STRATEGY FOR INTEGRATED SURVEYING TECHNIQUES FINALIZED TO INTERPRETIVE MODELS IN A BYZANTINE CHURCH, MESOPOTAM, ALBANIA

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1. INTRODUCTION

This chapter presents the research carried out on the Saint Nicholas monastic complex of Mesopotam (Albania) with the support of UNESCO. Under the auspices of the

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Regional Bureau for Science and Culture in Europe (BRESCE) an international cooperation programs supported by UNESCO office in Venice, which is in charge of safeguarding and valorizing the rich cultural heritage of southeastern Europe, this project was aimed at rediscovering, evaluating, and sharing the traditions, characters, and specificities that mark the complex mosaic of Albanian medieval and Byzantine architecture. After a UNESCO mission in 2004, which was aimed at gaining a deeper understanding of valuable Albanian monuments and sites, a project design was developed by a Scientific Committee comprised of researchers from several universities.[1] The multidisciplinary project, promoted by the Institute for Balkan Studies (Cà Foscari University, Venice) and led by Professor G. Macchiarella, was supported by UNESCO (Boriani and Macchiarella 2009), and co-financed by the Mediterranean DG, General Direction, of the Puglia Region (Italy).

The research followed the perspective of UNESCO and of the criteria set up by the World Heritage Convention (1974) for the protection of the Cultural Heritage (CH), which prioritized studies focused on the conservation of monuments at risk of abandonment and collapse (Macchiarella 2011). Even though not yet included in the Albanian Registry of Monuments, in the area under consideration there are several monuments from Byzantine and Ottoman times that are in damaged condition, similar to that of the structure in the presented case study, mostly for lack of adequate maintenance. Since systematic identification and study of all those monuments is necessary, the priority was given to the fortified Byzantine monastic complex of Mesopotam with the Church (katholikón) of Saint Nicholas. It appeared as the most interesting one, because of the many original and stratified features built up by time and human actions and in large part still to be re-discovered.

2. STATE OF THE ART OF INTEGRATED SURVEYING TECHNIQUES

Historians involved in this research assert that the structure of the Complex of Saint Nicholas represents a *unicum* in the history of Byzantine architecture that requires support by geometric, material, and structural assessment. Hence, surveying technologies have been proposed to collect data for the purpose of conserving and valorizing this monument. Based on the previous studies and survey campaigns, summarized in the first "Preliminary Report on the Research and Excavation Campaign" (Bitelli 2005), further campaigns involving geometric, stratigraphic, and structural surveying have been planned, in order to correlate inputs from the investigations by experts from different disciplines. The study of the Complex requires a strong multi-disciplinary surveying methodology: similar experience in World Heritage-nominated sites has underlined the role of rapid and cost-effective integrated survey strategies in the heritage assessment (Santana and Van Balen 2009). At the same time, it has been underlined that preventive conservation of complex World Heritage sites such as the Silk Road as well as complex territorial areas, such as the one here considered, requires improved tools enabling the correlation of technical, socioeconomic, material, and territorial data, thus increasing the knowledge of a site's contextualized history and hence facilitating its possible conservation (Vileikis 2011).

The use of advanced integrated surveying technologies, especially terrestrial laser scanning (TLS) (Lemmens 2007) and photogrammetric image block acquisition, allows researchers to reduce the time of the surveying campaigns and obtain data in support of the different objectives to be processed more quickly. The research carried out in the last

[1] Lithotype: this is a double-layered masonry: Tuff stones framed by brick.

decade demonstrates increasing attention to extracting geometric content from laser scans and photogrammetry (Kraus 2007), thus applying image-based surface measurement for heritage documentation.

Data processing, surface analysis, and automatic three-dimensional (3D) surface matching (Akca and Gruen 2007), integrated by multispectral image data, have great potential in a reconstruction process as they provide the ability to match geometric, historical, and morphological information, thanks to the strict relation between shape and images. In fact, nowadays modeling needs to be better oriented and strengthened through the integration of historical, material, and construction technologies data within the 3D-modeling processes.

Automatic texture acquisition (Wang 2008) through visual modeling (Pollefeys 2004) and virtual reality (Hartley 2004) is progressively focusing on merging geometric properties with multi-image data. The development of multi-photo matching algorithms allows accurate reconstruction of realistic models through 3D-texturing techniques based on dense clouds and 3D meshes (Barazzetti 2010). Such models are often left relatively unstructured to support knowledge information: they can be better refined with the support of discontinuities and break line extraction, more fruitfully readable with the contribution of other disciplines, such as stratigraphic analysis, to image decoding. Image and surface segmentation and homogeneous pattern analysis techniques for object recognition and reconstruction (ORR), when applied to 3D-city modeling can enhance feature extraction methodologies to obtain structured "true orthoimages" representing architectural surface items (i.e., facades, intrados vault surfaces, mosaic floors, painted walls). Such integrated techniques were used in the current study to improve the semantic, quantitative, and qualitative architectural decoding of complex objects, strengthening the potential of the geometric and thematic correlation essential to the architectural historical analysis, to its transformation during the centuries, and to its behavior.

The main motivation of this research it to overcome the limitations of undistinguished 3D models through the development of interpretative models that can increase our understanding of the experimental site, passing from a low level of decoding to a higher level of structured information, as described in the following paragraphs concerning the case of external 3D walls and the vault systems. Advanced 3D virtual reconstruction and visualization of complex architectures through image- and range-based 3D modeling to record cultural heritage (Remondino 2011) are increasingly being used for typological investigation and conservation (Rinaudo 2007). Recording by using photogrammetry and 3D scanning with multi-resolution data has been here addressed, enhancing the logic of developing 3D content objects to capture the complexity of the entire architectural system and of the single elements (e.g., walls, openings, opening closures, columns, pillars, domes).

Previous experiences highlight how geometric models of complex systems such as the vault system can help the reconstruction and interpretation of the different construction techniques adopted through the centuries, as a result of an LS and photogrammetric survey. These results can be reached if the modeling process more thoroughly integrates the analysis of the construction technologies with the geometric 3D texture of the brick block arrangement (Brumana et al. 2008). The geometric shape represented by the first rough mesh model generally reconstructed on the laser scans or on the photogrammetric digital terrain model (DTM) must be refined with a suitable interpretative model of the reality by integrating the stratigraphic analysis, as in the case of the wall model interpretation here described.

On the common grid of the texturized geometric constructive model of the visible surface, further surveying techniques can be better oriented with the support of non-destructive diagnostic analyses (e.g., thermal images), and progressively integrated in the virtual geospatial environment. The 3D content model can be further integrated by orthoimages generated on multispectral images, thus helping researchers to decode the texture of the structure, whenever it is not directly readable (Oreni 2012). Interesting results have been successfully obtained from different case studies in the investigation of the relation between the surveys and diagnostic analyses, coming from archaeological methodologies, mensio-chronological and archaeometric disciplines, such as the contribution of material analysis and dating applied to medieval architectures (Mannoni 1988).

An interdisciplinary study was carried out on the complex monument of the Basilica of S. Lorenzo in Milan, a Byzantine early Christian and Romanic age basilica (Fieni 2004), by integrating laser scanning and photogrammetric surveys (Monti et al. 2004) with stratigraphic analyses, which allowed researchers to investigate different construction phases. The archaeometric methodology of absolute dating, supported by technologies such as thermoluminescence and radiocarbon dating, applied to the burned wooden frustules within the mortar gave important results, enhancing knowledge of the monument's history, from the hypothesis of imperial mausoleum of General Stilicone, regent of the Emperor Onorio, to the hypothesis on the different chronological soils: from the original central dome (now collapsed) (Storz 1991; 1997), probably realized on the model of the S. Sofia Church of Constantinople, to the Romanic intervention and to the matroneum vault system (XVIth) (Fieni 2002).

The contribution of photogrammetry to the archaeometric approach (Brumana 1999) can be now improved by means of 3D content models of Mesopotam masonry typologies, openings and opening closures, and their transformations during the centuries. The literature on building activities in Byzantium (Bouras 2002) with respect to the Roman and Early Christian Age technique, together with considerations on the definition of dome systems within the Middle Age, represent an important starting point for the investigation of the vault system of the Byzantine complex of Mesopotam. This helps clarify the specificity of such architectural hazardous realization, with the string support of 3D-texturized object models.

The principal motivation of this research is to boost the content model representation to support the architectural interpretation and the knowledge of its behavior and of the different employed skills during the centuries, enhancing the strict relation between the geometry and the material construction content. The "surveying of global shape" applied to 3D paintings (Remondino et al. 2011) has demonstrated great potential for radiometric and geometric correlated analysis, applied in this case to the external wall frescos characterized by different 3D-stratigraphic units.

Hence, it is now desirable to boost the object content generation, in order to be able to correlate data beginning from the surface surveys: internal and external surface facades versus wall objects, intradox-extradox vault surfaces versus whole vault objects, assembling and relating them one to the other within a whole system. Open source geoportal and spatial data infrastructure (SDI) devoted to European Union region contextualized data (Cuca 2011) represent high potential for architectural purposes and data sharing. New tools are needed to manage 3D Geotiffs on 3D-textured web models.

Interpretive 3D models addressing the historical reconstruction of architectural monuments (Russo and Guidi 2011) can be progressively integrated by a complementary pattern model approach (Pesci 2011). Integrated surveying methodologies allow a global-local approach, with the detailed reconstruction of the different parts of the monument and of the structural elements thanks to the implementation of stratigraphic analysis and architectural interpretations of vaults, domes, columns, walls, center pillars, openings, etc. (Binda et al. 2006).

Within this process, the methodological approach used for the systematic analysis of the medieval monastic settlements north of Bari (Puglia, Italy), and in the Central Mediterranean area facing the Adriatic sea (Albanian coasts and Puglia region coasts) has shown many contact points and enhanced the comprehension of the Mesopotam site. This approach facilitated the valorization and the recovery of many important settlements, from Norman architecture to the period of the Anjou dynasty. The original construction and decorative characters with several oriental influences were studied, within an environmental frame of an agricultural economy, functional to the needs of the monastic communities in the area. Such deep and exhaustive investigation represents an important progress in knowledge (Belli D'Elia 2009; Triggiani 2009) that can support the stratigraphic analysis and surveys here carried out.

3. METHODOLOGY AND STRATEGY

The site and the church of Mesopotam show different and serious structural and materials problems of a complex morphological asset as result of the historic transformation and geographic context; therefore, geometrical surveying and modeling have been required to complete a diagnosis. The research has been carried out under the principle that only the conservation of the whole complex and of all its traces can guarantee an iterative, continuous growing process of knowledge, considering the site as a piece of the country's history. Furthermore, the comprehension and valorization of all the historic, architectural, material, and geographic elements could enhance an identity process of the residents, contributing to the growth of a sustainable tourist industry.

The interdisciplinary analyses carried out over the past five years, still in progress, are helping researchers to further understand the complex, through the sequence of the constructive phases that took place during the centuries. Different skills connected to different geometrical morphologies have been identified, providing the historians here involved with additional information. The paper shows that the understanding of the structural behavior is based upon an interrelated geometric and stratigraphic exploration, strictly connected to the historical hypotheses and to the environmental events. Consequently, by ensuring the connection between the attained level of knowledge and the future interventions, a conservation design of the whole complex can be guaranteed. Vice versa, interventions guided by the intention of bringing the complex back to the presumed original state and not related to the concept of the complex as a whole can alter the authenticity of the monument itself, its structural stability, and thus its conservation.

The presented results concern the geometrical and structural damage survey of Saint Nicholas church to support the different purposes of the multidisciplinary group involved in the project (Boriani et al. 2009; Cardani 2008). To ascertain the different construction phases, an accurate stratigraphic investigation was carried out, supported by a photogrammetric orthoimage that gave a metric texturized canvas to the thematic mapping.

The fact that the church shows a very significant crack pattern, and the walls are out of the vertical axis, required an on-site investigation by means of a geometrical survey, a structural damage survey by monitoring of the cracks for a period not shorter than 18 months, and the harmonization of the results in order to choose the most appropriate techniques for repair and intervention. A careful survey of the crack pattern of Saint Nicholas reported on plans, prospects, and sections, together with the geometrical survey of the out of plumbs, allowed a first interpretation of the structural damages.

In the meantime, an 18-month static monitoring of the main cracks allowed researchers to understand the mechanisms of damage that were probably caused by past earthquakes and soil settlements. Some of the damage processes are still active in certain parts of the church. In fact, a tendency to an outward rotation of the apse and of the facade was detected by monitoring survey data and further allowed the preparation of the geometrical model for the structural analysis, for the damage interpretation, and for the choice of the best repair techniques.

The methodological approach based on the integration of the different disciplines involved in the surveying and documentation process allowed researchers to achieve the important results of the phenomena modeling and to enhance the interpretation of important aspects: the historical transformation, the chronological phase detection, and the interventions occurred could be read by connecting the stratigraphic units to the global 3D geometric model, allowing an understanding of the current structural behavior with respect to the original ambitious project, to the restorations, and to the different skills involved in the different historical periods, as explained in the following paragraphs. The analysis of geometry, stratigraphy, and construction, the structural investigation and historic contribution, have been strictly correlated to obtain an interpretive model that is not just a sum of the single approaches, providing an added value to the whole process, able to orient the strategies of the future interventions, sustainable by the complex itself.

