Structural Assessment and Restoration of the Leaden Mosque in Berat, Albania

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ABSTRACT: The city of Berat, one of the oldest in Albania, is located in central Albania. The earliest traces of settlement date from 2600-1800 BC. Even though there is an abundance of cultural heritage monuments, little effort has been made in maintaining and preserving these structures. Frequent seismic activity, regular natural processes as well as human activity are some of the main causes of deterioration of those monuments. This paper aims to introduce a case study in structural assessment based on visual inspection and restoration strategies to be implemented in preserving an important historical monument of the Ottoman Period: the Leaden Mosque. Solutions for the structural problems and enhancing the existing structural capability are suggested. The strengthening techniques are proposed, taking into consideration preservation of the cultural, historical and architectural values of the mosque.

Keywords: *Cultural Heritage, Masonry Buildings, Structural Assessment, Mosque Retrofit, Restoration*

1. RESEARCH AIMS

This paper aims to introduce a case study on structural assessment and restoration strategies to be implemented in preserving an important historical monument of the Ottoman Period: the Leaden Mosque. The assessment was based on visual inspection. Data collection was done by the usage of new methods in digital photogrammetry and terrestrial laser scanner.

2.INTRODUCTION

The city of Berat, one of the oldest in Albania, is located on the right bank of Osumi River, in central Albania (Figure 1). The earliest traces of settlement date from 2600-1800 BC. During its existence, due to its special geographical position, it was subject of many wars and suffered near-continuous foreign occupation under the Roman, Byzantine, Bulgarian and Ottoman Empires. One interesting feature of the city is the coexistence of various religious and cultural communities down through the centuries. There are found the castle (known by locals as Kala) built in 13th century, many Byzantine churches (Saint Maria of Vlaherna, Saint Trinity, etc.), and several mosques (the Red Mosque, White Mosque, Leaden Mosque, etc.).

Figure1. Location of the city of Berat

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Nowadays, the city of Berat has an important role in Albania in terms of economy, history, tourism and cultural values.

Even though there is an abundance of cultural heritage monuments, little effort has been made in maintaining and preserving these structures. Frequent seismic activity, regular natural processes as well as human activity are some of the main causes of the deterioration of those monuments. It should be stated that preservation and conservation of the monuments in the city was greatly neglected. The situation has started to improve since the historical areas of the city of Berat were inscribed on the UNESCO world heritage list. The Leaden Mosque is one of the most important historical monuments of the city and it will be discussed in this paper.

3.ARCHITECTURAL FEATURES

The Leaden Mosque is one of the massive well-preserved mosques still functional in Albania found in the city center of Berat, a few hundred meters away from the municipality headquarters (Figure 2). It is the only domed mosque in the city. The mosque was built by the Skuraj family in 1553-1554. It used to be the focal point of a complex consisting of madrassa, primary school, soup kitchen and public baths.

