................................................................................. 8
Figure 5: Highest Max and Lowest Min Temp and Rainfall for Lahore (Source: Pakistan Meteorological Dept) ................................................................. 9
Figure 6: Thermal Comfort Chart of Lahore (Source: Weatherspark.com) ..................... 10
Figure 7: Humidity Comfort Chart of Lahore (Source: Weatherspark.com) ................ 10
Figure 8: Global Climate Risk Index 2000-2019 (Source: Germanwatch) ................. 12
Figure 9: Floods caused due to Monsoon Rains in Pakistan (Source: CNN- July 2018) . 13
Figure 10: Sink Hole created due to heavy rainfalls in Lahore (Source: CNN- July 2018) ......................................................................................................................... 13
Figure 11: Exterior Wall of the Lahore Fort collapsed due to heavy rainfalls (Source: CNN- July 2018) ............................................................................................................... 14
Figure 12: The Walled City in the context of Metropolitan Lahore (Source: Masood Khan) ......................................................................................................................... 16
Figure 13: Aerial View of the Lahore Fort Complex (Source: AKCSP) ......................... 17
Figure 14: Rooms added over Sheesh Mahal during the Sikh Period (Source: Kamran 2015) ......................................................................................................................... 17
Figure 15: Pavilion Aath Dara outside Shah Burj Complex (Source: Kamran 2015) .... 18
Figure 16: Lahore Fort Complex. (Source: UNESCO 2019) ......................................... 19
Figure 17: Aerial view of the Sheesh Mahal Complex (Source: Archnet) ...................... 20
Figure 18: Aerial view of the Sheesh Mahal Complex (Source: AKCSP) ....................... 20
Figure 19: Ground Floor Plan of the Sheesh Mahal Complex (Source: Aga Khan Cultural Services Pakistan-AKCSP) ................................................................. 23
Figure 20: Basement Plan of the Sheesh Mahal Complex (Source: AKCSP) ................. 23
Figure 21: Facade of the main hall opening into the courtyard (Source: Archnet) ....... 24
Figure 22: Facade of the Sheesh Mahal (Source: Sharma et.al.2005) ......................... 24
Figure 23: Main hall of the Sheesh Mahal (Source: Archnet) ....................................... 25
Figure 24: Main hall of the Sheesh Mahal (Source: The Getty) ................................. 25
Figure 25(left): Section of the Sheesh Mahal Complex looking North (Source: AKCSP) .... 26
Figure 26(right): Section of the Sheesh Mahal Complex looking East (Source: AKSCP) ......................................................................................................................... 26
Figure 27(left): Section of the Sheesh Mahal Complex looking West (Source: AKCSP) 27
Figure 28(right): Section of the Sheesh Mahal Complex looking South (Source: AKCSP) ......................................................................................................................... 27
Figure 29(left): West Elevation- Sheesh Mahal Complex (Source: AKCSP) .................. 28
Figure 30(right): North Elevation- Sheesh Mahal Complex (Source: AKCSP) ............. 28
Figure 31(left): West Elevation- Summer Palace (Source: AKCSP) ............................ 29
Figure 32(right): North Elevation- Summer Palace (Source: AKCSP) ....................... 29
Figure 33: Mirror work on the walls of Sheesh Mahal (Source: The Getty) ...................... 30
Figure 34: Marble Jali (Source: Kabir et al) ........................................................................ 30
Figure 35: Pietra dura on the marble columns (Source: Kabir et al) .............................. 30
Figure 36: Mughal Wooden Beams used in Sheesh Mahal roof (Source: AKCSP) ....... 31
Figure 37: Size of Mughal bricks used in the Sheesh Mahal (Source: Kamran et al.) .... 32
Figure 38: XRD pattern of the Mughal brick samples with peaks of quartz, albite, feldspar, hematite, and muscovite minerals (Source: Gular et al.) .......................... 32
Figure 39: Chemical Composition of Mughal Bricks (Source: Gulzar et al.) ................. 33
Figure 40: Elemental Composition of Mughal Bricks determined by SEM-EDS (Source: Gulzar et al.) ................................................................................................................... 33
Figure 41: Mughal Brick sample BSE-SEM micrograph (Source: Gulzar et al.) .......... 34
Figure 42: Mughal Brick Sample EDS spectrum (Source: Gulzar et al.) ...................... 34
Figure 43: Materials used for making traditional lime plaster and their purpose (Source: Kabir et al) ........................................................................................................................................ 36
Figure 44: Mortar samples from Sheesh Mahal water pond in the courtyard (left) and water channel on the roof (right) believed to be from the Sikh Period (Source: Kabir et al) .................................................................................................................. 36
Figure 45: Photomicrographs of mortar from Sheesh Mahal Water Pond from the Sikh Period (Source: Kabir et al) .................................................................................................................. 36
Figure 46: Photomicrographs of mortar from water channels on Sheesh Mahal roof from the Sikh Period (Source: Kabir et al) ................................................................................................................................. 37
Figure 47: Petrographic composition of Sheesh Mahal mortars from the Sikh Period (Source: Kabir et al) ................................................................................................................................. 37
Figure 48: XRD of water pond on the floor of Sheesh Mahal's roof (Source: Kabir et al) ........................................................................................................................................ 37
Figure 49: Courtyard of the Sheesh Mahal Complex (Source: Khan 2011) .................... 39
Figure 50: Courtyard of Sheesh Mahal (Source: Kamran 2015) .................................. 40
Figure 51: Sheesh Mahal Complex Axonometric Diagram. (Source: Kassim 2016) ...... 40
Figure 52: Sheesh Mahal Courtyard looking North (Source: Lahore Fort Master Plan 2019) ................................................................................................................................. 41
Figure 53: Sheesh Mahal cross-sectional diagram showing water flows. (Source: Kassim et al.) .................................................................................................................................................. 42
Figure 54: Water and Wind Flows in the Sheesh Mahal Complex (Source: Kassim et al.) .................................................................................................................................................. 42
Figure 55: Location of water source on every niche at the central masonry wall in Sheesh Mahal Basement (Source: Kassim et al) ................................................................................................................................. 43
Figure 56: Basement Plan of Sheesh Mahal showing water walls. (Source: Kassim et al.) .................................................................................................................................................. 44
Figure 57(left): Funnel with a side tube to illustrate the Bernoulli effect. Source: (Fathy 1986) ........................................................................................................................................ 45
Figure 58(right): Ventilation path running between solid portions of the underground Complex. Source: (Khan 2011) ................................................................................................................................. 45
Figure 59: Mashrabiy in Sheesh Mahal. (Source: Chaudhry 2004) .............................. 46
Figure 60: Floor Plan of Sheesh Mahal Basement and central masonry mass. (Source: Kassim et al.) .................................................................................................................................................. 48
Figure 61: Sheesh Mahal Basement Chambers (Source: Aown Ali 2012)............................. 50
Figure 62: Wind Tunnel in Sheesh Mahal Basement Chambers (Source: Aown Ali 2012) ................................................................. 50
Figure 63: Sheesh Mahal Basement Chambers (Source: Aown Ali 2012)............................. 51
Figure 64: Sheesh Mahal Basement Chambers (Source: Aown Ali 2012)............................. 51
Figure 65: Airflow and Temperature Profiles of Sheesh Mahal Basement with entered air velocity of 2.5 m/s (Source: Kassim et al.) ................................................................. 52
Figure 66: Cross-sectional temperature of the central wall (Source: Kassim et al.) .... 53
Figure 67: Temperature analysis across the central masonry wall in the Basement of Sheesh Mahal (Source: Kassim et al.) ................................................................. 53
Figure 68: Conservation of the roof through supports (Source: Kamran 2015) .... 55
Figure 69: British structure to support the Mughal beams (Source: Kamran 2015) .... 56
Figure 70: Visibly rotten beams showing damage to the roof of Sheesh Mahal (Source: Lahore Fort Master Plan 2019) ................................................................. 56
Figure 71: Deteriorated cornice and exposed masonry in Sheesh Mahal (Source: Lahore Fort Master Plan 2019) ................................................................. 57
Figure 72: Restoration of the roof of Sheesh Mahal 2021 (Source: AKCSP) ............. 57
Figure 73: Rotten beams of the Sheesh Mahal roof replaced 2021. (Source: AKCSP) ... 58
Figure 74: Restoration of Sheesh Mahal Roof 2021 (Source: AKCSP) ......................... 59
Figure 75: Sheesh Mahal Attic Chambers before (left) and after (right) recent 2021 restoration (Source: AKCSP) ................................................................. 59
Figure 76: Conservation of the basement chambers (Summer Palace) under the Sheesh Mahal Complex (Source: AKCSP) ................................................................. 60
Figure 77: Conservation of the basement chambers (Summer Palace) under the Sheesh Mahal Complex (Source: AKCSP) ................................................................. 60
Figure 78: Projected Change in Monthly Temperature of Pakistan for 2080-2099 (Source: World Bank) ................................................................. 62
Figure 79: High-temperature events and their potential impacts on masonry construction (Source: Author) ................................................................. 64
Figure 80: Cracks in masonry (Source: AKCSP) ................................................................. 65
Figure 81: structural cracks in masonry (Source: AKCSP) ................................................................. 65
Figure 82: Change in Cooling Degree Days in Pakistan for 2040-2059 (Source: World Bank) ................................................................. 66
Figure 83: Projected Change in Monthly Precipitation of Pakistan for 2080-2099 (Source: World Bank) ................................................................. 68
Figure 84: High Precipitation Events and their Impacts on Masonry Construction (Source: Author) ................................................................. 69
Figure 85(left): Deterioration of exterior masonry wall due to moisture infiltration (Source: AKCSP) ................................................................. 70
Figure 86(right): Deterioration of exterior masonry wall due to moisture infiltration (Source: AKCSP) ................................................................. 70
Figure 87: Deterioration of masonry at the top due to rainwater penetration (Source: AKCSP) ................................................................. 71
Figure 88: Deteriorated masonry due to rising damp (Source: AKCSP) ......................... 71
Figure 89: Deterioration of exterior masonry wall due to pollution and water damage (Source: AKCSP) ................................................................. 72
Figure 90: Potential impacts of pollution on masonry construction (Source: Author) .... 73
Figure 91: Weathering and erosion of exterior masonry wall in Lahore Fort (Source: Kamran 2015) .............................................................................. 74
Figure 92: Potential impacts of wind events on masonry construction (Source: Author) 76
Figure 93: Desertification and its potential impacts on masonry construction (Source: Author) ........................................................................ 76
Figure 94: Biogrowth on exterior masonry surface (Source: AKCSP) ....................... 76
Figure 95: Deterioration of wood beams in Sheesh Mahal Roof due to rot (Source: AKCSP) .............................................................................. 77
Figure 96: Potential impacts of biogrowth on masonry construction (Source: Author) 78
Figure 97: Potential impacts of earthquake on masonry construction (Source: Author) 80
Figure 98: Lahore Fort Buffer Zone (Source: Archnet) ....... 82
Figure 99: Lahore Fort Buffer Zone (Source: Lahore Fort Master Plan 2019) ............ 82
Figure 100: Flooding of the Lahore Fort during the Monsoon season 2020 (Source: AKCSP) .............................................................................. 84
Figure 101: Stagnant water in Shah Jahan Quadrangle (Source: AKCSP) ................. 84
Figure 102: Proposed Site Plan for Sheesh Mahal Basement (Source: Lahore Fort Master Plan) ................................................................. 86
Figure 103: Proposed Museum Plan for the Sheesh Mahal Basement (Source: Lahore Fort Master Plan 2017-2019) ............................................ 87
Figure 104: Basement Chambers being used for a conference (Source: AKCSP) ....... 87
Figure 105: Basement Chambers being used for an exhibition (Source: AKCSP) ....... 87
Figure 106: Disaster Risk Management Cycle. (Source: Managing Disaster Risks for World Heritage. UNESCO, 2010.) ........................................... 98
Figure 107: Managing Disaster Risks for World Heritage. (Source: Managing Disaster Risks for World Heritage. UNESCO, 2010) ......................... 98
Figure 108: Tools to build Resilience (Source: G20 2019 Japan) ............................ 101
## LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AKCSP</td>
<td>Aga Khan Cultural Services Pakistan</td>
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<tr>
<td>AKDN</td>
<td>Aga Khan Development Network</td>
</tr>
<tr>
<td>AKTC</td>
<td>Aga Khan Trust for Culture</td>
</tr>
<tr>
<td>ASHRAE</td>
<td>American Society of Heating, Refrigerating and Air Conditioning Engineers</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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DEFINITIONS

Building Envelope: The exterior shell of a building that separates the interior from the exterior.

