Chapter

Durability Issue for the Emperor Fasiladas Royal Palace in Gondar (Ethiopia)

Eskinder Desta Shumuye and Gashaw Assefa Bezabih

Abstract

The Royal Enclosure is the remains of a fortress-city in Gondar, Ethiopia. It was founded in the 17th century by Emperor Fasiladas and was the home of Ethiopia's emperors. Its unique architecture shows diverse influences including Nubian styles. The site was inscribed as a UNESCO World Heritage Site in 1979. Ghebbi is an Amharic word for a compound or enclosure. Due to climate conditions and human activities, the Royal palace is affected by severe structural damage. Presently almost some portion of the palace are under maintenance by mortar pointing to avoid negative effects of rainfall and other durability issue and temporary scaffolding to prevent from collapse of vulnerable structures. An analysis of damage of the palace is presented, based on weathering processes and structural conditions, as preliminary tool to detect and implement urgent and medium/long-term protection strategies for the conservation of the monuments. The chapter describes the major durability issue of the historical palace and determines the cause of the present durability problem and then recommends the possible remedial measure to alleviate the prolonged durability issue. The analysis was conducted by visual inspection and X-ray diffraction characterization methods. The chapter discusses the results obtained from the analysis of the mortar sample of the historical palace.

Keywords: durability, Gondar, Fasil Ghebbi palace, historical heritages, mortar

1. Introduction

Surrounded by a 900-metre-long wall with 12 entrances and three bridges Fasil Ghebbi resides on an area of about 70,000 square meters, Fasil Ghebbi is located in Gondar City in north western Ethiopia. The compound was Registered on the World Heritage List in 1979 and it contains palaces, churches, monasteries and public and private buildings. It served as the home of Ethiopian's emperor Fasiladas and various Emperors who ruled during this period in the 17th and 18th centuries. This is only one of its kind architectures shows diverse influences including Nubian, Arab, and Baroque styles.

Various rebuilding and repairs were undertaken from the late 1930s to the late 1960s. Under the Italian occupation (1936 to 1941), extensive and radical restoration work was done on many of the monuments, using cement and reinforced concrete [1, p. 79]. Due to Earlier inappropriate repairs together with changes in function have resulted in serious damage and major restoration work was carried out on the compound Under the UNESCO/UNDP assisted project ETH/72/014. The

Figure 1.
Fasil Ghebbi palace [29].

situation was partially reversed with the restoration works carried out by UNESCO in the 1970s, which replaced the cement and concrete work with the original mixes of lime mortar as well as with subsequent major conservation programs implemented since 1990 [2]. Even with the Mentioned Restoration efforts in 2013 Fasil Ghebbi was listed as one of the World Heritage in Danger by the united nations educational, scientific and cultural organization, and according to Gebrehiwot [3], recently, there were same activities by the Government of Ethiopia with the support of donors to conduct additional restoration and renovation works.

According to Eskinder [4] method of construction for the Royal palace walls were by stone masonry. The abundant type of construction materials which were used during the construction of the Royal Palace was mainly by Basaltic Rock and Pumice with a Local name of "Beha Dingay [ባሃ ድንጋይ]"; which is transported from "Kuskuam mariya" and "Azezo," respectively. The type of binding material which was used during the construction of the Royal palace was also identified as lime (CaO). It is clear that lime and gypsum have always been functionally important materials in building, and in the light of recent archeological investigation, it appears that these materials are equally important historically. And they are important not only in building history but in the general history of mankind [5] (**Figure 1**).

2. Methodology

To study the mineralogical composition of both the original binding mortar and the mortar used for restoration works, XRF (X-ray diffraction) technique were used to identify the change in mineralogical composition of binding materials. After extracting the mortar sample from the exterior wall side, mortar sample were crashed to a powdered and sieved from number 200 sieve [6, 7]. Hydration products such as $Ca(OH)_2$, $CaCO_3$, C-S-H, calcium silicate and quartz were also analyzed. Result from the XRF test of mortar sample also used to identify the difference in mineralogical composition between exposed mortar with that of the unexposed one.

Site visit also carried out for assessing the physical impact due to weathering problem, tilting of wall and mechanical impact related problem, presented using photographs. Pictorial comparison of the current situation of the palace building and appearance of the palace, 5 years before are also presented in this document to evaluate the impact of durability on the palace building. Furthermore, Hydrology and geological investigation are also covered.

