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An investigation of characteristics of Materials and Techniques used for the repair of Kala Burj, Lahore Fort, Lahore

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Abstract

An investigation of characteristics of materials and techniques used for the repair of Kala Burj, Lahore Fort, Lahore was carried out. Through experience, it was established that the conservation through repair work carried out on the significant building should be identical to the authentic original techniques and materials as accurate as possible. Objective behind it is to make connection with the past and to age in the same manner as the original material. This helps to add life to the historical structures. Hence, different methods were applied to investigate the materials originally used in the construction of this monumental building of Kala Burj like, the instrumental and non-invasive techniques. Investigation of mortar samples of Kala Burj displayed that mortar was a flexible blend of fine Ravi Sand and burnt lime. The ratio of constituents of kankar lime in the vicinity of Lahore city was found to be calcium carbonate ($CaCO_3$) 70% and 30% clay and sand along with some impurities. Nature has provided this material certain impurities to achieve the required bonding strength. Nearby soil was used to produce burnt lime from kankar. Anthropogenic and natural sources of fluorides, SO_3, CO_2, NO_3, and dust produced through the bustling traffic across the road were the major factors causing deterioration of the materials of the Kala Burj. Finally, after thorough analysis, the mortar with appropriate ratio comprising of sand, fine kankar and coarse kankar was recommended. The ratio suggested through analysis was 1.0: 1.0: 1.1 to 2.7.

Key words: Lahore, Kankar, Mughals, Masjidi, Alamgiri, Mortar

1. Introduction

A built heritage is an asset that reflects the values and culture developed through ages. Pakistan is an ancient land, as its civilization has been declared as one of the oldest in the world. Historically, it has been a passage of great kings and warriors and thus, remains the cradle of ancient civilizations. Its land is extremely rich in architectural heritage and sites [1]. Lahore city, the capital of Punjab province has always remained an important town, of Pakistan as every invader coming from the north considered Lahore to be an important obstacle in the invasion of the sub-continent. It's famous citadel, named as the Lahore Fort came into existence with the founding of the city itself. Limited excavations carried out in 1959, revealed the remains of six distinct periods namely, the British, Sikh, Mughal, Sultanate, Ghaznavid and Hindu in this historic Fort [2]. This fort is sited on the left bank of Ravi River and in the south western part of the Walled City. In the north south it was situated along River Ravi and along the route of Dehli to Kabul from east to west. Because of its unmatched historic value, it has been declared as protected and significant building in the World Heritage List in 1981 [3]. Its buildings depict an ensemble of structures constructed during different Mughal eras, from Emperor Akbar (1556-1605) to Aurangzeb Aalamgir (1658-1707) [4].

Although we have great variety of buildings, belonging to various periods in Lahore, but, it is only to the Mughals that we owe the stately and majestic monuments [5]. Being an Islamic Republic, Mughal buildings are an expression of our Muslim Culture [6] of almost the entire Mughal era. The different phases of evolution of building art from Emperor Akbar (1556-1605) to Aurangzeb- Aalamgir (1658-1707) are found in it [7].

1.1 Jahangir's Major Contribution to the construction of Lahore Fort

The Emperor Jahangir was known as the "Great Builder", because of his love for the construction of monumental buildings. He had great attraction towards art and architecture and during his rule he further contributed some eloquent buildings to the construction of the Lahore Fort.

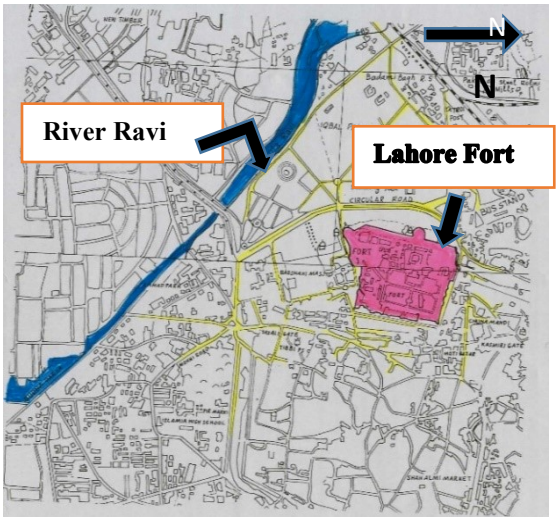

Fig. 1: Location of Lahore Fort in Lahore City, 2019 (source: Authors)

