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Conservation of coral stone architectural heritage on the coast of East Africa

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Abstract

Much of the architectural heritage on the coast of East Africa was built with coral limestone and today it suffers from a severe decay. Swahili architecture and European colonial architecture are part of this heritage. After many observations at sites such as Inhambane, Ilha de Moçambique and Ilha de Ibo, we think that the phenomenon of regeneration of soluble salts is the main cause of degradation of coral stone buildings.
Knowledge and mastery of the physical and chemical phenomena in coral stone buildings are the basis of the preservation process. But the techniques of the past, when known to the restorer, can suggest the best way for the restoration and maintenance practices (Some topics of this theme: lime from coral - sand fluvial from the Ibo Island - *murrapa* juice, as an additive for mortar).
Finally, the paper proposes the idea of preserving historic coastal settlements in an optimal equilibrium with natural environment assets.

Peer-review under responsibility of IEREK, International experts for Research Enrichment and Knowledge Exchange

Keywords: coral stone; conservation; soluble salts; tropical coasts, *murrapa*.

1. Introduction

My interest in coral stone buildings began in 2004 with the request for an opinion from the Director of the Cooperação Técnica da República Federal da Alemanha in Mozambique (former GTZ, now GIZ). The German Cooperators' intention was to use the recently restored church of Inhambane for an archaeological exhibition.

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They asked the Faculdade de Arquitectura in Maputo to assess the disintegration phenomenon of plasters reappeared on the church soon after restoration works and to suggest some procedure for achieve a regular course of the scheduled event[i].

2. Disintegration of coral walls

During my survey in Inhambane I was convinced that the major problem of deterioration in the church of Nossa Senhora da Conceição was caused by the migration of salts through the walls and that the slight deformation due to the collapse of the wall area facing southeast was to be considered stable. In a simple visual exploration of the oldest buildings in town, it was noted that the phenomenon of salt crystallisation must always have been present since their construction. In fact, many of the oldest buildings in Inhambane present quite a number of plastering patches; it is thus possible to compare samples of plaster in their time sequence in order to identify the different degrees of technical skills, strength and effectiveness. Even with no instrumental survey on the samples, the patches' position and mixture showed that in the past maintenance workers had realized that the problem to be solved was the inhibition of water penetration from the outside. They had made different types of mortar in order to get very low porosity plasters. In mixture of some patches I recognized *pozzolana* ash, in a relevant proportion. I thought it was not cement mortar because the analysed fragments showed a grey-red colour; furthermore, the ray-red granules were visible at first sight and the fragment, once compressed, lost its shape and became dust; that means it was made of a ductile material and then it didn't break sharply as it is typical of fragile things such as a fragment of cement mortar.