The following sections illustrate the different interpretive models—obtained from the different geometric stratigraphic surveys and from the structural monitoring—elaborated in a 3D GeoDatabase in function of purposes, characteristics, and objectives defined by the research project. The GeoDB has been finalized to: i) collect data on the shape of single elements, decoding the structure and the geometry of Saint Nicolas; ii) support the interpretation of all the traces and complex signs stratified on this artifact and its elements through the centuries; and iii) strengthen the logic of spatial correlation through historical object content modeling (HBIM).

The methodology adopted is anticipated to progressively move the geographic information models toward the logic of HBIM object generation, where spatially related full 3D objects, made by the sequence of the construction elements, have been reconstructed for different architectural purposes.

The objective is to obtain 3D texturized architectural object items (e.g., external–internal wall-facades with the sequence of the chronological phases, vault construction sequences, windows and opening/closing sequences) to be managed within the BIM environment, to relate phenomena detection and planning purposes for building management.

The research needs to be better oriented to experiment and verify the transition from "surface" to a concept of an "object" representation, able to support the BIM model for different aims. To enhance the object content model generation within the general model, the decomposition and reconstruction within the whole space has been strictly connected to the different descriptive, informative, thematic DB (material-degree mapping, disruption, stratigraphic units, constructive technologies, abacus of elements, structural behavior). The logic of semantic 3D content models related to many different pieces of information can better support lifecycle management of this monument, planned maintenance, and dissemination of results to the citizens. At the same time, a hard and critical aspect is represented by the verification of the current BIM suitability, based on parametric simplified models (Lee, 2006), with respect to the complexity of the architectural heritage. Plug-ins for efficient use of point clouds data (i.e., Leica CloudWorx for Revit 1.1 [2013, Leica Geosystems AG, Herbrugg, Switzerland]), need to further investigate complex object family generation and management, and this requires the implementation of new tools to support the complexity of the monument and of its elements, such as its vault systems and its complex walls, with the stratified opening and closures. The HBIM logic approach can dynamically support future knowledge, life cycle management, and conservation actions, within a self-feeding spatial data management system oriented to facilitate the single object interrelation, thanks to the iterative input of the different disciplines involved within the building information model.

4. HISTORICAL NOTES ON THE CHURCH OF SAINT NICHOLAS

The archaeological site that is the object of the research is located near Mesopotam (approximately 10 km from Saranda), in the province of Delvina (Rrethi the Delvinës), in the region of Vlora (Qark Vlora), Albania. The monastic complex is surrounded by the remains of a long fortification wall (with a perimeter of approximately 330 m, and an area of 80 × 120 m) on top of a hill facing the "Mesopotam plain" surrounded by the bend of the River Bistrica (Figure 1). The Mesopotam plain is separated by the mountains of the valley of the River Drin, where once flourished the Roman colony of Hadrianopolis and the Hellenistic town of Antiigoneia (Antigonea), founded by Pyrrhus, king of Epirus, and it is closed to the Phoinike center. Mesopotam is located in Northern Epirus, an area dense with historical and architectural stratified periods that need to be deeply studied in order to understand the peculiarity of the site and its transformations through the centuries.

It is worth noting that the Mesopotam area is characterized by a medium-high level of seismic hazard, with values of the peak ground acceleration (PGA, 475-year return period) in the order of 2.4 m/s^2 (Giardini and Basham 1993). On the basis of existing historical data and sources that outlined, before the research, a first chronological sequence of the construction of the Church of Saint Nicholas and the subsequent events that influenced its life (Meksi 1972, 2004), historical studies have been further carried out.

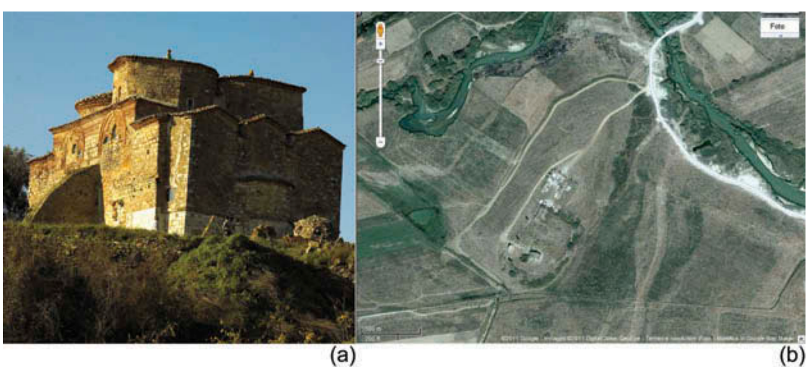


Figure 1. (a) Photograph of the Saint Nicholas Church and (b) the geographical context of the Monastic Complex of Mesopotam, confined by the Bistrica's river bend, surrounded by the remains of a large fortification wall with the Church inside. (b) © Google - Immagini, DigitalGlobe.

The church shows some peculiar features: a plan with two naves, divided by a central pillar upon which four domes were built. The interior of the church is divided into liturgical and architectural areas: the narthex in the west side and a *naos* in the east side of the church, ended by a single apse (Figure 2). On the exterior, some remains can be found, among which are those of a porch, which was erected on the North and on West side of the church, whereas on the South side there are various ruins, probably of a chapel; these parts are almost completely destroyed.

Even if the foundation of the complex can be dated back to the period before the XIII century (as testified by the seal with Saint Nicholas di Basilio Mesopotamites), almost all the historical references about the origin are not completely reliable. According to this hypothesis, it seems that the complex was re-established under the direct dependences of the patriarchate of Constantinople; the fact is confirmed by a legal document dated between 1220 and 1230. The real date, that could be around 1224–1225 (Macchiarella 2011), could be confirmed by the diagnostic analysis described in the following, thanks to an Eucharistic inscription almost certainly coming from the altar of the church; this is probably the date of the original project of the church of Saint Nicholas.

While 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.

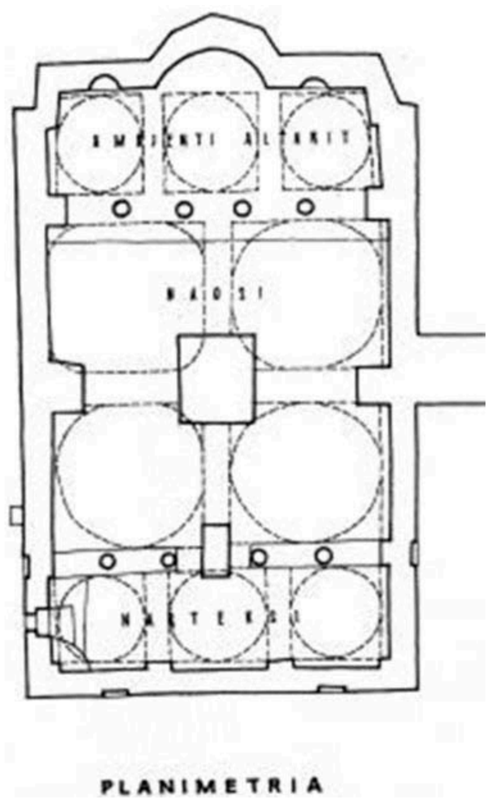


Figure 2. Plan of the Church (by Meksi).

A careful visual inspection allows one to describe the historical sequence of the events that influenced the structure of the church and the monastic complex of Mesopotam as reported below:

- 1224/1225: erection of the Church, reported by an epigraph located behind the altar (Giacoumis, Karaiskaj 2004; Macchiarella 2011).
- 1338: the site was fortified (Giacoumis and Karaiskaj 2004).
- Between the 16th and the 18th century, the area of Mesopotam was partially destroyed by earthquakes (Macchiarella 2011).
- 1793: a pillar was built to incorporate the original column on which the 4 domes rest (Meksi 1972).
- 1845: the iconostasis was rebuilt, as reported by an inscription located on the same iconostasis.
- 1927: Luigi Ugolini visited the Mesopotam site during his surveys in Albania (Ugolini 1927; 1928).
- 1972–1986: research and archaeological surveys of this site by A. Meksi (1972; 2004).

5. SURVEYING CAMPAIGNS, INSTRUMENT, DATA PROCESSING, AND ACCURACY

In order to support the investigation of the Mesopotam complex, the following campaign devoted to the on-site data collection by the interdisciplinary groups, including the geometric surveys, stratigraphic and thematic analysis, and monitoring has been planned and carried out.

5.1. On-Site Surveying Campaigns

- From 18.07.2006–19.07.2006, a first visit and on-site inspection were carried out by the Scientific Board with the presence of the groups described above, financed by the UNESCO-OPEN FORUM Discussion group–Mesopotam/Rusan in Saranda (Albania). In this framework, the surveying campaigns and the road map of the research were planned on the basis of the general report of the emergencies and of the requested analysis and competences that were drafted during this period to guide and co-relate the different surveys.
- From 29.11.2007–6.12.2007 (comprehensive of the travel), a first investigation campaign (geodetic network, laser scans, photogrammetric surveys of the external facades) was started by the B.E.S.T. surveying group. On this occasion also a further survey of the crack pattern was performed and a simple monitoring system measuring the crack openings was started by the D.I.S. group. Also the stratigraphic analysis led by Dr. M. Triggiani was carried out.
- From 26.07.2008–2.08.2008 (comprehensive of the travel), a second surveying campaign (GPS surveys, photogrammetric surveys of the internal fronts, laser scans of the external context and of the fortified perimeter walls) was completed.
- From 10.12.2010–11.12.2010, a visit was paid by L. Binda and P. Condoleo when the works by arch. Rechat had already started. The two researchers from DIS were not allowed to take pictures of the interior of the church by the architect, but could only memorize the situation.

5.2. Geometric Surveying: Instruments, Equipment Employed During the On-Site Campaigns, Data Processing, and Obtained Accuracy

Internal and external multiple scans were acquired to cover the complex of Saint Nicholas (n.16 scans, mean resolution 3mm÷10mm), and to cover the *claustrum* and the fortified wall (~ n. 30 scans). All the scans were georeferenced (Leica Cyclone 7.1.1[2008]) through the Ground Control Points (GCPs), targets, and natural points, to the Geodetic network (couple of Leica GPS1200 System and total station Reflectorless Leica TPS1200), realized all around the area (Figure 3). It allowed correlation of the single features (i.e., vaults, external walls) with the overall architecture and the whole context.

The laser scanning surveys were carried out in the two campaigns with a LeicaHDS3000 laser scanner (system performance 0÷50m scan range; accuracy in the distance measurement: 4 mm; accuracy in the position measurement: 6 mm; vertical and horizontal angle: 60 microradians; target acquisition accuracy: 1.5 mm) and a LeicaHDS6000 (accuracy in the position measurement of 3÷5 mm, and in the distance measurement of 2 mm, 0÷25 m scan range, 125 microradians vertical and horizontal angle).

The profiles and section extractions of the vaults and of other elements such as external and internal facades were processed using Leica Cloudwork, obtaining representation at the scale of 1:20 and 1:50.

A multi-scale 3D model interpretation was generated integrating the photogrammetric orthoimages of the internal and external prospects, obtained from

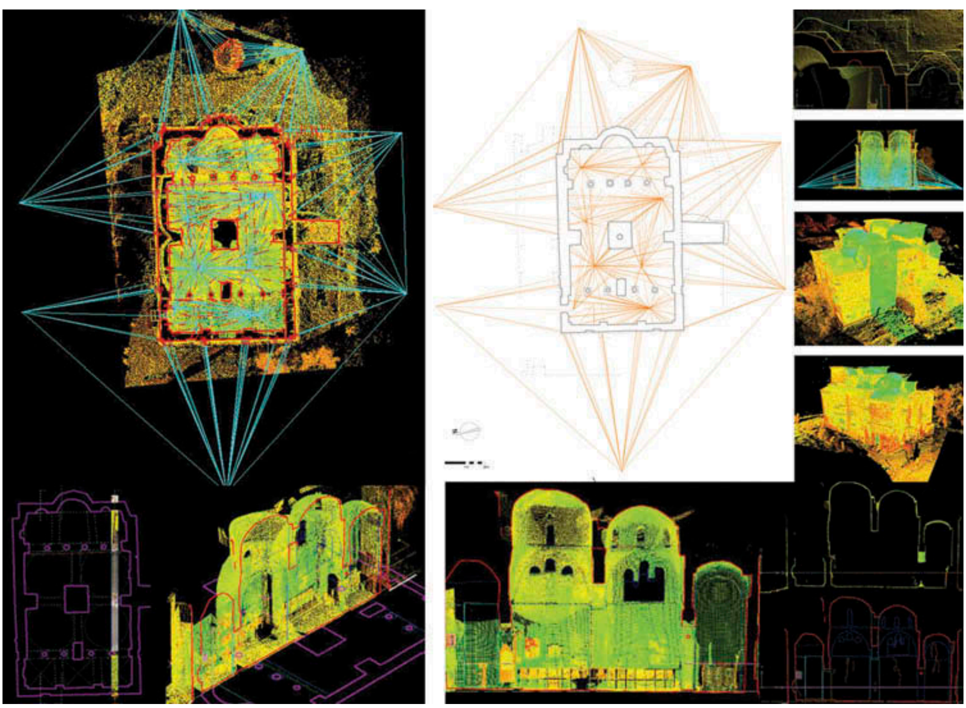


Figure 3. (center) Renderings of the egodetic network, (left and right) the laser scanner point clouds and the different views obtained, (bottom right) site surveying campaign, and (bottom) external and internal scans registered and georeferenced to the geodetic network, allowing the extraction of vertical sections and profiles.

different image blocks and strips (pixel terrain acquisition: 2÷5 mm image resolution, values conventionally used for representation at the scale 1:20 and 1:50, correspondent to 1/2 of the graphic error at the scale 1:20 = 2 mm and 1:50 = 5 mm); images were acquired with a high-resolution digital camera: Rollei db44 metric (4080 x 4076 pixels, Calibrated Lenses Distagon 40 mm, Planar 80 mm, Sonar 150 mm). Automated image block orientation (Photomodeler Scanner 6 [2008, Eos Systems Inc., Vancouver, Canada]) parameters were used for the orthoimage generation (SocetSet): a 5÷10 mm DTM was processed from the point clouds for the orthoimage projection.