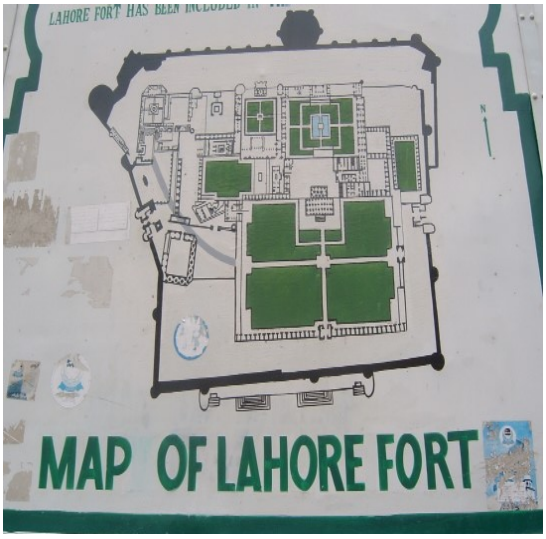

Fig. 2: Guide Map of Lahore Fort, 2019 (source: Authors)

Most of the construction of the Akbar's period has been carried out in cut and dressed brick work. This included a 112 ft. long arcade of beautiful ornamental flat arches in Kala Burj of Lahore Fort and Daulat Khana-i-Khas-o-Aam, (i.e., the double storied back portion of the Diwan-i-Aam [8].

1.2 The Kala Burj

Kala Burj is a Persian word, meaning" Black Tower [9]. In Lahore Fort, it is situated to the north side of the Fort and adjacent to Sheesh Mahal. Soon after his accession, the Emperor Jahangir ordered to expedite the construction of the Jahangir's Quadrangle, Makatab Khana and Kala Burj, the buildings were designed by the architect of the palace of Agra Fort, named Khawaja Jahan Mohammand Dost [10], the construction of these buildings in his memoirs, refers to the work at the Fort on several occasions and in 1620, while visiting the fort he praised the charming residences and soul touching sitting places [11]. It is unfortunate that very little work has been done regarding the scientific analysis of the problems occurring in repair of the Lahore Fort. The heritage, of which Pakistan feels proud, is not only threatened by the traditional causes of decay, but also facing the threatened phenomena of large-scale environmental pollution and rapidly changing socio-economic conditions [12].

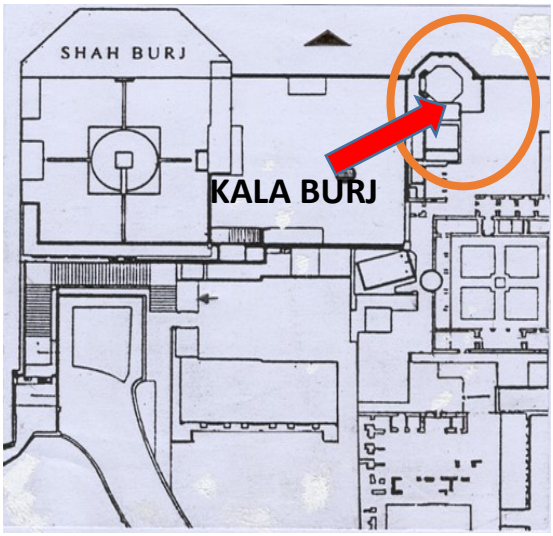

Fig. 3: Location Plan of Kala Burj in Lahore Fort, 2019 (source: Authors)

Fig. 4: A View of Kala Burj in Lahore Fort, 2019 (source: Authors)

2. Objective of Research

The erosion of the masonry work and degradation of great historic architectural monuments is a very serious issue these days. Wrong conservation results in the damage of historic edifices and craft. The appropriate mixes and ratios of the constituents for the repair mortar can only be suggested through the analysis of the original mortar through invasive and non-invasive techniques. The basic objective is that the conservation craftsman becomes aware of how the material was set out and applied [13]. Hence, this is the only way to conserve our monumental assets and cultural heritage.