Climate Change: A change in global or regional climate patterns and attributed to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.

Disaster: For the purposes of this thesis, disaster is defined as an accident or natural catastrophe that causes great damage to a building or a cultural heritage site.

Emergency: An unforeseen combination of circumstances or the resulting state that calls for immediate action.

Hazard: For the purposes of this thesis, hazard is defined as any phenomenon, substance, or situation, which has the potential to cause disruption or damage to a building.

Microclimate: A microclimate is a local set of atmospheric conditions that differ from those in the surrounding areas, often with a slight difference but sometimes with a substantial one.

Mitigation: For the purposes of this thesis, mitigation is defined as the action of reducing the severity of damage or deterioration caused to a building or a cultural heritage resource.

Passive Design: For the purposes of this thesis, passive design is defined as traditional, sustainable building design strategies that favor the use of available climatic resources such as the sun, rain, or wind.

Passive Cooling: A building design approach that focuses on heat gain control and heat dissipation in a building in order to improve indoor thermal comfort with low or no energy consumption.
Prevention: For the purposes of this thesis, prevention is defined as the act of reducing risks or factors that cause a building to deteriorate.

Response: The reaction to an incident or emergency to assess the damage or impact to the site and its components, and actions taken to prevent people and the property from suffering further damage.

Risk: For the purposes of this thesis, risk is defined as a situation or substance that causes physical harm to a building or a cultural heritage site.

Regional Architecture: for the purposes of this thesis, regional architecture is defined as architecture relating to, or characteristic of a region, relying on specific knowledge of climate, building materials, and technology, geography, topography, and culture.

Sustainable Design: For the scope of this thesis, sustainable design is defined as design that learns from the traditional building strategies, contextualizes those strategies for the present use, while considering climate change predictions for the future and making them resilient for the future.

Traditional Buildings: For the purposes of this thesis, traditional buildings are defined as buildings that use common, regional, and local forms, materials, and building knowledge in construction.

VerSus: VerSus is the acronym for Vernacular Heritage Sustainable Architecture. VerSus research project was based on the identification of strategies and principles within the vernacular heritage, to define a conceptual approach for sustainable architectural design.

Vulnerability: For the purposes of this thesis, vulnerability is defined as the state of a building or a cultural heritage site to be exposed to damage or deterioration.
Mashrabiya: A perforated, carved latticed screen.

Jali: A perforated, carved latticed screen.

Biofilm: A thin, slimy film of bacteria that adheres to a surface.

Blistering: Swelling accompanied by rupturing of a thin uniform skin both across and parallel to the bedding plane.

Crazing: The formation of a pattern of tiny cracks or crackles in the glaze of glazed terra cotta.

Delamination: A condition of stone in which the outer surface of the stone splits apart into laminae or thin layers and peels off the face of the stone.¹

Deterioration: The process of becoming impaired or inferior in quality, function, or condition.

Disintegration: The process of losing cohesion or strength.

Efflorescence: Migration of salts to the surface of a material in the form of whitish, powdery, or whisker-like crystals.

Encrustation: Growth or accumulation of materials (such as pollutants, salts, biofilm) on the surface of a material.

Erosion: Wearing away of the surface, edges, corners, or carved details of masonry slowly and usually by the natural action of wind or windblown particles and water.

Exfoliation: Peeling, scaling, or flaking off of the surface of stone in thin layers.

Flaking: Detachment of small, flat, thin pieces of the outer layers of masonry from a larger piece.

Rising Damp: The suction of groundwater into the base of masonry walls through capillary action.

Salinization: The process by which water-soluble salts accumulate in the soil.

Scaling: A condition of deterioration in which the material starts to come off in scales or thin pieces.

Settling/Settlement: to move downwards; sink or descend, especially gradually.

Spalling: A condition of masonry in which lens-shaped fragments detach partially or completely from the larger block.

Sub-florescence: Accumulation of water-soluble salts that recrystallize just beneath the masonry surface.

Sugaring: Granular disintegration of masonry is usually caused by salts dissolved in and transported through moisture.

Weathering: Natural disintegration and erosion of masonry caused by wind, rain, and resulting in granular and rounded surfaces.
1. INTRODUCTION

1.1. Thesis Statement

This research explores the traditional passive climate-control strategies that have been used in Pakistan’s traditional brick masonry construction to mitigate its hot arid climate and considers how these design solutions can be preserved and adapted in the rehabilitation of these historic masonry structures. The research further investigates the capacity and resiliency of these age-old strategies to perform under changing climate conditions and recommends methods to improve their performance.

The Sheesh Mahal Complex in Lahore Fort a case study to analyze the traditional regional form of passive cooling and the impacts of climate change on its performance efficacy. The Complex was built as a royal residence during the Mughal Period in the 16th century and incorporates hydraulic engineering, architectural design, and urban planning all together as an integrated whole. The research further examines how its current restoration can incorporate the existing passive environmental systems as part of a more sustainable conservation and management plan.

The research has also collected existing climate data on Lahore and investigated how one or more particular historic masonry traditions have addressed passive environmental climate control. Critical to this effort was an assessment of whether these solutions will remain effective under rapidly changing climate conditions. The research addressed issues of sustainability, climate change, measuring micro-climates, regional contexts, building envelopes, design interventions, adaptive reuse of historic buildings, and developing more sustainable design practices for historic preservation.
1.2. Significance of the Study

Pakistan is among the 10 countries that will be most affected by climate change. While the country contributes less than 1 percent of the world's greenhouse gases responsible for causing global warming, its 200 million people are among the world's most vulnerable victims of the growing consequences of climate change. The IPCC projects a global average temperature increase by 2081–2100 of 3.7°C under the highest emissions pathway (RCP8.5) whilst the model ensemble projects an average increase of 4.9°C for Pakistan in the same scenario. The projected rise in annual maximum temperatures is estimated at 5.24°C. To summarize, mean rainfall in the arid plains of Pakistan has decreased by 10-15%. The number of heavy rainfall events has increased. The number of hot days and nights has increased while the number of cold nights has decreased. The nation is facing ever-rising temperatures, drought, and flooding that present serious threats to the country's rich built heritage.

This research contributes to advancing best practices in preserving Lahore’s local masonry buildings by reinforcing their design benefits as sustainable architecture and making recommendations to improve their existing passive cooling strategies by improving their existing technology. These recommendations could potentially result in more appropriate interventions in historic buildings as well as applying the lessons learned to new contemporary design. The research addresses issues of sustainability, climate change, micro-climates, regional contexts, building envelopes, design interventions, adaptive reuse of historic buildings, and developing more sustainable design practices for historic preservation.

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Most new buildings create their interior climate through expensive mechanized climate control systems, often based on fossil fuel-derived energy. Existing regional and vernacular traditions have long addressed issues of mitigating or controlling building climate through passive means, thereby providing valuable lessons in the consideration and adaptation of passive solutions for new sustainable design. Given new methods to calculate and model a building’s environment-existing or proposed architecture can be analyzed to identify passive strategies for climate control. Considering climate change predictions and the large numbers of existing traditional buildings that will need to play a role in achieving net-zero carbon, sustainable solutions for a given region must look to its vernacular traditions for a more contextual, low-cost solution that is resource responsible and contributes to regional identity.

1.3. Research Methodology

This research is comprised of three phases. Phase 1- Literature Review: Compilation and analysis of research on the traditional masonry construction of Pakistan, collecting data on the climate of Pakistan and specifically Lahore, and researching predictions for climate change in the region. Phase 2- Case Study Analysis: analyzing the impacts of climate change on traditional brick masonry construction by using Sheesh Mahal as a case study. Phase 3- Assessment and Recommendations: providing recommendations for further research to mitigate the impacts of climate change on traditional brick masonry construction.
1.4. Research Diagram

This thesis proposes to study traditional climate-control strategies used in historic brick masonry construction in a hot arid climatic region in Pakistan to identify and analyze these design solutions and preserve and adapt, where appropriate, these methods in the rehabilitation of these structures.

(Source: Author)
2. CLIMATE CHANGE IN PAKISTAN

2.1. Climate of Pakistan

Pakistan lies in the temperate zone. The climate is generally arid, characterized by hot summers and cool or cold winters (Figures 1 and 2). The country experiences a mean annual temperature of 20.01 °C and a mean annual precipitation of 301.71mm (Figure 3). Average monthly temperatures for Pakistan are generally higher during the summer months from May to September. According to the World Bank, warming in Pakistan was estimated at 0.57 °C over the 20th century but has accelerated more recently, with 0.47 °C of warming measured between 1961–2007.³ The country receives very little rainfall. Since 1960, mean rainfall in the arid plains of Pakistan has decreased by 10-15% but the number of heavy rainfall events has increased. Heavy Monsoon rains during July and August, often result in flooding and present significant challenges to the infrastructure and built heritage in the county.

³ Climate Data on Pakistan is collected from The World Bank Climate Change Knowledge Portal. https://climateknowledgeportal.worldbank.org/country/pakistan
Figure 1: Annual Temperature of Pakistan for 1901-2016 (Source: World Bank)

Figure 2: Annual Rainfall of Pakistan for 1960-2016 (Source: World Bank)
2.2. Climate of Lahore

Lahore lies 217m above sea level and its climate is hot and dry for most of the year (Figure 4, 5). The winds are hot and full of dust during the daytime and cooler at night. Lahore experiences hot and dry weather during March and April. The heat reaches its peak during May and June when the weather is at its hottest and driest. During these months, the heat is oppressive; the humidity level is low with very hot and dry winds. From July to September, the region receives Monsoon rains which increase the relative humidity from 25% to more than 60%. The weather is cool and pleasant when it rains, otherwise, it is hot and humid. The high temperature during these months along with excessive humidity makes the weather very exhausting. After the end of the Monsoon season, the weather remains warm and dry during October and November. The extreme dryness during these months causes a lot of dust and haziness in the environment. From December to February, the region experiences pleasant, cool, and sunny weather, with a peak high of 20 °C and a peak low of 6 °C.4

Figure 3: Average Monthly Temperature and Rainfall of Pakistan for 1991-2016 (Source: World Bank)

Figure 4: Average Monthly Temperature and Rainfall of Lahore for 1991-2016 (Source: World Bank)
### Lahore (1931-2018)

<table>
<thead>
<tr>
<th>Month</th>
<th>Temperature (°C)</th>
<th>Monthly Heaviest Rainfall in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Highest Maximum</td>
<td>Lowest Minimum</td>
</tr>
<tr>
<td>Jan</td>
<td>27.8 (23/1952)</td>
<td>-2.2 (17/1935)</td>
</tr>
<tr>
<td>Feb</td>
<td>33.3 (27/1953)</td>
<td>0.0 (02/1934)</td>
</tr>
<tr>
<td>Mar</td>
<td>37.8 (26/1942)</td>
<td>2.8 (05/1948)</td>
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<td>Apr</td>
<td>46.1 (26/1941)</td>
<td>10.0 (01/1948)</td>
</tr>
<tr>
<td>May</td>
<td>48.3 (30/1944)</td>
<td>14.0 (14/1977)</td>
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<tr>
<td>Jun</td>
<td>47.2 (08/1972)</td>
<td>18.0 (04/1977)</td>
</tr>
<tr>
<td>Jul</td>
<td>46.1 (03/1945)</td>
<td>20.0 (04/1974)</td>
</tr>
<tr>
<td>Aug</td>
<td>42.8 (02/1947)</td>
<td>19.0 (10/1988)</td>
</tr>
<tr>
<td>Sep</td>
<td>41.7 (16/1938)</td>
<td>16.7 (23/1972)</td>
</tr>
<tr>
<td>Oct</td>
<td>40.6 (07/1951)</td>
<td>8.3 (31/1949)</td>
</tr>
<tr>
<td>Nov</td>
<td>35.0 (03/1943)</td>
<td>1.7 (30/1982)</td>
</tr>
<tr>
<td>Dec</td>
<td>30.0 (07/1998)</td>
<td>-1.1 (28/1950)</td>
</tr>
<tr>
<td>Annual</td>
<td>48.3 (30/05/1944)</td>
<td>-2.2 (17/01/1935)</td>
</tr>
</tbody>
</table>

*event occurred 5 times

*Figure 5: Highest Max and Lowest Min Temp and Rainfall for Lahore (Source: Pakistan Meteorological Dept)*

### 2.3. Climate and Comfort

ASHRAE defines comfort as “the condition of mind that expresses satisfaction with the thermal environment; it requires subjective evaluation”.

