Rehabilitation Techniques and Repair of Cambambe Fortress

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Extended Abstract

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September 2016

ABSTRACT

This document concerns the rehabilition of Nossa Senhora do Rosário church of Cambambe fortress, located in Cuanza Norte province, in Angola. This fortress was build in the XVII century by the Portuguese discoverers when they were colonizing the Angolan territory, which is the reason why it has a historical value.

It is a construction made of dry stone masonry, but in some places is seen some lime mortar. The exposure of this construction to the environmental effects, with few maintenance actions, led to her status to be classified as a ruin nowadays. Because of that, there are some problems that need repair, the most important are: nonexistence of roof; severe deformation of the main altar wall; masonry desintegration.

There were four possbile rehabilition solutions which were considered in this study, taking into account the history of the construction and its current state. The four solutions were evaluated according to three criteria: aesthetic criteria, structural reliability criteria and costs criteria. It was concluded that the best solution would be to build a new independent structure of the existing masonry, allowing support a new roof and, at the same time, be hidden and integrated, in order not to harm the original appearance of the church. This new structure consists of steel elements: columns, beams and triangular trusses that make the roof slope. The foundations are footings made of reinforced concrete.

It was also studied a solution to repair the severe deformation of the main altar wall. It was concluded that the more viable solution would be straighten up this wall using steel cables and lever winches, in a carefully monitored process. In this document is also recommended the using of a reinforced render in the masonry walls and the reconstruction of the top of the main facade, back side facade and belfry tower. The recommended finishing is with white painting.

Key-words: Cambambe; rehabilition; stone masonry; steel structure; roof.

1 – INTRODUCTION

The constructions are part of humanity history. Old buildings are "alive" image of past events, cultures and styles. The present generations should preserve the old buildings. The age of discoveries marked the expansion of the Portuguese Empire to the African Continent. The Christian religion was used as a means of colonization of people, and because of that many buildings were religious in character. In Angola, the construction of fortresses and churches was made as it progressed on the ground to the interior. Along the Cuanza river there are several buildings, like Muxima fortress, Massangano fortress and Cambambe fortress.

The Cambambe fortress was build in the XVII century and abandoned in the XIV century. It is a construction made of dry stone masonry, but in some places is seen some lime mortar. The effects of climatic actions and de nonexistance of maintenance led to her status is classified as a ruin nowadays with many anomalies. The first anomalies that ocurred were the lost of wall claddings and roof. Then the structural anomalies began to occur. The current status of the Cambambe fortress and its historical and patrimonial value justify the consideration its rehabilitation.

This document is about the rehabilition porposal of Nossa Senhora do Rosário church of Cambambe fortress, and the main goals are:

- Understand historical background of the construction;
- Description of the construction and of its current status;
- Identification of existing anomalies and diagnosis;
- Consideration of various possible solutions and choose of a rehabilitation solution;
- Engineering design of rehabilition of Nossa Senhora do Rosário church of Cambambe fortress, identifying rehabilitation techniques, materials and building processes.

2 – HISTORICAL BACKGROUND

On May 3rd 1560, Paulo Dias de Novais arrived at mouth of the Cuanza River, in Angola. On February 20th 1575, Paulo Dias de Novais landed in that country by the second time. It was when the Portuguese expeditions to the interior started, using the Cuanza river as a natural way to transporting people and materials [2]. As they progressed through unknown lands, the first prisons and fortresses were raised [3]. One of the reasons that led the portugueses to go inside Angola was the silver mines that supposedly existed in Cambambe [4] [5]. In 1604, Manuel Cerveira Pereira reached the mountains of Cambambe and ordered the construction of a fortress [6]. However, the existence of the mines was not real [5]. In 1641 the Portuguese people in Angola were disturbed by the pirates, so they took refuge in the fortresses like Muxima, Massangano and Cambambe. It was in these places that the Portuguese domain was most felt [1]. In 1648 pirates surrendered and Cambambe became a center of export routes from the interior to the seaside, and the reverse [7].

The first fortress in Cambambe was build by the governator Manuel Cerveira Pereira in 1604. It was a simple construction made of rammed earth. The interior of the fortress was a church with the name of Igreja de Nossa Senhora do Rosário [5]. A second fortress was build in 1646 by António Teixeira de Mendonça, João Zuzarte de Andrade e Bartolomeu Vasconcelos da Cunha (colonial administrators), because the first fortress was very weak [5]. Captain D. João de Lencastre ordered the construction of a third fortress in Cambambe, in 1691. The ruins of this fortress persist to the present days [5]. This fort was again restored in 1730 or 1731 and again was raised a church named Igreja de Nossa Senhora do Rosário. It was a construction made of stone masonry and clay, with lime mortar [8]. The architectural style was baroque [1]. The fortress was abandoned in the mid-nineteenth century. Since 1925 it is classified as a historical and cultural heritage and national monument in Angola [8].

