INTEGRATED SURVEYING METHODOLOGIES FOR STUDYING, PRESERVING AND MONITORING THE BYZANTINE SAINT NICHOLAS MONASTIC COMPLEX

Raffaella Brumana, Daniela Oreni, Branka Cuca
Building Environment Sciences and Technology, Politecnico of Milan,
Piazza Leonardo da Vinci, 32, 20133, Milan, Italy

Luigia Binda*, Paola Condoleo
Dept. of Structural Engineering, Politecnico of Milan,
Piazza Leonardo da Vinci, 32, 20133, Milan, Italy

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ABSTRACT

A laser scanner geometrical and crack pattern survey together with a 18 month crack monitoring was carried out on the Church of St. Nicolas near Mesopotam (Albania) was carried out in order to study the morphological and structural problems of the building. The research was carried out within a multi scale approach by a group of researchers from different Italian Universities supported also by UNESCO (Venice). The results are here presented, beginning from the laser scanner survey to the crack pattern monitoring, showing that the damages started long time ago, probably caused by earthquakes occurred in the area. The geometrical survey and the monitoring shows a continuous movement of the façade and of the apse outward, which should be controlled and limited by an appropriate choice for improvement and repair.

INTRODUCTION

The research here reported concerns the diagnostic investigation on St. Nicolas Monastic complex in Albania and it is part of the research carried out within an Italian-Albanian cooperation-project for the Study, Restoration and Revitalization of Byzantine and Ottoman Monuments in Southern Albania.

The archaeological site object of the research is placed near Mesopotam (about 10 km far from Saranda), in the province of Delvina (Rrethi the Delvinës), region of Vlora (Qark Vlora), Albania. The Byzantine Saint Nicholas Monastic Complex is surrounded by the remains of a large fortification wall (80x120m), on top of a hill.

The monastic complex was probably founded in the 11th Century by the Byzantine emperor Constantino I Monomachos (1042-1055). Originally the complex was very large and gave hospitality to numerous monks. Today only the church and some scattered ruins are visible. The church is still in use as an Orthodox church.

A multi-scale approach was carried out by a group of researchers from different Universities of Italy (Politecnico di Milano, University Ca’ Foscari of Venice, University of Bari, etc.) supported by UNESCO [1] [2]. The results presented here concern the geometrical and structural damage survey addressed to support the different purposes of the interdisciplinary group involved in the project [3] [4].

The site and the church itself show different and serious structural and materials problems. They required an on site investigation by geometrical survey, structural damage survey and interpretation monitoring of the cracks for a period no shorter than 18 months in order to decide for the choice of the most appropriate techniques for repair and improvement.

The church shows a very significant crack pattern and some out of plumb of the load bearing walls. The presence of different masonry typologies is also clearly visible. In order to ascertain the different construction phases it was necessary to carry out an accurate photogrammetric analysis, joined to a stratigraphic investigation.
The capitals and the details of the decorations but also the entire architectural system required a conservative restoration. A 3D modelling of these elements is important for their typological investigation and their conservation. Photogrammetric orthoimages of internal and external fronts have been obtained beginning from an image block composed, on the average, of 25-40 High Resolution images. Digital Surface Model (DSM) has been processed from 3-D image Matching. In the meantime, a 18 months static monitoring of the main cracks allowed to understand the mechanisms of damage (probably caused by past earthquakes and soil settlements) still active in some parts of the church. An outward rotation of the apse and of the facade could be detected. The results of the survey will allow the preparation of the geometrical model for the structural analysis and in the meantime for the damage interpretation and for the choice of the best repair techniques.

EXPERIMENTAL

The monument shows different and serious static and conservation problems, the main of which involve geometry surveying and modeling. Furthermore there is the presence of different masonry typologies which needs stratigraphic investigation, to which orthoimages can give a metric support to thematic mapping. In additional the important crack pattern needs monitoring and interpretation.