3. Case of deterioration

Considering the importance of preserving historical buildings, identifying the method of construction, investigating the cause underlying the occurrence of degradation and establishing the degradation mechanism is a priority. Historical mortars are complex systems, containing aerial or hydraulic binders or blend of them, aggregates sometimes reactive siliceous minerals that interact with the alkaline binder and, often, some additions. The reactions among the constituents and with the environment go on for long time.

Preservation and restoration of historic buildings represent, worldwide, serious concerns within the cultural community. Many valuable historical buildings are degrading because of a complex and combined effect of decay process, such as climate causes, structural issue, biological and botanical issue, insect and animal causes, air pollution, poor construction and inappropriate repair are considered as the major causes of deterioration [8]. The evaluation of the influence of each of the environmental factors in a given situation requires an understanding of which mechanisms are potentially of concern for the type of material or structure in question. In general, the main deterioration mechanisms include: Moisture, Environmental impact and Chemical actions [9].

3.1 Moisture

Moisture and temperature affect the chemical, biological, and mechanical processes of decay. The formation of a moisture layer on the material surface is dependent upon precipitation. It may also be generated as a result of the reaction of adsorbed water with the material surface, deposited particles with the material surface, and deposited particles with reactive gases [9].

Diana-Andreea stated the source of moisture in a historical buildings as Infiltration of groundwaters, because of the capillary rise and of the forces of electro-osmosis, Defective collection of rainwater and the lack of an effective vertical systematization, Condensation of water vapors from the air and from the pores of the building materials [10].

The soil between groundwater level and earth surface holds water by capillarity where this event is called as “surface water” or “capillary water” that cannot be removed by using any drainage system. The humidity rising up the building can cause serious damages on the structure [11]. According [Nigussie] to The groundwater around Gondar city can be found at a depth between 6 and 8 meters [12] consequently the groundwater at this depth cannot affect the durability of the structure (**Figure 2**).

Köppen-Geiger climate classification system classifies its climate as humid subtropical (Cwa), bordering with subtropical highland (Cwb). The annual average rainfall of Gondar city, Ethiopia is 1151 mm [13]. Rainwater Does not directly affect the deterioration of the walls; however, it may be acting indirectly in the mechanisms of deterioration it dissolves the mortar and it has a leading role in the activation of the primary mechanisms of deterioration of limestone rocks [14]. The rain water and the presence of moisture due to the rain water damages the exterior portion of the palace. The rain water is a combination of other soluble materials that causes