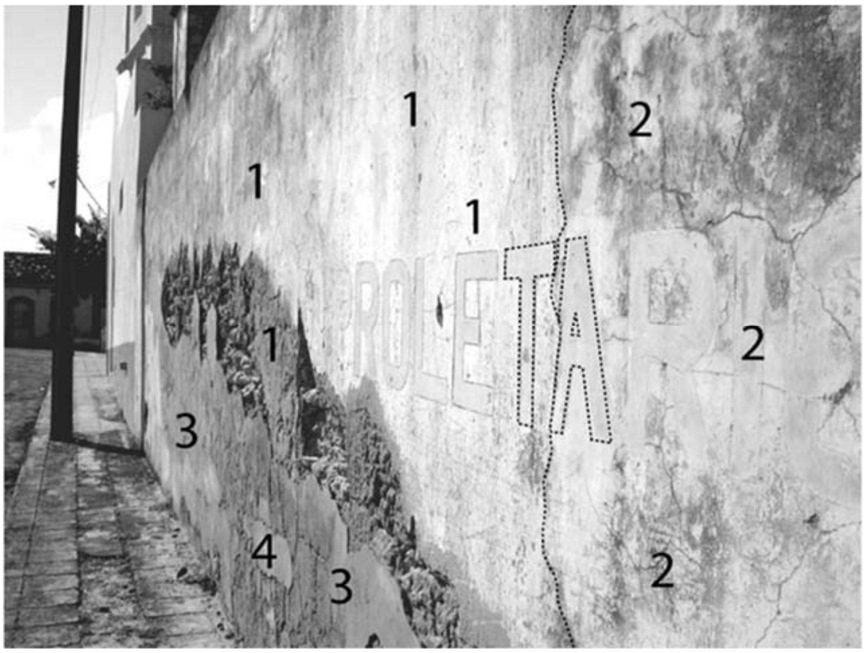

Fig. 1. Map giving the time cycle of disintegration of plasters and the wall in Inhambane.

In various processes of the historic heritage preservation, the salt migration phenomenon through the materials is being studied with the tools of chemistry. In literature may be found different ways to limit the process of disintegration of the masonry caused by the migration of saline solutions and the reformation of salt crystals due to water evaporation. In general, the disruptive phenomenon can be controlled working on a simple physical level, i.e. washing the walls with water, once the flow of saline solutions has been inhibited[ii].

When materials with open and homogeneous porosity are present, such as high-quality bricks or some types of compact rocks, the widespread moisture phenomenon can be controlled. The procedure is aimed at downsizing the capillary network by the use of lime or silica or various types of resins. These products are forced to flow and deposit themselves in the cavities at different depths, in a more or less predetermined thickness. In this way the pore width is reduced.

The presence of a certain degree of salinity in the dampness of the walls, such as sea salt (NaCl), does not involve serious conservation problems if the various elements can be kept in a state of fixed equilibrium. On the contrary, the combination of elements such as water and temperature usually shows an unbalanced behaviour. If the surrounding temperature varies, the concentration of a given saline solution can vary too. When salt concentration increases with water evaporation, excess salts may again resume their crystalline state.

3. Capillarity

Donatella Procesi performed some laboratory tests concerning porosity and water capillary absorption on coral stone samples taken from buildings of Mombasa and Mtwana[iii]. The results confirm the remarkable capacity of water absorption as typical of coral rocks. Similarly, the property of high water absorption is also a characteristic of mortar and plaster mixed with inert limestone coral. Thus we were able to confirm that most of the buildings of the old centre of Inhambane and of the Ilha de Moçambique are extensively affected by the phenomenon of water absorption due to the widespread capillarity of common construction materials; however, it should be noted that phenomena of capillary rising dampness were not observed in Inhambane nor in Ilha de Moçambique (Fig. 4).

In the last case we can only make a realistic proposition, as it was not possible to check in a systematic way whether the phenomenon still exists in the houses of concrete blocks built at a lower level in the town of *macuti*. The reason why there is no rising dampness may simply lie in the fact that these houses are located above the sea level. In any case, the delaying effect of capillary rising should be evaluated in the buildings where walls have large pores and cavities preventing or substantially reducing the tensions required by capillarity.

However, capillary phenomena are not to be excluded *a priori* and, in particular, there may be stagnant or waste rainwater caused by a poor drainage property of the soil when it is sealed by artificial flooring or by the breaking of horizontal and vertical pipes. Moisture or water stagnation, in adherence to the foundation walls of a coral limestone building, may cause the phenomenon of rising dampness when the stone porosity is mostly thin and continuous. The examined buildings in Inhambane and in Ilha de Ibo do not have these characteristics and then, possibly, the phenomenon of rising dampness would affect more the plasters than the walls. In the case of Ilha de Moçambique is necessary to make a special note[iv]

In Ilha de Moçambique stylistic reasons have led to the custom of creating channels for expulsion of rainwater from the roofs inside the walls. These channels, once at ground level, have a ninety-degree elbow and pass under the concrete sidewalk to drain the water directly onto the street. For various reasons this last stretch of the spillway is often clogged and so the water drained from the roof drains in the walls, fuelling the phenomenon of reformation of the soluble salts.