The 3D vault surface models and walls surfaces were reconstructed on the chained laser scanner clouds (Autocad [2008, Autodesk Inc., San Rafael, California, USA] and Geomagic Rapidform X064 [2008, Rock Hill, South Carolina, USA]), integrating the profiles and the break-lines and discontinuities extracted and recognized on the clouds and on the 3D orthoimages. Beginning from the skin-surface, the single elements (wall surfaces, vault surfaces, external facades) were reconstructed, generating 4D object items. A hierarchical aggregation of the single 3D objects was inherited by geo-database spatial logic, applied within city modeling. 3D object generation was progressively addressed to the logic of geospatial building information modeling with BIM (Autodesk Revit Architecture [2012, Autodesk Inc., San Rafael, California, USA]), experimenting through the object families' implementation linked to the data acquired.

The output products of the survey, the vertical and horizontal sections, 3D models of complex elements (vaults and walls), orthoimages of the fronts and 3D texturized model, together with thematic maps of the material analysis and stratigraphic layers, have been achieved in a geographic database. This GeoDB is a collection of spatial data and enables one to relate the information and analyses coming from different diagnostic studies. A spatial data infrastructure within open source webgis was implemented by the research group for architectural purposes, and thus it was available for such geographic and information data sharing (Brumana 2008).

As for crack monitoring, the measurements were taken each month from the end of November 2007 until the end of June 2009. The monitoring tool used was a removable extensometer DGE1250 (resolution 0.001 mm). Unfortunately, the measurements were stopped for 6 months from the June 1, 2008 until December 1, 2008.

6. STRATIGRAPHIC SURVEYING

The Saint Nicholas church is characterized by many different masonry typologies. To further investigate the construction phases, the stratigraphic analysis was carried out on the photogrammetric outputs.

6.1. 3D Orthoimage: A GeoDB to Support Stratigraphic Analysis

3D-orthoimages of the external facade surfaces and rectified images of the internal fronts were generated using photogrammetric image blocks, mostly composed of 25÷40 high-resolution images per block. A digital surface model (DSM) was obtained from 3D image matching and from the LS point clouds on the external fronts. The rectified images and orthoimages have an average of 2÷5 mm resolution of the terrain pixel, that corresponds to ½ graphic error of 1:20 and 1:50 representations, suitable for the restitution and for the required stratigraphic analysis. All the outputs were used for the stratigraphic analysis of the different structural units (U.S.), and for the identification of the construction phases.

The orthoimages integrated within a global GeoDB by the correspondent vertical section drawings (horizontal and vertical), were used for the metric thematic mapping of the stratigraphic units (Figure 4) punctually correlated to the corresponding geometric sections. This allowed the researchers to better understand the discontinuities, break-lines, and edge borders belonging to different adjacent units, extracted from the LS survey and represented on the profiles, enhancing the overall interpretation through the strict connection between the geometry and thematic mapping. Through the overlapping of the photogrammetric orthoimages of the external and internal fronts, using two radiometric levels of different opacity, various similarities between external and internal fronts could be detected, with the transformations occurred. For example, in the south wall, the case of a detail of the fresco next to the arch of the ancient entrance successively closed (Figure 4). In this way, it was possible to georeference cracks and fissure maps and to correlate the external and internal ones within the overall spatial information. To identify the surface correspondences and the related items (e.g., crack, stratigraphic units, opening closures) on the facades, a 3D object model in the logic of irregular wall object family was generated. The 3D facade, texturized with the orthoimage, contributed to show the footprint impression of the different chronological soils and stratigraphic units (Figure 5), supporting the reading of all the traces and the stratigraphic analysis (Figure 6).

6.2. Stratigraphic Investigation and Description of the Masonry of the External Prospects

Beginning from the description of the masonry typologies of the facade surfaces, the stratigraphy of the walls was derived. Starting from the historical and archaeological investigations of the settlement (Meksi 1972, 2004; Gega 1993), the research moved from inspection to deeper visual analyses to clarify the different problems emerging from observations. Furthermore, the analyses of the geometrical survey, stratigraphic investigations, and monitoring allowed relationships among the various studies to be identified.

The main objects of this part of the research were:

- identification of the typologies of masonry texture of the Church of Saint Nicholas, as a result of historic research and stratigraphic surveys;
- in-depth studies on the structure, the structural elements, and the structural behavior of the building.

Through the research carried out on the site of Mesopotam during the period 2006-2008, four masonry typologies were identified and georeferenced on the orthoimages of the fronts, as shown in Figure 5.

The detailed survey of the wall typologies shows a triple layer of masonry in the facades and of the lateral walls of the church.

In particular, the lower part of the church was connected to the porch with large blocks of limestone (37 × 50 cm) arranged in a regular layout (Type A);[2] concerning the manufacturing process, the stones were worked by axe, axe-hammer with one edge,

[2]On the Northern façade, this masonry, USM (Masonry Stratigraphic Unit) 220, is located above the narrow windows identified as EA (Architectural Element) 205 and 206. In the Western prospect, this type of masonry was identified with USM 115 and 116. Above the narrow windows identified as EA 103 and 111.

Figure 4. Orthoimages of the Southern façade. The photogrammetric orthoimages of the external (top) can be overlapped to the internal front (center), within a unique geographic system. Thanks to the GeoDB it allows to identify the surface correspondences and to connect them within the Irregular Wall Object Family sequences, generated by reading, georeferencing and mapping the stratigraphic analysis and the transformations to occur. (bottom right) Here a detail of the fresco along the right side of the arch probably representing the ancient entrance to the church successively closed.

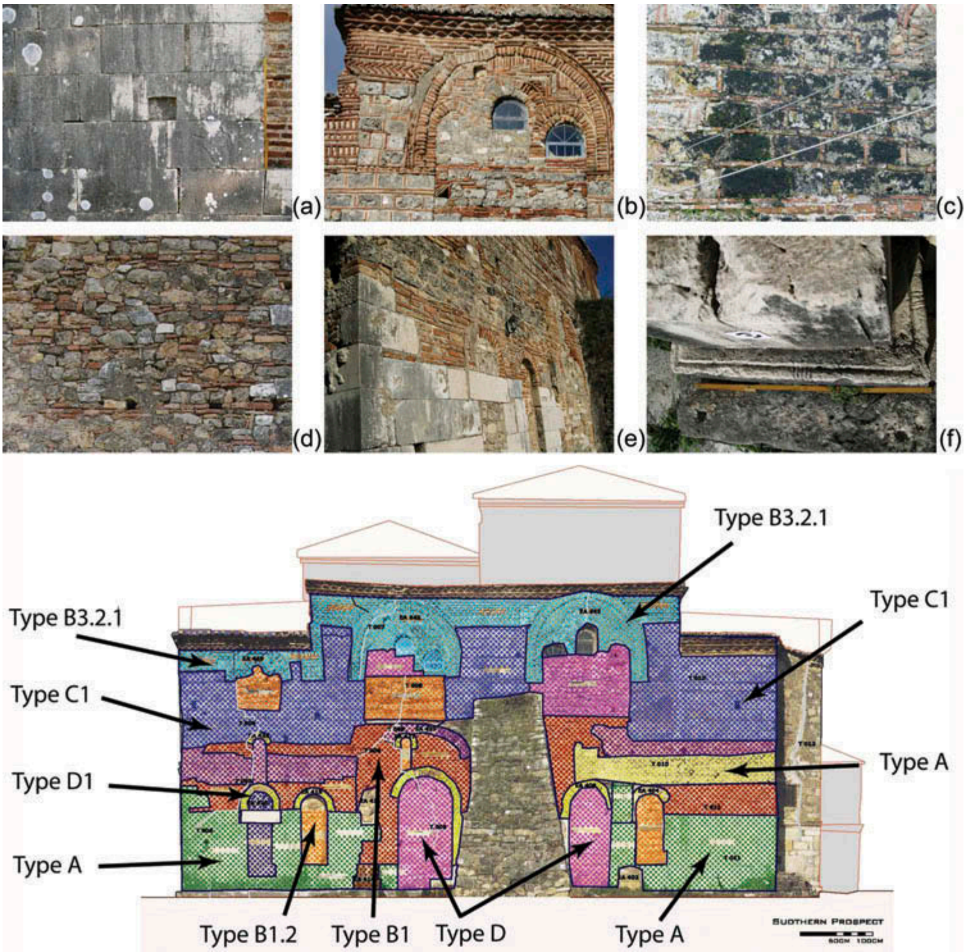


Figure 5. Illustration of upper masonry typologies of the Saint Nicholas: (a) Type A: large blocks of limestone (37 x 50cm) arranged in a regular layout; (b) Type B: different size of bricks worked on with a large use of mortar; (c) Type C: particular masonry called “brick cage” containing tuff-stones; (d) Type D: irregular restored masonry, characterized by irregular stones, wedges and a large use of mortar; (e) Type E: many vestiges of the destroyed portico; (f) Type 0: the spolia that are present on the wall masonry of the church. (bottom) The masonry typologies georeferenced and mapped on the orthoimage of the southern façade.

and hammer-head. The masonry shows that a stone was recently worked on the external wall of the apse. Various kinds of deterioration were detected on these stones: 1) presence of white mold (type A 1.3 and 2) blackening caused by humidity and condensation on the Western and Eastern prospects. Several stones are cracked at the bottom, where structural deformations were probably caused by movements and by the various collapses that occurred during the years.

The central part of the church (Northern, Western and Eastern facades) consists of a brick masonry section with thick mortar joints (Type B).[3] This masonry was used for

[3]EA 109 in the Western facade, EA 207-210 in the Northern facade and EA 402-413 in the Southern facade.

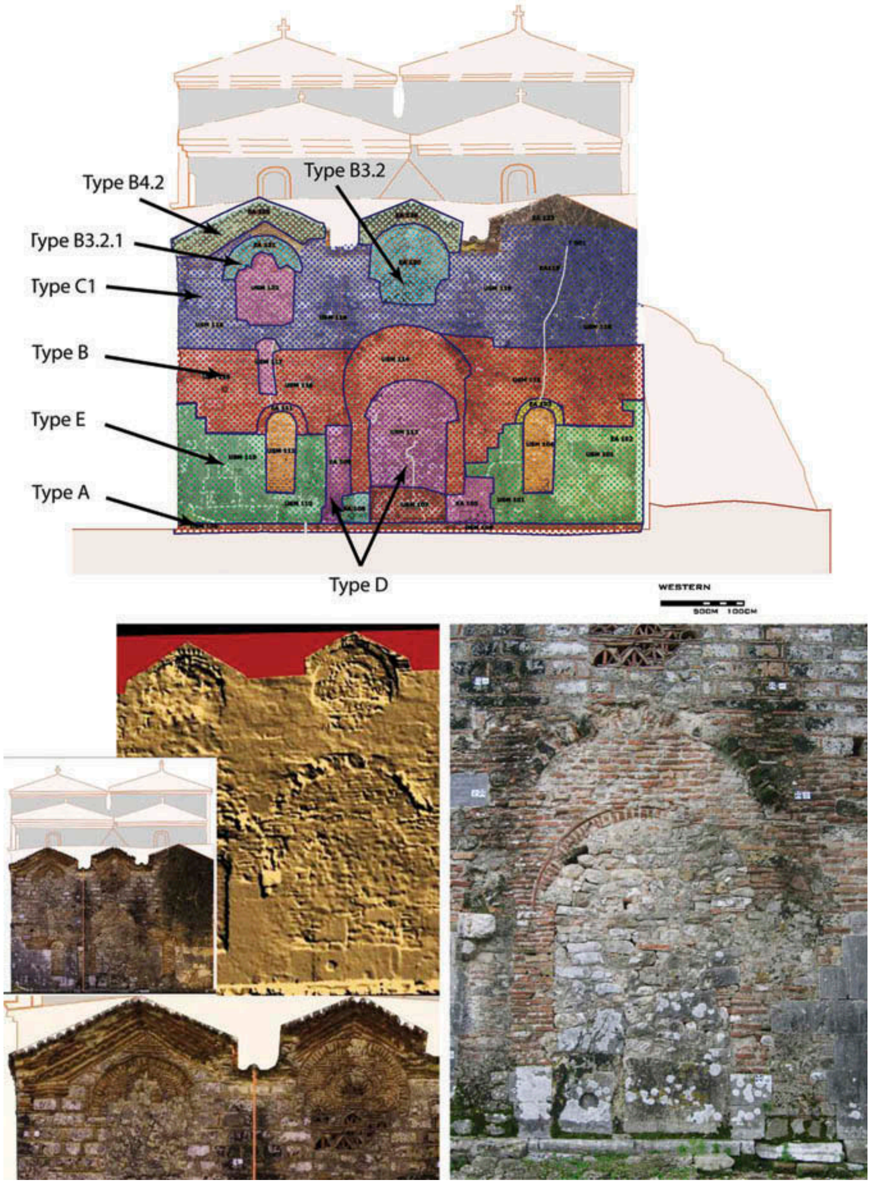


Figure 6. (top) Illustration of masonry typologies georeferenced on 3D textured western facade. (center and bottom) The 3DGeoDB of the western wall object: the 3D texturized façade on the 3D Laser Scan model with the images block shows the footprint impression of the different chronological soils and stratigraphic units (see at the two opening closures at top), thus supporting the reading of all the traces, the decoding and interpreting by the stratigraphic analysis. (bottom right) A detail of the sealed access on the 3D façade object with other two US.