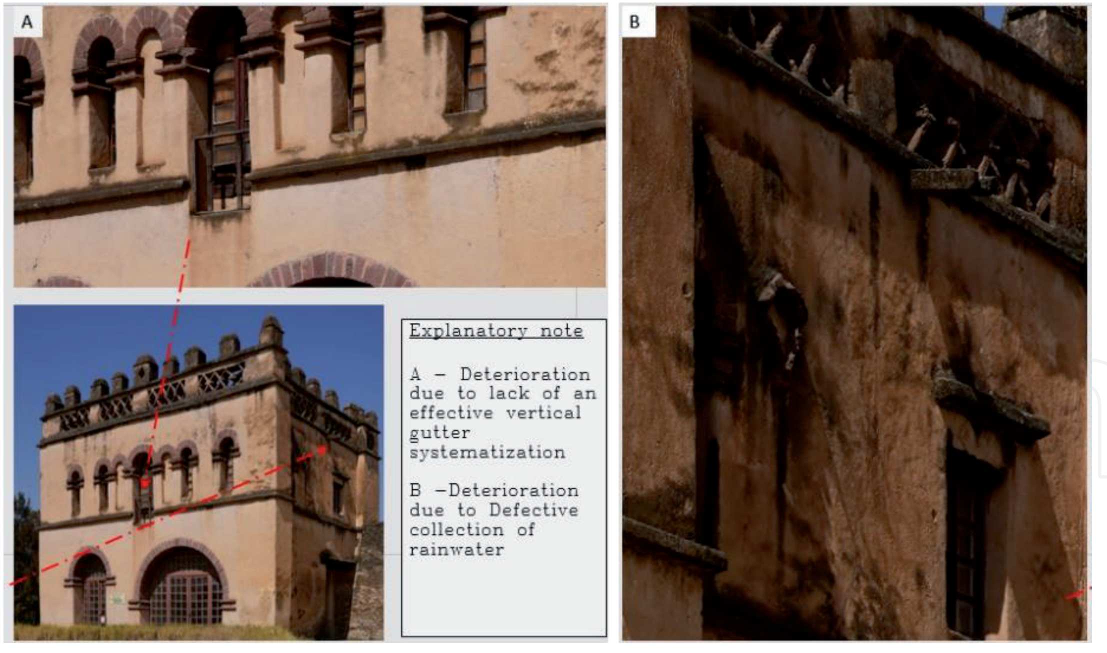

Figure 2.
The effect of improper rainwater removal on the face of the wall [29].

damaging manifestation when this rainwater vaporizes. In case of the Fasil castle, geomembrane was used to solve the effect of rain water dispersion through the wall cracks. However, the application is inadequate for the main palace. Two variables are important from the viewpoint of the damage caused by moisture: dew point and relative humidity of air.

Dew point is a characteristic of the water content of the large-scale air mass, whereas relative humidity depends on the local temperature and therefore on the local meteorological parameters. When the temperature of a material is below the ambient dew point, water condenses on the material, a moisture layer (condensation) can form, and the material damage may proceed. In most materials, an increase in relative humidity causes further deterioration due to more prolonged wetness time, higher deposition rates of pollutants and better conditions for biodeterioration [9].

Considering the fact that in order to properly develop heritage protection strategies, understanding of the future climatic conditions is of great importance, to come by/achieve these, various method have been developed in recent years in order to predict the evolution of certain meteorological parameters.

3.2 Chemical actions

Stone has been used as building materials for thousands of years. One of the reasons for this is the local availability of stones [15]. As it is proved in the Fasil Ghebbi palace, the appeal, stability and durability of stone are among the most important reasons for using it in stone masonry construction.

In addition to structural problems which is mainly causes by inappropriate methods of expatiation, defects due to poor workmanship and negative external effects [8]; atmospheric movement and humidity have played negative effects on conservation of historical buildings. Changes in temperature cause fragmentation and chipping in humid environments due to the presence of internal stress. Various acids formed by chemical reactions around plant roots lead to the deterioration of stones used during the palace construction. As seen in **Figure 3**, the roots of plants that flourish penetrate deep into the gaps between or the fractures on the stones used in the construction of historical buildings and induce chemical and physical weathering.

Figure 3.
The progressive biodeterioration processes on the surface of building materials: algae constitute the medium for the growth of fungi that pass through the building material by means of their hyphae. Dense formations of herbaceous plants [A] vascular plants [B] mosses and algae [source; Eskinder Desta].

Biological colonization is affected by substrate characteristics both physically and chemically. Due to the surface roughness of the masonry wall, algal cells can easily adhere to rougher surfaces, yet algae have the ability to extend on such surface. Microorganisms flourishing on the surface lead to microbiological deterioration and chemical deterioration. In most walls of the palace, which is exposed to the moisture; microorganism is observed on the facades of buildings, consist of bacteria and algae (including cyanobacteria), lichens and protozoa. Because of their resistance to high temperature and desiccation, lichens and vascular plants are generally play a role in the biodeterioration of the binding material of the masonry wall of the palace.

The formation of crusts tempted by cyanobacterial and algal growth also results in a longer moist retention at the wall surface, increasing the mechanical damage produced by the volume change in the pores of the stone [16] (**Table 1**).

The XRF result reveals that, from the total mineralogical composition of the original binding materials. The first abundant mineral from the original binding material is calcium which holds 18.7% of the mineralogical composition. The remaining mineralogical composition were occupied by quartz and rock fragment. From this result we can conclude that the amount of mineral composition which results cementitious properties of the binding materials is showing changes due the weathering effect.

All building materials are exposed to degradation processes which exert a stress on the building materials, then after a certain time it will cause major durability problem [17]. As seen from the XRF result the percentage of CaO is relatively less compared to the other cementitious materials, which results a lower cementitious property of the existing mortar. Degradation process is a gradual process leading to a reduction to the quality of the building materials.

