INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 12, Issue 2, April-June 2021: 493-506 www.ijcs.ro

PREVENTIVE PRESERVATION APPROACH FOR THE PRESERVATION OF UNIQUE EARLY NEOLITHIC ARCHITECTURAL REMAINS OF THE ARCHAEOLOGICAL SITE OF BEIDHA-JORDAN

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Abstract

The Neolithic site of Beidha in southern Jordan is a highly significant and unique site that documents the evolution of early human residential architecture. The architectural remains of the site have been seriously deteriorated over the years due to natural and human factors. The site value is being diminished and its existence is threatened. Therefore, this research is meant to be a response to this undesirable situation. This research aims at proposing conservation measures that can safeguard the site and minimize future risks. Due to its many advantages including preserving the authenticity and integrity of the site, cost effectiveness and sustainability, preventive conservation approach is adopted. This approach is based on the preservation of the architectural remains by avoiding the agents of deterioration and applying the minimum repairs using compatible materials. Field surveys, laboratory analyses and documentary research were used to examine and analyze the remaining structures in terms of their building techniques, building materials, and forms and causes of weathering and deterioration. Based on the obtained results two levels of preventive conservation measures proposed to safeguard and preserve the site: preventive measures that are based on avoiding the agents of deterioration and measures that are based on minimum intervention to inhibit the propagation of future damage.

Keywords: *Neolithic; Jordan; Preventive Preservation; Earth Mortar; Beidha Site*

Introduction

Neolithic architectural remains are valuable and rare structures that, by nature, should be treated with extreme caution when it comes to their conservation. The ideal conservation approach ought to fulfill certain requirements including the safe transmission of this heritage to posterity, preservation of existing material, protecting authenticity, respecting aesthetic and historical integrity, ensuring reversibility, minimum intervention and compatibility of materials [1, 2].

The conservation approach that satisfies all the previous requirements is the preventive conservation approach that is based on the prevention of further damage either by avoiding the causes of deterioration and damage and through minimum intervention to avoid further propagation and spreading of damage. This approach can contribute to the continuity and safeguarding of these highly significant architectural remains versus risks and at the same time ensuring the preservation of their integrity and authenticity. Preventive conservation approach is the right approach that can achieve this delicate balance. The fragile nature of Neolithic architectural remains makes preventive conservation even more suitable.

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Prevention entails protecting cultural property by controlling its environment, thus preventing agents of decay and damage from becoming active. Repairs must be carried out only when absolutely necessary using compatible materials to prevent further decay and damage propagation [3].

Preventive preservation approach is based on the examination of the environment of the cultural property for all possible factors that might enable deterioration to occur. This informed examination would enable the identification of the probable factors, whether natural or human, and the opportunity to mitigate or reduce the availability of those factors, in order to promote the longevity of the cultural property [4-6].

The implementation of preventive conservation involves several steps; examination and documentation of the site, diagnostic identification of causes of decay and damage, categorization of causes according to risk level, implementation of urgent measures, implementation of additional measures to minimize risk of damage, repairs to prevent further damage, implementation of regular maintenance, and implementation of monitoring program [1].

Beidha is a major Neolithic archaeological site that is located within the boundaries of the famous world heritage site of Petra in southern Jordan (Figure 1). It is well known among archaeologists as a site that displays many of the most important attributes of settled village life at a very early time. Among these attributes is the use of masonry architecture. Diana Kirkbride excavated Beidha in the late 50s and early 60s, with a final field season in 1983. Her findings at the site have been used to define the cultural period known as the Pre-Pottery Neolithic B [7-10].