GEOMETRICAL SURVEY AND 3D MODEL

Beginning from the three surveying campaigns carried out to cover the monument and the environmental context, it has been set up the base-model for the morphological and structural analysis: a virtual three-dimensional model of the church has been built up, in order to generate co-related Spatial Information Data for decoding the complex of Mesopotam. Integrated methodologies (photogrammetric and laser scanner) have allowed a global-local approach [5] for the punctual reconstruction of the different fabric bodies and of the constructive elements (i.e. vaults, domes, columns, wall), finalized to collect important and useful data for reading shape, structure, geometry and for the interpretation of all the traces and complex signs stratified along the centuries. The data have been available - within agile environment - to the different research groups involved in the research (historians, structural engineers, restorers and archaeologists).

From laser scanner point clouds the local out-of-plumb and verticality analysis for each indicative profile along transversal and longitudinal direction has been reconstructed. Geometric anomalies and discontinuities have been represented both on the sections obtained from the assembled profiles through the topographic network, and on the 3D synthesis model.

Laser scanner data for model deriving concept

The result of overcoming survey methodology traditionally used for geometric purposes to support structural analysis and behavior, based on topographic determination of the spatial coordinates (X,Y,Z) of discrete points, is here discussed. Through punctual ‘selection’ of the most relevant points along pre-determined directions, it was possible to reconstruct horizontal and vertical sections. Such a synthesis model is obtained from an ‘a-priori’ schema, well supported by total stations, where the expected behavior has a heavy weight respect to un-expected answers, but obliged by the limited time-cost discrete data acquisition, where the operator decides which and where, point by point, oriented by the requested information collected from specialists that will use survey output.

The experimental here faced, favored by the campaign outside Italy and by the effort in moving instruments, involved the use of Laser Scanner (LS) data acquisition in order to reduce time/cost.
of the on site operations, and in order to support geometrical analysis allowing to better orient monitoring phases carried out to control crack pattern and movement during the time with classic control system easy to be managed by local skills, as explained in the following paragraphs. Demanding on lab the possibility to dynamically select priorities of the restitution process, orienting and implementing data, where necessary, in function of the requests carried by specialists on reading first result, following an iterative methodology, where the different disciplines are in condition to address the research and knowledge focusing objectives in the time. LS allows the acquisition of enormous number of points (clouds) in few minutes, with high accuracy, thus it has been erroneously deducted a coincidence of the point clouds with the ‘concept model’. The expected result is to have an immediate model, in the sense of a result which doesn’t need any intermediated role of the scientific competences/context analysis/knowledge/geometric synthesis/historic background. The correspondence between surveyed points and interpretation model is cancelled by this wrong acception. The richness of information carried out by each point need to be interpreted by refining investigation, decoding instruments and representation tools [6]. As the Information Society has pointed out in these year, too much data can mean ‘no data’, if interpretation methods doesn’t grow up to avoid losing of information: the more we want to avoid softcopy reverse engineering of the reality, the more we need to strengthen conceptual schema in reading the manufact through interdisciplinary connection and representation methodology to manage multiple input within virtual space-time model. In addition, LS survey doesn’t catch the points that exactly belong to a profile, to the discontinuities, to the edges, to all those points we would like to obtain to simplify the reality. Infact the surveyed points are only function of a range angle (H,V) set up at the beginning of each surveyed clouds. Consequently the surveyed point doesn’t immediately represent the schematized reality. We expect they cover an area ‘around’ the exactly position we would like to determine: consequently we cannot connect them directly without ‘interpreting’, selecting and abstracting the model to be reconstructed. Here are illustrated two different approaches within the interpreting effort, tested to extract information, from the GeoDB made up by the 3D data point, oriented by the conceptual model, in function of purposes, characteristics, and objectives: we named them ‘profile oriented models’ (from clouds to profile to 3D model) and ‘surface oriented models’ (from clouds to 3D model to profiles).