architectural decorations over the portals and windows of the church. It is found as "cloisonné" decoration (type B 3.2 and B 3.2.1), and in the frames under the external roof (type B 4). Numerous reconstructions of this masonry, identified with type B 3.1.2 (reconstruction of the arches) and B 3.2.2 (cloisonné repair), were detected. The upper part of the church

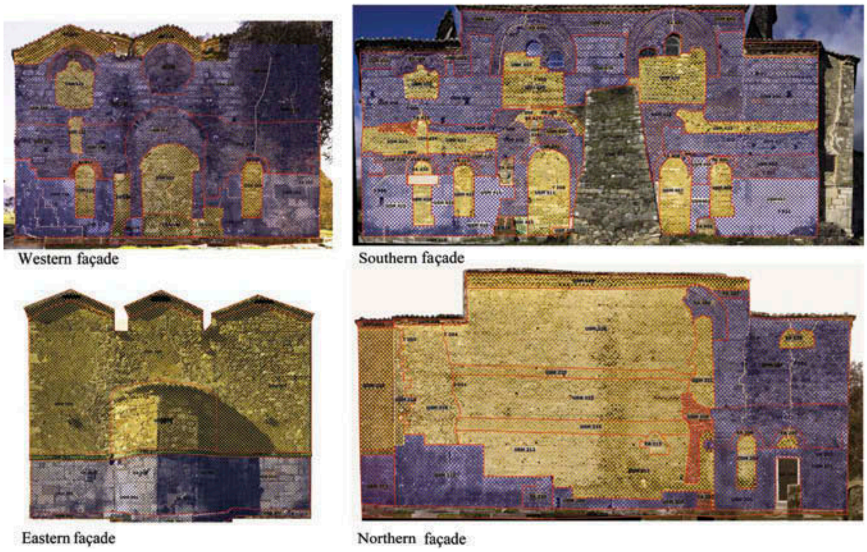


Figure 7. Illustration of the stratigraphic analysis of the walls. The GeoDB generated on the stratigraphic analysis allows to extract the synchronic and diachronic sequences of the hypothesized chronological soils and the transformation occurred during the centuries. The stratigraphic study of the walls: blue = masonry of 12th to 13th century; yellow = masonry of 16th to 17th century.

is made with the masonry called "brick cage" containing tuff-stones[4] (Type C). It shows regular courses characterized by the use of mortar joints. It can be found practically in all the prospects of the church above the type B masonry (Figures 5-7).

Masonry Type D is related to the past restoration activities of the church. It's an irregular restored masonry with irregular stones, wedges, and a large use of mortar. This masonry was used to close openings mostly in the Southern (Figures 4-5) and Western (Figure 6) prospects. Some courses of this masonry can be found also in the Eastern prospect of the church, due to the reconstruction of the apse after its collapse (Figure 7).

Two particular kinds of masonries were identified: Type E is not a real masonry, but it can be found at various spots where the remains of the collapsed porch appear. This type clearly shows the ruins of the stone vaults in the Northern prospect. A subtype of this masonry, related to the porch (E 2), identifies holes in the masonry mostly in the Western and Northern prospects of the church (Figure 7).

Type 0 identifies the *spolia* present on the walls of the church. As in the previous case, this is not a real masonry, but its special features can be observed on the church prospects. It also provides an important timeline to identify the historical sequences of the site, where ancient settlements are yet to be investigated. All these masonry typologies are related to the architectural models of Epirus and Albanian medieval architecture, as in Byzantine architecture, where they were commonly used separately. As a matter of fact, Type A with large blocks of limestone can be found at Saint Stephan's church in Skoder, as well as in the Byzantine church of Apollonia.

[4]The upper windows are identified as AE 119, 120, 121, and AE 121.

It is worth noting that there are many examples in the Byzantine architecture of carved *cotto* ornaments and brick frames used for narrow windows and doors, mostly in the 12th and 14th centuries (Osterhout 1999). These elements were present in the Northern Greek and Epirus area. Similarly, there are many examples in Byzantine architecture of Type C. Comparisons can be made with the Greek churches of Paregoretissa in Arta, Katholikon in Dafni, and Nesebar in the Bulgarian region. This solution, however, was mostly present in Albania. Near Mesopotam, in the district of Butrint, the ruins of a medieval church were identified of which only the apse, that shows a "brick cage" masonry, survived. This type of masonry (Type C), and also Type B (brick masonry with thick mortar joints) can be found in other churches, such as the great medieval basilica of Butrint, or in the Holy Trinity of Berat, which is the most outstanding example of this architecture (Figure 8).

6.3. Stratigraphy of Saint Nicholas Walls

The stratigraphic study of the walls of the Church allowed researchers to detect three special elements: (i) the ruins of the porch, (ii) the occlusion of original portals and narrow windows, and (iii) the sequence of different masonries. The presence of paving stones inserted into the masonry of the Church (type 0.3.1) is visible on the Western prospect of the church. The main portal was closed using this masonry type, and there are many examples also on the Eastern lateral prospect of the church, related to the collapse of the apse. This masonry type allows one to detect two events that can be related to different historical phases: the collapse or demolition of the porch and the closure of the main openings of the church.

The ruins of the porch are very clearly visible on the Northern prospect of the church, in the area adjacent to the facade. These remains show a masonry characterized by regular

Figure 8. Photograph of SS. Trinity of Berat.

courses of bricks with thick mortar joints (Type E1) in the Northern and Western facades.[5] In the Southern wall, this masonry is visible in USM 421, and was probably an earlier detail added to the external chapel, which did not allow the access to the church. The presence of the porch is visible at different spots in the masonry (Type E2) related to type E 1, and by the ruins of the vaults located along the walls of the church.[6]

6.3.1. Opening closures The church is characterized by many opening closures that were punctually investigated. On the Western facade, the openings identified as USM 104, 112, and 113 were closed. USM 113 was the main access to the church, now closed (Figure 6), while the others were not entrances to the church, but simple openings in the facade with three arches. The masonry used for the filling of the arches is rather rough and, inside the church, it is possible to see a rough closure with filling material. Along this prospect, the upper windows[7] have been closed, showing a rough masonry,[8] while EA 120 shows decorative "cloisonnè" bricks (Type B 3.2.1) observed also on the original openings. Inside the church,[9] there are little niches, while the EA 121 is also closed.

On the wall of the Northern prospect, only two openings[10] in the lower part have been identified (Figure 7): the slightly arched door that, after the restoration of 1700, is the only access to the church, and the one filled by rough masonry. Inside the church, a pillar supporting the dome hides this opening. This pillar was certainly built after the construction of the church. In this part of the church, along the Eastern side near the apse, it is possible to observe a little niche completely occluded by rough masonry. In the upper part of this external wall, small details of the original window still survive.[11] This masonry is identified as Type B 3.2.1.

On the Southern prospect (Figures 4 and 5), the occluded openings were identified.[12] Inside the church there is a fragment of fresco,[13] where in the past there was an entrance to the church.[14] Only two occluded openings can be considered real entrances to the church, while the others[15] are arched doors already found in the Western and Northern external facade of the wall (Figures 6 and 7). In the upper part, there are three openings, all occluded,[16] and these windows are also visible from the internal side.

On the wall of the Eastern prospect, there are no visible remains of the openings.

6.3.2. Discussion about sealed openings By mapping all the walls of the church, and relating external and internal walls, it is possible to observe certain typical elements. The architecture of the church was originally characterized by a sequence of portals and doors with slightly arched and narrow windows. This sequence is clearly visible on the

[5]USM 122.
[6]EA 119 and 120.
[7]EA 203 and EA 206 (identified as USM 2040.
[8]EA 260.
[9]EA 404 (USM 404), EA 408 (USM 407), EA 412 (USM 411), EA 418 (USM 417), EA 420 (USM 419).
[10]Near USM 411.
[11]EA 412.
[12]Respectively EA 408, EA 412 and EA 404, EA 418, EA 420.
[13]These occluded openings are identified as EA 443, occluded by USM 437, EA 445, occluded by USM 447, and EA 449, occluded by USM 450.
[14]USM 113
[15]USM 214, EA 408, EA 412.
[16]USM 409.

Western and Southern walls; on the Northern side, however, it is barely visible, and not at all visible on the Eastern one. It is possible to see openings with ogival arches in the middle part of the Western prospect,[17] as well as in the middle parts of the Northern and Southern prospects.[18] In the Southern prospect, there is probably another access to the church hidden by a buttress;[19] there are also smaller openings on the same prospect.[20] This system of architectural elements is also visible from the internal prospects of the church, and it is related to the porch (Western and Northern wall) and to the chapels (Southern wall). Through these findings it is possible to assume that the porch was an original structure, probably destroyed between the 15th and 18th centuries, and that the chapels were therefore added later to the church.

6.4. Historical Sequences of Masonry Typologies and Considerations

The GeoDB allows one to filter the diachronic and synchronic unit sequences of the hypothesized chronological phases and the transformation that occurred across the walls and their facades (Figure 7). Types are to be considered the different construction typologies above described, while the subtypes made by the different layers of the masonry belong to different phases.

- 17th century (Figure 7): This is the original phase of the church: three layers of masonry belong to this phase. Type A, with subtypes A1.1, A1.2, and A1.3, is located in the lower part of the church.[21] There are a second[22] and a third[23] type of this masonry in the Northern, Southern, and Western part of the church, one used as a decoration "a cloisonné" (Type B 3.2.1) of the narrow windows and the other is the so-called "brick cage" (Type C).
- Reconstructions of 16th-17th century (Figure 7): After several earthquakes, a number of reconstructions of the church took place until 1700, when an internal central pillar

[17] EA 103 and EA 111 on the Western prospect, EA 205 and EA 206 on the Northern prospect, EA 404, EA 418 and EA 430 on the Southern prospect.

[18] Going into detail, Type A masonry can be found in the Western prospect, identified as USM 101 and USM 110, in the Northern prospect, identified by USM 201, USM 211 and USM 217, in the Southern prospect, identified by USM 401 and USM 415, and in the Eastern prospect, identified by USM 301 and USM 302. In the upper part there is a brick masonry (Type B), identified in the Western prospect by USM 114, USM 115 and USM 116; in the Northern prospect identified by USM 220; in the Southern prospect identified by USM 403, USM 423, USM 424, USM 428, USM 429; none in the Eastern prospect.

[19] This masonry is identified in the Western prospect by EA 120 and EA 121; in the Northern prospect by EA 260; in the Southern prospect by EA 443 and EA 445.

[20] Identified in the Western prospect by USM 118, in the Northern prospect by USM 224, in the Southern prospect by USM 436, USM 438, and USM 440.

[21] This is identified in the Eastern prospect by USM 309 and in the upper part of the apse by USM 308. In the Northern prospect, this masonry typology is identified in the part nearest to the apsidal area (USM 216, USM 218, USM 219).

[22] USM 113 and USM 122 on the Western prospect; USM 407, USM 411 and USM 437 on the Southern prospect.

[23] The Seminary "Albania e Adriatico Meridionale. Studi per la conservazione del patrimonio culturale (2006-2008)" coordinated by Prof. M. Boriani and G. Macchiarella has been held (November 23th 2011), at the Politecnico di Milano with the presence of Apollon Baçe (Cultural Heritage, Albania) all the international research groups involved and in collaboration with the Direzione Regionale per i Beni Culturali e Paesaggistici della Puglia e la Soprintendenza per i Beni Architettonici e per il Paesaggio per le province di Bari e Foggia, and supported by the Assessorato al Mediterraneo della Regione Puglia and by the Sezione Cultura dell'Ufficio UNESCO di Venezia (BRESCE).

to support the dome was built. Different typologies of masonry belong to this phase and are located in every prospect of the church. These masonry typologies are identified mostly on the Northern and Eastern prospects that were probably the most damaged by the earthquakes. Many different types of masonries can be observed: Type C 2.3, a "brick cage" characterized by large blocks of limestone corresponding to the original masonry, but clearly the result of restoration. This type is identified mostly on the Northern prospect.[24] This type shows also decorative brick herringbone. This type was an attempt to remake the original masonry identified with Type C 1. A number of masonry restorations are located on the Eastern prospect, while fewer on the Northern and the Western ones show irregular restored masonry, with irregular stones, wedges and a large use of mortar (Type D). This testifies to a single restoration made in the 17th century. In the Western and Southern prospects, this masonry typology was used to close the openings and to consolidate masonries damaged in the Southern prospect.