The coralline sedimentation forming Ilha de Moçambique emerges from the highest levels of the coastal carbonate platform, as in most of the islands in northern Mozambique. Likewise the ground of the old centre of Inhambane lies more than two meters above the average ocean water level, while the settlement on the island of Ibo is built between eight and thirteen meters above average sea level. The presence of cisterns partially excavated in the soil or pits dug in the rock completely, all used for drinking water in old houses, indicates that the whole ancient settlement was not suffering from rising salt damp because at a higher level than the ocean. In some places of Ilha de Moçambique the foundations of the walls were built directly on coral reef rock, cut out in the required thickness, both in civil buildings and in the fortress of São Sebastião. I believe that even the decision to incorporate directly the soil ridges in the walls has been done because it was clear to builders that the rock, usually, was dry.

In general, the observed cases of disintegration occur on the external face of perimeter walls of buildings. When terraces or roofs are missing, the disintegration of the walls occurs both inside and outside.

4. From dampness to instability

4.1. Ancient walls of Inhambane

The Customs building of Inhambane offered, in surveys of 2004, the opportunity to examine an intact sample and so understand how the Portuguese masons proceeded in their constructions during their early experiences of colonial urbanization. The ongoing work of transforming a window in a public gateway revealed to me the wall construction typology, the general state of de-cohesion of its materials and the static function held by the most recent additions to the plaster. The construction typology was confirmed by the observation of other decaying buildings in town and can be schematically described as follows:

- 1. The walls are made of roughly hewn coral limestone blocks of poor hardness. The blocks are orderly placed with the likely purpose of directing gravity center weights towards the inside of the wall. The expedient of foreseeing a likely inside slippage of each block is a good practice in building dry stones walls. The wall blocks consist of aggregate limestone elements of biological origin; among them we can see the skeletons of the most common corals of the region. Tofo, an area east of Inhambane, is among the places expected to supply the material. Another source can be found in the flattening of the building area;
- 2. The mortar looks disintegrated, especially at the lowest levels where it is often reduced to dust. In similar conditions, the blocks are often in direct contact; the result is a dangerous overloading on individual points. Mortars are composed of many broken fragments of shells, suggesting beach sand was used or that calcined shells were not incompletely cooked;
- 3. The plaster thickness is not always the same because of the irregularities of the block faces, and it has different texture and composition according to the various areas examined, probably because of repeated maintenance works.

4.2. Wall dampness and water penetration.

- Water gets inside a wall in a liquid or vapor state. In particular, the walls we examined were affected by rain. The presence of damp or water causes disruptive phenomena that are different depending on the material and environmental conditions of walls. The walls examined in Inhambane and in two islands have, in general, these main features.
- 1. The rain hits the exposed face of the perimeter walls. Differently from what happens with rising dampness because of capillary action, the speed of horizontally penetrating water is very rapid if the porosity of the plaster and the walls is large. In the case examined, both the plaster and the walls are very porous.
- 2. The presence of wind and rain and the marine environment suggest that the walls are soaked by salt water. The salt soaking of the external walls may be caused directly by the spraying of seawater raised and dispersed by the wind or by a mixture of sea and rain aerosol, that is the chemical compound NaCl + H2O. In conditions of saline solution the salt concentration may be very low, but the penetration of the liquid may be higher than that of the aerosol.
- 3. Studies carried out in the Faculdade de Arquitectura in Maputo on the building systems in the early periods of colonization indicate that the use of marine materials was a widespread practice in constructions. Beach sand and seawater were probably used for the mixture of mortar required to bind and protect coral blocks. A more rigorous way to know for sure if salts were present in the initial stage of construction of wall is the analysis in scientific laboratories of samples taken from a protected area, as the internal partition walls of a building may be[v].
- 4. The crystallization of the salts already present in masonry or reintroduced, cyclically, by marine aerosols has a great impact on plasters. Beyond plasters, the salts in solution propagate through the wall because of the water absorbed from the rain.