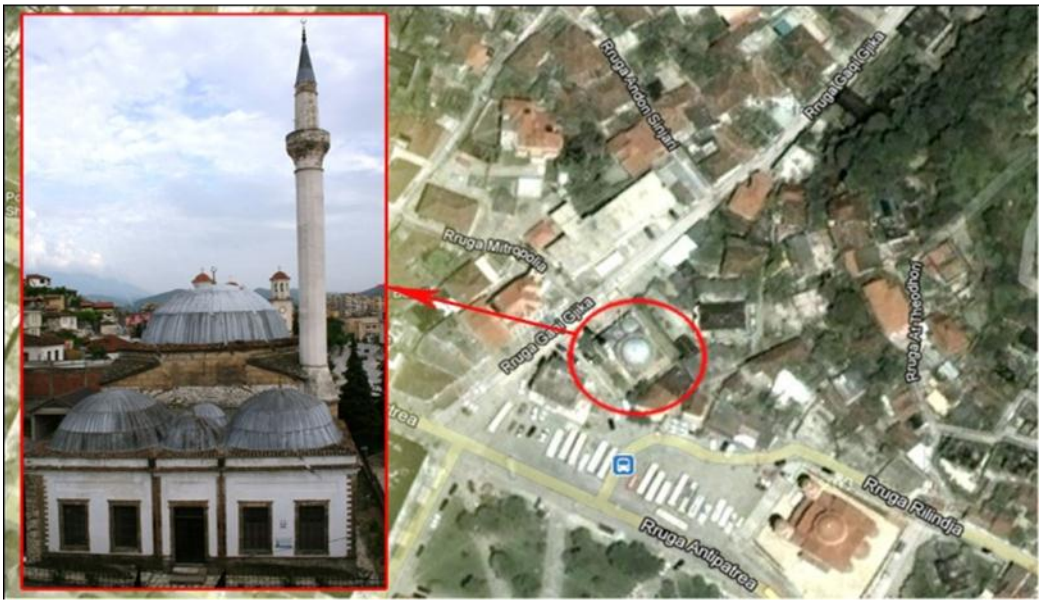


Figure 2. Location and main façade of Leaden Mosque

Considering the architectural features, the style used in erecting this structure is an early classical or classical work. The comprising parts of the mosque are: a prayer hall a having squared plan 12 x 12 meters, the last prayer hall and the minaret. The main supporting system of the mosque is comprised of load-bearing walls and the domes. The wall thickness is 1.05 meters and the main dome is 0.35 meters thick and rises up to a height of 11 meters above the ground. The cubic mass and the dome are connected by melon-like ribbed pendentives. Triangular shoulders covered with clay tiles, are arranged in such a way to provide a base for the octagonal drum. The last prayer hall is covered by four domes, two of which are supported by two marble columns at the center of the porch. The south-east façade of the mosque is built by horizontal yellow limestone bricks bonded together with red clay bricks placed vertically. There are five windows; two at the lower level, two above them and one on top of all having a pointed arch frame. The south-west and north-east façades are similar with each other and have the same architectural features as the south-east façade.

The interior of the prayer hall is painted in a light golden color, whereas the last prayer hall is painted white. The inner sides of the pendentives are shoved and decorated with stalactite works.The minaret is located on top of a decagon base at the western part of the mosque. Ashlar neatly-cut blocks were used to build the slender shaft, the balcony and the upper part of the minaret, but nowadays it is covered with yellowish plaster. [1]

4.ASSESSMENT METHODOLOGY

The structural assessment of historical structures has to be carried out due to safety and serviceability reasons. The methodology used for this research is based on the assessment of visible “symptoms” that structural defects and distresses had caused throughout the structure. The first step of the inspection procedure was filling in a simple assessment form. The form consists of: general details of the structure (address, rough area, number of story, height), type of roof, types of construction materials, conditions of load bearing walls, condition of connections, earthquake hazard level, possible failure mechanisms, etc. [2]

The evaluation process starts with the crack pattern survey. Every visible crack is identified and categorized as structural or non-structural. Recommendations were given based on the current structural conditions; whether to retrofit, demolish or conduct a further more detailed analysis. The severity level ranges from none (contains no structural damage), light, moderate, severe to near collapse (a heavy damage element or structure). The results of the visual inspection procedure provide a good picture of the actual conditions.

In order to evaluate the structural performance of an existing masonry structure, its geometry, the characteristics of its masonry texture, typical cross section, the actual conditions of the joints, physical, chemical and mechanical properties of stones and mortar should be known. [3]

Gathering of the necessary data was enabled by a calibrated high-resolution digital camera (Nikon D90) firmly mounted onto the laser scanner (Optech ILRIS 3D Intelligent Laser Ranging and Imaging System) together with Topcon GPT 3007 Total Station provided a combination of scan data and image data. The laser scanner facilitates the procedure of measurements. It enables a field view of 360º along horizontal and a 60º view in vertical plane. By this way, full panoramic view could be generated. Laser scanner provides high resolution and high accuracy scanning data from 3 meters to beyond 1 kilometer. The generated point cloud provided accurate details of the surface pattern of the structure and mapping coordinate system of the volume the mosque covered (Figure 3). Moreover, the misalignment of the walls and other structural defects could be observed and documented. By this way, the main state of damages was evidenced.