Final consideration on the transformation and the construction of chronological phases can be derived thanks to the integration of 3D photogrammetric/LS surveys and stratigraphic analysis.

The first interpretation of the structural damages, of the masonry typology analyses, and of the stratigraphic study of the walls shows that historical events have profoundly modified the appearance of this church. The building was originally inspired by models of Byzantine architecture, erected between the 12th and 13th centuries, and characterized by a peculiar central plan covered by four domes.

In the external part, there was originally a porch that was destroyed, most likely between the 15th and 17th centuries, by earthquakes that affected the area of Mesopotam. After these historical events, the church was restored during the 18th century. Many openings and accesses were occluded in the walls, and part of the apse that had collapsed was rebuilt. During these restorations, the same materials (limestone and brick) were used. It was only after masonry typology analyses and stratigraphic studies of the walls, however, that the differences became clear.

Finally, it is very important to underline that the presence of passing through cracks shows important structural damages, encouraging a multidisciplinary approach to understand the problems of conservation. The complexity of all the considerations made on the stratigraphic analysis required to develop from the laser scanner and photogrammetry surveys a suitable synthesis model inclusive of the knowledge information, in order to spatially correlate the richness of the masonry types and the chronological sublayers.

7. FROM LASER SCANNER DATA TO "INTERPRETIVE MODEL"

In the traditional survey, the spatial coordinates' determination of discrete points by means of total stations allowed one to obtain horizontal and vertical sections reconstructed through the punctual "selection" of the most relevant points surveyed along pre-determined directions. Such methodology was based on synthesis models obtained from an "a priori" schema, guiding the operator in the selection of the points to be acquired. Consequently, the representation process is quite static and forced, with a low degree of freedom.

[24]USM 113 and USM 122 on the Western prospect; USM 407, USM 411 and USM 437 on the Southern prospect.

On the other side, as already known, the LS technique allows the acquisition of millions of high-accuracy point clouds in a few minutes that can be geo-referred together, providing quick "global 3D cloud models" that allow a global overview of the site. It allows researchers to reduce on-site time and costs of human employment, and, at the same time, to postpone during the elaboration process the selection of the priorities, allowing them to orient the restitution and implement the access to the cloud DB, where necessary, with a dynamic selection as a function of the different purposes and needs. In this way, the survey representation guarantees a self-perpetuating knowledge process with an iterative approach able to receive the interdisciplinary contribution during the process itself.

The large number of points can be erroneously assumed to be a "conceptual model," giving the illusion of catching the "real" shape of the object and its contents, an immediate model (in the sense of un-intermediated) that does not need any collaborative action by the different scientific competences during the modeling process. Thus, during the research, little effort may be devoted to developing a useful interpretive model, including the decoding process (here the historical, stratigraphic, and structural analysis, but other contributions have been underlined as necessary to the process, such as geo-radar analysis, earthquake sequence information, and so on).

If those inputs are not included in the representing phase, the model obtained can be meaningless and unable to represent a useful level of the reality and the automatic reconstructive process can produce impractical models that do not achieve the potential of the methodology. As pointed out by the Information Society, too much data can imply "no data" in the sense of knowledge information: to avoid a useful softcopy of reality, it is necessary to strengthen conceptual schema in reading the artifact (and its elements) through interdisciplinary work enhancing representation methodologies, enhancing decoding methodology based on the strict relation between geometries and the adopted construction technologies, and on the interdisciplinary contributions.

Moreover, given the acquisition technology, LS does not capture the points that belong exactly to one vertex or to a certain profile or edge, nor all the points necessary to simplify the reality. In fact, the surveyed points are a function of a range angle set up by the operator and, consequently, they do not immediately represent a schematized reality. It is expected that a single surveyed point covers an area "around" the exact vertex position to be determined: thus, it is not possible to define the exact position of vertexes without an "interpretative selection." Interpolation algorithms, different levels of simplification and schematization, as a function of the reality and of the purposes, can help the process of recognizing complex shapes and surfaces, planes, circumferences, spherical morphologies, and so on. Automatic mesh generation that excludes the interpretation phase is barely useful for investigation purposes, as it does not allow one to refine the models obtained in this way. In the C.H. domain, virtual soft copies of the reality are to be avoided, as they reduce the potential of surveying disciplines to a pure representation, without providing contribution to any interdisciplinary interpretation.

The following sections illustrate different interpretive models, collected in a 3D GeoDB elaborated as a function of purposes, characteristics, and objectives defined by the research project. LS has been addressed to: i) methodologically support the geometrical analysis; ii) give macro preliminary elements to orient the monitoring phase; and iii) eventually provide a basis for the control of changes of the crack pattern over time, strictly connected to the monitoring. In fact, a traditional monitoring system has been installed on-site, which is easily managed by local skills.

7.1. "Oriented Profile Models" For Geometry Reconstruction: The Interpretation of Architecture, Structural Elements, and Materials

In order to generate a global model of the whole complex, all the scans acquired by the different positions were connected through target points and natural tie points and geo-referenced to the geodetic network, in a unique global reference system through a GPS survey (Figure 3). A GeoDB of all the internal and external coordinate points was obtained, with the exception of the extrados of the tholobate domes and of the roofs due to the inaccessibility of the top of the church (lack of scaffolding and elevation structures) and due to a partial lack of visibility by the LS station points.

To extract horizontal and vertical profiles from the GeoDB, the data processing was based on the reconstruction of the geometry, obtained by a local interpretation of the specific strongly irregular shapes, and of all the elements that characterize the building. To give an exhaustive representation of the geometrical characteristics, multiple slices were extracted on a dense distribution of the internal and external point clouds (1÷2 cm), along predetermined directions, selected in cooperation between the survey experts and the other colleagues with structural competences.

The continuity of the profiles was reconstructed through a careful examination locally based on the analysis of the architectural elements, on the discontinuities, on the recognition of the structural and decorative parts, and on the complex stratigraphic unit sequence, strictly relating the stratigraphic unit mapped on the orthoimages to the LS profiles. Each discontinuity on the masonry has been punctually related to the stratigraphic unit.

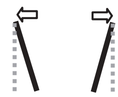
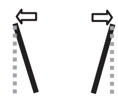
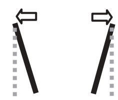
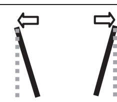
To the reconstruction process, obtained by merging geometric and thematic information, was given the name of "profile-oriented models." In some cases, to reconstruct the discontinuity lines (hard and soft break-lines) along the edges or corners (architectural frames, openings, opening closures, pilasters, friezes, US, etc.), LS data were integrated with the photogrammetric survey for the break-line extraction and object recognition, obtaining a better interpretation of the structure (Figures 9 and 10).

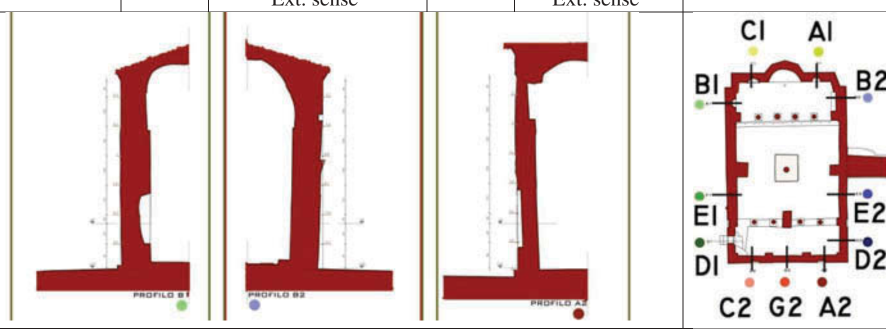
In the simplification and schematization of the building model, it was necessary to take into account not only the scale of representation but also the characteristics of the construction materials used (stone, plaster, stucco, wood, masonry types, etc.) and the irregularity of the surface finishing (e.g., the past interventions or patches applied to some elements). It was therefore necessary to evaluate, on a case-by-case basis, how to interpolate the selected points to generate complex surfaces or to simplify almost regular planes to ensure they would be constructively sustainable and congruent. This interpolation was done to avoid any misleading of the geometric support for the further analysis to be carried out on the structure. Geometric anomalies and discontinuities have been represented on the sections and on the 3D synthesis model. All the sections were made available from the different research groups involved.

7.2. From the Profiles to the Structural Model

On the basis of horizontal and vertical sections, local out of plumb and verticality analyses have been reconstructed for each important profile along transversal and longitudinal directions, considering the wall structure and excluding the overhanging masonry frames. To understand the structural behavior, the multiple cross sections were correlated one to the other within a 3D model. All the "out of plumb" parts of the building, more affected by cracks and geometrical or constructive anomalies (e.g., different thickness and

Table 1. Summary of the minimum-maximum out-of-plumb values along profile directions at the top and bottom level within a homogeneous profile interval, showing a general geometric outward location. Below: internal and external vertical sections along pre-defined directions.

Height (m)	Profile	Vertical deviation: out of plumb values (cm)	Profile	Vertical deviation: out of plumb values (cm)	Geometric Schema Profile
0.00÷0.80 6.40~	**B1** ⇦	2.6 0.4 Ext. sense	**B2** ⇨	13.7 0.2 Ext. sense	
0.00÷0.80 6.40~	**A2** ⇦	4.0 2.0 5.0 3.0 Ext. sense	**A1** ⇨	9.2 1.6 Ext. sense	
0.00÷0.80 6.40~	**E1** ⇦	6.0 9.0 0.0 Ext. sense	**E2** ⇨	10.0 9.0 0.0 Ext. sense	
0.00÷0.80 7.0~	**C2** ⇦	13.8 3.6 0.0 Ext. sense	**C1** ⇨	9.2 2.0 0.0 Ext. sense	



shape of the masonry elements) were extracted for this purpose. Some important considerations on the general behavior were deduced from these sequences. The values obtained were compared along an ideal line collected at one meter from the ground, along the whole height of the wall, to obtain the direction assumed by the vertical walls. All the out of plumbs were summarized in a descriptive synthetic table (Table 1), highlighting an outward rotation trend of the top of the structure with respect to the bottom, with values different from those at the position of the vault elements, which were the ones most damaged.

7.3. Interdisciplinary Morphological/Constructive Models to Decode the Complex History of Saint Nicholas

A morphological 3D model was developed to dynamically decode the complex history of this artifact (Figure 9), by integrating the horizontal section (plan) with the vertical profiles along specific multiple directions. The 3D model was then progressively oriented to the interpretation of the constructive model, as a key to the historic interpretation of this

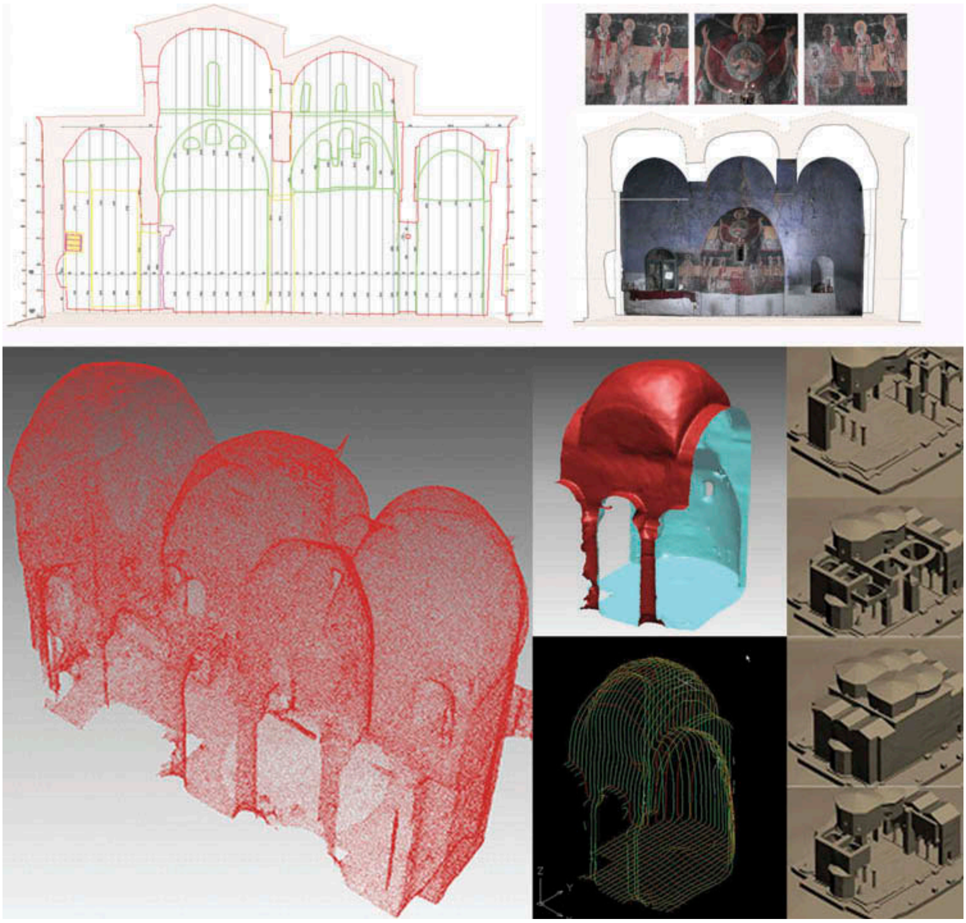


Figure 9. (top left) Illustration of longitudinal section with the dimension of the out of plumbs of the external walls indicated. (top right) Rendering of the transversal section with the orthoimage of the apsidal front. The sections have been obtained with the punctual integration of the breakline and the interpretation of the structure, materials, elements and discontinuities, helping the stratigraphic analysis and using their result to refine the model with an iterative process. (bottom left) The points cloud vault model of the narthex. (bottom center) The first rough 3D models and automatic extraction of un-decoded sections from 3D mesh. (bottom, right) The three-dimensional simplified model of the church.

architecture through the interdisciplinary contributions. The geometric survey enabled the researchers to reproduce the present morphological shape of the church, which is a result of the stratified interventions and changes from its original conformation.