3 – DESCRIPTION OF THE CURRENT STATE OF N. SR.ª DO ROSÁRIO CHURCH, CAMBAMBE FORTRESS

The N. Sr.ª do Rosário church is a roughly rectangular plant construction, with approximate dimensions of 11 meters wide by 30 meters long. Inside the church there are two main rooms: the altar room and the antechamber room. The altar room is the smallest, with a área of approximately 16 m^2. The antechamber room has an área of 66 m^2. There is also a small compartment behind the altar with reduced area. On the wall between the altar room and the antechamber room there is an arch made of solid brick masonry. The altar wall is more ornately, also with an arch made of solid brick masonry, but with more elaborate archivolt. There are pilasters with ornate chapiters, niches and solomonic columns, indicating a baroque architecture (Figure 1). The walls have, on average, from 6 to 7 meters in height, at which was the roof structure. The top of the wall between the altar room and antechamber room has a triangular geometry at the top, suggesting a roof with two slopes.

The foundations of this type of buildings are usualy made just for the simple continuation of resistant walls into the ground, and may or may not have an increase on the thickness of the walls [9]. The resistant walls are made of dry stone rubble masonry, but in some places is seen some lime mortar, with stones with different sizes and some solid bricks and other ceramic elements. The current walls are about 1,40 meters thick (Figure 2). The doorways and windows are materialized by slaughtered discharge arches of ceramic brick, also the vertical sides of the openings. There are four exterior buttresses, reinforcing structure for horizontal pulses and improving the connection between orthogonal walls and overall performance of structure. Apparently, there are no “headers” (stones that take up the whole thickness of the wall) or other cross members to the walls.

At the time of construction, mortars were constituted mainly by air lime and aggregates from the construction site itself, and may even sometimes be simply ground or sludge [11]. However, It may have existed further interventions where mortars with different constitutions were used. The stones used in the walls of the church are mostly or even entirely from the region of Cambambe and are consolidated sedimentary rocks with brown color and sometimes purple.

Figure 1 – Altar wall.

Figure 2 – Main facade walls.

4 – PATHOLOGIES OF THE CONSTRUCTION

Cracking in masonry walls

Is a structural anomaly that can be verified in various places. One of them is the connection between the rear wall and left lateral wall. The occurrence of these cracks may be associated to the following:

- horizontal pulses of the roof support structure;
- relative movements between walls due to hygrothermal variations;
- absence of connection elements between the walls.

Those cracks develop along much of the butress height, with 6 meters in total, approximately. The opening of the cracks is variable, it may reach about 5 centimeters on the top of the wall. Another place where cracking is visible is the connections between altar wall and lateral walls. In this case cracks are in the top of the wall, with 2 to 3 meters of extension (Figure 3). The cause of this anomaly is related mainly to the disconnection of the walls for lack of connecting elements and to the deformation of the altar wall. These slots are the most relevant, but there may be other lesser extent and lesser severity along the remaining walls.

Disaggregation of masonry

Is a non-structuran anomaly that affects mostly entire walls and is defined by the loss of particles to the minimum mechanical stress. The main agent is water, which begins to infiltrate the wall, where it forms voids and pathways that lead to the formation of weak areas. The masonry laying mortar, which in some areas may even never have existed, is currently very scarce and may have significantly lost its agglutinative capacity, which contributes to the structural strength deficit of the walls (Figure 4) [9] [10].

Lacuna

This anomaly is characterized by loss of constituents of masonry walls, usually loss of stone elements. It is preceded by other anomalies, like cracking, disaggregation, erosion and eventually accidental mechanical actions. It can be a serious anomaly if the wall thickness is substantially reduced, reducing its resistant capacity [10]. It occurs primarily at the top of the walls.

Deformation of the altar wall

The cracking observed in the connection between altar wall and lateral walls indicate a deformation associated with the collapse of this wall and its consequent disconnection of the remaining walls (Figure 3). The most likely causes are:

- High slenderness of the wall;
- Lack of reinforcement elements of connections with orthogonal walls;
- Lack locking perpendicular to the wall plane;
- Horizontal loadings (for exemple: the wind).

Loss of roof and wall claddings

The roof support structure, which is presumed to have been in wood, have exceeded long ago its useful life-time, and it was destroyed by some agents as: water, sunlight and biological agents. The wall claddings also left to exist because of its degradation which essentially is due to the presence of water.

Figure 3 – Cracking and deformation of the altar wall.

Figure 4 - Disaggregation of masonry.

5 – POSSIBLE SOLUTIONS FOR THE CHURCH REHABILITATION

Four solutions were considered for the rehabilitation of the N. Sr.ª do Rosário church:

Solution 1 – Execution of a new reinforced concrete structure in grooves made in the masonry (strengthening). The strenght capacity for vertical loadings is associated with this new structure, in particular the weight of a new roof to execute.