The factors that affect the comfort of a human body can be divided into three categories: Environmental (temperature, humidity, wind, radiation), Personal (metabolic rate, activity, clothing), and Contributing Factors (food, age, gender, body shape, state of health, etc.).

The environmental factors are impacted by the climate, such as air temperature, air movement, humidity, radiation.

The thermal comfort index of Lahore varies from sweltering hot during summer months to cold during winter months (Figure 6). Similarly, the humidity comfort index of Lahore varies from miserable during the summer months to comfortable during the winter months (Figure 7).

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5 Andris Auliciems et al., *Thermal Comfort* (Brisbane: PLEA, 1997).
6 Ibid.
These thermal and humidity comfort levels are important to understand since they dictate how buildings are designed to achieve comfortable environments for human occupancy.

Figure 6: Thermal Comfort Chart of Lahore (Source: Weatherspark.com)

Figure 7: Humidity Comfort Chart of Lahore (Source: Weatherspark.com)
2.4. Thermal Comfort in Traditional Buildings

Climate and culture have influenced traditional architecture for centuries. Historic buildings have traditionally tried to manipulate climate through conscious modifications of microclimates in and around the buildings. Hasan Fathy identified the elements in traditional buildings which create a specific microclimate for each site. These elements (also known as microclimate moderators) include the configuration of buildings, their orientations, and arrangement in space, the design of open spaces such as streets, courtyards, gardens, and squares, building materials, surface textures, and colors of exposed surfaces of buildings. Fathy argues that these man-made elements interact with the natural microclimate to determine the factors affecting the comfort of the built environment: light, heat, wind, and humidity.

Traditional buildings are designed to achieve comfort through passive design strategies, such as courtyards, wind channels, thermal mass, evaporative cooling. These architectural strategies are identified in the Sheesh Mahal Complex and discussed in detail in the next chapters. Further research is required to understand the impacts of climate change on these microclimate moderators in traditional buildings. As the climate changes, extreme weather events could impact the efficiency and even limits of these traditional strategies. It is therefore important to include mitigation measures in the conservation management of these traditional buildings.

2.5. Climate Change in Pakistan

Pakistan is vulnerable to climate change and its impacts such as fluctuations in temperatures, variations in precipitation, droughts, floods, and environmental pollution.

According to the Global Climate Risk Index 2021 released by Germanwatch, Pakistan is among the 10 countries that were most affected by climate change from 2000-2019 (Figure 8).9

According to the World Bank Climate Change Projections, temperature increases in Pakistan are significantly higher than the global averages.10 The IPCC projects a global average temperature increase by 2081–2100 of 3.7°C under the highest emissions pathway (RCP8.5) while the model ensemble projects an average increase of 4.9°C for Pakistan in the same scenario. The projected rise in annual maximum temperatures is estimated at 5.24°C. To summarize, mean rainfall in the arid plains of Pakistan has decreased by 10-15% while the number of heavy rainfall events has increased. The number of hot days and nights has increased while the number of cold nights has decreased.

![Figure 8: Global Climate Risk Index 2000-2019 (Source: Germanwatch)](image)

9 Eckstein et al., *Global Climate Risk Index 2021 Who Suffers Most Extreme Weather Events?*
Figure 9: Floods caused due to Monsoon Rains in Pakistan (Source: CNN - July 2018)

Figure 10: Sink Hole created due to heavy rainfalls in Lahore (Source: CNN - July 2018)
Figure 11: Exterior Wall of the Lahore Fort collapsed due to heavy rainfalls (Source: CNN- July 2018)
3. CASE STUDY: THE SHEESH MAHAL COMPLEX, LAHORE FORT

3.1. Historical Background

The Lahore Fort, commonly known as Shahi Qila, is situated in the northwest corner of Lahore’s historic core, also known as the Walled City of Lahore (Figure 12). The river Ravi, which now flows along the north-western edge of modern-day Lahore, historically once flowed along the edges of the Walled City, flowing south-west around the Fort. The Sheesh Mahal represents over 398 years: across the Mughal Period, Sikh Period, British Period up to the present day. Although its origin is undocumented, the present fortifications of the Lahore Fort were begun by the Mughal Emperor Akbar in the late 16th century. The Fort was successively added to, enriched, and transformed by emperors Jahangir, Shah Jahan, and Aurangzeb. The Sheesh Mahal Complex (Palace of Mirrors or Crystal Palace) was used by the Mughal Emperor Shah Jahan during 1631-32 A.D. as the Emperor’s residence when he stayed in Lahore. After the death of the emperor Aurangzeb, Sikhs rose to power in the second half of the 18th century. Under the rule of Maharaja Ranjit Singh and his successors, many transformations were carried out in the Lahore Fort including the Sheesh Mahal Complex and its upper story. During this period various structures were added to the roof by Maharaja Ranjit Singh, Sher Singh, and Nao Nihal Singh (Figure 14). A pavilion, Athdara, was built outside the Shah Burj Complex later during the Sikh Period and was used by the emperor to appear before an audience (Figure 15). In 1849, the British Military occupied the Fort and made several modifications, alterations to the structures inside the Fort. The 21 monuments that survive within the boundaries of the Fort compose an outstanding repository of the Fort’s multifaceted history and varied forms of Mughal architecture (Figure 13). Collectively, as part of the larger Lahore Fort Complex, these monuments have been inscribed as UNESCO world heritage since 1981.

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Figure 12: The Walled City in the context of Metropolitan Lahore (Source: Masood Khan)
Figure 13: Aerial View of the Lahore Fort Complex (Source: AKCSP)

Figure 14: Rooms added over Sheesh Mahal during the Sikh Period (Source: Kamran 2015)
3.2. Site Context

The Sheesh Mahal Complex, situated inside the Shah Burj Quadrangle, is located in the extreme northwest corner of the Lahore Fort (Figure 16, 17). The Shah Burj Quadrangle comprises various pavilions centered around a courtyard. During Jahangir’s period, work began on the Shah Burj Quadrangle, but after his death, the comprehensive redesign of Shah Burj and the overlays and replacements in most of the earlier constructions were carried out under Shah Jahan. These complex designs represent Shahjhanani style architecture, characterized by complexity, symmetry, and intricacies in ornamentation and architectural details. Shah Jahan defied the rectangular envelope of the earlier Fort and introduced a new architectural idiom, a large rectangle with a half octagon at its north protruding from the confines of the old apron wall at the north-western corner of the Fort. The Sheesh Mahal Pavilion is located on the north side of the Quadrangle. For the purposes of this thesis, the Sheesh Mahal Pavilion including the mirrored
hall and rooms towards the north, and the basement chambers have been referred to as the Sheesh Mahal Complex (Figure 18).

The Circular Road existed towards the North of the Complex, which was re-routed to create a green buffer zone for the Fort in 2016. The Walled City of Lahore expands towards the South of the Fort. On the East, there is Circular Road, Kashmiri Gate, and area of Badami Bagh Lahore, while Badshahi Mosque exists towards the West side of the Complex.

Figure 16: Lahore Fort Complex. (Source: UNESCO 2019)
Figure 17: Aerial view of the Sheesh Mahal Complex (Source: Archnet)

Figure 18: Aerial view of the Sheesh Mahal Complex (Source: AKCSP)
3.3. Physical Description

The Sheesh Mahal Complex is built on a semi-octagonal plan (Figure 19, 20), approx. 30 feet above grade and comprises series of dalans (loggias), verandahs (porticos), and pavilions around an open courtyard with a central water body. The courtyard is paved with variegated marble. The main entrance to the Shah Burj inner court is provided through a big arched gateway in the shape of an ornate vestibule. The interior is treated with fresco panels. The spacious central Dalan has the main verandah (hall R1) 26.5 feet wide and 67.5 feet long that opens into the courtyard through a marble arcade with openings of multifold arches (Figure 21,22). The ceiling of the main hall is decorated with aiena kari (mirror work) that dates back to the Mughal period, while the mosaic on the walls is believed to be from the Sikh Period (Figure 23,24,33).\textsuperscript{12} At the back are rooms that historically overlooked the river Ravi and were used by the emperors as residences. The roof of the central hall rises to two stories. The side rooms at the front are double storied. The central portion of the façade comprises five cusped marble arches supported by coupled columns whose bases are inlaid with precious stones. The interior of the spandrels over the arches is adorned with pietra dura (Figure 35). The Complex has many openings facing north and south which allow the north prevailing winds to enter. The north and west elevations of the Complex overlook the fortification wall, also known as the Picture Wall. The north wall of the Palace in the central chamber has a large marble screen with a Jali pattern (Figure 34).

Below the Complex are basement chambers, which were used by the emperors and their families as residences during hot summer months. The basement of the Sheesh Mahal was constructed under the reign of two emperors Jahangir and Shah Jahan. Before the construction of

the Sheesh Mahal, there was a need to stabilize the lower basement walls which were deteriorating rapidly. A retaining wall, also known as the Picture Wall, was constructed to stabilize the basement. The Picture Wall extends from the Western façade of the Complex to the North façade. The Sheesh Mahal Complex was constructed on top of this heavily ornamented Picture Wall. The basement chambers below the Complex are incorporated with sophisticated passive cooling design strategies: wind channels, water walls, thermal mass, etc. to achieve thermal comfort. The basement chambers have recently been conserved and are currently being used for various exhibition purposes.

Figure 19: Ground Floor Plan of the Sheesh Mahal Complex (Source: Aga Khan Cultural Services Pakistan-AKCSP)

Figure 20: Basement Plan of the Sheesh Mahal Complex (Source: AKCSP)
Figure 21: Facade of the main hall opening into the courtyard (Source: Archnet)

Figure 22: Facade of the Sheesh Mahal (Source: Sharma et al.2005)
Figure 23: Main hall of the Sheesh Mahal (Source: Archnet)

Figure 24: Main hall of the Sheesh Mahal (Source: The Getty)
Figure 25(left): Section of the Sheesh Mahal Complex looking North (Source: AKCSN)

Figure 26(right): Section of the Sheesh Mahal Complex looking East (Source: AKSCP)
Figure 27: Section of the Sheesh Mahal Complex looking West (Source: AKCP)
Figure 29(left): West Elevation - Sheesh Mahal Complex (Source: AKCSP)

Figure 30(right): North Elevation - Sheesh Mahal Complex (Source: AKCSP)
Figure 31(left): West Elevation- Summer Palace (Source: AKCSP)

Figure 32(right): North Elevation- Summer Palace (Source: AKCSP)
3.4. Construction

The Sheesh Mahal is a brick masonry structure constructed with burnt Mughal bricks covered with lime plaster. The columns are made of white marble and adorned with semi-precious stones at the base. The main hall of the Sheesh Mahal is approx. 26.5’ x 67.5’ in dimensions. The roof of the Sheesh Mahal was originally made of massive wooden beams approx. 14” x 14” in cross-section.
and spaced about 28” spanning from the front wall to the back wall (Figure 36). A bamboo lath was fastened to the beams and covered by a layer of lime plaster varying from two to more than six inches in thickness. Mirrors were attached to this plaster.14

![Figure 36: Mughal Wooden Beams used in Sheesh Mahal roof (Source: AKCSP)](image)

3.5. Masonry Characterization

The Sheesh Mahal Complex masonry is composed of low-fired bricks approx. 7” long, 5.5” wide, and 1” thick laid in a lime mortar (Figure 37).15 The Complex was constructed over the reign of two Mughal Emperors, Jahangir, and Shah Jahan. Even though the bricks appear similar, studies show a difference in their strength from the two periods. The bricks from the Jahangir period have an average strength of 57871 psi, while those from the Shah Jahan Period have an average strength of 12566 psi.16

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15 Ibid.
16 Ibid.
The chemical and mineralogical characterization of Mughal bricks shows that the bricks were mainly composed of SiO$_2$, Al$_2$O$_3$, and Fe$_2$O$_3$ with low amounts of Na$_2$O, K$_2$O, MgO, and trace amounts of calcium compounds (Figure 38-42). The estimated temperature range of these bricks is 850-900 °C based on the mineral transformation and microstructure studies conducted. The absence of high-temperature products (mullite and cristobalite) peaks reveals that the temperature did not exceed 900 °C. Additionally, these bricks are characterized as low density and high porosity under scanning electron microprobe. Furthermore, studies reveal that the soil of Lahore is composed of clay, silt, and fine sand fractions.