As demonstrated also by the investigations made 40 years ago (Meksi 1972), the ancient plan of the church was formed by a unique nave (naòs) covered by four domes, filtered by two colonnades made up by four columns each. The original plan was characterized by two apses instead of the unique apse visible today: traces of the two previous apses are visible outside the church. During the restoration carried out in the 18^{th} century, after an earthquake, the two apses were replaced by a unique central apse, probably in the attempt to preserve the external aspect of the four-edge polygon and the basement with large regular stones. A large block of masonry as the remains of one apse is still lying on the floor behind the church.

The survey reconstruction of the actual state of the plan (Figure 10) shows a rectangular shape of 22 × 36 m, with three main areas well distinguished: in the center there is the naòs, covered by four domes; adjacent to the naòs are two areas corresponding to the inner narthex (at the west side), and to the bema (east side toward the apses); they are separated from the central area by two transversal elements, made by five arches on four columns, with the central arch at the west side raised with respect to the others. To improve the structural comprehension, each area was analyzed and represented with the models of the single constructive elements (e.g., continuous wall-object, punctual elements, vault system) (Figure 9).

The surveys here carried out hallowed us to highlight that the structure of Saint Nicholas represents a unique schema in the history of Byzantine architecture, both for the plan organization and for the complex spatial system sustaining the domes with the central column/pillar, the lateral columns and the continuous walls, that needs to be more thoroughly investigated in the future.

The four domes of the central areas rest on pillars built in the walls, and, at the center, on a massive pillar, probably built during the 18th century, after several devastating earthquakes: this pillar has been created by incorporating the original circular column, to avoid the collapse of the vault system and of the whole structure surrounding the original column, which most probably had a too-small dimension. The dimension appears similar to the other narthex columns in the church, as demonstrated thanks to the little hole (10 × 10 cm) made in the pillar, clearly visible on the results of the laser scanner survey (Figure 10).

This ambitious structure of the four domes on a unique column was probably too unstable to resist an earthquake: a masonry buttress was leaning toward the longitudinal south wall, so as to "work" with the central pillar to support the whole vault system and to limit the structural support of the domes and their thrusts. The structural schema appeared very slender and ambitious with respect to the seismicity of the area. On each dome, eight windows had been opened, but most of them are now closed, perhaps to increase the stiffness of the structure to resist earthquake damage, as well as the partially closed trefoils, which can be noticed on the facades: some of them are still visible, in particular in the south, west, and north facades (Figures 6 and 7). In the upper part of the east and west facades, it is possible to observe the six gables of the three cupolas that lay underneath. In fact, externally the volume of the building is composed of three parts with three different heights: the two lower bodies of the domes narthexes (west, east), and four higher domes in the middle. Inside the church, there is a perception that the space is gradually rising from the inner narthex to the altar, as shown in the longitudinal section (Figure 9). The four domes have different heights: two domes near the apse (Figure 10, Domes 1 and 3) are higher than the ones near the west narthex (Figure 10, Domes 2 and 4). Given such complexity, the modeling process has been focused on the dome study.

8. GEOMETRICAL INVESTIGATION FOR THE CONSTRUCTIVE AND STRUCTURAL ANALYSIS OF THE DOMES

The complex spatial organization of the Saint Nicholas domes represents the core of the "unicum" schema in Byzantine architecture. Hence the investigation focused on geometric, construction, and structural analysis to gain elements for the comprehension of their history and behavior to address sustainable conservation actions. The four domes that cover

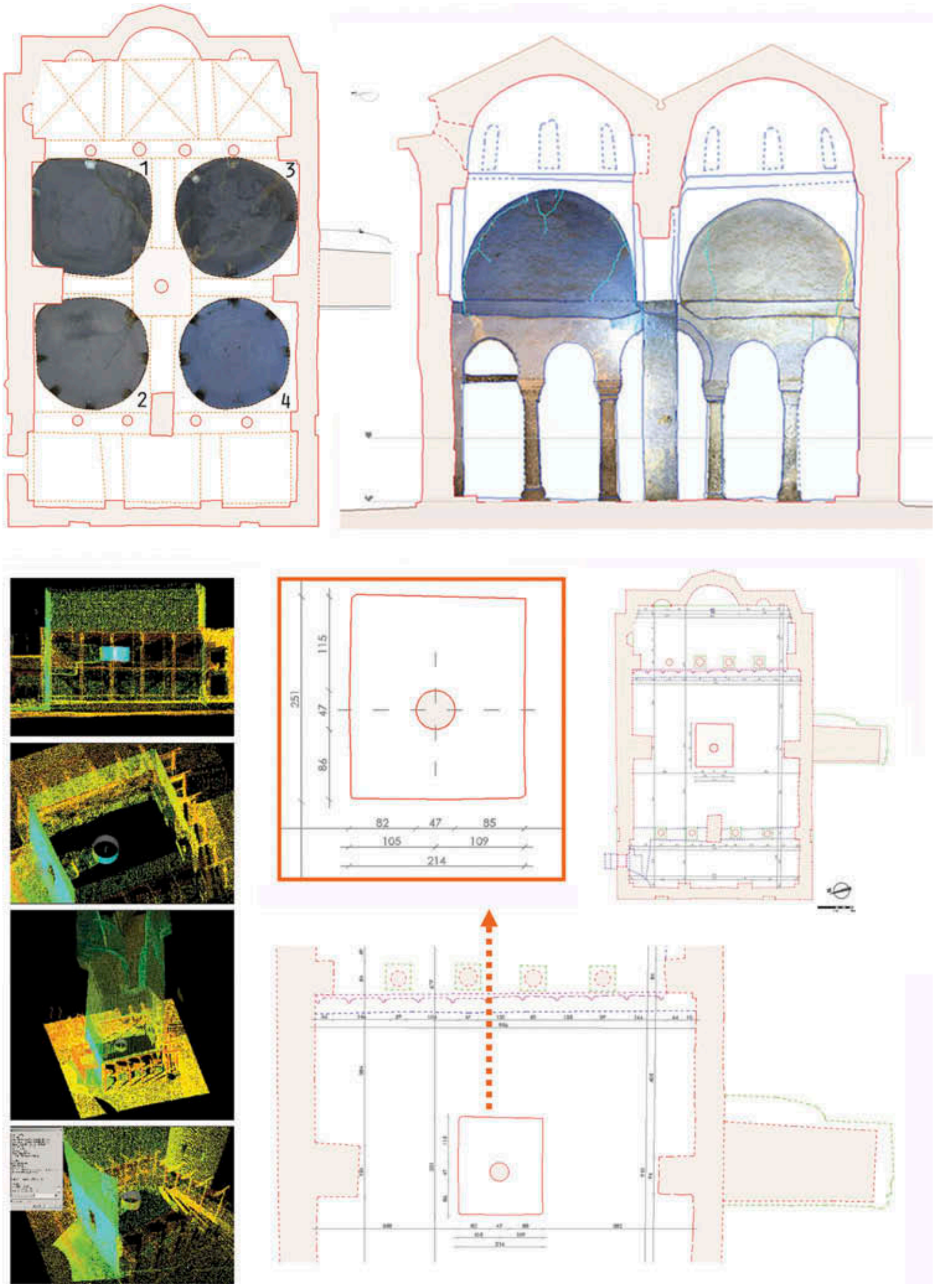


Figure 10. (top left) Plan of the global complex structure of San Nicolas with the orthoimages of the domes and the irregular shapes. (right) Plan of the transversal section in correspondence of Dome 1 and 3, with the double domes system, and the complex structural spatial system of relationship of the two masonry arches at the level of the tambour and of the five arches of the narthex on the columns, with the higher central arch. (bottom left) 3D points cloud views and plan of the central pillar: the survey allowed to identify the shape of the central column inside the pillar, built around to redistribute the weights from the four domes system.

the central naòs present irregular differentiated geometry, with visible deformations and cracks. The historical-archival investigations and the comparison with the present geometry allow only the formulation of hypotheses. Little is known regarding the construction techniques and the thickness of the vaults. Furthermore, the four domes are covered at the intrados with very cracked plaster, which does not allow to evaluate the texture and the materials used for the construction apart from a portion of the brick texture. So the impossibility of inspecting the extrados of the domes, and thus of measuring the thickness, made it necessary to pay special attention to the geometric survey of the intrados.

To describe the complex geometry of the intrados of the four domes, a 3D model was reconstructed from the LS point clouds. Four radial slices were automatically extracted along the predetermined main directions (0°-45°-90°-135°, with 0° being the North-South). Each profile was reconstructed, thus allowing us to interpret the different morphological shapes of each dome. A function of interpolation (least square interpolation) was applied to the vertical and horizontal sections, and to geometrically analyze the shape of the domes: a linearized semi-circumference function was interpolated on the surveyed points. A circumference interpolating algorithm was implemented within a software that allowed us to insert the surveyed point coordinates belonging to each slice. The result is the calculation of the interpolated circumference parameters (center, radius), along the horizontal and vertical profiles extracted and the calculation of the keystone of the dome. The process allowed us to understand the current state of art of the physical shape, to filter the anomalies with respect to an ideal shape of construction and to different construction typologies employed during the centuries.

The deviation between the surveyed points and the ideal curve hypothesized has given precious information about the construction age, the state of damage, and the changes in the domes: Figure 10 shows the results obtained for the geometric analysis of the domes on the horizontal projection (Dome 1, 2, 3, 4), while Figure 11 shows the compared results of Domes 3 and 1. In particular, the southeast (SE) Dome 3 (Figure 11, upper left and center left), together with the southwest (SW) Dome 4 (Figure 11, top right and center right) can be inscribed into a hemisphere, and both of them are characterized by a "perfect" semicircular section, highlighting the advanced construction skill of the ancient builder. These two domes (3 and 4) are characterized by different geometric anomalies with respect to an ideal geometrical shape, well approximated by an hemisphere. Dome 4 is more regular than is Dome 3, of which the irregularities could be attributed to the crashes near the altar during an earthquake.

The model of each dome, characterized by few discontinuities, was obtained by integrating the break-lines along the springer and the base line of the windows (Figure 10), beginning from the profiles previously reconstructed. Having an accurate 3D model of the intrados surface of the domes allowed us to perform complex geometrical analyses: the recognition of their generative source was accomplished to presume their original shape.

Regarding the elaboration phases, the modeling phase of morphologic analysis, point cloud filtering, profile integration, triangulation and mesh generation, and 3D final models was processed with Rapidform XO64). Such 3D models were texturized with the oriented image blocks, with the aim of providing to individual specialists a supplemental analysis tool, useful not only as a basis for thematic mapping, but offering also the possibility of visualizing the evolution of the cracks. On the 3D texturized dome model, crack maps were georeferenced by structural experts on diagnostic analysis.