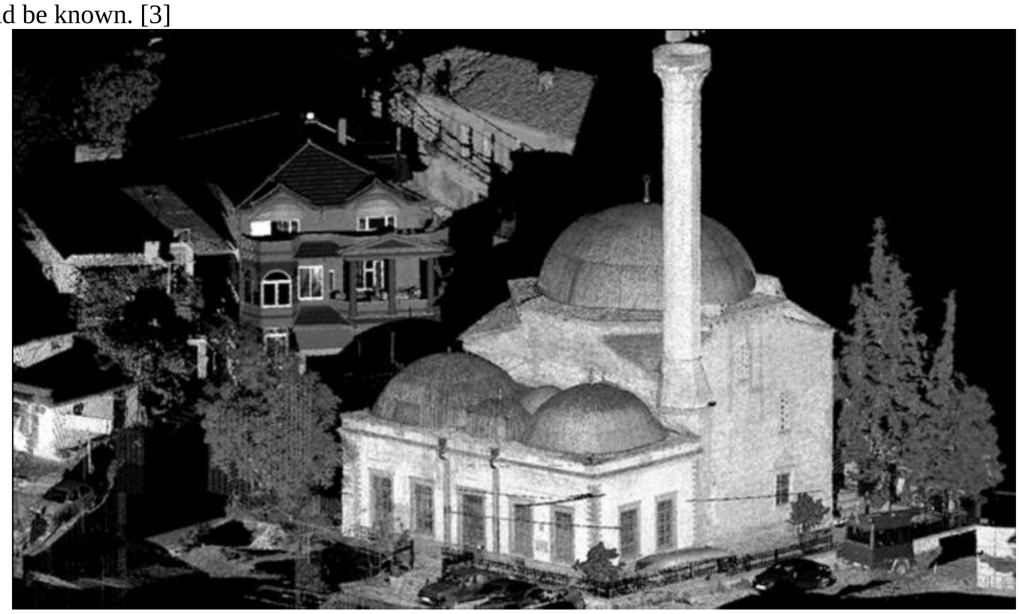


Figure 3. Point cloud of the Leaden Mosque

5.PATHOLOGY

The assessment results have shown that the Leaden Mosque's current structural conditions could be stated as adequate to carry static loads. However, there are structural and non-structural problems evidenced (Fig.4). The roofing system is seen to be inefficient. Improper isolation enables leakage and penetration of rainwater inside the mosque. Thus, moisture spots and spall of plaster are seen in many regions of the interior.

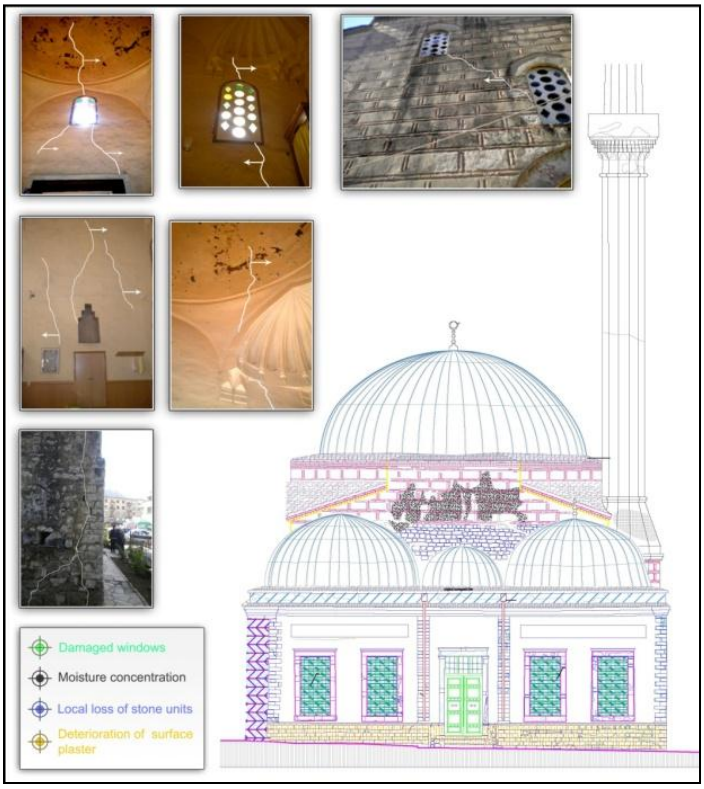
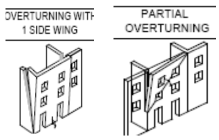