Figure 38: XRD pattern of the Mughal brick samples with peaks of quartz, albite, feldspar, hematite, and muscovite minerals (Source: Gulzar et al.)
Figure 39: Chemical Composition of Mughal Bricks (Source: Gulzar et al.)

Figure 40: Elemental Composition of Mughal Bricks determined by SEM-EDS (Source: Gulzar et al.)
Figure 41: Mughal Brick sample BSE-SEM micrograph (Source: Gulzar et al.)

Figure 42: Mughal Brick Sample EDS spectrum (Source: Gulzar et al.)
3.5.1. Mortar Analysis

The mortar used in the Sheesh Mahal Complex is made of lime, which was traditionally prepared by burning kankar, a type of clay, mixed with curd, Dal Urd (pulse), San (jute fiber), Gond (plant gum), Gur (jaggery sugar), Batashe (raw sugar), Sirish-i-Kahi (glue), Bhus (straw) (Figure 43).\(^{19}\) Studies reveal that sand used for the mortars is fine-grain sand, composed mainly of quartz, with amounts of biotite, chlorite, muscovite, magnetite, zircon argillite, haematite/limonite, and illite/mica are present in a significant amount. The sand composition is comparable to the sand from River Ravi. To achieve the required gradation, kankar, brick pieces, and rarely slag, and possibly pieces of marble were used. Textural studies indicate that gypsum was not a primary constituent. Its presence may be due to atmospheric pollution.\(^{20}\)

Studies further reveal that the main components of the mortar are calcite and quartz, with minor accessory minerals such as illite/muscovite, albite, and gypsum. Gypsum and fluorite are believed to be secondary materials found due to anthropogenic agents, such as pollutants emitted by vehicles. The formation of calcite is related to the carbonation of lime in the mortar, while gypsum and nitrates are believed to have formed due to the action of sulfates and nitrates (Figure 44-48). Studies recommend new mortar composition consisting of sand, fine kankar, and course kankar in 1:1.3:1.5.\(^{21}\)

\(^{20}\) Ibid.
\(^{21}\) Ibid.
<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Materials</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Curd</td>
<td>Dahi used for soft finishing</td>
</tr>
<tr>
<td>2</td>
<td>Dal Urd</td>
<td>Pulse is used as plastersizer</td>
</tr>
<tr>
<td>3</td>
<td>San</td>
<td>Jute Fiber for better bonding</td>
</tr>
<tr>
<td>4</td>
<td>Gond</td>
<td>Gum from plants used as retarder</td>
</tr>
<tr>
<td>5</td>
<td>Gur</td>
<td>Jaggery sugar for hardening</td>
</tr>
<tr>
<td>6</td>
<td>Batashe</td>
<td>Raw sugar used as bonding agent</td>
</tr>
<tr>
<td>7</td>
<td>Sirish-i-Kahi</td>
<td>Glue increase bonding strength</td>
</tr>
<tr>
<td>8</td>
<td>Bhus</td>
<td>Straw used for reducing cracks</td>
</tr>
</tbody>
</table>

Figure 43: Materials used for making traditional lime plaster and their purpose (Source: Kabir et al)

Figure 44: Mortar samples from Sheesh Mahal water pond in the courtyard (left) and water channel on the roof (right) believed to be from the Sikh Period (Source: Kabir et al)

Figure 45: Photomicrographs of mortar from Sheesh Mahal Water Pond from the Sikh Period (Source: Kabir et al)
Figure 46: Photomicrographs of mortar from water channels on Sheesh Mahal roof from the Sikh Period (Source: Kabir et al)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Minerals</th>
<th>Mineral Percentage of Water Channel (Sample No.-4)</th>
<th>Mineral Percentage of Water Pond (Sample No.-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Illite/Mica</td>
<td>14.0</td>
<td>13.9</td>
</tr>
<tr>
<td>2</td>
<td>Carbonate</td>
<td>60.4</td>
<td>62.8</td>
</tr>
<tr>
<td>3</td>
<td>Gypsum</td>
<td>4.2</td>
<td>3.8</td>
</tr>
<tr>
<td>4</td>
<td>Quartz</td>
<td>12.8</td>
<td>10.5</td>
</tr>
<tr>
<td>5</td>
<td>Biotite</td>
<td>2.1</td>
<td>1.9</td>
</tr>
<tr>
<td>6</td>
<td>Chlorite</td>
<td>0.9</td>
<td>0.6</td>
</tr>
<tr>
<td>7</td>
<td>Muscovite</td>
<td>1.3</td>
<td>2.1</td>
</tr>
<tr>
<td>8</td>
<td>Haematite</td>
<td>1.9</td>
<td>1.7</td>
</tr>
<tr>
<td>9</td>
<td>Magnetite</td>
<td>1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>10</td>
<td>Zircon</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>11</td>
<td>Argilite</td>
<td>0.9</td>
<td>1.4</td>
</tr>
<tr>
<td>12</td>
<td>Flourite</td>
<td>Traces</td>
<td>Traces</td>
</tr>
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</table>

Figure 47: Petrographic composition of Sheesh Mahal mortars from the Sikh Period (Source: Kabir et al)

Figure 48: XRD of water pond on the floor of Sheesh Mahal's roof (Source: Kabir et al)
3.6. Passive Design in the Sheesh Mahal

The Sheesh Mahal Complex is designed with sophisticated passive cooling systems. These systems exhibit examples of intelligent, aesthetically pleasing, contextual, traditional techniques designed specifically for hot arid climates. It is important to study these passive systems in detail in order to preserve them, and to learn from these strategies so that they can be applied in contemporary architecture as low-cost, regional solutions to design comfortable spaces in hot arid regions.

3.6.1. Courtyard

The Mughal architecture incorporates strong geometric planning where buildings are arranged around a central courtyard. This arrangement has long been recognized as an environmental as well as aesthetic design device in hot-arid climates where there is a large diurnal temperature swing. The courtyard acts as a central gathering point and is often layered with water and vegetation to achieve thermal comfort and aesthetics. In hot arid regions, the use of courtyard typology is especially useful as temperatures drop significantly in the evening. The courtyard is incorporated into the architectural design as it provides a comfortable outdoor space for a social gathering after the sunset.

In the Sheesh Mahal Complex, the courtyard is used for ventilation through the stack effect. The air of the courtyard is heated directly by the sun and indirectly by the warm buildings throughout the day. During the evening, this warm air rises and is gradually replaced by the already cooled night air from above. This cool air accumulates in the courtyard in laminar layers.

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and seeps into the surrounding room, cooling them. Additionally, the courtyard is incorporated with a central water body to cool the ambient hot air. The floor of the courtyard is paved with stone slabs of variegated marble. Four water channels paved with Sang-e-Abri (red limestone) are believed to have carried water from the basin underneath principal buildings to keep them cool (Figure 49-52).

Figure 49: Courtyard of the Sheesh Mahal Complex (Source: Khan 2011)


Figure 50: Courtyard of Sheesh Mahal (Source: Kamran 2015)

Figure 51: Sheesh Mahal Complex Axonometric Diagram. (Source: Kassim 2016)
3.6.2. Water Bodies

In most traditional architecture in hot arid regions, water is used to modify the microclimate in and around the buildings through evaporative cooling and natural ventilation. Mughal Architecture is well known for its use of water in architecture and landscape for its functional, aesthetics, and environmental purposes. According to Fathy, water is important to increase the humidity and to promote thermal comfort in hot arid environments. Water is used to cool down the incoming hot air, which is then supplied to the interiors for evaporative cooling and ventilation.

The courtyard of the Sheesh Mahal Complex is designed with a central pool (16m x 16m x 15cm), decorated with pietra dura using semi-precious stones. Furthermore, the basement of the Complex is designed with a solid central masonry mass wall with 16 niches cut into the solid masonry mass (Figure 53,54). Each of these niches has a water wall, also known as *Salsabil*. The *Salsabil* is a marble plate that was historically placed at an angle against the wall inside a niche to permit water to trickle over it, thus facilitating evaporation and increasing the humidity of the surrounding air (Figure 55,56).

![Figure 53: Sheesh Mahal cross-sectional diagram showing water flows. (Source: Kassim et al.)](image)

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Figure 54: Water and Wind Flows in the Sheesh Mahal Complex (Source: Kassim et al.)
Figure 55: Location of water source on every niche at the central masonry wall in Sheesh Mahal Basement (Source: Kassim et al.)

Figure 56: Basement Plan of Sheesh Mahal showing water walls. (Source: Kassim et al.)
3.6.3. *Wind Channels*

In traditional building design, energy to cool a building during hot summer months is harvested from nature. In the design of wind channels, the technique of using the suction caused by low air pressure zones is used to generate steady air movement indoors (Figure 57). This principle is applied in the passive cooling design of the basement chambers of the Sheesh Mahal Complex. The ventilation paths running between the solid portions of the underground basements become narrow along the outer edges of the walls to accelerate air movement in the space (Figure 58).

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Figure 57(left): Funnel with a side tube to illustrate the Bernoulli effect. Source: (Fathy 1986)

Figure 58(right): Ventilation path running between solid portions of the underground Complex. Source: (Khan 2011)

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3.6.4. Mashrabiya

*Mashrabiya,* a characteristic feature of Islamic Architecture, is an opening with a lattice screen arranged often in a decorative and intricate geometric pattern. These screens control the passage of light and airflow, reduce the temperature of the air current and increase the humidity of the air current while ensuring privacy.\(^{29}\)

In the Sheesh Mahal Complex, the rooms are designed with *Mashrabiya* (lattice screens) towards the north façade, which historically overlooked the Ravi river. These lattice screens, in addition to their aesthetics also have functional purposes. They allow the hot wind to escape, accelerating ventilation and air circulation in the interiors. They also provided privacy to the interior spaces from the outdoors (Figure 59).

![Mashrabiya in Sheesh Mahal](image)

*Figure 59: Mashrabiya in Sheesh Mahal. (Source: Chaudhry 2004)*

3.6.5. **Thermal Mass**

Thermal mass is the property of a material that allows it to absorb, store and release heat. This is especially useful in hot arid climatic regions, where temperatures are high during the day and drop significantly at night. Brick masonry walls have a high thermal mass which is why this material has been used frequently in traditional building technology in hot arid regions. According to Dekay et al., masonry storage walls delay the transfer of heat from the sunny side of the wall to the room by several hours. The masonry walls of the Sheesh Mahal are made of burnt bricks and lime (Figure 60). The thickness of the basement masonry wall expands from approximately 12 feet to 15 feet deep at the northern wall, which provides structural stabilization as well as thermal inertia. This thermal mass of masonry walls in the Complex is used for passive cooling. The masonry walls absorb heat from the interior spaces during the day and release the heat slowly during the night, thus allowing the space to be cooled through passive ventilation.

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Figure 60: Floor Plan of Sheesh Mahal Basement and central masonry mass. (Source: Kassim et al.)
3.6.6. *Evaporative Cooling in the Basement*

The basement of the Sheesh Mahal is integrated with passive cooling features such as water channels, water walls, and wind tunnels. These intelligent passive designs create a sort of thermal flywheel effect and effective evaporative cooling strategies in the basement. A CFD study was conducted in 2016 to study the cooling and flow behavior in the basement of the Sheesh Mahal. The study modeled the cooling effects of the water ducts based on their locations and their source to understand the behavior of the capacity of heating and cooling properties of the inner central masonry walls. It also investigated the flow behavior of the air in the space to verify the effectiveness of the passive systems (Figure 65, 66, 67). The results highlight that there are significant differences in the temperature drop between the entering and leaving airflow. Inlets in which the long air that stays inside the basement induce higher temperature drops as much as 50% and thus suitable to maintain a fluctuation indoor temperature during the summer seasons. The results also show that cooling can happen by up to a temperature difference of 2 °C between the air entering and leaving. The results show clear evidence of the cooling capabilities of the basement of the Sheesh Mahal.