Comparing the presumed shape of the vaults with the surveyed shapes, it was possible to highlight some areas characterized by abnormal shapes, flattening, settlement, or

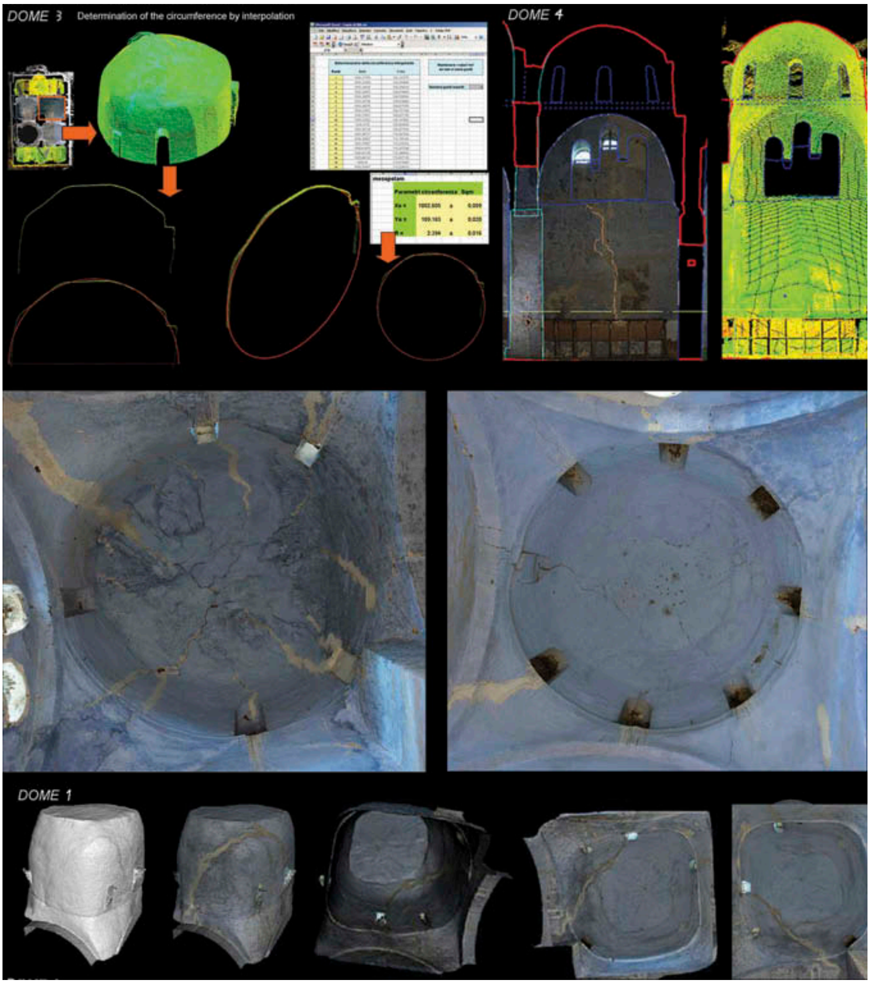


Figure 11. (top right and center) Illustration of Southeast Dome 3 and (top left) southwest Dome 4. The geometric analysis of the domes modeled on the points and the section extracted by the 3D model. The determination of the circumferences with statistic function (least square interpolation) is the result of the interpolation of the linearized analytical equation assumed, on the observations (surveyed points along the profiles): the shape of each correspondent dome and their differences, highlights the same spherical genesis, with a more irregularities, respect to the ideal circumference, that in the Dome 4. (bottom) N-E Dome 1: the 3D texturized dome model shows an evident large flattening surface at the top respect to the Domes 3 and 4.

other configuration that could suggest failure or degradation phenomena, past or on-going. Similarly, the better understanding of the areas affected by settlements, as shown in the case of the southeast (SE) dome, has led to the subsequent phase of the selection of areas to be further investigated by means of a diagnostic analysis of the structure. Furthermore, the investigation of the "generation curves" obtained from the vertical profile and "direction curves" along the base-line of single domes could also be useful to understand the possible construction techniques adopted for this type of dome during the Byzantine age.

The geometric analysis of the northeast Dome 1 (Figure 11) shows an evident large flattening surface at the top of the dome. Considering the typical skills of workers in the

18th century, it can probably be presumed that this part was built by the less skilled workers employed during the successive reconstruction phases, probably after the collapses that occurred during an earthquake. In fact, in the case of Dome 1 (Figure 11), the geometric analysis shows a clear degeneration of the top of the dome: the shape evolves from an arch to a plane surface, where the arch degenerates to its bowstring, evidencing the lack of skill of the workers. Processes of losing skills in the reconstruction of such complex vault system are typical of the decline periods and testify once more to the excellence of the construction, taking into account the complexity of the plan and the high spatial control reached by the workers.

Four high tholobates with an irregular octagonal plan are placed upon the four domes. The sequence of the double couple of the dome system transfers its weight on a couple of masonry arches at the level of the tholobate, along the two longitudinal walls (south and east), and along the two central lines on the column-pillar element; along the transversal direction, the domes are sustained by columned apertures of the five arches of the two narthexes leaning on the four columns: the two narthex areas have been covered by three hemispherical domes characterized by an irregular profile, detected by the laser scanner survey. The ones on the east narthex have suffered deeper rearrangements in the columns and at the cover, due to the collapse of the two original apses.

Unlike the symmetric vault system of the two narthex volumes, the particular asymmetric configuration of the central "*naòs*" volume is thought to be obtained through a sophisticated constructive control by the skilled workers, also in the capability to join two different spatial systems. The ambitious design of the church is demonstrated by the sophisticated central schema realized by highly skilled workers: in fact, to each dome of the central pairs of the "*naòs*" corresponds the three arches of the narthex wall (made by five arches), and with one dome within the narthex, and with the central dome of the narthex connecting all the lines of thrusts coming from the two lateral domes.

The complex constructive system allows one to match the centrality underlined by the higher arch of the narthex (with respect to the four lower narthex arches), both from the structural point of view and in terms of semantic spiritual meaning. At the same time, it combines the coupled pair domes of the central "*naòs*" with a three-dome/five-arch system with a masterful ability of dominating a sequence of odd and even elements. The result is that the two pairs of domes of the "*naòs*" and the three hemispherical domes of each narthex are "falsely" sustained by the four narthex columns (Figures 9 and 10): in fact, the columns are not directly corresponding to the line of force of the central domes and of the narthex domes, and consequently to the direction of the thrusts of the domes themselves, but wisely support this function. The support of each dome of the naòs is shared by the two columns of the corresponding second and fourth arch of the narthex, and the central arch of the narthex represents the point of equilibrium to ensure the proper connection between the opposite lines of thrusts coming from the adjacent pairs of domes. To strengthen the support to the domes on the arches of the narthex, a timber tie has been inserted within a capital of the external column, to readapt reused elements coming from different provinces.

The morphological analysis can be further implemented within an interactive system to improve the knowledge of the constructive techniques of the domes, the historic context of the skilled workers involved, and the place of their origin intersecting the different competences here involved. At the same time, the lower skilled level of the subsequent intervention was sufficient to hold a new equilibrium able to read the complex spatial system within a complex geographic context characterized by the sequence of the earthquake: such equilibrium needs to be underlined and preserved as a piece of the history to better allow the conservation of the complex of Saint Nicholas as explained in the following chapters.

9. CRACK PATTERN SURVEY AND MONITORING

The interior and the exterior walls of the church show a diffused crack pattern that involves the facade, the apse and the longitudinal walls of the church, as well as the interior of the church (Figure 12a, b). The cracks continue also on the vaults (Figure 13) in a complex pattern, which could represent the symptom of a difficult situation for the overall stability of the building. It is rather difficult to interpret this kind of crack pattern, which is probably also due to past seismic events and seems to have been present for a long time. To develop a quantitative description of the evolution of the crack pattern, a grid of 19 points was set up (ASN1 to ASN19) where the crack opening was regularly monitored; to rule out the role of the thermal deformations, the temperature was monitored as well. Moreover, for the purpose of studying the structural behavior, the crack pattern was superimposed on the photogrammetric output, and a thematic geo-referenced map of the crack pattern was generated.

Through the aforementioned stratigraphic analyses, certain fissures and cracks in the masonry assume great significance, particularly those found during the investigation on the building structure. Those taken into consideration and referred to as “discontinuities” of the masonry are fissures and cracks located in the external wall of the church, but clearly corresponding also to those visible inside the church. Following is a detailed description of the cracks on the different parts of the structure:

9.1. Western Prospect

C 001 is located near the openings identified by EA 104, in the lower part of the wall, and by EA 119. This crack is visible also from the internal prospect, and is caused by the rotation of the Southern prospect.

9.2. Northern Prospect

On this prospect, there are four cracks. Two (C 002 and C 003) are located in the area corresponding to the Western internal narthex. C 002 is caused by the rotation of the Western facade or by the opening of the access to the church. C 003, on the contrary, is

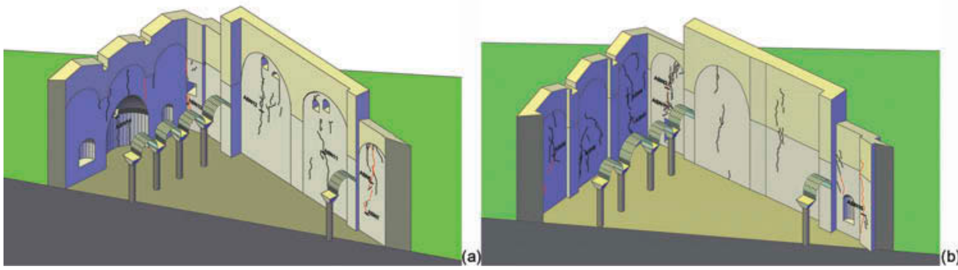


Figure 12. Rendering of the surveyed crack pattern on the base of the 3D texturized surface of the vertical wall: (a) northeast and southwest side; (b) northwest and southeast side.

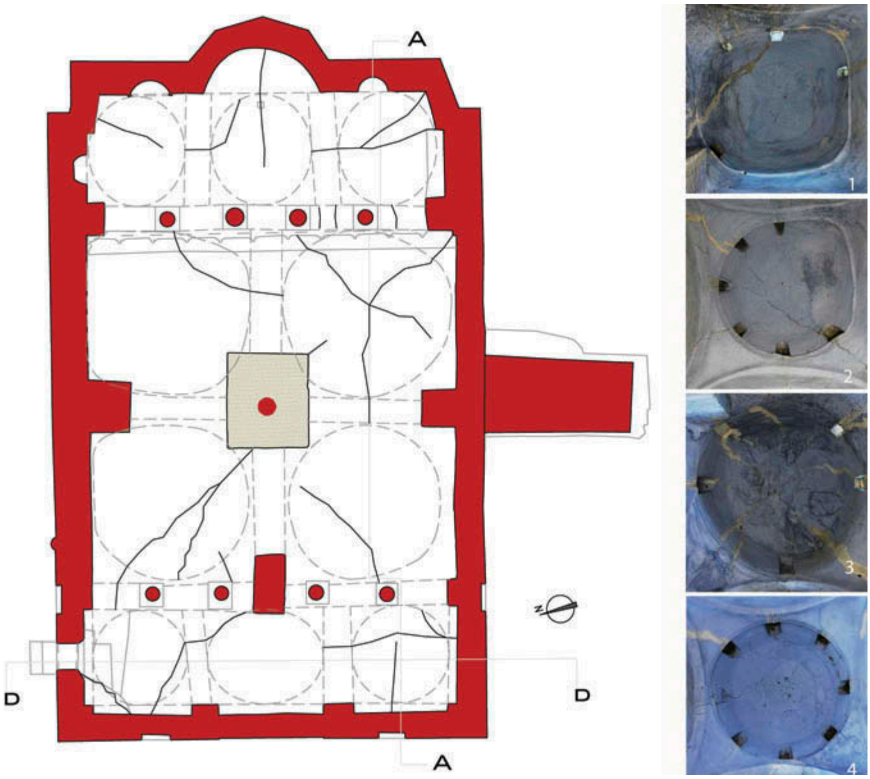


Figure 13. (left) Illustration of the surveyed crack pattern of the vault system, and (right) on the base of the 3D texturized domes. Bottom left 1, right 2. Top left 3, right 4.

caused by a local masonry crack, and on the internal prospect it is blinded by a pillar built as a buttress for the edification of one of the domes. Cracks 003 and 004 are caused by the restoration described when USM 212, USM 215, USM 222, USM 223, and USM 228 were mentioned. It is very interesting to underline how these cracks on the internal prospect are dissimulated by the great pillars that support the domes. On the contrary, C 005 is caused by a detachment of this prospect from the Eastern prospect, and then by a dissection and torsion of this prospect.

9.3. Southern Prospect

On the Southern prospect, there are a great number of fissures and cracks in the masonry, largely because this part of the church has suffered the most significant damage over the centuries. This part of the church, however, was not rebuilt, as was the case for the Northern prospect, and therefore it shows fissures and out of plumb sections corresponding to the rotation of the church walls. It is for this reason that we refer to C 006 located in the Western part of this prospect near the openings identified by EA 430 in the lower part, and by EA 449, in the upper part. Also clear is the out of plumb section corresponding to C 007 near EA 445. This is a crack in the masonry structure, for which it was necessary to restore part of the masonry (identified by USM 447) of the upper window. This fissure continues down and divides itself with C 008 and C 009, ending on USM 411, which occluded the lower access to the church. This fact implies that the fissure was born after the occlusion of this access.

Similarly, C010 is a crack caused by the collapse of the apse and the consequent weakening of a number of other structures. Inside the church, this fissure has been hidden by a buttress for the edification of a dome. Instead, in the Eastern part of prospect, the deep fissure C012 is clearly visible in the external and internal part and was caused by the collapse of the apse.

9.4. Eastern Prospect

On this prospect, there are no fissures caused by cracked masonry and rotation but only thin cracks caused by restoration.

9.5. Comments on the Results

Before deciding on any restoration intervention technique, it was necessary to collect information on the history of the area and of the building and especially to study the movements of the cracks over a rather long time. Due to the impossibility of reaching the vaults, given 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 14a), the position of the measurement bases are reported. As mentioned above, the crack monitoring was carried out continuously each month from the end of November 2007 until the end of June 2009, with a six-month interruption from the beginning of June 2008 until the beginning of December 2008.

Figures 14b and 15a, b show the diagrams corresponding to the measurements carried out, together with the temperature variation. A positive value of the displacement corresponds to opening of the crack. From Figure 15a, it is possible to see that cracks ASN2, ASN3, ASN6, ASN8, ASN9, and ASN10 are not completely stable. From Figure 15b, it is plain to see that cracks ASN15, ASN16, and ASN17 are not stable. In detail, the movement of ASN17 counteracts those of ASN15, ASN8, ASN1, and ASN2.