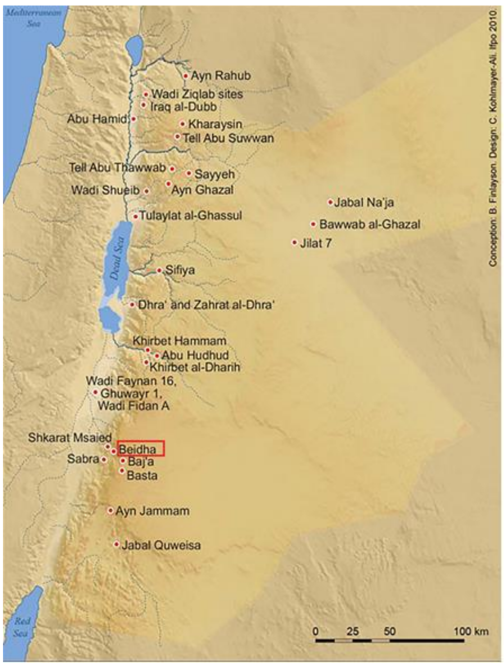

Fig. 1. Location of the archaeological site of Beidha in southern Jordan

The fieldwork revealed that Beidha is a multicomponent site with three discrete periods of habitation: an early Natufian period of occupation around 9000BC. After a period of abandonment, the site was settled again during the Neolithic period (7000-5000BC) with three distinct occupational phases (A, B, and C) characterized by different housing styles. This was followed by abandonment until the site was developed by the Nabataeans in the period between 300BC - 100AD [11, 12].

Beidha is a unique site in terms of the evolution of its architecture with a long continuous history of use. Archaeological research reveals evidence of a continuous architectural sequence ranging from clusters of round post houses, through individual sub-rectangular examples, and then ultimately true rectangular buildings (primarily corridor buildings) as shown in figure 2 [13].

Fig. 2. General view showing the three styles of houses at Beidha

The Beidha architectural sequence is, at present, unique in the Levant, PPNB: Beidha is currently the only southern Levantine site that documents this transition in residential architecture. The most important change in architecture most archaeologists look at is the change from the primitive circular to the rectilinear structures. Beidha is one of the best examples of this change whereas both typologies of architecture are present in one site and in a fairly good preservation condition [14, 15].

Beidha has been undergoing degradation and collapse of structures since it was firstly excavated 60 years ago due to a combination of human and natural factors. Architectural remains have been exposed to both human and natural damage and decay since that time. Despite the fact that Beidha unique features are being constantly depleted, limited conservation works were carried out at the site aiming at stabilizing the friable structures The lack of regular maintenance and conservation have caused deterioration and collapse of built structures. This highly significant and unique site is under imminent threat and urgent conservation measures need to be implemented without delay.

This research main aim is to propose measures that can preserve the architectural remains of Beidha in their existing preservation condition and to minimize future deterioration and damage. The research specific objectives are to document the state of conservation of the site, to identify the types of weathering and deterioration forms and their root causes, and to propose conservation measures that can ensure the preservation and safeguarding of the site. Characterization and of the nature and properties of the original mortar used in Beidha is one of the objectives of this study. This is an essential step for the formulation of appropriate compatible repair mortars both aesthetically and functionally required for the future conservation of the site.

Experimental

Condition Assessment

A combination of documentary research, survey, visual examination, digital recording and laboratory analyses were used to examine the architectural remains and their surrounding environment. High resolution digital photography was used to document the existing condition of the site. The condition assessment of the site was made based on field survey conducted over a period of one year and documentation of all forms of existing deterioration and damage. The conditions were recorded graphically. Then a comparative analysis was done of the current condition of the site with a previous condition based on photographs and data collected from people who have earlier worked at the site. The identification of the root causes of decay and damage was done through development of hypotheses about the link between causes and effects of deteriorations while recording the conditions of a site. These hypotheses were later modified based on studying historical photographs, and documentary research concerning geology, environment, climate, history and the architecture of the site [16-18].

Because of the advanced stage of the deterioration of mortar and some stone blocks of the masonry walls, a field survey of the materials used in the construction of the structures was conducted. Samples from the mortar and stone blocks were collected for laboratory analysis. A multi method approach using chemical and mineralogical methods was used for the characterization of the mortar materials and the identification of their chemical and physical properties.

Mortar and stone analysis

As a rule, conservation interventions on archaeological structures requires the use of compatible repair mortars with the original materials. Consequently, the complete characterization of the chemical, physical and mechanical characteristics of originally employed mortars is imperative to the success of the conservation process [19].

In order to collect representative samples that cover mortar used at various typologies of architectural structures that belong to different time periods, a stratified random sampling approach was used. Ten samples were taken from the earlier PPNB phase rounded houses, 9 samples from later PPNB phase rectangular structures and 4 samples from village wall. The sampling of the mortars was carried out using a hammer and a chisel, removing the first layer in contact with the atmosphere. Eight samples of stones that are in good preservation conditions and 3 samples of stones that show weathered flaky surfaces were collected.