The purpose of this research is to know the constituents of the original mortar used in Kala Burj through preliminary analysis so that the newly applied material for conservation is visually and physically compatible to the un-weathered material. Otherwise, the application of new impermeable and excessively strong material can result in the deterioration of our historic monuments [14].

3. Research Methodology

In the recent decades, the mortar analysis techniques have progressed extensively in parallel with the conservation industry. The analytical procedures pioneered by Ian Constantinides, Fielden and others were basically based on the methods laid down by John and Nicola Ashurst's English Heritage Technical Handbooks [15]. Their techniques have now been replaced by more sophisticated methods, but are confined to certain strengths and limitations.

Fig. 5: Area of Kala Burj from where Sample was Collected, 2019 (source Authors)

As we know that sand is the main ingredient by volume in mortar, and its gradation can be identified through laboratory testing. Hence, this useful information can be applied in the determination of color and texture of sand with some accuracy to match the original mortar for conservation [16].

Fig. 6: Kala Burj Mortar Sample No. 3, 2019 (source Authors)

Following Techniques of analysis were employed to provide a thorough and accurate description of the mortar of past samples.

- Photography of Samples
- Qualitative analysis
- Quantitative analysis
- Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM/EDS)
- Petrography of samples
- XRD (X-Ray Diffraction)

While taking the mortar sample care was taken that it was original and did not belong to the renovated part of the building [17].

3.1 Techniques of Analysis and Sample Collection

Conservation of historic buildings and monuments is a very scrupulous job. While conducting conservation care must be taken in the sample collection from the particular monument.

To find out the characteristics of mortar used in Lahore Fort, original sample was gathered from the building called Kala Burj, for the purpose of analysis. Non-invasive methods consisting of visual inspection, photography, qualitative and quantitative analysis were conducted. Photography was used for documentation of the mortar condition. Light binocular or polarized microscopy was applied to determine the distribution of mineral components. Wet chemical analysis was carried out after dissolution in acid for the measurement of

soluble silica to provide data for its hydraulic property. Instrumental techniques, like SEM/EDS, petrography and X-Ray diffraction were also conducted to know the elemental identification, quantitative compositional information and the exact minerology of the constituents [18].

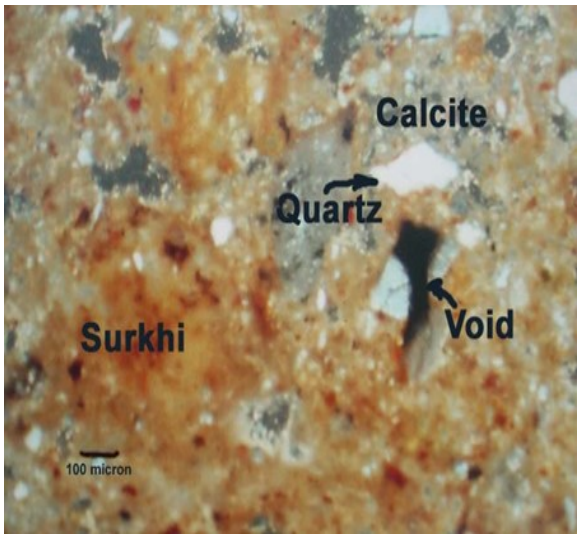

Fig. 7: Micro Photographs of Sample Showing Calcite, Surkhi and Quartz of Kala Burj, 2019 (source Authors)

Table 1: Sem/Eds Analysis of Kala Burj Sample of 3000mm^2

No	Material	Quantity	Percentage
1	Brick	46 mm^2	1.53
2	Kankar	127 mm^2	4.2
3	Marble	119 mm^2	3.96
4	Slag	10 mm^2	0.33
5	Lime	3000mm^2-302mm^2=2698 mm^2	89.9

3.2 Qualitative Composition of Kala Burj sample

In order to understand and analyze the deterioration patterns and their impact on the tower, it is crucial to fully describe and characterize its building materials. This includes the identification of the mortar's physical and chemical properties in its current state. The original mortar sample was collected from the wall of Kala Burj, as shown in figure 5. To obtain a better observation through naked eyes, the sample was first wiped, then washed with water, and then again rinsed with dilute hydro chloric acid (HCL) as in figure 6.