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Figure 61: Sheesh Mahal Basement Chambers (Source: Aown Ali 2012)

Figure 62: Wind Tunnel in Sheesh Mahal Basement Chambers (Source: Aown Ali 2012)
Figure 63: Sheesh Mahal Basement Chambers (Source: Aown Ali 2012)

Figure 64: Sheesh Mahal Basement Chambers (Source: Aown Ali 2012)
Figure 65: Airflow and Temperature Profiles of Sheesh Mahal Basement with entered air velocity of 2.5 m/s (Source: Kassim et al.)
Figure 66: Cross-sectional temperature of the central wall (Source: Kassim et al.)

Figure 67: Temperature analysis across the central masonry wall in the Basement of Sheesh Mahal (Source: Kassim et al.)
3.7. History of Conservation of Sheesh Mahal

Over the centuries, the Sheesh Mahal has faced many challenges including temperature changes, heavy rains, vandalism, lightning, and termite effect which caused damage and deterioration to the structure. Efforts to conserve, preserve and restore the Complex have been conducted throughout its history. Various conservation efforts were carried out during the British period to preserve the Complex including providing temporary supports to support the ceiling. After independence, numerous efforts were made by the government of Pakistan to conserve the Sheesh Mahal. These efforts have been mainly focused on emergency stabilization and preservation of the ceiling and mirror work in the main hall of the Palace.

In 1904, the ceiling of the Sheesh Mahal was damaged due to a lightning incident. Restoration and preservation efforts were carried out by the Archaeology Survey of India in 1904-05 to repair the damaged ceiling. The ceiling of the main interior hall has been repaired several times during 1904-05, 1922, 1963-64. In 1973, the additions made during the Sikh Period on the roof of the Complex were removed. During 1991-92, serious cracks were observed in the ceiling of the Complex. During the Monsoon rainfalls of 1999, the water leakage in the roof of the Complex exacerbated damage to the mirrored ceiling. In 2000, the Lahore Fort was placed on the World Heritage Site Danger list. From 2003-2005, conservation of the ceiling was carried out, along with efforts to restore the roof to protect it from rainwater. In 2008, the roofs of the Sikh Period Chambers on the Northside were restored and in 2009, the façade of the entrance gateway to the Complex was restored.33 Recently, the roof of the Sheesh Mahal has been restored by the Aga Khan Cultural Services Pakistan (Figure 72-75). Additionally, efforts have been made to preserve the Western and Northern exterior masonry wall of the Sheesh Mahal (The Picture

These efforts include cleaning the exterior wall of bio growth, replacing damaged cornice and damaged or missing bricks, preserving existing ornamentations including frescos and glazed tile work. Furthermore, efforts have been carried out to install adequate drainage systems on the roof and along the western and northern exterior walls of the Complex. The basement chambers have been conserved and are currently being used for exhibition purposes (Figure 76, 77).

Figure 68: Conservation of the roof through supports (Source: Kamran 2015)
Figure 69: British structure to support the Mughal beams (Source: Kamran 2015)

Figure 70: Visibly rotten beams showing damage to the roof of Sheesh Mahal (Source: Lahore Fort Master Plan 2019)
Figure 71: Deteriorated cornice and exposed masonry in Sheesh Mahal (Source: Lahore Fort Master Plan 2019)

Figure 72: Restoration of the roof of Sheesh Mahal 2021 (Source: AKCSP)
Figure 73: Rotten beams of the Sheesh Mahal roof replaced 2021. (Source: AKCSP)
Figure 74: Restoration of Sheesh Mahal Roof 2021 (Source: AKCSP)

Figure 75: Sheesh Mahal Attic Chambers before (left) and after (right) recent 2021 restoration (Source: AKCSP)
Figure 76: Conservation of the basement chambers (Summer Palace) under the Sheesh Mahal Complex (Source: AKCSP)

Figure 77: Conservation of the basement chambers (Summer Palace) under the Sheesh Mahal Complex (Source: AKCSP)
4. THE IMPACTS OF CLIMATE CHANGE ON TRADITIONAL BRICK MASONRY CONSTRUCTION

4.1. Potential impacts of climate change on traditional brick masonry construction

Pakistan is expected to have a considerable increase in the frequency and intensity of extreme weather events. According to the climate change projections for 2040-2059, the mean annual temperature in Pakistan will rise by 2.34 °C causing an increase in average monthly temperatures. There will be an increase in monthly maximum and minimum temperatures. Annual maximum 5-day rainfall will rise by 8.7mm causing an increase in the intensity of the precipitation. This will lead to flooding events resulting in overwhelming the building systems. The increase in average temperatures and precipitations will cause moisture content fluctuations.

4.1.1. Higher temperatures/ Increase in Annual Temperatures

Pakistan is projected to have a drastic increase in monthly temperatures from 2080-2099 (Figure 78). The value of monthly temperature change varies between 0 and 4 degrees. Furthermore, Pakistan is expected to experience extreme weather events related to high temperatures, such as droughts, heatwaves, and an increase in heat islands. These extreme events present significant challenges to the historic masonry structures.

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Figure 78: Projected Change in Monthly Temperature of Pakistan for 2080-2099 (Source: World Bank)

Higher temperatures and variations in temperature will cause thermal movements in the built structures which can lead to expansion and shrinkage of the masonry. Under extreme circumstances, the expansion and shrinkage cycles can cause cracks in the masonry resulting in water penetration inside the structure during heavy rainfalls. Higher temperatures can also lead to droughts, resulting in a severe lack of moisture in the soil. The lack of moisture in the soil may cause shrinkage and swelling, resulting in uneven settling, cracking, and destabilization of
masonry walls. Additionally, an increase in the temperature will increase the frequency and intensity of heatwaves. These heat waves may increase the cooling loads of buildings during peak summer months, eventually affecting the building performance and increasing energy costs. Another impact of higher temperatures is an increase in urban heat islands, which results in poor air quality and increase air pollution. They also reduce nighttime cooling which is an essential component of passive cooling systems. Further research is required to evaluate how higher temperatures and extreme weather events related to them affect the performance of passive cooling systems in traditional buildings.

Figure 79: High-temperature events and their potential impacts on masonry construction (Source: Author)
Figure 80: Cracks in masonry (Source: AKCSP)

Figure 81: Structural cracks in masonry (Source: AKCSP)
4.1.2. Increase in Cooling Degree Days

ASHRAE defines Cooling Degree Days as “the difference in temperature between the outdoor mean temperature over 24 hours and a given base temperature, used in estimating cooling energy use”.

Cooling Degree Days represent how warm temperatures are and represent the demand for energy needed to cool a building. According to climate change predictions, the number of Cooling Degree Days for Pakistan is expected to increase (Figure 82). Higher cooling degree days mean that more energy would be required to cool the buildings. Similarly, an increase in cooling degree days could also impact passive cooling systems to achieve thermal comfort in traditional buildings.

Figure 82: Change in Cooling Degree Days in Pakistan for 2040-2059 (Source: World Bank)

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4.1.3. Higher precipitation/Increase in Annual Precipitation

Even though there is great uncertainty around projections for future precipitation in Pakistan due to South Asian Monsoons\textsuperscript{37}, a trend towards an increase in future annual precipitation is supported by the published research.\textsuperscript{38} According to the IPCC’s projections, monthly precipitations will increase for the summer months, particularly from July to September (Figure 83). Additionally, there is expected to be an increase in the intensity of rainfall which will result in more flooding. These weather events will present significant challenges to historic masonry structures.

Higher precipitation and an increase in annual rainfall will increase the wetting of traditional brick masonry structures. Typically, the traditional brick used in historic buildings in Pakistan is low-fired and quite porous. An increase in the intensity of rainfall will result in flooding, which may cause prolonged wetting, and increase the severity of wetting and drying cycles. Prolonged wetting may result in saturation of the building materials, reducing the shear strength of masonry materials like brick. Additionally, degradation in the shear strength of masonry may induce loss, particularly in the mortar. Depending on their drying ability, bricks may also be more vulnerable to frost damage during the winter months.\textsuperscript{39} Additionally, an increase in precipitation may also result in faster biological colonization, weathering, and dampness. Furthermore, extreme precipitation and wind-driven rain may result in deeper

\textsuperscript{37} Monsoon Rains are heavy rains that accompany the seasonal wind of South Asia that blows from southwest in the Summer.
penetration of moisture in the building, affecting thermal expansion with accompanying stresses. Deeper penetration may result in water seepage through the walls.\textsuperscript{40}

\textit{Figure 83: Projected Change in Monthly Precipitation of Pakistan for 2080-2099 (Source: World Bank)}

\textsuperscript{40} Nijland et al.
### Potential Threats to the Masonry Structure at the Sheesh Mahal Complex

<table>
<thead>
<tr>
<th>Site/Stratum</th>
<th>Macro (Site and Building; Courtyard, passive systems, wind barriers)</th>
<th>Micro (Structural components; walls, foundations, floors, façade, basement, roof)</th>
<th>Micro (Material; brick, mortar, plaster, finishes, etc.)</th>
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</thead>
<tbody>
<tr>
<td>Moisture Phenomenon (atmospheric, soil):</td>
<td>Flood</td>
<td>Risk of flooding, erosion, and soil loss due to prolonged wetness.</td>
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<tr>
<td>Risk Factors</td>
<td>Rapid onset</td>
<td>Increased mechanical stress on the drainage system.</td>
<td></td>
</tr>
<tr>
<td>Likelihood</td>
<td>Physical 1*</td>
<td>Foundation damage, uneven settlement, cracking.</td>
<td></td>
</tr>
<tr>
<td>Risk of Occurrence</td>
<td>Physical 1*</td>
<td>Liquefaction, structural integrity, and potential loss of life.</td>
<td></td>
</tr>
<tr>
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</tr>
</tbody>
</table>

### Water-atmospheric condition

<table>
<thead>
<tr>
<th>Site</th>
<th>Macro (Site and Building; Courtyard, passive systems, wind barriers)</th>
<th>Micro (Structural components; walls, foundations, floors, façade, basement, roof)</th>
<th>Micro (Material; brick, mortar, plaster, finishes, etc.)</th>
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</thead>
<tbody>
<tr>
<td>Water-related phenomena</td>
<td>Risk of Occurrence</td>
<td>Risk of Occurrence</td>
<td>Risk of Occurrence</td>
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<tr>
<td>Likelihood</td>
<td>Rapid onset</td>
<td>Increased mechanical stress on the drainage system.</td>
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</tr>
<tr>
<td>Risk of Occurrence</td>
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<tr>
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<tr>
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<td></td>
</tr>
<tr>
<td>Risk of Occurrence</td>
<td>Physical 1*</td>
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</tbody>
</table>

### Industrial conditions

<table>
<thead>
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<th>Site</th>
<th>Macro (Site and Building; Courtyard, passive systems, wind barriers)</th>
<th>Micro (Structural components; walls, foundations, floors, façade, basement, roof)</th>
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<td>Rapid onset</td>
<td>Increased mechanical stress on the drainage system.</td>
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<tr>
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</tbody>
</table>

### Light extremes

<table>
<thead>
<tr>
<th>Site</th>
<th>Macro (Site and Building; Courtyard, passive systems, wind barriers)</th>
<th>Micro (Structural components; walls, foundations, floors, façade, basement, roof)</th>
<th>Micro (Material; brick, mortar, plaster, finishes, etc.)</th>
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<tr>
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<td>Risk of Occurrence</td>
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<td>Likelihood</td>
<td>Rapid onset</td>
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</table>

### Increased frequency and intensity of wetting and drying cycles

<table>
<thead>
<tr>
<th>Site</th>
<th>Macro (Site and Building; Courtyard, passive systems, wind barriers)</th>
<th>Micro (Structural components; walls, foundations, floors, façade, basement, roof)</th>
<th>Micro (Material; brick, mortar, plaster, finishes, etc.)</th>
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<td>Risk of Occurrence</td>
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<tr>
<td>Likelihood</td>
<td>Rapid onset</td>
<td>Increased mechanical stress on the drainage system.</td>
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<tr>
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</table>

### Curing risks

<table>
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<th>Macro (Site and Building; Courtyard, passive systems, wind barriers)</th>
<th>Micro (Structural components; walls, foundations, floors, façade, basement, roof)</th>
<th>Micro (Material; brick, mortar, plaster, finishes, etc.)</th>
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<td>Risk of Occurrence</td>
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<td>Likelihood</td>
<td>Rapid onset</td>
<td>Increased mechanical stress on the drainage system.</td>
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<tr>
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<tr>
<td>Risk of Occurrence</td>
<td>Physical 1*</td>
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<td></td>
</tr>
</tbody>
</table>
Figure 85(left): Deterioration of exterior masonry wall due to moisture infiltration (Source: AKCSP)

Figure 86(right): Deterioration of exterior masonry wall due to moisture infiltration (Source: AKCSP)
Figure 87: Deterioration of masonry at the top due to rainwater penetration (Source: AKCSP)

Figure 88: Deteriorated masonry due to rising damp (Source: AKCSP)
4.1.4. Pollution

Pollutants in the atmosphere from CO2 emissions result in acid rain. Acid rain removes nutrients and minerals from the soil that trees need to grow, which can adversely impact the landscape on the site. Additionally, soluble salts, transported to the building through soil or acid rain, could deteriorate the performance of brick masonry walls. The decay is caused by the crystallization of salts in the porous structure of the masonry, which causes mechanical stress on the material and may rupture the microstructure of the brick or mortar, causing cracks in the masonry. Furthermore, these soluble salts are transported to the masonry structure through water, resulting in efflorescence and subflorescence. These salts can also cause weathering of stones through dissolution.