Characterization Methodology

A multi method approach that integrates different analytical techniques was adopted for the characterization of the physical and chemical properties of the mortar samples [20]. X-ray diffraction and Petrography were used to evaluate the mortar mineralogy through the identification of the morphology, dimension and type of aggregates, binder, additives, apparent porosity and secondary or decay products. The binder and aggregate ratio was determined by "Calicmetry" which includes the dissolution of samples in dilute hydrochloric acid. Each mortar and plaster sample were cut into two halves. The first half was used for the preparation of thin sections and the other half was used for the XRD, and calcimetery. The portions used for thin section preparation were dried at 40 C and then were consolidated by impregnation under vacuum with epoxy resin in order to preserve the original granular arrangement. Thin sections were cut and polished following the standard procedures [21]. The prepared thin sections were studied by using Leica polarized light microscope. Photomicrographs were taken by a camera attached to the microscope.

XRD was performed on a SHIMADZU X-Ray Diffractometer - 6100 target Cu tube fitted with monochromatization Ni filter. Target Cu voltage of 30kV and current of 40mA were used. Measurement Range 2θ: 10 to 50 degrees. Scan Speed 43 degrees/minute. The patterns were.

Chemical analysis to determine the binder aggregate ratio of the mortar was done by Clacimetry method in combination with mineralogical and petrographical analysis. Calcimetry is based on breaking down the mortar sample into constituent parts and provides data on the nature of the binder by gauging the extent of its reaction with hydrochloric acid (HCl) [22]. Carbonate content in the samples was determined using the "Dietrich-Fruhling gas volumetric method" calcimeter that meets standards DIN 19684 [23].

The sieving - pipette gravitational sedimentation method was used to analyze the aggregate particles size distribution according to the procedure described by Folk [24].

Mineralogical analyses of the stone samples were carried out by XRD and chemical analyses were carried out by inductively coupled plasma-Optical Emission Spectrometry (ICP-OES) method using Thermo Scientific iCAP PRO XPS ICP-OES.

Results and discussion

Buildings Materials

The field survey and laboratory analyses show that the structures of Beidha were built using local materials. Undressed limestone and earth mortars were the basic building materials used in the construction of the houses and the city wall. Thin layer of lime plaster was used to cover some internal walls and floors and tree trunks (Oak, Juniper) were used as posts to carry the roofs which were made of reeds covered with mud. Currently the only remaining building materials are the stones, remains of the binding mortar of the walls and some scattered patches of the floor plaster. Stones have survived and are in good preservation conditions while the mortar suffered severe deterioration and disintegration and wood posts were completely decomposed as indicated by the cavities left behind as shown in figure 3.

Fig. 3. Remains of one of the houses showing stones, remains of the mortar and the gaps resulted from the loss of the wooden posts

Forms and Extent of Weathering and Decay

Mortar weathering and disintegration

The most noticeable problem that has caused loss of strength and integrity of structural remains in Beidha is the weathering and disintegration of the binding and rendering mortar. Mortar decay resulted in weakening of the overall structure and collapse of stone especially the upper part of the walls (Fig. 4). This type of weathering can be noticed clearly where there is a great difference between the strength of mortar and building stones, so the weathering clearly appears on the mortar.

Fig. 4. Decay and loss of mortar lead to weakened structures

Mortar weathering has been caused by many natural agents particularly running water and persistent dampness as earth mortar is vulnerable to water damage. High levels of moisture gradually destroy the clay matrix, leading to increasingly friable mortar, a loss of structural integrity and ultimately the deformation of masonry elevations. Other factors such soluble salts, wind, plant growth effect and daily cycles of fluctuation in temperature and relative humidity which caused change in volume and dimensions of the mortar have contributed to the acceleration of the weathering process.

Selective Deteriorated Stones

Unlike mortar, most stone blocks used in building Beidha structures are in good preservation condition indicated by their good mechanical strength. However, it has been observed that few examples of the stone blocks have been selectively deteriorated as manifested by their flaky surfaces and weakened structures. Laboratory analyses by XRD and ICP-OES prove that the basic difference between the deteriorated stone blocks and the preserved ones is their content of the iron oxide limonite - $FeO(OH)\cdot nH_2O$. The deteriorated stones contain a high percentage of 5.26% of limonite while the preserved ones contain as low as 0.78%. Limestone that contains high percentage of limonite is weaker, softer and has more porosity and less specific gravity when compared with limestone that contains no or low percentages of limonite [25]. This explains the selective weathering of these stones as shown in figure 5.