Figure 4. Structural problems in the Leaden Mosque

There are observed structural cracks at the pendentives level, which are thought to have been caused by lateral stresses (earthquakes). Assessment form data are shown in Table 1. From the assessment results, it is seen that load bearing walls are the ones containing more cracks. A diffuse series of visible cracks are present in all façades of the mosque.

Table 1. Assessment form

DATE	09/09/2011
ADDRESS & LOCATION / ROUGH AGE OF BUILDING	GAQI GJIKA ST. / 40.704497, 19.955453 / YES / 360 yrs
STRUCTURAL SYMMETRY	EXISTS IN PLAN
ROUGH AREA	576 m^2
NO. OF STORIES	1 STORY + mezzanine
TOTAL HEIGHT [M]	11 m
WALL CONSTRUCTION	BRICK & STONE
WALLS ARE LOAD BEARING	YES
STRUCTURAL QUALITY OF WALLS	ADEQUATE
TYPICAL WALL THICKNESS [M]	1.05 m
LOAD RESISTING ELEMENTS	DOME, WALL, PENDENTIVE
CONNECTIONS	ADEQUATE
ROOF	DOME
STRUCTURAL APPENDAGES	YES , external Minaret
MORTAR/ CEMENTING MATERIAL	OTHER : KHORASAN MORTAR
DAMAGE LEVEL : WALLS ROOF	MODERATE MODERATE
DAMAGE LEVEL of: 1. **Pendentives** 2. **Wall corners** 3. **Doors, windows**	1. MODERATE 2. LIGHT 3. LIGHT
POSSIBLE FAILURE MECHANISM	
EARTHQUAKE HAZARD LEVEL	VERY LOW
RECOMMENDATION	RETROFITING

Most of the cracks inferred from the damage survey presented a diagonal and vertical trend. Creep of the masonry units is believed to be the cause of vertical parallel cracks which eventually may lead to collapse of the wall. This phenomenon is accompanied by occurrence of chipping and possible local failure. Propagation of the cracks from pendentives to the load bearing walls is observed in all four facades. In the places where openings are present, a different crack pattern is seen. For instance, the tensile and shear stresses are concentrated close to the edges of these openings possibly due to local concentration of loadings. Hair-line cracks are seen in the interior of the walls. [4]

6. BASIS OF INTERVENTION DESIGN

The intervention strategies are suggested taking into consideration the improvement of the structural performance of the mosque under static and dynamic loads as well as preserving the mosque’s unique historical and architectural values. They are in accordance with international conservation practices and ICOMOS (International Council on Monuments and Sites) Recommendations.

The intervention philosophy aims not only to repair the damaged elements, but even to maintain the ones which may suffer from possible failure in the future. Any intervention must improve the structural performance as well as respect structural mechanism and have the least effect on changing the structural identity. [5]

Strengthening and repair of an existing structure is more complex than building a new one. There are many unknown factors such as continuity of structural elements, load path, material properties and locations of previous interventions which make the procedure more difficult. [4]

Additionally, also external factors such as the lack of maintenance, load increase due to modifications of the structure, soil settlements, mechanical shocks due to earthquakes, fire, etc. should be taken into account.

Structural assessment results have shown that one of the most common problems is deterioration of surface plaster, local loss of masonry units and hair-line cracks. Structural cracks were mostly concentrated on load-bearing walls. The interventions can be categorized as recoverable and non-recoverable. It is preferable to perform recoverable interventions (as in this study), leaving the opportunity for future and better developed interventions [6].