Figure 89: Deterioration of exterior masonry wall due to pollution and water damage (Source: AKCSP)

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<th></th>
<th></th>
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</thead>
<tbody>
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<td>Pollutants</td>
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<td>3</td>
<td>Short and long-term</td>
<td>No potential impact</td>
<td>Pollution</td>
<td>Site (Site and building, landscape, passive systems, water supply), Courtyard (Passive systems (wind tunnels, water walls)), Foundation (solid brick), Basement, Walls (brick masonry thickness: 3.6m to 4.7m at North side), Floors (marble, lime mortar), Roof, Façade (brick, ornamented with fresco, glazed ceramic and terracotta tiles), Brick (low-density, high porosity, fired, 203.2mm x 101.6mm x 330.2mm), Mortar (25.4mm thick lime based mortars), Plaster (lime based), Finishes (stonework, mirrorwork, Pietra Dura).</td>
</tr>
<tr>
<td>Changes in deposition of pollutants (wet or dry deposited)</td>
<td>3</td>
<td>3</td>
<td>Short and long-term</td>
<td>No potential impact</td>
<td>Erosion</td>
<td>Site (surface crust or encrustation), Courtyard (surface crust or encrustation), Foundation (weathering, erosion), Basement, Walls (weathering, erosion), Floors (weathering, erosion), Roof, Façade (weathering, erosion), Brick (wear and tear of mortar from joints), Mortar (weathering, erosion), Plaster (weathering, erosion), Finishes (weathering, erosion)</td>
</tr>
<tr>
<td>CO2 emissions, Carbonic Acid</td>
<td>3</td>
<td>3</td>
<td>Short and long-term</td>
<td>No potential impact</td>
<td>Acid rain</td>
<td>Site (increase in human environmental comfort due to pollution), Courtyard (increase in human environmental comfort due to pollution), Foundation (erosion), Basement, Walls (erosion), Floors (erosion), Roof, Façade (erosion), Brick (erosion), Mortar (erosion), Plaster (erosion), Finishes (erosion)</td>
</tr>
</tbody>
</table>

Figure 90: Potential impacts of pollution on masonry construction (Source: Author)
4.1.5. Wind

Wind-driven rain, wind-transported salts, and wind gusts can potentially damage the masonry structure. Wind-driven rain is a contributing factor to water penetration and moisture loads of exterior masonry walls. Wind-driven rain may also cause erosion and facilitate moisture penetration deeper into the masonry structure. Soluble salts can be transported to the masonry structure through wind and deposit on the surface in the form of efflorescence. These soluble salts can be transported further into the structure through moisture movement and cause crystallization pressure on the brick or plaster structure, eventually resulting in micro-cracks. Furthermore, wind gusts can cause erosion and weathering of masonry structures over time through increased cycles of evaporation and salt recrystallization.

Figure 91: Weathering and erosion of exterior masonry wall in Lahore Fort (Source: Kamran 2015)
4.1.6. Desertification

Desertification is a type of land degradation in which a relatively dry land region becomes increasingly arid due to a decrease in precipitation and loss of water bodies. Desertification can potentially adversely impact the landscape on site. Desertification may exacerbate the risk of land subsidence. Land subsidence occurs when a large amount of groundwater is drawn from the soil, which may result in collapsing of the soil. Droughts can significantly decrease groundwater and cause soil erosion over time, which may result in uneven settlement of the soil, foundation, and/or masonry walls. Additionally, droughts can cause soil shrinkage which may result in cracking of the foundations and/or masonry walls. Lowering of the water table and scarcity in water may impact passive cooling systems in the Complex such as water bodies. There is a need to monitor the groundwater under the Lahore Fort site for sustainable management of groundwater. Run-off water management and recycling should be incorporated in the Master Plan for the Lahore Fort.

### Potential Threats to the Masonry Structure at the Sheesh Mahal Complex

<table>
<thead>
<tr>
<th>Climate Related Phenomenon</th>
<th>Risk/Threat</th>
<th>Nature of Risk/Threat</th>
<th>Risk Probability (High, Medium, Low)</th>
<th>Risk Duration</th>
<th>Macro (Masonry, masonry, concrete, palette, brick, mortar)</th>
<th>Micro (Brick, mortar, plaster, finishes, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>Rain</td>
<td>Physical</td>
<td>2</td>
<td>Short and long term</td>
<td>No potential impact</td>
<td>No potential impact</td>
</tr>
<tr>
<td></td>
<td>Drained rain</td>
<td>Physical</td>
<td>2</td>
<td>Short and long term</td>
<td>No potential impact</td>
<td>No potential impact</td>
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<tr>
<td></td>
<td>Transported soil</td>
<td>Physical</td>
<td>1</td>
<td>Long term</td>
<td>No potential impact</td>
<td>No potential impact</td>
</tr>
<tr>
<td></td>
<td>Gusts, change in direction</td>
<td>Physical</td>
<td>1</td>
<td>Short and long term</td>
<td>No potential impact</td>
<td>No potential impact</td>
</tr>
<tr>
<td>Droughts</td>
<td>Risk/Threat</td>
<td>Nature of Risk/Threat</td>
<td>Risk Probability (High, Medium, Low)</td>
<td>Risk Duration</td>
<td>Macro (Masonry, masonry, concrete, palette, brick, mortar)</td>
<td>Micro (Brick, mortar, plaster, finishes, etc.)</td>
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<tr>
<td></td>
<td>Phenomenon</td>
<td>Nature of Risk/Threat</td>
<td>Risk Probability (High, Medium, Low)</td>
<td>Risk Duration</td>
<td>Macro (Masonry, masonry, concrete, palette, brick, mortar)</td>
<td>Micro (Brick, mortar, plaster, finishes, etc.)</td>
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<tr>
<td></td>
<td>Climate Related</td>
<td>Phenomenon</td>
<td>Risk Probability (High, Medium, Low)</td>
<td>Risk Duration</td>
<td>Macro (Masonry, masonry, concrete, palette, brick, mortar)</td>
<td>Micro (Brick, mortar, plaster, finishes, etc.)</td>
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<td></td>
<td>Desertification</td>
<td>Threat</td>
<td>Risk Probability (High, Medium, Low)</td>
<td>Risk Duration</td>
<td>Macro (Masonry, masonry, concrete, palette, brick, mortar)</td>
<td>Micro (Brick, mortar, plaster, finishes, etc.)</td>
</tr>
</tbody>
</table>

**Figure 92: Potential impacts of wind events on masonry construction (Source: Author)**

**Figure 93: Desertification and its potential impacts on masonry construction (Source: Author)**

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76
4.1.7. Biological effects

Biogrowth is defined as the colonization of masonry structures by plants, microorganisms such as bacteria, cyanobacteria, fungi, algae, rot, etc. showing as black, green, or brown deposition on the surface of masonry in areas susceptible to moisture accumulation\textsuperscript{43}. Biogrowth is aesthetically unpleasing but can also cause deterioration of masonry finishes over time through loss of adhesion between the mortar and plaster and intergranular disintegration. Biogrowth can be a sign of moisture related problems in buildings. Wood is especially susceptible to biological attacks, particularly rot. Biological colonization, if remains untreated, can lead to material disintegration and deterioration.

![Figure 94: Biogrowth on exterior masonry surface (Source: AKCSP)](image_url)

Figure 95: Deterioration of wood beams in Sheesh Mahal Roof due to rot (Source: AKCSP)
4.1.8. **Earthquake**

According to the Asian Development Bank analysis, Lahore is vulnerable to earthquake damage. Seismic activities can cause movement in masonry structures, resulting in an uneven settlement, cracking of foundations, and/or masonry walls. Shear and flexural stresses can develop in masonry walls due to seismic activity. Additionally, cracking may occur in marble and other masonry elements such as plaster, mortar, finishes.

Climate change presents significant threats and increased energy loads not only for new construction but also for historic buildings. Further research is required to study and measure the impacts of extreme weather events caused by climate change on historic masonry construction in Pakistan. Phillipson in his study of the durability of building materials under a changing climate states that changes to the climate will cause a change in the rate of development of existing weathering mechanisms. He argues that if no intervention is made to address the weathering mechanisms, there is a risk of increased deterioration leading to more serious building defects. These defects could have direct consequences for the internal environment and for building occupants. Adequate measures, treatments, and interventions will be necessary to prevent this fast decay and to protect valuable cultural heritage buildings in Pakistan.

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### Potential Threats to the Masonry Structure at the Sheesh Mahal Complex

#### Climate Related Phenomenon

<table>
<thead>
<tr>
<th>Nature of risk (biological, chemical, physical, physiochemical)</th>
<th>Risk Probability (5=High, 1=Low)</th>
<th>Risk Vulnerability (5=High, 1=Low)</th>
<th>Risk Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro (Site and building, Courtyard, passive systems, wind tunnels)</td>
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<td></td>
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<tr>
<td>Meso (Structural components; walls, foundation, floors, facade, basement, roof)</td>
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</tr>
<tr>
<td>Micro (Material; brick, mortar, plaster, finishes, )</td>
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</tbody>
</table>

#### Biological Effects

- **Biogrowth (fungi, insects, bacteria,)**
  - Biological
  - Risk: 5
  - Duration: Long-term

  - Potential impacts include:  
    - Decline in original plant growth can impact the appearance of the landscape
    - Large tree roots may damage foundations
    - Plant roots may damage masonry walls,
    - No potential impact on bricks in extreme cases,
    - No potential impact on mortar, film formation
    - No potential impact on plaster, film formation

#### Earthquake

- **Physiological**
  - Physical
  - Risk: 4
  - Duration: Rapid onset

  - Potential impacts include:  
    - Can cause movement in foundation, resulting in cracking
    - Shear and flexural stresses can develop in masonry walls, resulting in cracking
    - Cracking can occur in marble due to shear stresses
    - No potential damage

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Figure 96: Potential impacts of biogrowth on masonry construction (Source: Author)

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Figure 97: Potential impacts of earthquake on masonry construction (Source: Author)
4.2. Potential Impacts of Climate Change on Sheesh Mahal Complex

Climate change and its impacts present a serious potential risk to the Sheesh Mahal Complex. The current Master Plan proposes the adaptive reuse of the Sheesh Mahal basement into a museum. This study analyzes the museum proposal and its potential impacts on the historic structure under a changing climate.

The Master Plan for Lahore Fort 2017-2019\textsuperscript{46} was created by the Aga Khan Trust for Culture (AKTC) in collaboration with the Walled City of Lahore Authority (WCLA). The Plan aimed to present a new vision for the conservation and rehabilitation of the Lahore Fort World Heritage Site. The ‘Lahore Fort Precinct and Buffer Zone Master Plan’ creates a buffer zone of approximately 57 hectares, around the Lahore Fort to protect the site from urban development, heavy traffic, and resultant pollution around it (Figure 98,99). Additionally, a large green space has been added to the buffer zone known as The Greater Iqbal Park. The 2018 Master Plan also proposed a series of water-related interventions to address the flooding of the site during the monsoon season (Figure 100,101). A revised drainage plan with catchment areas has been proposed, which is currently being implemented.