Fig. 5. Selective weathering of limestone blocks that contain high percentages of limonite

Collapses and fallen stones

This sort of damage is observed at many locations at the site and is caused by a combination of different human and natural factors particularly walking by locals and visitors over the fragile structures.

Stone cracking

Cracking of some of the building stones, which are flat and with large surface area in comparison with thickness, could be attributed to excessive load as a result of the accumulation of deposits over the wall with the laps of time (Fig. 6). Other cause may be binding mortar weathering and fall of some small supporting gravel underneath the stone which creates an uneven distribution of load from the weight of stone above and directed over small areas of the stone surface.

Fig. 6. Stone cracks due to excessive load

Lost of Wood Posts

Wood posts were set up during the beginning of constructing of Beidha houses. They were used to transfer the load of the walls horizontally and distribute the force between stones. Wood is an organic material that is very susceptible to biological and physical deterioration caused mainly by fluctuations of humidity and temperature [26]. All wooden posts were totally lost leaving gaps between wall stones. This resulted in imbalanced distribution of the force and concentration of force over some stones which caused them to crack and fall apart as shown in figure 7.

Fig. 7. Gaps between stones as a result of wooden posts deterioration

As earth mortars have very low tensile strength, they provide little restraint to movements caused by change in load patterns.

Proposed Preventive Conservation Measures

Based on the identification of deterioration and damage forms and factors, two levels of preventive conservation measures are proposed: The first level is preventive measures that are based on avoiding the agents of deterioration and the second level is preventive measures that are based on repair and consolidation of existing structures to prevent propagation of further damage. In this level the principles of minimum intervention, compatibility of repair materials and reversibility are respected.

Preventive measures to avoid agents of deterioration

Diversion of Runoff water

The average mean rainfall in millimeters per year in Beidha is about 200-300mm/y. [27]. However, the nature of rainfall at Beidha is described to be a short period of great abundance causing a quick rise in the level of water and the formation of streams of water moving to the lower places carrying soil, and gravel. The size and amount of stuff carried out by the stream is proportional to its speed and the amount of water. The sandy soil of Beidha has very low absorption affinity of water, which causes very fast rise in the level of rainwater and the formation of streams. The site is located in flat area surrounded by Rocky Mountains from all the sides, near the maximum flow point of the catchment area which makes running water a serious damaging factor that causes instant mechanical damages and long-term increase of dampness [28].

Based on understanding of the hydrology of the area, the best solution for this problem is the diversion of the runoff water away from the site. This can be achieved by constructing channels mainly alongside the mountain to divert water to the lower area outside the site, as represented in figure 8.

Fig. 8. Proposed water diversion channels

Vegetation Treatment

Plant growths at improper locations over and beneath stone structures have caused a great deal of pressure which led to disintegration of mortar and sometimes creating serious structural problems. Besides causing such type of damage, higher plants can affect chemically by giving out exudes that react with the stone surfaces [29]. Higher plants growth can be best controlled by uprooting them at their initial stages of growth. The use of herbicides can be considered but is not recommended.

Control of Animal Grazing

Animal grazing especially goats is very dangerous as animals walk over the fragile structures looking for grass and extracting it from between the stones which lead to disjointing the stones and further weakening the structures. The binding mortar is partially removed with each plant extracted from the wall. Also, animals' waste negatively affects the site's aesthetic value and help in increasing plants growth by acting as natural fertilizers. Animals can be prevented from entering the site by fencing and guarding the site.

Control of tourism activities

Beidha lies within the boundaries of world heritage site of Petra. Tourism industry markets the site as premier destination which results in big influx of tourists visiting the site. As the site has not been prepared for tourism, visitors wander at the site without any organization and they walk over the fragile stone structures causing a great deal of damage. Visitation of the site should be stopped until a site management plan that includes clear guidelines for visitors' management and a delineated visitors trail are developed.

Preventive measures to curb propagation of further damage

The proposed measures are meant to stabilize the existing structure in order to prevent or at least slow down further damage and prolonging its existence. The proposed conservation measures strictly respect the principles of minimum intervention, reversibility and compatibility of the used materials with the original ones. The treatment involves replacing missing or cracked stone blocks, strengthening the core with compatible materials, treating the wall foundations, filling of joints and cracks, consolidation by injection and re-pointing. The stone is in fairly good condition, however when it comes to the mortar, it is obvious that it's in a bad condition and lost most of its binding properties, thus it became very weak and no more able to keep the stones attached to each other. Therefore, most conservation treatment should be focused on applying mortar where it is needed to strengthen the existing structure and inhibit further damage. Ideally, repair mortars will be similar in character, appearance and performance to the original material of construction. This should be based on precise characterization and understanding of the original mortar composition and properties.