6.1. Strengthening interventions for the dome

The most important concern about the dome is protecting the interior from atmospheric agents like rain and snow. In order to achieve this, the roofing system should be improved. Leaden layer of the cap should be checked for possible misalignment of the layers, and repaired where damaged. The water collecting system should be changed as it is seen to be inappropriate.

Non-structural cracks less than 10 mm wide should be filled with grout or hydraulic mortar injection. Injection mix would seal the cracks, protecting the wall plaster from exposure to water. The injection technique is widely used in restoration projects of historical constructions (Bell tower of Monza, Church of St. Sofia in Padua, Outerio Church, Portugal, etc.). [7]

6.2. Strengthening interventions for load bearing walls

It is observed that the load bearing walls suffer the most from structural problems. They exhibit both visible surface degradation as well as structural cracks. The intervention procedure consists of reducing the shear and tensile stresses on the walls by adding additional tensile and shear resisting elements where necessary. One of the objectives to be achieved is that connections should be flexible rather than rigid to avoid stress concentrations and guarantee the durability of the structure. [5]

Injection is suggested to be used in areas where non-structural cracks less than 10 mm wide are found. The most useful feature is the increase of continuity of masonry. Furthermore, neither aesthetics nor architectural features of the mosques will be altered when applied.

The cracks near the openings should be repaired with longitudinal FRP bars bonded with epoxy resin or mortar (Fig.5). This method is based on integration of the high tensile strength properties of FRP into the unreinforced masonry wall and would improve the tensile and shear resistance of the load bearing walls as well as their ductility. The procedure implies insertion of FRP bars about 10 cm inside the wall and refill of the cavity with the same type of mortar. [8]

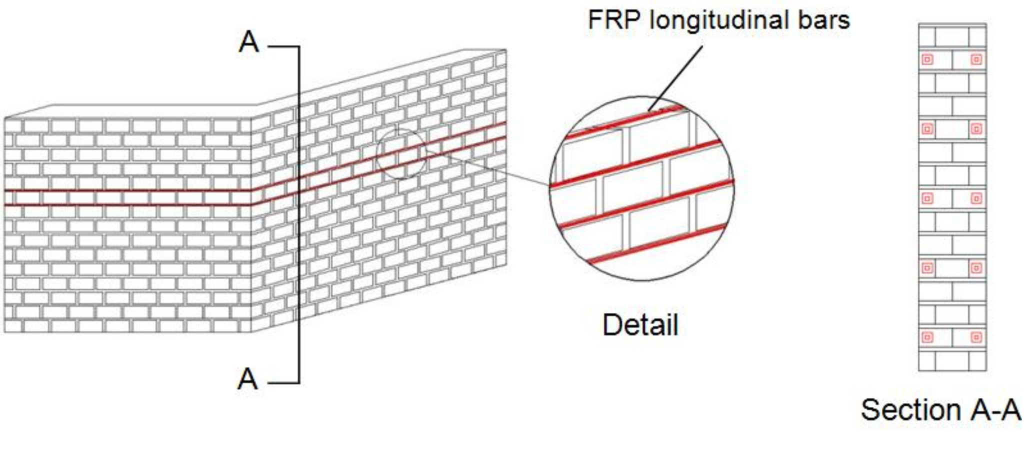


Figure 5. Application of strengthening with FRP bars

Additionally, local reconstruction “cucci scucci” technique is suggested to be used in the places sanding phenomenon is seen and where massive loss of building units is observed. The substituting units must have to the same architectural features, and should be compatible with original facades. This method was applied in restoration of Tower of St. Giustina Basilica in Padua.[9]

7.RESTORATION

Restoration project intends to preserve the mosque for further generations and enhance its architectural values. According to restoration proposal (Fig.6):