4.3. The length of the disaggregation cycle in the coral wall.

The perimeter wall of the ancient military square of Nossa Senhora da Conceição in Inhambane was built using the same technique as the church. In it there are some areas where the disaggregation phenomenon is in progress; in these areas we can obtain information on deterioration and also on the length of the phenomenon.

To understand the type of deterioration it was necessary to graphically determine the mapping of the various patches of plaster and imagine a timeline. First, homogeneous areas were identified on the basis of a visual evaluation of materials. After this first step, it was easy to determine which patches were applied first and which ones later. Each area has its own specific characteristics in relation to the phenomenon of deterioration and in this way it is possible to evaluate the vulnerability of the plasters, water penetration and salt crystallization.

Within the area mapped is included the engraved word "PROLETARIO..." displaying some timelines in the patched plaster and, consequently, giving a time dimension to the cycle of disintegration of plasters and the wall itself.

The painted graffiti allows the definition of three different periods. The first one is the one where the graffiti is intact because the plaster isn't deteriorated. A patch was laid in a subsequent period; it is the one containing the final part of the graffiti, re-made. The third period is the one of the contemporary degradation still in progress, affecting the initial plaster and the subsequent patches (Fig. 1).
When we consider the contents of the graffiti and the fact it was written on fresh plaster, we can say that the plaster of the first period was laid towards the late 70's of the 20th century, during the first period of national liberation. In this case I have deduced that the time required for the salt crystals to cause the collapse of the wall should be about 25 years.

5. Different hardness in coral rocks

I should be to reduce the phenomena of deterioration of the architectural heritage in coral stones to a few key cases, with the intent to focus on a few prior directions of preservation: the aim is to make easier a possible practical application, especially if it is intended for an architectural heritage not based on monuments.