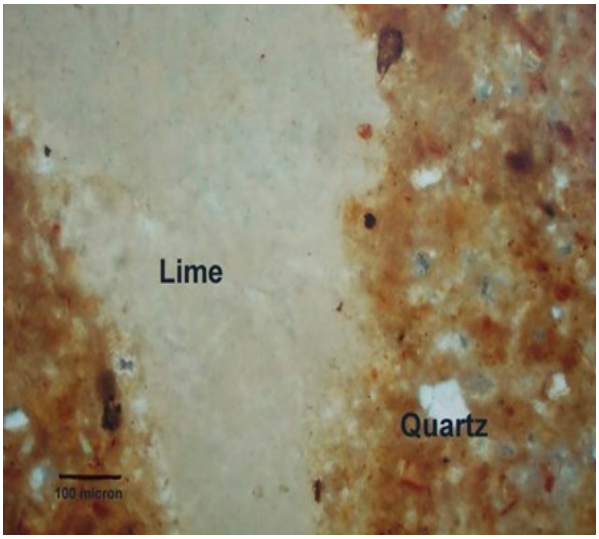

Fig. 8: Micro Photographs of Sample Showing Lime of Kala Burj, 2019 (source Authors)

3.2.1 Qualitative Composition: Micro Photographs of Mortar from Kala Burj (Jahangir's Period 1605-1630)

Micrograph of Kala Burj mortar sample contains extensive details of microstructures. Qualitative composition of Kala Burj mortar included brick and surkhi, slag, kankar, white marble pieces, fiber and lime. Through the micro photographs of the mortar samples, the constituents of the mortar of Kala Burj, were investigated, as shown in figures 7 & 8.

3.2.2 Quantitative Composition: Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM/EDS) of mortar from Kala Burj (Jahangir's Period 1605-1630)

In order to analyze the quantities of different variables that constitutes the mortar of Kala Burj, it went through the process of scanning electron microscopy. The electron micrograph scanning reveals a microstructure archetypal of lime mortar with tiny calcium carbonate crystals somewhat gelatinized (CSH formations) and also hydraulic lime. This furthermore authenticated the practice of limestone pieces (locally popular as kankar) as the core aggregate accompanying sand and the quelled bricks, which happen seemingly recrystallized as fine calcite and CSH aggregates and familiarize as clusters.

Scanning electron micrographs of investigated mortar (on thin sections and cross sections) pointed out calcite lime binder having

various quantities of aggregates shown in Table.1 on the basis of their function in the masonry work as in addition to contingent upon acid digestion. The detected major portion of the aggregates comprises of Kankar-carbonate and quelled brick pieces with sand (as fine aggregate). This observation pointed out use of locally available kankar (carbonate source for lime), obtained from the B-horizon of soil profile in addition to the high-level river terraces around the cities of Lahore and Kasur.

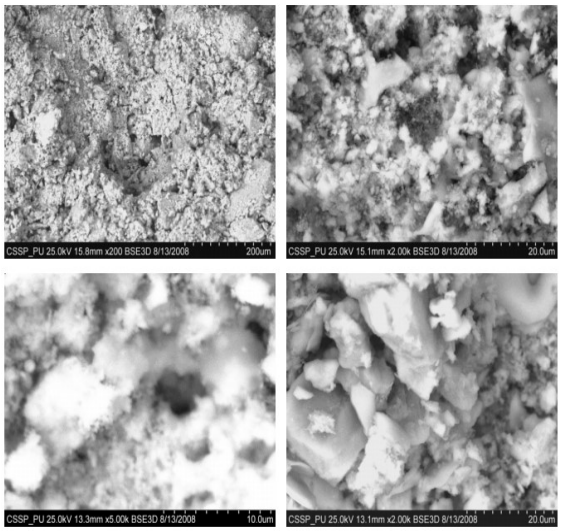

Fig. 9: SEM images of sample of Kala Burj at various magnifications, 2019 (source Authors)

3.2.3 Petrographic Composition of Mortar (Kala Burj)

Petrography is a testing technique that focuses on detailed descriptions of material through atomic absorption, X-ray diffraction and laser-induced breakdown spectroscopy in a modern petrographic laboratory. Thin mortar sections were studied under petrographic polarizing microscope. Results shown in Table 2. have been achieved after a detailed analysis. Results of X ray Diffraction from from Institute of Geology, University of the Punjab shown in fig.11.