Bio-deterioration of the binding material occurs due to alive organisms or the products of its metabolism. The process of colonization of a mortar is favored by its characteristics (porosity, mixture and roughness). These properties facilitate the retention of water in the binding material and the consequent growth of algae and cyanobacteria. As shown in **Figure 3**, it is the common durability issue in the royal

Oxide formula	Shorthand notation	Cement	Original binding material (lime) based
CaO	C	64.5	18.70
SiO2	S	17.945	35.46
Al2O3	A	4.4	7.98
Fe2O3	F	3.5	11.02
MgO	M	3.7	5.48
K2O + Na2O	K + N	1.2	2.65
Others	....	0.2664	2.22
H2O	H	—	5.12

Table 1.
Chemical composition of mortar samples from the main palace wall (%wt.) [4].

palace. For instance, biodeterioration of mortars of the Mosaics of Italica and some other Spanish archeological sites (Baelo Claudia, Medina Azahara) solved by the development of the biocide mortar, the biocide is adsorbed in sepiolite avoiding a quick leaching and increasing the effectiveness [18].

When lime is mixed with water, it forms calcium hydroxide, called slaked lime [19]:

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad (1)$$

The reaction of calcium hydroxide with carbon dioxide is faster, forming mortar mixture that gain strength more quickly.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (2)$$

Some cement compounds having both free alumina and silica, and the sulfates, forming sulfa-aluminates (ettringite) and sulfa-silicates, causes degradation of mortar. Mortars may suffer from external sulfate attack when exposed to sulfate-rich environments or from internal sulfate attack due to the presence of sulfate compounds in the constituents. Sulfate ions can react with the cement's hydration products to form ettringite and gypsum. These new phases encourage considerable expanding pressure of the adjacent cementitious matrix, resulting in cracking.

3.3 Maintenance issue

Conservation involves works undertaken to preserve the condition of the building to its original state and this also includes the subsequent maintenance works [20]. In most cases, having a well scheduled and properly constrictive maintenance is considered as a key factor for prolonging the life span of the historical structures. **Figures 3** and **4** reveals that, due to several factors a wide spread lack of binding mortar in between the stone masonry is noticed. To alleviate the above problems mortars and reduced the rock fragmentation; as shown in Figure mortar repointing has been submitted to may interventions in a certain period. Consequently, it is also challenging to determine the same kind of binding mortar as that of the one used in the constative stage. However, as Fernando et al. stated that during the rehabilitation of stone masonry walls, compatibility and durability of the intervention are very important [8, 21].

The major raw materials used for restoration works (lime) were transported from the south west part of Ethiopia, which makes it very challenging to perform a frequent restoration work. Some of the maintenance related issues of the Fasil Ghebbi palace are listed underneath [4, 22] (**Figure 5**) (**Table 2**).

Figure 4.
A widespread lack of binding mortar in between the stone masonry [source; Eskinder Desta].

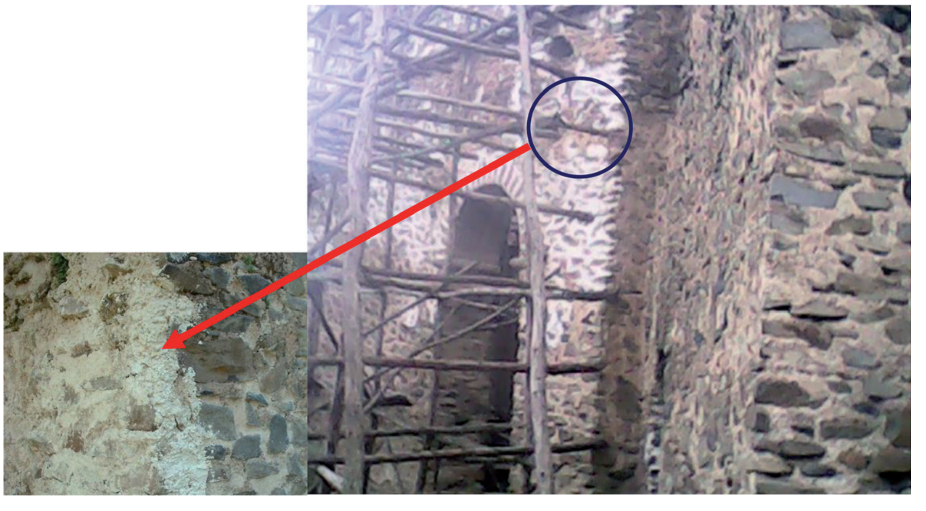

Figure 5.
Mortar repointing used during the restoration of the palace [source; Eskinder Desta].