Profile oriented models to reconstruct geometric behavior
In order to generate a synthesis global model, all the scans acquired by different position to cover the whole complex, has been connected one to the other through a topographic network and tie points. The resulted points are related within a unique refereeing system (Figure 1) obtaining a GeoDB, a Data Base of all the internal and external point coordinates coming from different scans. In order to obtain a systematic profile extraction, horizontal and vertical, from the GeoDB, it has been adopted profile oriented model, where data processing for profile reconstruction is based on the discretization from the whole clouds. To give an exhaustive interpretation of geometric behavior of the architectural complex, along predetermined direction, selected in cooperation with structural competences, it has been extracted slices made by internal and external points (Figure 2). Once obtained the single slices, the profile continuity has been reconstructed through an interpretation effort, relating knowledge of architecture, distinguishing structural elements, decorative ones, integrating breakline information along the edge by discontinuity reading (architectural frames, pilasters, friezes, etc.). The GeoDB allows to extract profile - that can be implemented any time - along any direction requested to deeper investigate the geometric behavior. The objective is to generate multiple sections along
different directions for the structural purposes, to valuate out of plumbs along themselves (Figure 3), generating a 3D synthesis model on the profile base (Figure 4). Once reconstructed the internal-external profiles on a dense cloud points distribution (~ 1÷2cm), it has been obtained a dense geometric DB for reading out of plumb behavior: to summarize some values, it has been evidenced values at ~ 1 meter interval for a descriptive synthesis table, evidencing an outward rotation trend at the top of the structure respect to the bottom values (Figure 4).

Figure 1. 3D topographic network and georeferenced Laser Scanner point clouds: external and internal scans has been registered and georeferenced to the topographic network. Extraction of the plan from the 3-D point clouds: the reconstruction of the geometry and its irregular shape is obtained by local interpretation (Leica Cloudwork © and Cyclone© within CAD environment).

Figure 2. The registration of external and internal scans (11432501 points, mean resolution 1 cm, n.16 scans) for the 3D model point generation, and details of vertical profile extraction and generation. Characteristics: Leica HDS 3000, System performance 0÷50 m scan range: Accuracy in the distance measurement = 4mm; Accuracy in the position measurement = 6mm; Angle (vertical and horizontal) 60microradians; target acquisition accuracy 1,5mm; modeled surface precision = 2mm. Leica HDS 6000, 0÷25 m scan range: Accuracy in the distance measurement = 2mm; Accuracy in the position measurement = 5mm; Angle (vertical and horizontal) 125microradians; target acquisition accuracy 2mm; modeled surface precision = 1mm.
Figure 3. Some of the reconstructed internal-external profiles and the sections obtained along the pre-defined direction. A detail of a portion showing the outward behavior.

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Profile</th>
<th>Vertical deviation: out of plumb values (cm)</th>
<th>Profile</th>
<th>Vertical deviation: out of plumb values (cm)</th>
<th>Geometric Schema Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00÷0.80 6.40~</td>
<td>B1 ⇩</td>
<td>2.6, 0.4 Ext. sense</td>
<td>B2 ⇩</td>
<td>13.7, 0.2 Ext. sense</td>
<td></td>
</tr>
<tr>
<td>0.00÷0.80 6.40~</td>
<td>A2 ⇩</td>
<td>4.0, 2.0, 5.0, 3.0 Ext. sense</td>
<td>A1 ⇩</td>
<td>9.2, 1.6 Ext. sense</td>
<td></td>
</tr>
<tr>
<td>0.00÷0.80 6.40~</td>
<td>E1 ⇩</td>
<td>6.0, 9.0, 0.0 Ext. sense</td>
<td>E2 ⇩</td>
<td>10.0, 9.0, 0.0 Ext. sense</td>
<td></td>
</tr>
<tr>
<td>0.00÷0.80 7.0~</td>
<td>C2 ⇩</td>
<td>13.8, 3.6, 0.0 Ext. sense</td>
<td>C1 ⇩</td>
<td>9.2, 2.0, 0.0 Ext. sense</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. The table summarize the min-max out of plumb values along profile direction at top and bottom level within homogeneous profile interval, showing a general geometric outward.