The Buffer Zone sectors and components:

- Proposed Buffer Zone
- Zone of Special Value
- Area for New WHC Nomination
- Present World Heritage Site
- Including (Harmer Garden)
- Buffer Zone North Sector
- Buffer Zone East Sector
- Buffer Zone South-East Sector
- Buffer Zone South-West Sector
- Buffer Zone West Sector

1. Greater Iqbal Park
2. Mianwali-Pakistan
3. Fort Road including Akbari Gate
4. Begum Shahi/Maryam Zamani Mosque
5. Rim Market
6. Gali Sher Pallean and Shahya Pallean
7. Fort Road
8. Ali Park
9. Immediate surroundings of Ali Park
10. Triangle
11. Access to Hazuri Bagh
12. Access to Billahwala Mosque
13. Shahpurian Bazaar
14. Punjab Dental Hospital
15. Lady Willington Hospital

Figure 98: Lahore Fort Buffer Zone (Source: Archnet)

Figure 99: Lahore Fort Buffer Zone (Source: Lahore Fort Master Plan 2019)
The Master Plan addresses some of the issues related to extreme weather conditions, namely flooding through the creation of the buffer zone and revised drainage plan. However, other threats and opportunities should be explored for their impacts on the site and its various historic structures. Pakistan is one of the countries that will be most affected by climate change in the form of extreme temperatures, heavy rainfalls, and floods. The conservation principles and recommended conservation techniques for the Lahore Fort do not address the full potential impact a changing climate will have on the physical structures. The Plan mostly analyzes the historic structures as they exist today and provides a comparison of current and historical (original) conditions. Under these new circumstances, it is critical to study the potential future impacts of climate change on Lahore Fort and incorporate appropriate mitigation strategies into the Master Plan.

The Sheesh Mahal Complex is constructed of a low fired, high porosity, less dense brick masonry structure, covered with lime plaster. The façade of the Complex is faced with a marble veneer inlaid with semi-precious stones. The ceiling of the main hall is adorned with tile mosaics and the whole protected by a wood timber roof. This complex assembly of materials is especially vulnerable to extreme temperature and moisture fluctuations leading to short- and long-term degradation. As the atmospheric moisture and temperatures for Lahore change due to climate change, the building materials, and ornamentation will be affected by water infiltration, changes in humidity cycles, heat waves, freeze-thaw, and flooding, among other risks. These climate risks and their potential physical impacts on the Complex have been identified in this research. Further studies need to be conducted to monitor the predicted change in historic building materials of the Complex and to conduct a detailed risk assessment of the building.
The Sheesh Mahal Complex utilizes passive cooling strategies in its design. These strategies are inherently sustainable characteristics of the Complex. However, these building systems evolved over centuries to observed climate parameters that are no longer in place. And
their efficacy might be challenged due to the extreme weather conditions as a result of climate change. The courtyard of the Complex utilizes a stack effect to cool the ambient air and provide a comfortable micro-climate. An increase in Urban Heat Islands and a decrease in nighttime cooling due to climate change could result in a reduction of thermal comfort levels of the courtyard for occupants and push the limits of material behavior.

The courtyard of the Sheesh Mahal Complex is designed with a central water body that is supposed to cool the ambient air in the courtyard and provide thermal comfort. The current Master Plan for the Complex proposes to restore the water bodies and make them functional again. However, studies need to be conducted regarding anticipated temperature rise and its impact on these water bodies before the plan can be implemented. A decrease in the water table due to climate change could result in scarcity of water throughout the Lahore Fort. It could also potentially impact water bodies and their functionality in the Sheesh Mahal Complex.

The Master Plan for Lahore Fort proposes to design a museum in the basement chambers (also known as Summer Palace) below the Sheesh Mahal Quadrangle (Figure 102,103). The proposal is currently under consideration and proposes to introduce exhibition spaces in the Summer Palace. The museum would provide exhibition spaces for the artifacts collected from the Fort. It would also provide educational opportunities for the public. However, further studies need to be conducted to analyze the impact of the proposal on the historic basements. Museums generally require a mechanically controlled environment through air conditioning. Mechanical systems added to the basement could potentially disrupt the passive systems in place in the Complex. A disruption in the passive systems could affect the thermal comfort levels in the Complex. It could also potentially impact the building materials. Mechanically controlled

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environments do not function the same way as passively cooled buildings. Changing environmental effects have an impact on building behavior and performance.⁴⁸ The Complex is constructed of brick masonry which is a porous historic building material. When moisture travels inside the building, it is evaporated through the porous bricks. In a mechanically controlled air-conditioned building, if the moisture travels inside the building it would be trapped. The trapped moisture could cause damage to the structure, building materials, as well as the ornamentations on the façade and ceiling. As the temperatures and humidity levels and rainfall events increase due to climate change, the potential damage due to entrapped moisture could also increase.

Figure 102: Proposed Site Plan for Sheesh Mahal Basement (Source: Lahore Fort Master Plan)

Figure 103: Proposed Museum Plan for the Sheesh Mahal Basement (Source: Lahore Fort Master Plan 2017-2019)

Figure 104: Basement Chambers being used for a conference (Source: AKCSP)
Figure 105: Basement Chambers being used for an exhibition (Source: AKCSP)

88
4.3. Risk Scenario Planning for Sheesh Mahal Complex

Risk Scenario Planning is the use of risk scenarios that challenge built heritage, to consider events, conditions, and the potential impacts of these events on cultural resources. In this research, various risk scenarios have been identified and the events related to these risks and their potential impacts on traditional masonry construction have been assessed in detail at macro, meso, and micro levels. These scenarios have been constructed based on assumptions derived from information about the current and projected climate of Lahore. These scenarios help us understand the potential impacts on masonry construction when climate risks such as precipitation, floods, temperature change, earthquake, pollution, acid rain, etc. overlap. These scenarios will be useful to identify various challenges the masonry construction at the Sheesh Mahal Complex will face in the future and to prepare short and long-term plans to mitigate their impacts.

4.3.1. Flood and earthquake risk scenario

Short-term damage: weathering, erosion, blistering, efflorescence, delamination, exfoliation, cracking of walls, individual bricks, mortar, plaster, finishes, foundation

Long-term damage: element loss, collapsing of walls, water penetration, and uneven settlement of the soil and foundation.

Climate Change Projections for Lahore by the Asian Development Bank⁴⁹ project a high risk of earthquakes. Seismic activity combined with heavy monsoon rains could have strong adverse impacts on the Sheesh Mahal Complex. Due to floods and seismic activity, the soil,

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foundation, floors, lower parts of the masonry walls at the Complex and its elements could become vulnerable. Floods can cause saturation of the bricks, mortar, plaster, finishes, marble floors, foundation, and soil. Prolonged wetness of building elements can lead to deterioration issues including weathering, erosion, cracking, blistering, efflorescence, delamination, exfoliation, and material loss in extreme cases. Salts will be activated due to floods and will infiltrate the building materials with water. Salts inside the masonry or just behind the surface (sub fluorescence) can put pressure on the material causing them to crack. The crystallization process exerts pressure on the pores of the masonry, causing it to break apart or spall. In addition, salts within porous materials can retain moisture, leading to the decay of other materials that it comes in contact with, for example, metal reinforcing.⁵⁰

Frequent floods could increase stress on the drainage systems of the site. In a scenario where the system gets overwhelmed, water can accumulate on the site. Flooding can deteriorate lower levels of the façade closer to the ground and lower parts of the wall due to prolonged wetness. Seismic activity can cause shear and flexural stresses to develop in already saturated masonry walls. As a result, the walls might develop cracks, settle, or collapse in extreme cases. Water can infiltrate into the basement through the cracks. Building foundations might be damaged as flooding will compromise structural integrity through water infiltration exerting high pressure and resulting in cracking. Seismic activity could also cause movement in the soil and foundation and add additional strain on the building elements whose structural integrity has already been compromised due to flooding. This could result in material loss, collapsing of walls, or uneven settlement of foundations in extreme events.

4.3.2. Extreme precipitation and acid rain risk scenario

*Short-term damage:* cracking, rising damp, efflorescence, sub fluorescence, flaking, peeling of finishes, and plaster

*Long-term damage:* weathering, erosion, uneven settlement of foundation and exterior walls, structural cracks, detachment of plaster and finishes, spalling, material loss.

An increase in precipitation due to heavy Monsoon rains combined with pollutants (sulfates, chlorides, and nitrates) present in the atmosphere will activate the salts which could accumulate on the building surface in the form of efflorescence and subflorescence. Heavy rainfall can transport soluble salts deeper into the masonry structure through prolonged wetness and cause deterioration. When salts in the porous brick structure crystallize, they induce pressure which can result in deterioration of the masonry units. Deterioration due to salt crystallization is characterized by local scaling of the surface, microcracking in the mortar, loss of binder-aggregate bond and cohesion of binder, flaking, peeling, and in severe cases spalling. Additionally, stones particularly marble may experience deterioration including cracks, granular disintegration, and efflorescence due to salt crystallization.

Extreme precipitation combined with soluble salts can cause weathering and erosion of exterior walls through dissolution. Heavy rainfalls can induce stress on the drainage system in place and could also overwhelm the system in severe cases. Failure of the existing drainage system could result in the accumulation of water at the base of exterior walls and result in rising damp and moisture-related issues in the exterior and interior masonry structures. Salts introduced into the wall through rising damp can attack and dissolve the binders in plaster causing them to

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51 Bakar, Ibrahim, and Johari, “A Review: Durability of Fired Clay Brick Masonry Wall Due to Salt Attack.”
lose their strength and structural integrity, resulting in detachment of plaster from the masonry. Furthermore, rising damp can transport salts deeper and higher into the masonry. As a result, we might see efflorescence and moisture damage on the interior walls of the basement and the first floor, as well as mid-levels of the façade.

Intense rainfall combined with atmospheric pollutants can cause adverse impacts on the landscape around the site. Nitrates and sulfates present in the acid rain can be absorbed by the soil and impact tree and plant growth around the site as acid rain removes nutrients and minerals from the soil that trees and plants need to grow.

4.3.3. High temperature and extreme precipitation risk scenario

Short-term damage: micro-cracks, shrinkage, and swelling of bricks, mortar, plaster, stone, and finishes

Long-term damage: uneven settlement of soil and foundations, flaking, granular disintegration of stone, weathering, erosion, deterioration of façade

Lahore is expected to experience a significant rise in the temperature along with extreme precipitation events. Fluctuation of weather between high temperatures and periods of extreme precipitation can cause extreme wetting and drying events. These events might increase the risk of ground subsidence in the Sheesh Mahal Complex and cause cracking and heaving of soil, resulting in loss of stratigraphy and damage to the building foundation and structure.\(^\text{52}\) Uneven

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settlement of the soil and the foundation can destabilize masonry walls, which might result in collapsing of the walls if exposed to prolonged continuous cycles of wetting and drying.

Materials exposed to varying thermal conditions will undergo dimensional change as a result of the vibration and movement of atoms and molecules. When materials are exposed to cycles of high and low temperatures, as experienced during the day, between day and night, and between summer and winter, the material will experience corresponding cycles of expansion and contraction. Within a homogeneous material, such as brick masonry, the cyclic movement between the surface and the body of the material can lead to shear failure and the detachment of the surface layer.\(^{53}\) Increased frequency of wetting and drying cycles will cause swelling and shrinkage of masonry units, plaster, mortar, and finishes. The shrinkage and swelling of the materials cause a reduction in shear strength of these elements, leading to detachment, cracking, material loss in extreme cases. Furthermore, higher temperatures will result in increased crystallization due to increased evaporation rates, leading to increased rates of structural cracking and deterioration.\(^{54}\) An increase in temperature along with an increase in precipitation will also increase bio growth, fungal/insect attack on the façade, plaster, and finishes.