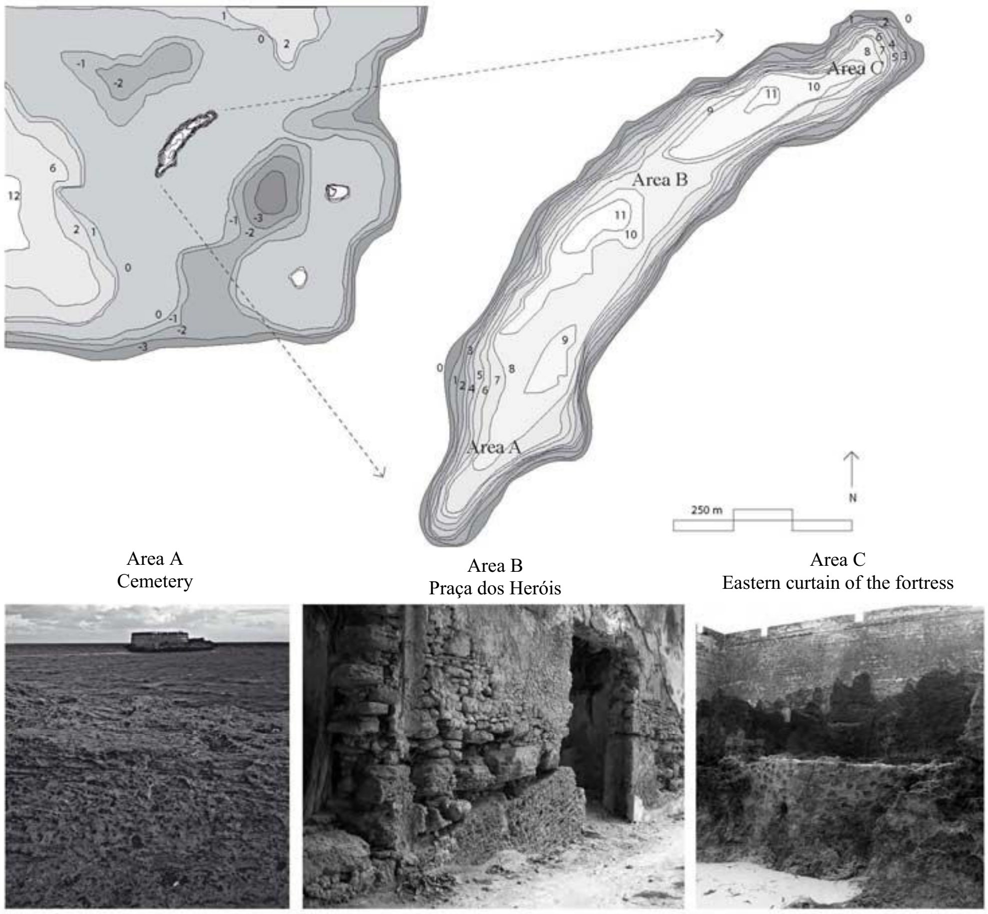

Fig. 2. Rocks observed on three different areas in Ilha de Moçambique.

My field survey and comparisons among different sites do not allow simplification adopted by chemical experts, from experimental tests of samples. I made simple direct observations comparing them with the limited information available about the geology and geography of the region.

In the historic settlements at Lamu and Mombasa Donatella Procesi has identified and defined two types of material: "coral breccia or the Pleistocene coral" and "true coral reef stone". While some authors, dealing with constructions of coral limestone, use the generic term of madreporarian stone[vi].

For a conservator architect, it is important to have an exact knowledge of the lime type the buildings were built with, because the conservation methods or the restoration techniques can change according to the physical and chemical characteristics of the construction materials.

Strong blocks of bioclastic limestone were used for the walls of the faces and flanks of the ramparts and the curtains of the fortress São Sebastião, but in Ilha de Moçambique houses and palaces were built using limestone of different physical consistency and porosity, of different mechanical strength and of different capacity to moisture absorption.

One of the founders of contemporary geology helps us to understand why, in a site of such a small size as Ilha de Moçambique (1 sq. km), calcareous sediments are present with different physical characteristics, even if they have the same biological origin. Amadeus W. Grabau clearly describes a model of sedimentation of biogenic marine limestone. He published his model of sedimentation based on a study on coral reef of Alpena in Michigan in *A Textbook of Geology* (1920)[vii].

A field check, using the Grabau's diagram, has allowed getting elements of knowledge useful to restoration practices in Ilha and relevant to the issues of the architectural and environmental heritage conservation. We can observe levels of sedimentation of silt and debris produced by various reef biota in different places on the island. The most interesting surveys were made at both ends of the island, north and south, and in some parts of the center. In the south beyond the cemetery, there is a small lookout where there are clear traces of excavation for leveling of the soil and for obtaining building stone.

From a morphological exam, the rocks observed on three different areas in Ilha (A, B, C Areas, in Fig. 2) appear to have had the same genesis. It is however very clear that the cohesion of their sedimentary layers is different in limestone outcrops in the centre of the island (B Area) compared with the rocks next to the sea (A and B Areas).

Fig.3. Coral stonewall at the Praça dos Heróis in Ilha de Moçambique. In 2004, 2008 and 2011.

The importance of this aspect in the condition of the coral rocks in different parts recalls the topic of water action on limestone. The idea is to evaluate the conditions in time of the rocks of coral or madreporic origin; looking at the environmental chemistry which tells us that, in the presence of fresh water, the dissolution of calcite is easier, while in the presence of sea water precipitation is more likely to occur[viii].