Solition 2 – Repair of masonry walls with techniques such as: injections of binder grouts in masonry; reinforced render in masonry; treatment and injection of cracks; insertion of metal elements in masonry. The repair of the walls should enable them to support a new roof [10].

Solution 3 - Building of new reinforced concrete or metal structure, independent of the existing construction, supporting a new roof. This new roof has only the function of preserving the building as a ruin, not proceeding to their rehabilitation.

Solution 4 – Building of a reticulated structure of reinforced concrete or metal, independent of the existing construction, but which can be hidden so as not to harm the aesthetics. This new structure must support a new roof, similar as possible to the original.

It is of great interest that the chosen solution allows restoring of the original features of the construction, or at least not cause great aesthetic impact to the current characteristics. Solution 3 is excluded, because does not allow the rehabilitation of the building and affects the current appearance of it. Solution 1 does not seem very appropriate, mainly because the structural model is difficult to analyze, due to the simultaneous operation of the masonry structure and concrete, and because there are significant costs (opening grooves, containment of the walls and execution of foundations). With Solution 2 is difficult to know the resistance of masonry walls after reinforcement, and therefore make structural design. Also the need to strengthen the foundations or the foundation ground can become a costly process. Solution 4 seems to be more appropriate. At the aesthetic level, it is possible to "hide" the new structure building a masonry wall, similar to existing masonry, ahead of new structural elements. At the structural level, the calculation is simplified because the new structure is responsible for strenght capacity (excluding the weight of the walls). This solution also allows the rebuilding of the top of the main facade, back side facade and belfry tower, and the aplication of reinforced render in masonry and white painting, based on the documented examples of churches of Muxima and Massangano.

6 – REHABILITATION SOLUTION FOR THE ROOF

The roof slope (30º) is indicated by the top of interior main walls. In the belfry tower, which should be built as explained in Chapter 6, is also provided a new roof. For the roof cladding is recommended the type "telha lusa" of roof tiles. Under roof tiles is a structure composed by wooden laths, with two layers. The first layer supports roof tiles, the second layer, arranged perpendicularly to the first, ensures roof ventilation. Under the second layer of wooden laths it is recommended the placement of sandwich panels, whose functions are: improvement of indoor thermal comfort; allow working platform for building and maintenance.

The roof is supported by a steel structure consisting of: roof beams, trusses, beams, columns and foundations. The roof beams are IPE 160 metalic profiles, whose spacing is determined by the maximum permissible span of sandwich panels (1.25 meters). The trusses are composed of LNP 150 16 metal profiles type (Figure 5). Steel was chosen because wood requires more skilled labor and is more difficult to obtain good quality elements. The LNP profiles have the advantage of allowing the assembly of trusses simply by screwing of their flaps. Trusses are supported by HEB 400 steel beams and columns of the same type. Columns are strategically located in the corners, allowing them to be coated with masonry. In any metal structure should be provided a protection scheme against corrosion and against fire. Foundations are footings made of reinforced concrete, eccentric in both directions to avoid their location under the walls. The omission of the steel structure of the roof is made with the use of wooden planks that are attached to metal rails. Metal rails are suspended by metal bars fixed to the metal trusses.

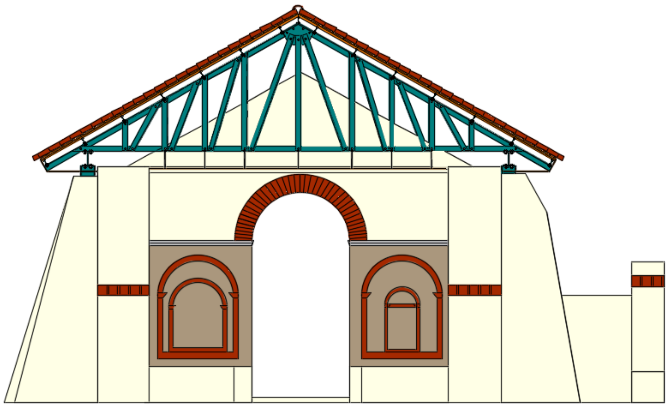

Figure 5 - Current roof support structure section.