**Surface oriented model**
In case of the geometric analysis of the intrados shape of the 4 domes, having few discontinuities to be managed (principally the line of impost), it has been firstly reconstructed a surface oriented model from the cloud points. Once obtained the first global model for each dome, it has been analyzed automatically extracting the profiles along the predetermined main directions, in order to interpret the different morphological shapes. It has been applied a least square interpolation to the geometric analysis with a linearized semi circumference function.

In the figures 5 and 6 the results obtained for two domes are presented. The process shows a ‘perfect’ semi-circumference profile and spherical geometric genesis shape in the original dome A, evidencing the advanced constructive skill.

In the case of Dome B, which was probably reconstructed after a collapse, the geometric analysis shows a clear degeneration of the top of the dome from a curve arch to a planar surface, where the arch degenerate to its bowstring, evidencing lack of skill during reconstruction phases along the centuries.

The extrados survey of the dome wasn’t completely surveyed for inaccessibility of the top coverage by LS rays visibility. Experimental of UAV (unmanned aerial vehicle) flight to acquire photogrammetric image block are on course in similar test field, to allows data implementation in critical and dangerous accessing areas, for which the research group is developing a photogrammetric platform prototype that can be used in case of further campaign [7].

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**Figure 5.** Dome A, S-E side (n.3, see at the schema in figure 8). The geometric analysis of the dome modelled on the points and the profile extracted by the 3D model interpolated with a circumference function.

**Figure 6.** Dome B, N-E side (n.1, see at the schema in figure 8). The 3D model of Dome reconstructed on the LS points, texturized with fissure map from the orthoimage generated photogrammetrically. The modelling phase for morphologic analysis, triangulation and mesh generation, has been processed with software Rapidform ©.
CRACK PATTERN MONITORING AND DAMAGE MECHANISMS

Photogrammetric orthoimages for crack pattern and stratigraphic analysis
The monument shows different and serious static and conservation problems, presence of different masonry typologies is observable. In order to further investigate the construction phases is necessary a photogrammetric output joined to a stratigraphic investigation. For this purpose 3D orthoimages has been generated on the external and internal surfaces, from photogrammetric image block processing. The integration of the correspondent vertical section drawings, with the metric support of the rectified images (5mm resolution of the terrain pixel), has been used for thematic mapping (such as degree mapping, etc.): it has allowed to georeference crack and fissure maps, relating external and internal spatial info (Fig.7).

Figure 7. Photogrammetric orthoimages of the external and internal fronts and their overlapping, with a detail of the fresco in correspondence of the arch (the image block is composed, on average, of 25÷40 High Resolution images, terrain pixel resolution, ~5mm).
Thematic georeferenced map has been generated with cracks pattern to support structural analysis and behavior. The interior and the exterior walls of the church show a diffuse crack pattern related by the superimposition of photogrammetric output. The cracks interest the facade, the apse and the longitudinal walls of the church (Figure 7) and the interior of the church (Figures 8a,b). The cracks continue also on the vaults (Figure 9) showing a complex pattern which could represent a difficult situation for the stability of the building. It is difficult to interpret the crack pattern which seems to be present since long time ago and probably also due to past seismic events which were probably interesting the area long time ago.

Before deciding any repair or retrofitting technique for the intervention it seemed wise to collect information on the past history of the area and of the building, and especially to study the movements of the cracks in a rather long time [2].

Due to the impossibility of reaching the vaults for the lack of appropriate scaffolding or stairs, the measurement bases were applied to the longitudinal walls, the facade and the apse. In the plan (Figure 10) the position of the measurement bases are reported.

Two engineers, Malo and Bledi Mane, owners of a laboratory for geophysical measurements in Saranda, took the duty of carrying out free of charge the measurements each month from the end of November 2007 until the end of June 2009. The tool used to carry out the monitoring is a removable extensometer DGE1250 (resolution 0.001mm) (Fig.8) temporarily offered by BOVIAR Srl from Rozzano (Milan, Italy). We thank both the enterprises for their offer. The two engineers were suggested by Prof. Stavri Ristani from Tirana Vice Minister of Public Works in Tirana who always was assisting us with the engineers. Unfortunately the measurements were stopped for six months from the 1st of June 2008 until the 1st of December 2008 and then continued fortunately until today.