This topic should be handled together with wall disintegration due to the crystallization of soluble salts, repeatedly

dealt with in this text. In a tropical region it is interesting to examine the single action of fresh water in an unprotected wall of porous stone and limestone binder, because of the warm rains. Water's property to dissolve limestone is known and it is also known that water, at a temperature between 30° and 35° C, precipitates calcite. We made an attempt at evaluating the consistency of rock outcrops on which Ilha's houses are built, as well as we have observed the rocky ridges, cut according to the thickness of the walls where they were embedded.
The rock ridges embedded in walls of the fortress of São Sebastião seem compact at first sight; the lack of cracks under the significant weight of the fortress above, demonstrates the high degree of mechanical resistance to compression.

The same can't be said for the rock ridges embedded in the buildings of the central area of isle where the thin layers of sediment accumulation have no cohesion; the powder coming from limestone, due to dampness and water, is deposited on the soil. Furthermore, it would be interesting to evaluate deeply the consistency of the ridge to check its compactness and porosity. The primary purpose is an assessment of its load capacity and, secondly, to see how much hot torrential rains brought to the precipitation of calcite. If it found an acceptable compaction, a systematic consolidation of the material wouldn't be necessary; so an ordinary plaster like the built wall might be protected the natural rock (Fig. 3).

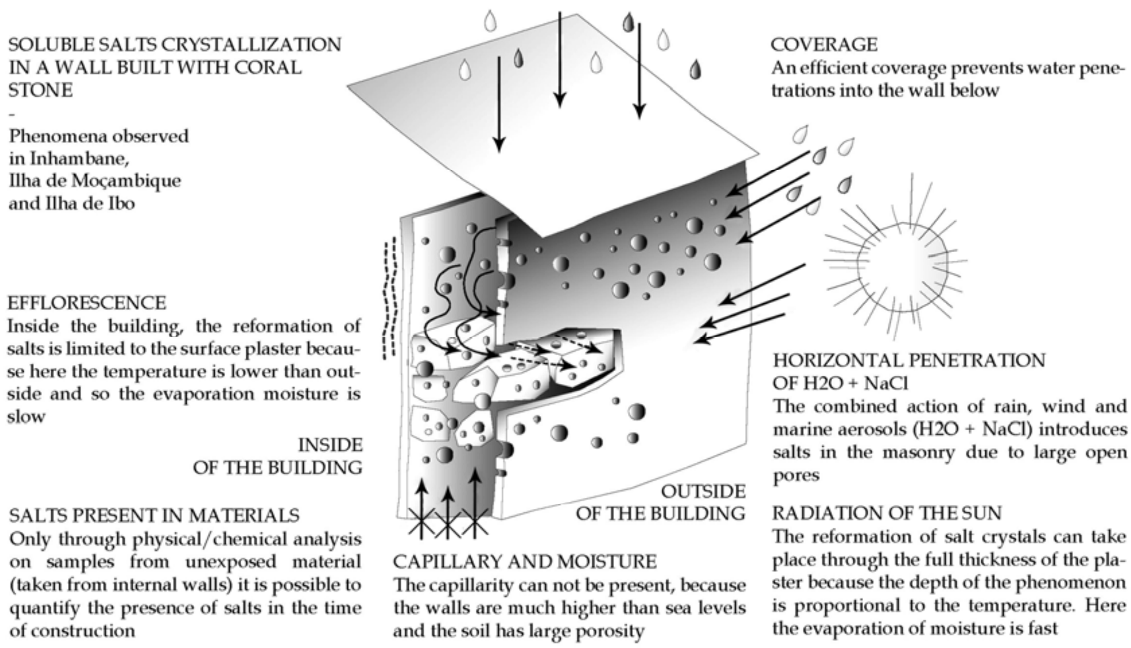

Fig. 4. Soluble salts crystallization process, as was observed in Inhambane, Ibo and Ilha de Moçambique, during the past ten years.