Characterization of original mortar

Preliminary results show that the mortar used for binding and rendering in Beidha structures is an earth mortar mixed with lime. X-Ray diffraction analyses (Fig. 9) show that all analyzed samples have quartz and calcite in addition to the clay minerals chlorite and kaolinite.

Clay and lime acted as binders and quartz as aggregate. XRD analysis of local subsurface soil show similar patterns, which indicates that mortar, was produced from local materials.

Petrographic microscopy of the mortar samples showed that the mortar matrix is composed of calcite as binder and quartz as aggregate (Fig. 10). Most of the quartz granules were sub-rounded to sub-angular and showing wavy extinction which indicates that it was crushed and intentionally added. Shreds of flint, Iron oxide, and charcoal were observed in some samples. All mortar samples showed a good adhesion and sticking between the binder and the aggregate.

Calcimetery results showed that the average carbonates content is around 16% of the total weight of the samples which is similar to percentage of carbonates in the local soil. Sedimentation analyses showed that mortar contained 40% of sand (Quartz), 39% of silt, and 4% of clay.

The mortar used in Beidha is characterized by having a mixed binder of lime and clay. The builder's choice of soils with law percentages of clay and enriched in calcium carbonate may indicate that they had empirical knowledge about the role of calcium carbonate as binder. They might have deliberately chose the type of soil rich in carbonate to produce a more durable and resistant mortar.