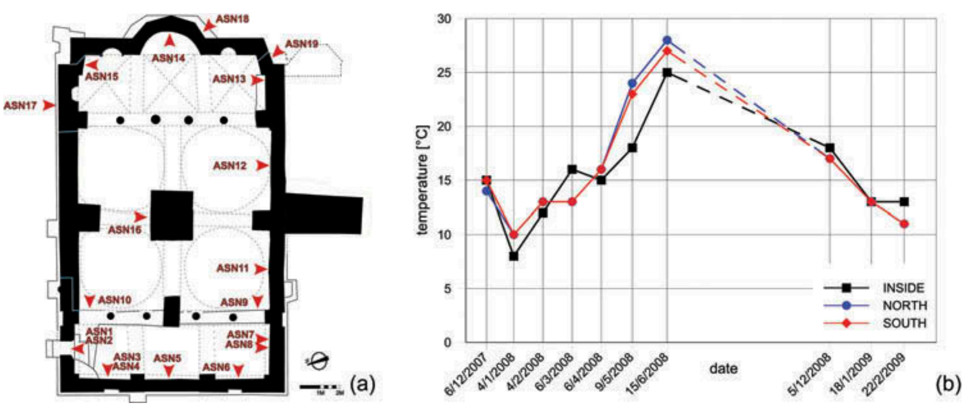


Figure 14. (a) Diagram of positioning of the measurement bases. (b) Graph of temperature variation along the measurement times.

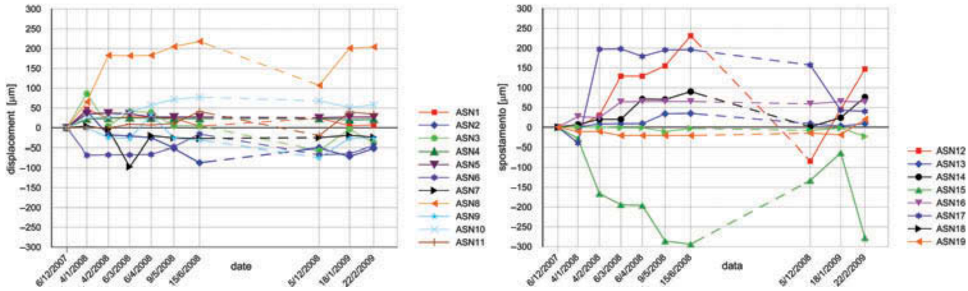


Figure 15. Graphs of the monitoring displacement along the time from first measurement.

10. SURVEYS, HISTORICAL HYPOTHESIS, AND FURTHER ANALYSIS

The results of the research are strictly related to the knowledge of the geometry, of the structural behavior, and of the construction techniques through the centuries: all together they have better clarified the spatial–temporal context of architectural typologies, and of the hypothesis made by the historians who are relating the complex of Mesopotam with the fall of Constantinople (1204). The actions of the two patriarchs of Serbia and of the Epirus-Bulgarian region, in exile at Nicaea, the strategic Epirus area, probably justify the provenance of skilled workers from those areas and the ambitious structure realized on the complex dome spatial system.

The surveys have highlighted an extraordinary plan and spatial organization within the Byzantine scheme of the church, generally characterized by one unique central dome or by five domes on the center Greek cross plan, with lateral chapels. The internal space of Saint Nicholas represents a variation of this geometrical scheme, due to the four central domes. The central column of the four domes is aligned along the axis of the central arch of the columned apertures and with the hypothetic pre-existing two apses, thus transforming this centralized space also in a longitudinal perspective. The historians are working on the hypothesis that such original structure and uniqueness–integrated by a richness of symbolism of the decorative apparatus of the alt-reliefs with animals and natural symbols-is justified, if this monastery was considered as one intellectual center of the religious awakening of the orthodox interpretation after the traumatic event of 1204 and the affirmation of the local church of the Bulgarian-Epirus region. Through a daring architectural project with an aristocratic matrix, this church seems to be an attempt at offering a common house to the two patriarchates: the one in Constantinople, in exile at Nicaea, and the one of Ocrida (Macchiarella 2011).

The Church of Saint Nicholas at Mesopotam witnessed several transformations, as well as a complex sequence of wall typologies, with different material types, such as stones (lithotype) and bricks. These different masonry construction techniques have been derived from Byzantine times and from historical events, which marked the shape and structure of Saint Nicholas. The geometric and thematic survey highlighted different skills employed in the different phases of the construction and of interventions, supporting the historical hypothesis, that need to be further investigated.

Different obstacles have to be overcome to plan the continuation of the research in such direction. The physical inspection of the extrados of the vaults is necessary to understand the arrangement and construction techniques: it has been planned in the last campaign through an aperture from the tholobate, but has been postponed until the realization of a scaffolding.

On the basis of the results, further on-site surveys have been planned to acquire geometric information on the roof and inside the tholobates on the extrados surface. The photogrammetric images block implementation in areas critical or dangerous to access due to their structural instability, such as the one here considered, and need new sustainable survey techniques: hence the research group is planning, for the next campaign, the use of experimental ultra-light indoor and outdoor micro-unmanned aerial vehicles (micro-UAVs) equipped with image-based sensors (Barazzetti et al. 2010), integrated with light thermal cameras (Flir TAU1, resolution 640x480). The testing of this equipment is currently ongoing in similar fields of inspection. The aim is the further investigation of the construction techniques and inspection of the texture of the extrados: they are expected to give important information about the thickness of the domes, the brick order, their direction, and their arrangement (herringbone texture or parallel rows), as well as on the dimension of the mortar joints devoted to generate a structural object model on the vault system.

Unfortunately, the planned campaigns are nowadays impossible, due to the hazardous "restoration" realized in 2009–2012, without considering the result of the research: the removing of the central pillar to highlight the original covered column and of the buttress of southern facade are putting the monument at risk of collapse, forcing the monument to be closed to the public, at the moment, as underlined by the Seminary held to discuss the results.

11. RESULTS AND DISCUSSION

The virtual model of the Saint Nicholas complex, based on a geometric 3D model integrated by metric images and by thematic mapping, has been conceived to be shared by different users and specialists. This case demonstrates that an added value can be gained by integrating the interdisciplinary competences and data sharing during the on-site surveys and orienting the data processing of each other. To strengthen the data distribution, all the drawings, sections, photogrammetric images, 3D LS point GeoDB, and models should be published as GeoData within an on-line geoportal. In the domain of communication, regarding architectural heritage there is a lack of web services for the dissemination of geometric and thematic data that can represent a barrier in the full employment of the result obtained, limiting the international and in this case the national debates, before the decision making and intervention. To dynamically sustain life cycle management (LCM) of monuments, an SDI must be developed that can be implemented with specific architectural and archaeological requirements, corresponding to the geographic territorial and urban domain.

From the results of the monitoring collected up to now, and from the elaboration of the laser scanner survey, the tendency of the facade and of the apse to rotate out of plane around the passing through existing cracks seems to be confirmed (Figure 16). The out-of-plumb sections of the facade and of the apse, measured by the laser scanner survey, are also shown. The results seem to validate the interpretation provided by the monitoring of the cracks for 18 months.

The movement of the structure seems to be still active, with the mechanisms of the facade and apse moving out of plane that are typically caused by earthquakes. As a matter of fact, even though the damages could have been caused by a past earthquake (or also by soil settlements), a direct correlation between the observed crack pattern and past earthquake is hardly possible, because several interventions were carried out during the century. Other movements are visible on the longitudinal sides of the walls (north, south), but they seem to be more stable.

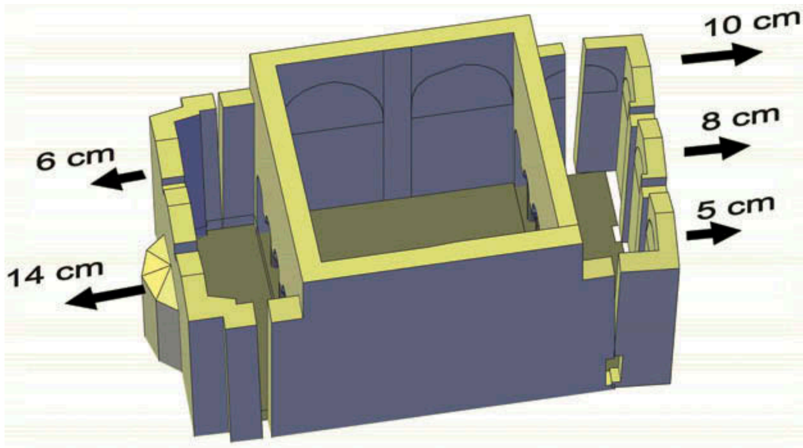


Figure 16. Rendering of the first interpretation of the damage mechanisms after the geometrical survey and the monitoring of the simplified model object representation.

Over a longer time, the measured movements could cause partial collapse. Therefore, an intervention is needed to limit the movements as much as possible and also to improve the ability of the structure to meet possible further earthquakes. To stabilize the main movements, it is necessary to provide a confinement by positioning steel rods at the top of the walls, around the perimeter of the church. The rods can be placed both internally or externally to the walls, but the solution with internal rods is preferred, because of the better protection from corrosion. The tie rods could be made of stainless steel. A similar confinement could be obtained also by positioning another set of tie rods at half the height of the walls, to provide a better connection. The cracks can be subsequently filled by injection of grouts based on hydraulic lime. Transversal ties should be placed to reduce the thrust of arches and vaults in that direction. It is not necessary to remove the previous repair interventions carried out, such as the buttress on the south wall and the pillars in the internal part: they could be left as witnesses of the history of the monument.

12. CONCLUSIONS

The collaboration between experts of the geometrical survey with experts of the stratigraphic analysis and of the structural behavior of the monuments and the interpretation of the structural damages has shown that a multidisciplinary approach can be useful for the comprehension and conservation purposes of the Mesopotam complex. Comments on the structural behavior have been made in a brief report regarding the geometrical and crack pattern survey together with a report on the simple monitoring of the crack pattern for 18 months (including a six-month interruption). A first interpretation of the results seems to indicate the tendency of the facade and of the apse of the church to rotate out of plane in what seems an unstable situation. Some preliminary suggestions are given to prevent the movement to progress into a dangerous situation. However, much deeper investigation is needed regarding the characteristics of the constituent materials (mortars and bricks), together with mechanical on-site testing of the masonry (flat jack) and non-destructive testing techniques. It is also suggested to collect more information on the past seismicity of the area and on the past possible damages caused by earthquakes.

As described in the paper, further investigations need to be done on the construction techniques of vaults and roofs of Saint Nicholas to better understand this unique, ambitious complex. Its peculiar characteristics were highlighted by the geometric model and the structural behavior, addressing the choice of the future interventions that could guarantee a stabilization, that was threatened during the seismic events of the past, and that has been, unfortunately, been put at risk by the lack of maintenance.

The implementation of interpretive models, built upon integration of geometry with stratigraphic analysis, and the analysis of structural functioning and behavior, can also give a key to the historians, helping them to strengthen the complex historic frame of the events of southeast Europe during the Middle Ages, and the hypothesis formulated upon the studies on Mesopotam. It could give important information on the creation of an aristocratic order that would justify the complex plan and structural system of Saint Nicholas Church, the use of highly skilled workers (perhaps not only local ones) and of capitals and bas-reliefs with provenance from the Byzantium areas, as underlined by the historians.

In conclusion, the survey has to be further addressed towards SDI definition to develop object generation related to the functional and structural elements (walls, vaults, domes, pillar, columns, opening closures, etc.) overcoming the representation of the skin surface. The implementation of geometric models integrated with a more elaborated analysis on constructing techniques and texturing would allow us to obtain volume representations dedicated for a comprehension of the structural behavior of complex systems. The integration of specific information on materials; assembling techniques of bricks, stone, and mortar rows; and stratigraphic units can generate better focused and more useful 3D content models, thus refining historical constructive models and carrying out finite element analysis devoted to the structural comprehension. The result can usefully deploy the comprehension of a historicized geography of the sites and regions.

As underlined in the preliminary study setting the bases of the International Landscape Convention, the important role of geographic historical context in understanding, safeguarding, and valorizing the social economic anthropic and cultural dynamics has been highlighted (UNESCO, 2011): a special interest in geo-spatial data, considered as an intrinsic component of any information, even regarding the fields of cultural heritage and landscape, is increasingly expressed at the international level. Architectural SDI is, in fact, considered as "a key element of individual and social well-being and . . . its protection, management and planning entail rights and responsibilities for everyone" (cite). Remote virtual access to architectural SDI programs needs to be improved to allow a better understanding of architecture and its elements within a geographical multi-scale frame. As evidenced by the Mesopotam case study, Saint Nicolas can be located within a complex environmental, historical, and sociological context, co-related inside the complex area covering the regions of the Bulgarian-Epirus and Serbian regions, and related to the events that occurred after the fall of Constantinople, thus providing an iterative knowledge advance both under the architectural domain and the area of Mesopotam, within a larger territorial context. Thus, in the conviction that it can better support the addressing of its conservation through sustainable actions and comprehension by the citizen, filling the gap between the two scales (the scale of the architectural modeling and the geographic scale).

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