The Figures 11a, b and 12 (temperature variation) show the diagrams corresponding to the measurements carried out. Possible value of the displacement means opening of the crack. From Figure 11a it is possible to see that the cracks ASN2, ASN3, ASN6, ASN8, ASN9, ASN10 are not completely stable. From the Figure 11b it is visible that the cracks ASN15, ASN16, ASN17 are not stable. In detail, the movement of ASN17 counteract the one of ASN15 and ASN8 the ASN1 and ASN 2.
Figure 9: a) N-E and S-W side; b) N-W and S-E side

Figure 10: Positioning of the measurement bases

Figure 11: a, b, Diagram of the monitoring displacement along the time from first measurement
RESULTS & DISCUSSION

The virtual model of the complex of St. Nicholas - based on geometric 3D model integrated by 3D metric images - has been conceived to be shared to the different user and specialist. This case has demonstrate that the difference in information growing is made by the interdisciplinary competences and data exchange. In order to strengthen data distribution aim, all the drawings, sections, photogrammetric images, 3D LS point GeoDB, models, need to be progressive available on web by publishing GeoData within geoportal [8]. In Architectural Heritage communicating domain there is a lack of web services based on geometric and thematic data dissemination, that ask for Spatial Data Infrastructure to be developed and implemented for specific architectural and archaeological modeling, respect typical 3D urban and environmental web data [9], in order to dynamically support life cycle during the future.

From the results of the monitoring collected up to now and also from the observation of the laser scanner survey it seems to be confirmed the tendency of the facade and of the apse to rotate out of plane around the passing through existing cracks (Figure 13). In the Figure also the out of plumb of the facade and of the apse measured by the laser scanner survey is reported. The results seem to validate the interpretation allowed from the monitoring of the cracks for 18 months, even with a 6 months interruption.

Figure 12: Temperature variation along the measurement times

Figure 13: First interpretation of the damage mechanisms after the geometrical survey and the monitoring
The system movement seems to be still active, even if it could have been caused by a past earthquake, being this mechanisms of facade and apse moving out of plane typical of caused by earthquake damages. Another cause could be also soil settlements. Other movements are present in the longitudinal sides of the walls but they seem to be more stable.

The measured movements can bring in a long time to possible states of partial collapse, therefore an intervention is needed to stop as much as possible the movements and to improve the behaviour of the structure to possible further earthquakes.

In order to stabilise the main movements a confinement is necessary, which can be realised by positioning steel rods at the top of the walls around the perimeter of the church. The rods can be positioned internally or externally to the walls (better internally, in order to protect them from corrosion). The tie rods can also be realised in stainless steel. Similar confinements can be executed also by positioning another set of tie rods at half the height of the walls in order to have a better connection. The cracks can be subsequently filled by injection of grouts base on hydraulic lime. Transversal ties can also be positioned in order to reduce the thrust of arches and vaults in that direction.

The old repair carried out in the past as the buttress on the right end side of the church and the pillars in the internal part can possibly be left as remains of the past history of the church. It is not necessary to remove them.

CONCLUSIONS

The interaction between the geometrical survey and the interpretation of the structural damages was very useful and was showing multidisciplinary approaches can be useful for conservation problem [10].

A brief report has been made of the geometrical and crack pattern survey and of the simple monitoring of the crack pattern for 18 months (missed for 6 months).

A first interpretation of the results seems to indicate the tendency of the façade and of the apse of the church to rotate out of plane with a movement which seems to be not stable.

Some preliminary suggestions are given in order to prevent the movement to progress into a dangerous situation. More investigation is needed on the characteristics of the component materials (mortars and bricks) and of the masonry by mechanical on site testing (flat jack) and NDTs.

It is also suggested to collect more information on the past seismicity of the area and on the past possible damages caused by earthquakes.

More investigation need to be done on the vaults and roof constructing techniques and damages

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