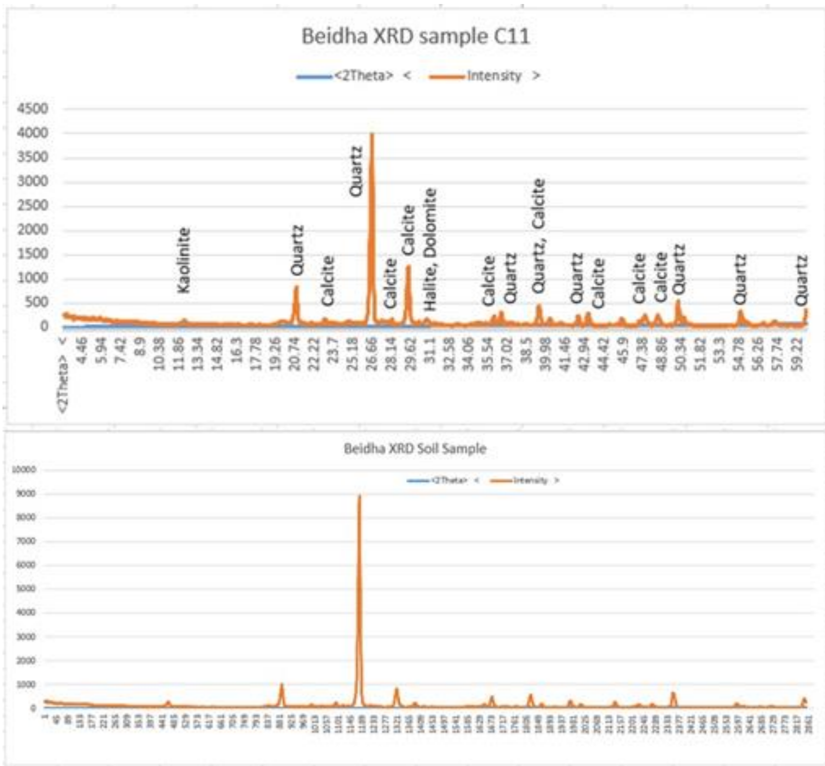

Fig. 9. X-Ray diffractograms of original mortar and soil

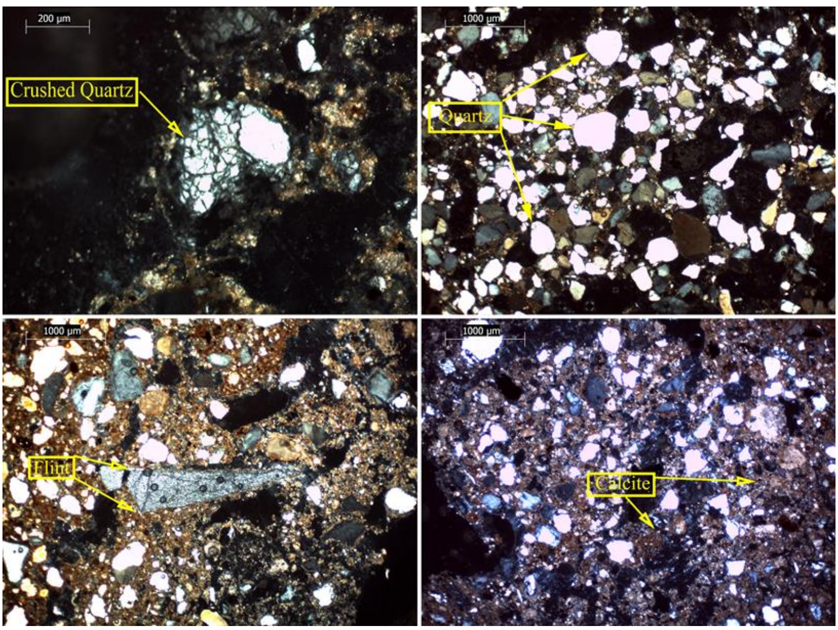

Fig. 10. Photomicrographs of mortar under crossed-polarized light

Mineralogical and chemical compositions of ancient mortar are essential for the reconstruction of repair mortar that is compatible with the original one. However, further analysis to determine the physical and mechanical properties of the mortar are required to enable the effective preparation of the compatible repair mortar. Laboratory analyses are being conducted by the researchers on various mortar mixtures made from local materials with same composition as the original mortar in order to optimize their mechanical strength and moisture absorption properties.

Consolidation of the walls

Consolidation of the walls can be done by applying repair mortar in the voids and deep joints between the stones, which are susceptible to fall. Proper application of mortar provides more cohesion to the friable structures. Depending on the condition of the structure, different techniques of mortar application can be used including grouting, repointing and injection.

Capping the Walls

Capping is applying a layer of mortar over the fragile stone walls to prevent their collapse especially for the upper stone courses. Capping acts as a protective layer that reduce significantly the effect of rainwater falling at the wall and eroding mortar, also it penetrates the wall and move down through voids in the mortar washing the mortar from inside the wall. Capping also help in fixing the stone blocks at their location by the effect of the weight of the capping layer. Capping is advised to be applied after stabilizing and repointing.

Re-installing of Wood Posts

Wood posts should be reinstalled at their original locations, to protect the structures from further damage and stone failings. Wood posts were used as a construction material in Beidha structures to transfer the load of the walls horizontally and distribute the force over the whole height of the wall, which helps in preventing collapse. The complete deterioration of the wood posts created gaps between the wall’s stones and imbalanced distribution of the force that caused a concentration of force over some stones. This resulted in stone cracking and falling as shown in the Figure 11.

Fig. 11. Re-installing wood posts in the gaps

Conclusions

The highly significant and irreplaceable architectural remains of the Neolithic site of Beidha have suffered serious deterioration and damage. Irrespective of the site value and significance and being located within the boundaries of the World Heritage Site of Petra, very little conservation or maintenance efforts have been done so far. The site is in real danger of complete depletion which will represent a big loss not just for Jordan but for the whole world.

This study proves that the fate of the site can be changed from depletion to preservation by applying inexpensive preventive conservation measures that can minimize the deterioration and damage of the site thus avoiding major costly restoration interventions. The proposed preventive conservation measures are based on either avoiding of agents of deterioration or applying minimum repairs by using compatible materials with the original fabric. The proposed measures are cost effective, easy to apply and can ensure the preservation of the integrity and authenticity of the site which make this approach feasible for safeguarding of this uniquely significant site and similar Neolithic sites.

Acknowledgments

The authors are grateful for Deanship of Scientific Research at Yarmouk University and USAID/Jordan Tourism Development Project II (Siyaha) for supporting this project. This research has started at Yarmouk University and completed during my sabbatical stay at Rathgen-Forschungslabor -Staatliche Museen zu Berlin. I am grateful for the laboratory staff, particularly its Director Prof. Dr. Stafan Simon, for the constructive discussions and exchange of ideas. This research mission could not have been possible without the generous financial and logistical support of Alexander von Humboldt Foundation-Germany.

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Received: Octomber 02, 2018
Accepted: August 24, 2019