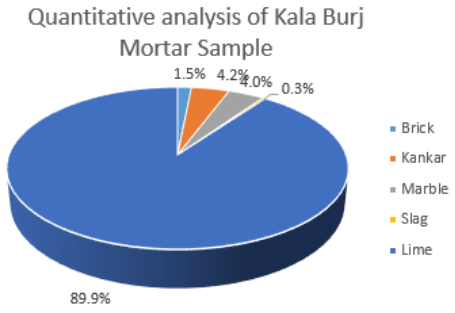

Fig. 10: Chart Showing Quantitative Analysis of Kala Burj, 2019 (source Authors)

Table 2: Petrographic Composition of Mortar Sample (Kala Burj)

No	Minerals	%	Minerals	%
1	Carbonate	59.3	Haematite	1.9
2	Illite/Mica	14.4	Magnetite	1.2
3	Quartz	11.2	Argillite	1.1
4	Gypsum	5.5	Chlorite	0.8
5	Muscovite	2.3	Zircon	0.1
6	Biotite	2.2	Flourite	Traces

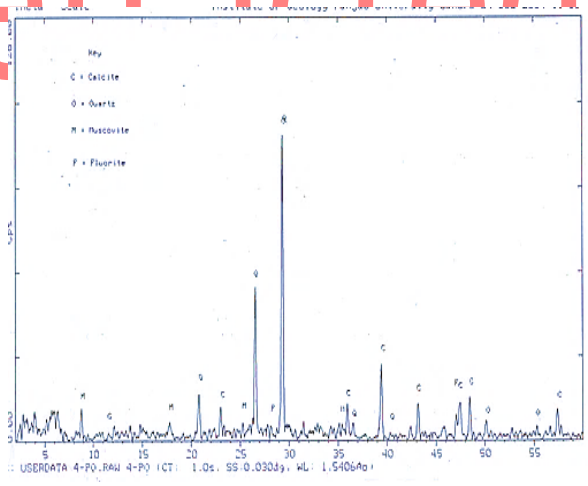

Fig. 11: X-Ray Diffraction of Kala Burj Lahore Fort, 2019 (source Institute of Geology, University of the Punjab)

Through the analysis by X Ray Diffraction, it was found that quartz and calcite are the key constituents of mortar.The minor ingredients detected were illite/muscovite, albite and gypsum. Flourite was also detected in small quantity. In addition to this, gypsum also appeared as secondary material. The presence of gypsum may be related to the soxes and noxes from the vehicles around the Lahore Fort. The origin of flourite was not clear, but may be due to steel works in the area, which

produced it as flux (across the Masjidi Gate). Flourite may also be present in the ground water.

4. Quantitative Analysis of Ratios and Percentages of Sand and Lime

4.1 Percentage of Sand and Lime

Table 3: Percentage of sand and lime (CaCO3) in kala burj mortar sample, lahore fort

No	Sample	Residual Wt. X100 Actual Wt.	Resid-ual Sand % *	Mort-ar 100 %	$CaCO_3$ weight Loss %
1	Kala Burj	18.899 X 100 / 36.44	52%	100	48%

4.1.1 Ratio of Sand and Lime

Table 4: Ratio of sand and lime in kala burj mortar sample

No	Sample Place	Sand %	Lime CaCO3 %	Ratio
1	Kala Burj Wall	52%	48%	1.1:1

Sand includes impurities like clay, magnesium, silt, fluorite, chlorite etc.

4.2 Percentage of Sand and Quick lime

Take the atomic weight of CaO which is 40+16=56 and multiply it with weight loss of CaCO3 and then divide it with 100. It will give the percentage weight of CaO and Sand.

Table 5: Percentage of sand and quick lime (CaO) in kala burj mortar sample

No	Sample	At. Wt. Cao X Wt. Loss / 100	Mor-tar %	CaO %	Sand %
1	Kala Burj Mortar	56 X 48 / 100	100 %	26.838%	73.12%

4.2.1 Ratio of Sand and Quick Lime (CaO)

Table 6: Ratio of sand and quick lime (CaO)

No	Sample	Sand %	Q.Lime %	Ratio
1	Kala Burj Mortar	73.12 %	26.88%	2.7:1

4.3 Percentage of Sand and Slaked Lime

Table 7: Percentage of sand and slaked lime Ca(OH)2 in lahore fort mortars

No	Sample	At. Wt. Ca(OH)2 X Wt. Loss / 100.	Ca(OH)2%	Mortar 100%	Sand %
1	Kala Burj Mortar	74 X 48 / 100	35.52%	100	64.48 %

Then take the atomic weight of Ca(OH)2 which is 40+32+2=74 and multiply it with weight loss of CaCO3 divide it with 100 it will give the weight of Ca(OH)2 and Sand in percentage.