7 – REHABILITATION SOLUTION FOR THE WALLS

Have been considered two solutions to the wall of the altar. The first would be the dismantling and reconstruction, which in addition to being a rather lengthy process, would mean the loss of the equity value and original architectural value of that wall. The second solution is about straightening and repair of that wall, which seems to be more reasonable. The straightening can be accomplished using tensioned steel cables which introduce a horizontal force corresponding to the required displacement to check the verticality of the wall. The steel cables are attached to horizontal lever hoists, which can be fixed to the ground by nailing. The cables must be an even number (minimum 2) to not create eccentricities when application of forces. The cables pass through the wall in the region of the arch. In the posterior face of the wall must be a metal plate or wooden plank, supported by a temporary structure, which allows homogeneous distribution of forces on the wall. The process should be carefully monitored through direct observation and possibly also using topographical equipment. If there is any anomaly in the wall the process should be stopped immediately. To the altar wall is also suggested the execution of adherent nails with rebars of steel protected against corrosion inserted into holes previously open to various height, in the wall connections with the side walls. Nails must be later sealed with an appropriate grout composed by natural hydraulic lime (NHL). It also suggests restoring the front side of the wall to recover its ornamentation.

It is proposed the reconstruction of the belfry tower 4 meters above its current height, using a masonry similar to existing masonry, with natural hydraulic lime mortar. The walls of belfry tower overlaps the metal structure in this área. In the belfry tower there are four openings materialized by discharge arches in masonry. It is also proposed the reconstruction of the main and back side facades, with the same type of masonry and discharge arches in window áreas (Figure 6).

For the current walls (all walls excepting the ornamented sides of altar wall and ante-chamber wall) it is proposed the aplication of reinforced render technique to to repair and consolidate the masonry. This technique should also be applied to areas to build. The application of this technique allows the final painting with white color, as in other churches of the same era (Muxima and Massangano) (Figure 6). Finally, it is recommended to apply wooden doors and windows with protection wood shutters.

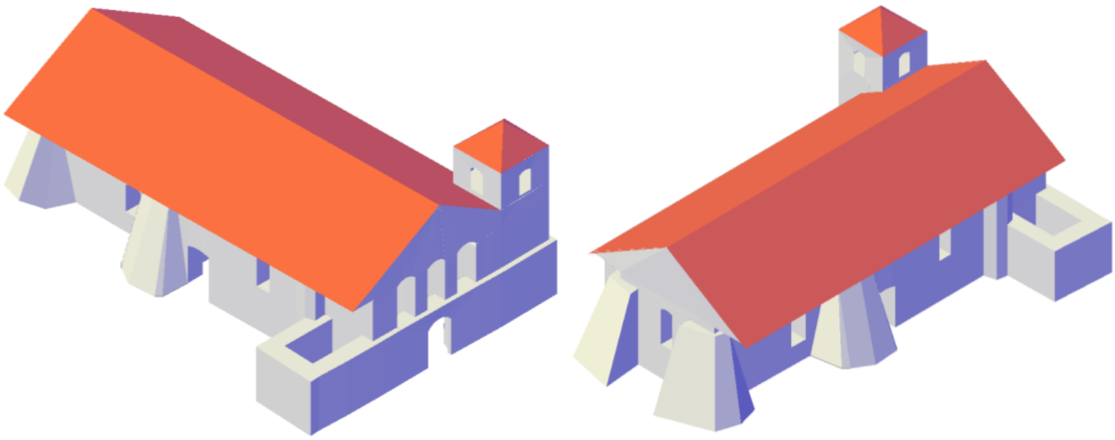

Figure 6 - General rehabilitation aspect (two perspectives).

8 – CONCLUSIONS

In the case of Cambambe fortress, its abandonment for more than a century it resulted in the complete lack of maintenance, which led to increasingly rapid degradation of building materials, construction elements and, in general, the construction itself. The fact of being a historical building means it has a very high patrimonial value. So it is of great interest that conservation measures are taken.

The choice of intervention methodology should be weighted according to the features of construction, the purpose of rehabilitation, associated costs, the available resources and the degree of intrusion and conflict with the original structure. The construction/rehabilitation techniques are also heavily conditioned by local labor and transport conditions. The location of Cambambe fortress in the countryside with few resources and hard access, compromises significantly the choice of techniques to employ.

The reconstruction of roofs in ruins is difficult because the strenght capacity of the walls isn't known, and even its reinforcement can not guarantee the structural reliability. It was concluded therefore that the most suitable solution would be the construction of a structure independent of the existing walls, but that may be omitted, not violating the aesthetic criterion. It is a steel structure, which is a material that requires less time consuming construction processes. Roof slope is materialized by trusses and the cladding elements are ceramic roof tiles (telha lusa). Steel structure is hidden by application of wooden planks.

It was concluded that the best solution for the altar wall anomalies would be straightening using the cables and winches, because it doesn't involve the loss of authenticity of the original wall and because the associated processes are easier to perform. In addition, it is suggested to reinforcing the connections of this wall with orthogonal walls by nailing. The reconstruction of the belfry tower was recommended as well as the top of the main and back side facades, which implies an increase of gravity loads applied to existing walls. Thus it suggests the application of reinforced render technique for structural repair and masonry confinement. The application of this technique allows the final paiting with white color.

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