**4.3.4. Higher temperature and less rainfall risk scenario**

*Short-term damage:* micro-cracking, detachment of plaster, finishes, spalling

*Long-term damage:* uneven settlement of soil, foundations, destabilization of masonry walls, structural cracks, collapsing of walls

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An absence of rainfall allows for salts to accumulate on the building surface. Higher temperatures increase the evaporation rate of moisture in the building materials, which increases the crystallization of salts. An increase in crystallization of salts in the pores of masonry structure could increase the rate of structural cracking and deterioration. Additionally, extremely high temperatures can add stress to the building fabric through sudden thermal shocks. Higher temperature can cause thermal expansion in the masonry, and lack of moisture in the building material due to lack of precipitation can cause shrinkage due to moisture loss. These swelling and shrinkage cycles can lead to damage in the masonry including micro-cracking, as well as structural cracking and spalling in extreme cases. Furthermore, higher temperatures and a lack of precipitation can result in soil shrinkage due to lack of moisture. As a result, gaps and cavities can be created between the soil and the foundation which can cause uneven settlement of the foundations and destabilize masonry walls. The destabilization could lead to the development of structural cracks in the walls or collapsing of walls in extreme cases.
5. RECOMMENDATIONS TO MITIGATE THE IMPACTS OF CLIMATE CHANGE ON TRADITIONAL MASONRY AT THE SHEESH MAHAL COMPLEX

The impacts of climate change are of major concern to the Sheesh Mahal Complex and other historic structures in the Lahore Fort. This chapter provides recommendations on strategies that can be adapted to mitigate the impacts of climate change on the site. The recommendations are based on Preventive, Corrective, and Management actions adapted from UNESCO’s climate change mitigation strategy for cultural heritage.55

5.1. Preventive Conservation

Preventive Conservation is defined as “all measures and actions aimed at avoiding and minimizing future deterioration or loss”.56 These measures and actions are non-destructive and indirect which means that they do not interfere with the building materials and structures. The Sheesh Mahal Complex and other historic structures at the Lahore Fort should be regularly inspected and monitored for signs of deterioration including the presence of moisture, cracks, bio growth, salts accumulation, weathering and erosion, incipient spalls. Furthermore, non-climatic stress factors on the site such as pollution, inappropriate conservation treatments, management neglect, inappropriate site practices, poor workmanship and supervision, inappropriate alterations, and additions should be reduced to enhance its resilience to the impacts of climate change. Site stewards should identify and promote synergies between adaptation and mitigation.

5.2. Corrective Actions: Adaptation, Mitigation, and Preservation

56 ICCROM- Terminology to characterize the conservation of tangible cultural heritage. http://www.icom-cc.org/242/about/terminology-for-conservation/#.YHD0dMnPz6B
It is recommended to conduct climate change vulnerability analysis and risk assessment for the site to develop an appropriate risk management plan. Vulnerability analysis and risk assessment are tools that can be used as initial steps in the adaptation planning process. A climate change vulnerability assessment identifies factors that contribute to the vulnerability of the site, which can include both direct and indirect effects of climate change, as well as non-climate stress factors. Risk assessment for a cultural heritage site includes identification and analysis of various potential risk factors that might adversely impact the site. Climate tailored programs including guidance and capacity building for the site should also be included in the adaptation and mitigation plan.

5.3. Collaboration and Cooperation

Best practices and climate research should be considered when developing the site management plan. The impacts of past and current climate change on the site should be documented and analyzed. Continuing effectiveness of traditional skills and use of traditional materials and best practices considering climate change should be assessed as a basis for developing proposals and for adapting them to cope with climate change.

5.4. Risk Preparedness

Disaster risks on the site should be identified, assessed, and monitored to enhance early warnings and to strengthen disaster preparedness at the site. Underlying risk factors should be reduced using knowledge, innovation, and climate risk analysis. Planning for disaster will include regular inspection and survey of buildings and structures, preparation and maintenance of records, preparation of risk assessment, assessment of housekeeping, monitoring of work conditions,
preparation of inventories, sourcing of information, providing practical instructions, and reviewing and monitoring procedures.\textsuperscript{57}

5.5. Disaster Risk Management

A comprehensive disaster risk management plan should be prepared for the site including prevention of hazards such as fire, mitigating the impacts of hazards such as earthquakes and flooding, reducing the vulnerability of the site and its environment, training the staff in self-protection strategies. The Plan should provide clear, flexible, and practical guidance for the site manager and their team. The Plan should also spell out the tools, techniques, and implementation strategies for prevention and mitigation, emergency preparedness and response, recovery, maintenance, and monitoring of the site before, during, and after a disaster.\textsuperscript{58} The Plan should further identify and assess the main disaster risks that might result in negative impacts to the heritage values of the Complex and other assets on the site. The Plan should be integrated with the existing site management plan for the Lahore Fort.


\textsuperscript{58} Centre, “Climate Change and World Heritage Report on Predicting and Managing the Impacts of Climate Change on World Heritage and Strategy to Assist States Parties to Implement Appropriate Management Responses.”
Figure 106: Disaster Risk Management Cycle. (Source: Managing Disaster Risks for World Heritage. UNESCO, 2010.)

Figure 107: Managing Disaster Risks for World Heritage. (Source: Managing Disaster Risks for World Heritage. UNESCO, 2010)
5.6. Climate Change Adaptation Strategies

Appropriate climate change adaptation strategies should be developed for the Sheesh Mahal Complex and the Lahore Fort that involves identifying, preparing for, and responding to observed or expected climate changes to retain the current conditions and historic value of the site and to recover gracefully from climate variations or to adjust to changing conditions that may include major transformations in practices. Adaptive Decision Making, as defined in the U.S. Department of Interior Technical Guide, is “a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood”.

5.7. Scenario Planning

A climate scenario is a plausible representation of the future climate that has been constructed in investigating the potential impacts of climate change. Scenario Planning is the use of scenarios that challenge planning participants to consider novel conditions, the consequences of those conditions on resources and issues, and analyze how the scenarios affect the appropriateness of management responses. Scenario planning is an important tool for long-term strategic planning of cultural heritage sites and for mitigating the impacts of climate change on these sites. Scenario planning enables the stakeholders of a site to identify key climate sensitivities in resources and management concerns, examine a range of relevant and plausible future conditions, and explore management options that can be appropriate and effective across a range of potential futures. This research explores various climate change scenarios and their

60 L.O., Mearns, and Hulme M. “Climate Scenario Development.” Accessed April 10, 2021.
61 Ibid.
potential impacts on the Sheesh Mahal Complex. Further research is required to fully explore the
potential of scenario planning for the site to prepare short- and long-term plans for the Sheesh
Mahal Complex and the Lahore Fort that are resilient under a variety of potential future scenarios
for the site.

5.8. Building Resilience

Resilience, as defined by the IPCC, is “the ability of a social or ecological system to absorb
disturbances while retaining the same basic structure and ways of functioning, the capacity for
self-organization, and the capacity to adapt to stress and change”. Resilience is the capability to
anticipate, prepare for, respond to, and recover from significant multi-hazard threats with
minimum damage to social well-being, the economy, and the environment. It is important to
take actions to build the resilience of historic masonry structures in Lahore Fort against the
impacts of climate change.

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change/glossary.
Figure 108: Tools to build Resilience (Source: G20 2019 Japan)
6. CONCLUSION

Cultural heritage in Pakistan is vulnerable to climate change and its impacts such as greater fluctuations in temperature, variations in precipitation, droughts, floods, and environmental pollution. According to climate change predictions, Pakistan is expected to have a considerable increase in the frequency and intensity of these extreme weather events. Significant historic masonry structures in Lahore Fort including the Sheesh Mahal Complex are vulnerable to the changing impacts of climate and risks and threats associated with it.

Higher temperatures and variations in temperature can cause thermal movements in masonry structures resulting in expansion and shrinkage of the masonry. The expansion and shrinkage cycles under extreme conditions can cause cracks in the masonry structures, making them more vulnerable to moisture penetration. Higher precipitation and intense rainfall can then penetrate the masonry as well as overwhelm the existing drainage systems and flood the site, resulting in prolonged wetness of the masonry structures. Prolonged wetness can reduce the shear strength of masonry and make the structure more vulnerable to biogrowth. Intense rainfall combined with acid rain can activate soluble salts and transport them deeper into the masonry structure, resulting in cracking, efflorescence, subflorescence and weathering. Crystallization of these salts in the porous masonry structure can cause significant damages over time. Droughts and desertification due to a general decrease in rainfall and higher temperatures can cause soil erosion over time. Seismic activities can cause movement in masonry structures and can cause shear and flexural stresses to develop resulting in cracking of foundations, and/or masonry walls.

Risk Scenario Planning is useful to identify the risks and threats related to climate change and their impacts on masonry structures. A comprehensive climate change vulnerability analysis and risk assessment is needed for the Lahore Fort to develop an appropriate risk management
plan. Climate tailored programs including preventive conservation, risk preparedness and adaptation strategies need to be developed for the Lahore Fort its various historic monuments.
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Acid Rain, vi, 61, 78, 80, 81, 89
Adaptation, vi, 53, 57, 85, 87, 92, 95, 96, 97, 99
Adaptive Reuse, 1, 2, 69
Biogrowth, x, 66
Climate Change, vi, xiii, xvii, 1, 2, 3, 9, 52, 55, 67, 71, 73, 74, 84, 85, 87, 88, 89
Cooling Degree Days, vi, 55, 56
Courtyard, vii, viii, 15, 18, 21, 31, 33, 36, 73
Cracking, 53, 64, 67, 78, 80, 81, 82, 89
Cultural Heritage, 89
Desertification, vi, ix, x, 64, 65
Disintegration, vi, ix, vi, xiii, 66, 80, 81
Droughts, 9, 52, 53, 64, 89
Earthquake, vi, 67
Efflorescence, 61, 63, 78, 79, 80, 81, 89
Erosion, ix, xvi, 63, 64, 78, 79, 80, 81, 84, 89
Evaporative Cooling, 8, 36, 42
Flooding, xvii, 2, 5, 52, 56, 57, 69, 71, 79, 86
Hot Arid, xvii, 1, 33, 36, 41
Intense Rainfall, 89
Jahangir, 12, 15, 18, 27, 28, 91, 96
Lahore, v, vii, viii, ix, x, xvii, 1, 2, 3, 6, 7, 8, 11, 12, 13, 14, 15, 16, 18, 19, 27, 28, 30, 34, 35, 36, 41, 42, 47, 48, 63, 67, 69, 70, 71, 72, 73, 75, 76, 78, 81, 84, 86, 89, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101
Lahore Fort, x, xvii, 1, 11, 12, 14, 15, 16, 35, 47, 48, 63, 69, 70, 71, 72, 73, 75, 76, 84, 86, 89, 94, 97, 98, 99, 101
Mashrabiya, v, viii, xiv, 40
Masonry, vi, vii, ix, x, xiv, xv, xvi, xvii, 1, 2, 3, 26, 27, 36, 38, 41, 42, 46, 47, 48, 52, 53, 54, 55, 56, 57, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 71, 74, 78, 79, 80, 81, 82, 88, 89, 96
Master Plan, vii, ix, x, 35, 48, 69, 70, 71, 73, 75, 76
Mitigation, vi, xii, 85, 97
Monsoon, vii, x, 5, 6, 11, 47, 56, 72, 80
Mortar, viii, 27, 30, 31, 32, 57, 61, 66, 67, 78, 80, 81, 82
Mughal, viii, ix, xvii, 1, 12, 18, 26, 27, 28, 29, 33, 36, 48, 91, 96, 98, 100, 101
Passive Cooling, xvii, 1, 2, 19, 33, 39, 41, 42, 53, 55, 73
Pollution, ix, 9, 30, 53, 61, 62, 69, 78, 84, 89
Precipitation, vi, 5, 9, 52, 56, 57, 64, 78, 80, 81, 82, 83, 89
Preventive Conservation, vi, 84
Prolonged Wetness, 78, 89
Resilience, vi, x, xvii, 88, 96, 97
Rising Damp, ix, 60, 80
Risk, vii, 67, 69, 71, 78, 80, 81, 82, 85, 86, 89
Risk Scenario Planning, vi, 78, 89
Shah Jahan, x, 12, 15, 18, 27, 72
Sheesh Mahal, v, vii, viii, ix, x, xvii, 1, 3, 9, 12, 14, 15, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 66, 69, 71, 73, 75, 76, 78, 81, 84, 89, 91, 97
Stack Effect, 33, 73
Subflorescence, 61, 80, 89
Thermal Comfort, xiii, 7, 19, 33, 36, 55, 73, 74
Thermal Mass, 41
Ventilation, 33, 36, 39, 40, 41
Vulnerability, xiv, 85, 86, 89
Weathering, 57, 61, 63, 67, 78, 79, 80, 81, 84, 89
Wetting and Drying, 57, 81, 82
Wind Channels, 8, 19, 39
Wind-Driven Rain, 57

INDEX