4.3.1 Ratio of Sand and Slaked Lime

Table 8: Ratio of sand and slaked lime (CaO) in kala burj mortar, lahore fort

No	Sample	Mortar	Sand %	S. Lime Ca(OH)2 %	Ratio
1	Kala Burj Mortar	100%	64.48%	35.52%	1.8:1

4.4 Proposed ratio between sand and lime

Table 9: Ratio between sand and lime for conservation in Lahore Fort

No	Sample Place	Ratio: Sand~ Lime	Ratio: Sand~ Quick Lime	Ratio: Sand~ Slaked Lime
1	Kala Burj	1.1:1	2.7:1	1.8:1

4.5 Following was the result based on the above ratios:

Table 10: Ratio and range of fine lime and coarse kankar lime for mortar making

No	Sample Place	Ratio and Range of Fine Kankar Lime and Coarse Kankar Lime(Burnt) (Unburnt)
1	Kala Burj	1.0 : 1.1 to 2.7

Table 11: Proposed range of ratios for sand, fine kankar lime and coarse kankar lime used in conservation of kala burj in lahore fort, lahore

No	Sample Place	Ratio and Range of Sand: Fine Kankar Lime: and Coarse Kankar Lime for Mortar used in Conservation.
1	Kala Burj	1.0: 1.0: 1.1 to 2.7

5. Conclusions

Through the techniques of analysis as discussed, it was found that Kankar Lime is formed of Hydraulic Lime (CaCO3) + Surkhi + Sand with some impurities like sand and clay. The kankar is burnt in a kiln at the temperature range of 700-9000C. As the Kankar burns, it gives off CO2, leaving behind Quick Lime or CO. Mixing of water in proper ratio in quick lime, sand or aggregate produces the required mortar to bind the bricks, blocks or stones . Care must be taken that the Quick Lime (CaO) is to be added to water in the pits or container immediately after calcination. Not water but quick lime is added to water in small quantity.The slaking lime is raked and stirred till the reaction ends.

Through analysis it was also found that the Kankar of Punjab consists of 70% calcium carbonate and 30 % clay, sand and other impurities. As regards the textural investigation, it was found that gypsum being soft and in increased volume, formed because of the deterioration of the mortar. In fact it is not the main constituent of original mortar. It has replaced calcite. It appeared in the mortar fractures may be due to environmental soxes and noxes.The scattered arrangement of grains is the evidence that it developed afterwards.

6. Suggestions and Recommendations

Although Lahore city has great variety of buildings belonging to various periods, but most of the monumental and majestic buildings have been constructed by the Mughals. Being an Islamic Republic, these buildings are an expression of the Muslim Culture.Thus, it is our moral duty to uphold and gather full knowledge of our Heritage.

- Analysis of the samples of original mortar for past workmanship can be used as a reference and Studies should be carried out to provide references for further information.
- Through research work we can understand the changes and advancement in technology that took place during various Mughal Periods.
- We can get an answer to the clue as to why the building is still intact although being 400 years old, although there are some damaged portions needing immediate repair.
- Negligence and delay in timely repair and maintenance may result in the damage of our monumental assets and cultural heritage.
- Wrong conservation may result in the wastage of time and money as in the case of Dalans of Jahangir's Quandrangle which was renovated in 1998.
- This is only possible if we have full knowledge of the underlying principles of workmanship, regarding the ingredients and types of mortar used.
- The causes of decay of material in Lahore Fort are natural climatic conditions, human vandalism, neglect and weaknesses.

- For a succesful conservation it is pertinent for the crafts man to understand the history and technology of his craft and before commencement should analyse that specific historic work.
- The relevant department should conduct regular trainings and workshops for the conservation craftsmen.

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