6. The fortress and other buildings

Reading materials and structures of the fortress of São Sebastião in Ilha de Moçambique must be accompanied by the knowledge of stages that have marked the construction of the fortress itself. This architecture should be fully examined and the studies, prior to the 80's of the last century, of its transformations should be resumed to understand its history and its current physical structure. From my survey it seemed that the idea of designing the fortifications as a set of flexible rather than brittle materials was seriously considered in the 17th century transformations at the bulwarks São Gabriel to the southwest and Santa Bárbara to the south-east. This hypothesis, obviously, should be verified by tests and stratigraphic surveys.

The knowledge of materials and structures of the fortress of São Sebastião to Ilha de Moçambique must be accompanied by the knowledge of the stages that have marked the construction of the fortress itself. This architecture must be fully investigated and the studies of the 70s of last century on its transformations should be resumed in order to understand its history and its present physical structure. From my research it seemed that the idea of designing fortifications as a set of flexible materials rather than brittle materials was seriously considered in the transformations of the 17th century of bastions of San Gabriel and Santa Barbara. This assumption, of course, should be verified by testing and stratigraphic surveys.

In 1991 UNESCO included Ilha de Moçambique in the *World Heritage List*. This date was preceded and followed by numerous activities in the cultural and political fields. The document which best expresses the desire to learn, restore and enhance the heritage of Ilha in a period of neglect and general disinterest, is the *Relatório/Report Ilha de Moçambique* published in English and Portuguese by the Secretaria de Estado da Cultura of Moçambique and Arkitektskolen i Aarhus in Denmark, dated 1982-1985[ix].

6.1. Roofs

When I revisited Ilha in 2009, the fortress was not yet open to the public because of renovation works in progress. The characteristics of the building site clearly revealed that the works planned for the first phase of restoration had been largely implemented.

In the tender documents for the rehabilitation works by UNESCO, the strategy governing their action seemed very clear; the rehabilitation was intended as a part of a wider program of cultural preservation and social development. In brief, restoration has to become an extraordinary opportunity to improve the conditions of society as a whole; the process is time consuming and takes in the various aspects of a society strongly focused on economic development, but still keeping its historical and traditional characters. The choice of prolonging the process of the heritage conservation is also beneficial to the recovery of the fortress, because of the complexity and the participation of different social elements.

Thanks to the studies and applications of the past three decades we can now say that the restoration of a historical monument of great size requires a programmatic approach distributed along a reasonable period of time. Facing complex historical layers in structures, forms and uses, designers and contractors are generally able to identify the most appropriate technical solutions for a good rehabilitation or restoration. But they are often faced with the need for substantial financial resources. In this case an intelligent conservation program may establish a protocol of interventions distributed over a long period of time and hierarchically arranged according to those criteria of necessity and urgency of the monument itself[x].

The work at the top of the hierarchy was the restoration of the high platforms and the terraced roofs, completed in 2009. The work has achieved two important tasks: the drastic reduction in the degradation of the structure, now effectively protected from sea storms and torrential rains, thus eliminating the phenomenon of walls disaggregation due to the reformation of soluble salts; secondly, the restoration of the system of collection and storage of rainwater for domestic use by the islanders and their guests. Actually, the fortress is no longer a great monument in a state of abandonment and an incipient condition of decay, but now protected and made safer by implemented structural safeguards, can wait for further restoration in a lasting condition and be visited by scholars and tourists.

Since 2009, I have visited several times the fortress. The programs of restoration of this important monument are suspended and the site looks once again abandoned to the effects of climate and the sea. It is hoped a special maintenance program after each restoration phase. The owner can take care of this monument with a modest amount of money. It is sufficient to adopt simple maintenance practices following the guidelines developed by restorers, before, during and after each restoration phase.

6.2. Plasters and mortars

The coral stone buildings require a constant care of the plasters which, together with roofs, ensure the necessary level of protection of the walls to avoid the phenomenon of disintegration due to salt.

The practice of patching may be performed as in the past, using slightly porous plasters to avoid the penetration of marine aerosol and rain. Looking at some remains on the high curtain walls is very easy to recognize that the fortress of Ilha de Moçambique was plastered in the past, as it was also the fortress of Ilha do Ibo.