No.	Sample description	Lab. No.	TW/HWT (gm)	Magnetite	Ilmenite	Calcite	Quartz
01	Restoration site	20209/14	10/9.95	1	Tr	*50	2

*Remark: * = clay size calcite; R. F = rock fragment; Tr = trace element.*

Table 2.
Chemical composition of mortar samples from the restoration site [4].

3.3.1 The absence of guidelines regarding to maintenance for historic building

There are no specific guidelines, procedures, method and system established by the concerned authorities regarding to maintenance of historical buildings.

3.3.2 Unplanned approach

The unplanned approach is the main approach adopted in the most of historic building interviewed. In addition, most of the maintenance work only take an action whilst the elements of the historical heritage display failure and malfunction.

Figure 6.
Active durability issue due to the presence of grass and alga on the wood floor terrace [source; Eskinder Desta].

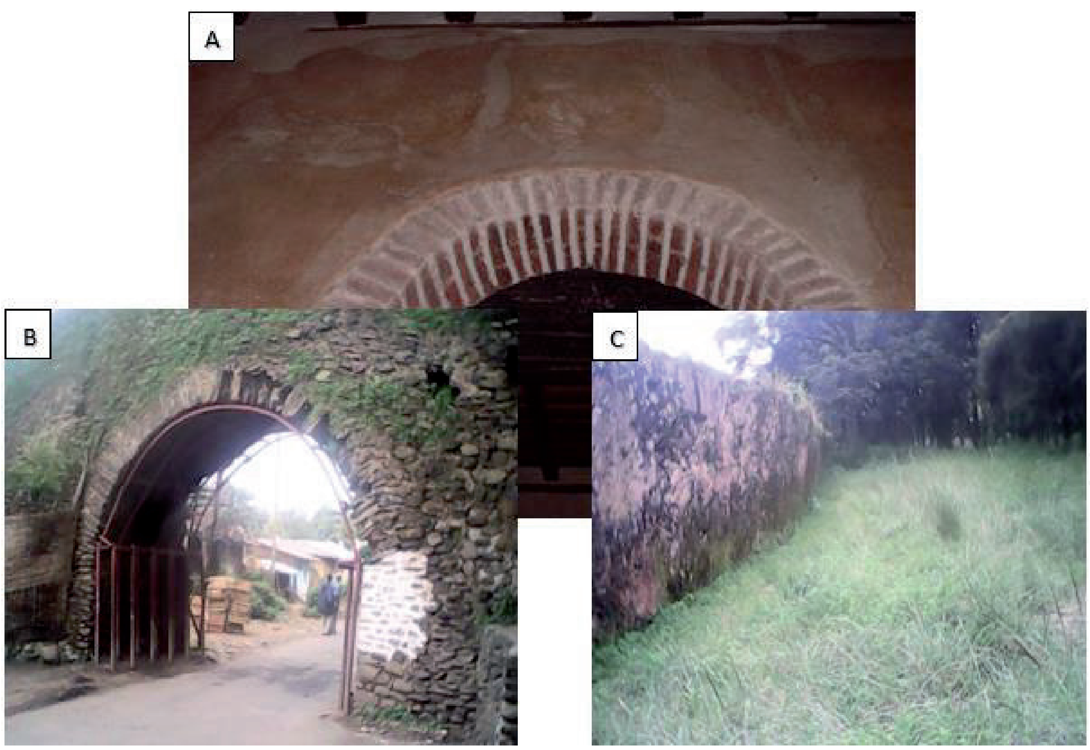

Figure 7.
Active durability issues risking the palace: (a) crack formation inside the palace internal partition wall (repointed surface), (b) steel frame support aimed for the enhancement of stone masonry dome structure, and (c) tilting of the stone masonry wall inside the main palace yard [source; Eskinder Desta].