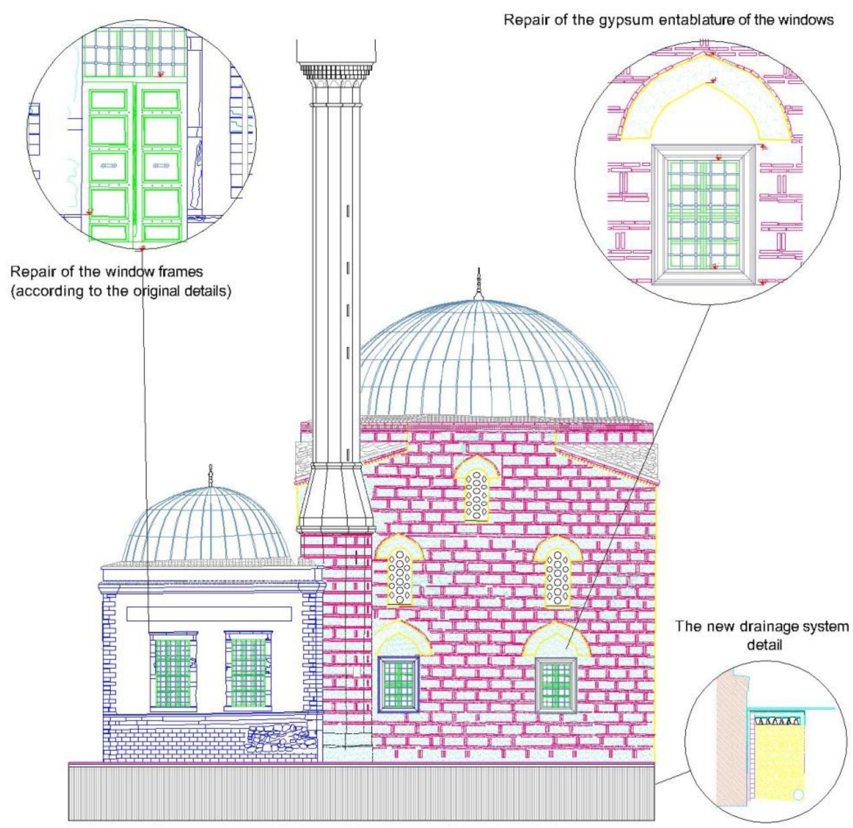


Figure 6. The proposed interventions on the west façade.

1. All the original materials and elements of the structure that do not exhibit any deficiency will be kept unchanged.

2. All the missing elements will be replaced with new ones having the same properties.

3. Deformed sections of the leaden cover of the roof should be fixed, and all the cover should be cleaned.

4. Broken tiles should be replaced with original corrugated tiles.

5. Microbiological formations on the stone walls of the façade and in the interior should be removed.

6. Old plaster should be repaired where spall is seen. Khorasan mortar should be used in making the new plaster.

7. Rubble stones of the façade should be cleaned mechanically using salt. Missing stones of the facades should be replaced with new ones which would be prepared using the powder of the original stones bonded with hydraulic lime repairing mortar.

8. Earlier improperly made interventions to repair stones with cement-added mortar, should be removed without damaging the original material.

9. Gypsum entablature of the windows should be repaired, and rotten timber windows should be replaced with new ones that have the same details as the original ones.

10. There should be a detailed check on the walls of the facades which contain discontinuities of building elements like gaps, swelled or cracked regions. Lime mortar should be used to seal those gaps.

11. In order to prevent sanding and to minimize the risk of flood, a new groundwater drainage system should be made around the perimeter of the mosque.

8. CONCLUSION

In this paper, structural assessment of the Leaden Mosque based on visual inspection was presented. From the visual inspection results, it is seen that the general structural conditions of the Leaden Mosque seem adequate to carry static loads. However, in order to preserve this mosque for the future, intervention strategies mentioned above should be implemented. The suggested intervention strategies consider improving structural performance of the mosque under static and dynamic loads as well as preserving the mosque's unique historical and architectural values. This study could be a good guide for structural assessment and restoration of other Ottoman mosques in Albania.

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