That is a restoration issue to be faced with special care for formal, historic and material reasons. With reference to the fortresses of Moçambique and Ibo, we see two different treatments on surfaces of curtain walls during the most recent restoration. In the case of São João Baptista fort of Ibo, in 2007 were placed some missing parts of the curtain wall and the whole painting was renewed with whitewash. Otherwise, during the restoration of 2009, the curtain wall of the fortress of São Sebastião was only integrated in some limited points, but not protected by a new painting imitated from remains of ancient painting still existing today. The two solutions were probably suggested by the different condition in which the walls of two architectures were maintained in recent decades, while still both military buildings were in use: the periodic renewal of the whitewash in the fort of Ibo and the abandonment of the practice of surface protection in the fortress of Moçambique.

Finally, why these two different maintenance practices in the recent past? The simple answer is suggested by the observations that we have above entitled "Different hardness in coral rocks".

In the construction of the roof terrace and in mixing the mortar for plastering is used, traditionally, a natural additive called *murrapa*. The main effect of its use is the hardening of mortars and, at the same time, their waterproofing. An experimental examination of this product is not yet been produced, nor is there a comprehensive knowledge of this traditional technology. During my studies I have limited myself to visit some site where the liquid *murrapa* was used, to observe the conditions for growth of this climbing plant and, at last, to find its botanical classification.

7. And finally the *murrapa*

Mentioned by historian Alexandre Lobato and sociologist Carlos Lopes Bento, the traditional use of a product called *murrapa* has had a technological approach in the two scholars, Pedro Quirino de Fonseca and Júlio Carrilho. Their observations about the uses of *murrapa* were part of studies on Ilha de Moçambique and Ilha de Ibo. Their description is limited to the process performed in the building site: the stems of the plant are cut in pieces and then are placed in a container full of water for twenty-four hours or more. During this period of time on the surface is formed a gel layer which is produced by the cut pieces. This gel mixed to lime, makes mortar rigid and impermeable[xi].

Accompanied by a mason of Ilha de Moçambique, I reached a place called Lumbo where specimens of *murrapa* grow. Taken a sample of leaves and stems I could finally to acknowledge the scientific classification of the plant. In Brian Morris's systematic definition the *murrapa* is classified as *Cissus integrifolia*. In addition to the botanical characteristics, Morris also reports a regional name *Mthambe (Nthambitambi)*, very similar to *Ntamba (Ntambatamba)* name used in Ibo, as Carrilho reveals[xii].

In the handbook Conservation and Design Guidelines for Zanzibar Stone Town, published by The Aga Khan Trust for Culture, we find the information that in Zanzibar a seaweed extract is used as a binder in lime whitewashing. The sea wee is *Eucheuma Denticulatum* commonly growing along the coast of Zanzibar[xiii].

The use of natural substances as binders, as binding materials in the mixture or as a protection should be studied as a specific theme. We know that the substance produced by the *murrapa* is used in traditional practices, but there is no evidence as to the quality of the effects[xiv].

I observed this effect in an earthen plaster applied to the reed walls of a traditional house at Lumbo near Ilha de Moçambique. This plaster, very resistant, was made by mixing clayey earth and liquid *murrapa* in a water solution. I have no reports about the use of simple *murrapa* solution as repellent or waterproofing on walls or terraces made of coral limestone. I said "solution", but perhaps it is more appropriate to say "emulsion". Once clotted, this substance is almost insoluble in water. However, if the trunks of *murrapa* stems are crushed and put to soak in water for about a week, it continues to pour copiously a substance that tends to coagulate and separate from water. Until the liquid of *murrapa* is immersed in water, perhaps we can speak of a colloidal solution. This substance can pass from a liquid to a semi-solid state and vice versa when, for example, it is transferred from the soaking container to another one for sieving its impurities.

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