3.3.3 Lack of maintenance staff training and expertise

The maintenance staff training, and expertise is the most important component in the maintenance process for historical building. Furthermore, the lack of maintenance staff training, and expertise also results for outsourcing their maintenance tasks to the contractor which even do not have related practical experience in the maintenance of historical heritages.

3.3.4 Lack of financial support

The main problem in maintenance of historical heritage building is also luck of financial support. The financial support is fundamental element in order to assurance the cultural significance will be preserve and conserve properly.

3.4 Visual inspection

Considering the stone masonry elements and their environmental conditions, the durability risks originates from both the aggressive agents in the atmosphere, human activity and seasonal biological colonization's. Based on the state-of-the-art knowledge, the possible deterioration process comes from different perspectives. Some of these buildings have deteriorated and still deteriorating for such reasons as intentional human activities, non-maintenance, climatic factors, and anthropogenic and biological impacts.

During the visual inspection of the main palace building, there were identified advanced signs of surface decay due to water infiltration in the basement and fissures on the wall and wooden floor of the main palace balcony. Following are some of the most problems spotted in the fail Ghebbi palace. Along with the respective reference figures.

a. Emission of vascular plant roots lead to the degradation of rocks and binding materials, which increase the formation of cracks in between the masonry stone layers and wall surface and thus facilitating deterioration.

b. The presence of vascular plant affects the visual esthetics of building by covering the surface of the buildings.

c. Seeds and small tree located on the building attracts animals and insects such as birds, ants and termites. Affects both the visitors and the durability of the buildings.

The investigation commenced with a visual inspection of the internal and external palace wall. As shown in **Figure 6**, the damage appeared to intensify on the outside wall surface and building components compared with that of the internal wall surface. The visual examination was followed by measuring the slope deflection of the masonry wall as shown in **Figure 7c**.

4. Engineering geology investigation

Gondar city of Ethiopia at an elevation of about 2133 meter above sea level is entirely covered with volcanic rocks and basalts [23]. The engineering geology of the site play an important role in any restoration and conservation activity. Therefore, it becomes very crucial to identify the engineering geology of the palace. So that, accordingly proper remedial measure can be planned. The lack of basic knowledge about geological – geotechnical characteristics of the urban environment and proper planning underlies many several social, geotechnical, and economic issues [24]. Such as, erosion, slope stability, landslide and building cracks, etc., which endanger peoples and infrastructural networks. Three geomorphological processes (weathering, physical impact, faulting and intrusion) were identified in the area, which are responsible for the formation of the present wall slide and crack

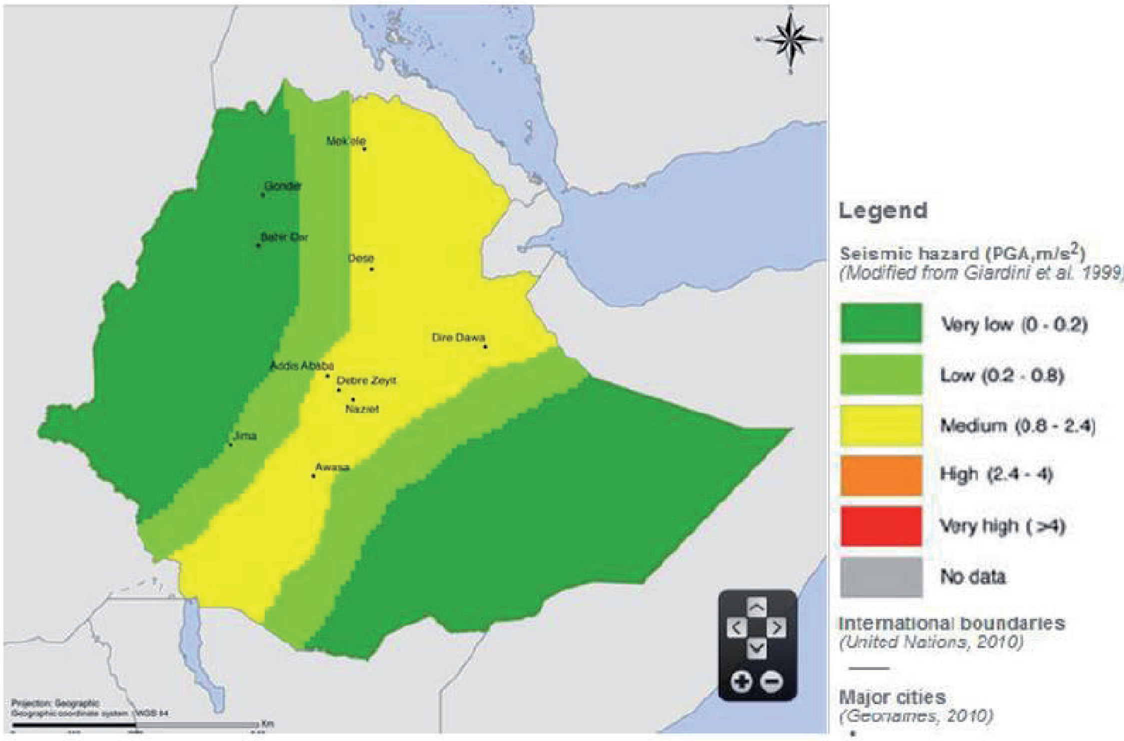

Figure 8.
Seismic hazard classification of Ethiopia [27].

Figure 9.
Iyasu Castle Fasil at Ghebbi [29].

formations. The first two processes are found to be more active and seasonal actions with existing structures and affect the floor, wall and the wooden extended veranda of the palace.

In seismically active area, and the effects of earthquakes on monuments, buildings and assets are critically destructive, given the weak mechanical behavior of masonry when struck by seismic loads [25]. Unfortunately, only when such seismic events occur do institutions and general public become aware of the serious vulnerability of the national architectural heritage.

According Haile [26] East Africa have three main zones of seismic weaknesses in the crustal segments: the East African rift system, the Gulf of Aden, and along the Red Sea. When we examine the location Seismic classification for the location around Gondar its far from the mentioned high risk areas and the Gondar city is classified as in a range from very low to low seismic hazard [27, 28] (**Figure 8**).

Even if the seismic zonation of Fasil Ghebbi is safe but in there have been a major geological incident in the Fasil Ghebbi as reported by Briggs [29] Iyasu Castle was partially damaged by earthquake in 1704 and the ground floor collapsed under the British bombardment in world war II. **Figure 9** illustrates destructive effects the earthquake that occurred on the Fasil Ghebbi at Iyasu Castle in 1704.

5. Hydrogeology

Brimblecombe [30] states water is a critical factor in damage to heritage, it may even be more critical than temperature at same cases. Based on his survey on heritage managers ranked the potential problems faced in a changing English climate as: (1) Rainfall (2) Flooding and soil moisture content (3) Extreme weather (winds and rainfall) (4) Temperature and relative humidity (5) Pests and diseases.

Climate change and world heritage report states intense rainfall and flooding (sea, river) could cause physical changes to porous building materials and finishes due to rising damp; damage due to faulty or inadequate water disposal systems; historic rain water goods not capable of handling heavy rain and often difficult to access, maintain, and adjust erosion of inorganic, organic materials due to flood waters sub soil instability, ground motion and subsidence relative humidity cycles/shock causing splitting, cracking, flaking and dusting of materials and surfaces. Temperature changes diurnal, seasonal, extreme events could results deterioration of facades due to thermal stress freeze–thaw/frost damage, damage inside brick, stone, ceramics that has got wet and frozen within material before drying, biochemical deterioration [31].

Krauss and Fischer [32] studied endangerment of the Palmyra to flooding using DEM and concluded that Temple of Bel lies on a locally higher area the tombs to the left are located mostly on the mid slopes but also remnants can be found in the endangered lower areas which is exposed to flooding. Using simple digital elevation model generated using *Arc GIS* utilizing elevation obtained from Google Earth it can be seen in **Figure 10**, that most of the structures in the Fasil Ghebbi are situated on the upper elevation therefore the risk of flooding during peak rainfall is minimal.

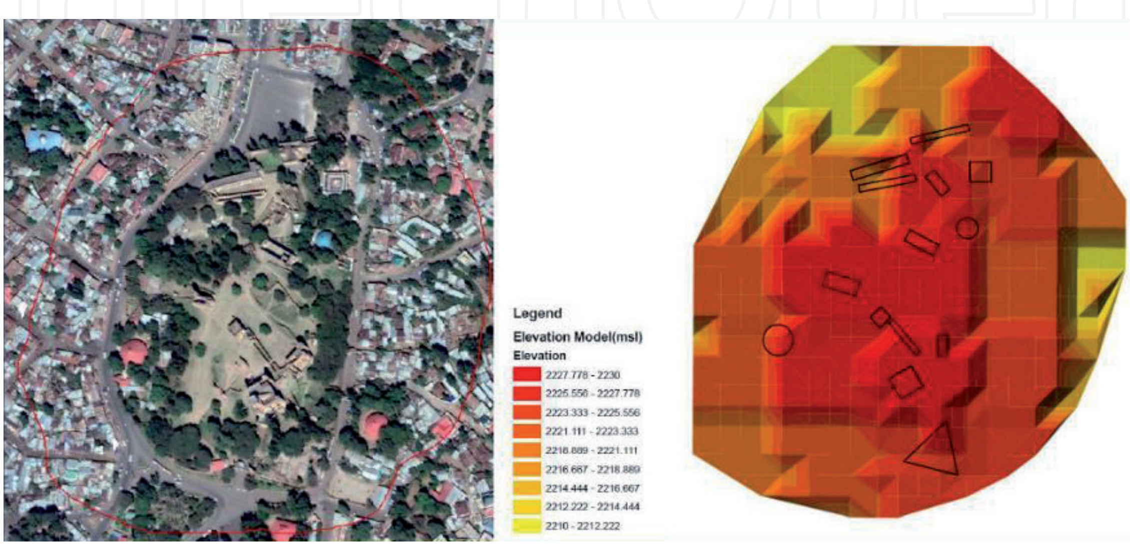

Figure 10.
Fasil Ghebbi digital elevation model.

Figure 11.
Biological growth at Fort San Lorenzo (Panama); source and Fasil Ghebbi [source; Eskinder Desta]. A. Biological growth at Fort San Lorenzo (Panama). B. Biological growth at Fasil Ghebbi.

Figure 12.
Some selected spots inside the royal palace before and after restoration. (A and C): in 2015; (B and D): in 2019 [source; Eskinder Desta].

Historic buildings are more porous and draw water from the ground into their structure and lose it to the environment by surface evaporation. Their wall surfaces and floors are the point of exchange for these reactions. Increases in soil moisture might result in greater salt mobilization and consequent damaging crystallization on decorated surfaces through drying [31].

Climate and biological effects may include changes to lichen colonies on buildings, spread of existing and new species of insects, increase in mound growth. According to UNESCO climate change and world heritage report [31] this factors may cause changes in appearance and collapse of structural timber and timber finishes. As an example; **Figure 11** shows the biological growth at Fort San Lorenzo [33] and Fasil Ghebbi [4] (**Figure 12**).

6. Conclusion

This paper reviews the state-of-the-art knowledge on the durability issue of Fasil Ghebbi palace, Gondar, Ethiopia with long service life. In conclusion it can be said that the protection of the built heritage against chemical changes, prolonged weathering and human intervention threats is a very complex issue, where many factors have to be taken into consideration, among the most important factors are: the traditional construction techniques, the current and future meteorological parameters and the availability of building materials.

The research points out that climate change and human interventions are a real threat to the fail Ghebbi palace. Unless measure is taken for the protection of human impact and weathering related problem on the surface of the building or overall building, these historical heritages will ultimately be endangered. Deterioration related to vegetative organisms was found in Fasil Ghebbi palace; specifically, in rainy seasons these effects were more intensified particularly on the wall that did not face the sun.

Structural instability is also observed for done shaped masonry walls and partitions walls located close to the main traffic road because of the effect of traffic vibration and deliberate mechanical impact. The effect of moisture already has spotted on the appearance of almost all building inside the royal palace, affecting the esthetic value and reducing the bearing capacity of the building.

During the restoration work, it is highly important to select binding materials that exhibit similar properties to the original building material. The research indicates that the Fasil Ghebbi palace is are extremely vulnerable concerning future moisture related durability issue and aging, it is urgently needed to find protection solution and setting a guideline for periodical inspection and restoration work.

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