2019 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Florence, Italy, December 4-6, 2019

Integration and modelling of 3D data as strategy for structural diagnosis in Endangered Sites. The study case of Church of the Annunciation in Pokcha (Russia)

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***Abstract* – Cultural Heritage and its variety of Built Heritage is increasing a scientific cognitive approach from European Committees, related to the difficulties of its protection and management. This is primarily due to the lack of emergency protocols of structural knowledge and documentation on architecture and ruins, for the protection and intervention on an Endangered Heritage that is going to disappear.**

The consideration of structural documentation applied to Historical Built Heritage, as in the case study of Pokcha Church (Russia), reviews the declination of integrated products of 3D survey into Reality-Based Models, with the possibility of systematizing data through methodological phases and controlling the quality of numerical components into 3D polygonal models, in different levels of details and integration of survey data. These models are intended in the capacity of their shape to conserve morphological qualities about structural behaviour, and to fit into computational platforms of analysis, for information on tensional behaviour and emergency risks.

I. ENDANGERED SITES: TOPICS AND EMERGENCY FOR DOCUMENTATION

The analysis of Cultural Heritage, in parallel to the development of communitarian guidelines for its protection [1], is determining a growing scientific cognitive approach to European and Worldwide sites [2]. The variety of Built Heritage, including from localized historical buildings and monuments to extensive targets of historical centers, sites and territorial landscapes, intends a wider field of knowledge and intervention in terms of both structure, policy and extension. This justifies the difficulty of its protection and preservation, assisting to a fragmented reality of separated protocols of documentation, directly derived into computation and administrative actions. Thus, the difficulties in the sharing of information and data integration are influencing and slowing the entire approach in particular regarding the so-called “Endangered Heritage”, that class of heritage particularly affected by proven or potential threats that define a high level of risk for its preservation [3].

Actually, the revision of those sites officially recognized highlights the coexistence of a double type of cognitive emergency on Built Heritage: on the one hand the classification of the site in its double meaning of physical container and cultural visualizer, on the other the growing request for parameters and specific analysis frameworks for the definition of the emergency value of the building, conditioning the relative useful time for intervention.

Thus, it follows a growing demand in the identification of these sites [4], both geographical and typological, expanding the dissemination and application of proportionate monitoring and knowledge practices, preliminary to intervention on territory [5], with the aim of triggering a growing process of safeguard policies [6].

The attention to safeguarding methodologies for existing heritage is receiving an awareness-raising improvement of research, able to develop new generations of digital products combining a Survey-based phase of digital documentation of Cultural Heritage, necessary for a correct and complete understanding of the characteristics and parameters of units and contexts of Built Heritage, to a Compute-based action of cognitive and interactive models, with the elaboration of 3D digital products for investigations and simulations on shapes and structures.

New representation systems produce new expectations related to digital communication, changing the objectives and constantly renewing the demand in analytical terms of cognitive requirements, also in response to necessities more linked to the computational nature of interaction within the models themselves, now capable of providing quantitative as well as qualitative answers. The difficulties on the development of reliable diagnosis of historical structures can be reconducted to the need of new methods of analysis, that can exploit computation through methodologies and cognitive practices experimented on the visual and graphic aspects of the documentation of architecture [7], in its present configuration as linked to its constructive and safeguarding rules.

Fig. 1. Examples of Endangered sites along Upper Kama Route (Russia): Bondjug, Uzhginskay, Usolye, Parakseva

II. HISTORICAL STRUCTURES AND THEIR CONNECTION TO ARCHITECTURAL DOCUMENTATION

The consideration of structural diagnosis applied to Historical Built Heritage, as capacity of knowledge of stress behaviours and prevision of damage mechanisms, has a central part in the development of documentation protocols for the safeguarding of heritage. The review on risks and priorities of endangered buildings [8] highlights the focus on the character of *Robustness*, as strength of architecture and its elements to withstand a level of stress derived from the combined action of degradation and function alteration of both materials and environments [9].

In this way, the theme of 3D models configures as a way of deriving and indexing information from investigation on historical structures, and as a possibility of interconnecting metadata and databases among them, moving to systematized data through methodological phases and 3D products. The model, whose numerical component determines and characterizes every aspect of its reliability, can become a tool for the management of the asset in terms of computing and planning interventions both in the short, medium and long term, and also for its enhancement.

These considerations are encouraging, both methodologically and contextually, the structuring of project ideas aimed at defining strategies of integration of data for the development and promotion of Structural Reality-Based Models on architectural heritage. On a scientific level, the experimentation of Reality-Based models for structural diagnosis will develop a multidisciplinary and implementable methodology, capable of preparing a standardized product, the polygonal model, in different levels of details and integration for the management of the existing Built Heritage. This species of model in intended for the intervention both in "emergency" and in "long term", in the calibration of his procedural computing, and in a both aware-scientific and a practical-operational direction, in the capacity of its shape to decline into morphological and computational platforms of analysis. The methodological process aims to be as far as possible fast, extendable and replicable, to facilitate interchange and make possible a complete knowledge and management capacity through 3D models of built assets in a state of emergency.

III. AN EXPERIMENTAL CASE STUDY: THE CHURCH OF THE ANNUNCIATION IN POKCHA (RUSSIA)

The case of Blagoveshchenskaya Church, or Church of the Annunciation in the village of Pokcha, within the Cultural Heritage Route of Upper Kama in Russia, consolidates a central historical-architectural phase characteristic of Cherdyn district, synthesizing the value of historical evolutionary urban events in the stratification of its structures and walls, today abandoned in a state of ruin.

The original wooden complex was replaced in 1785 with a new one in stone and brick masonry, subdivided in multiple environments: the main body, with a quadrilateral planimetry, constituting a nucleus for the refectory, the chapels of St. George (southern) and St. Nicholas (northern), the bell tower and the entrance narthex. In 1910, a reconstruction intervention modified structurally and morphologically large portions, in particular the bell tower, entirely replaced, and the eastern section of the central vault and the altar, reconstructed with the insertion of a 5-headed chapter; the interiors in plastered stone, with paintings and ornaments from 1870, are preserved instead. The general coat of the building with an additional red brick facing contributes to the strengthening of the external envelope and gives the possibility of inserting additional devices of tension resistance into the stratified walls.

The history of the site goes through restoration works attempted starting from 1920, until the complete abandonment in 1940 and the re-conversion into a power central: the energy issues linked to the new function led in the 90s to the partial collapse of the main pavilion vault and of the bell tower roof, after repeated flashes attracted by the electrical system. As result of the extensive damage, the church was excluded from the list of architectural monuments of interest, precluding any new intervention and restoration initiative, and leaving the site to collapse.

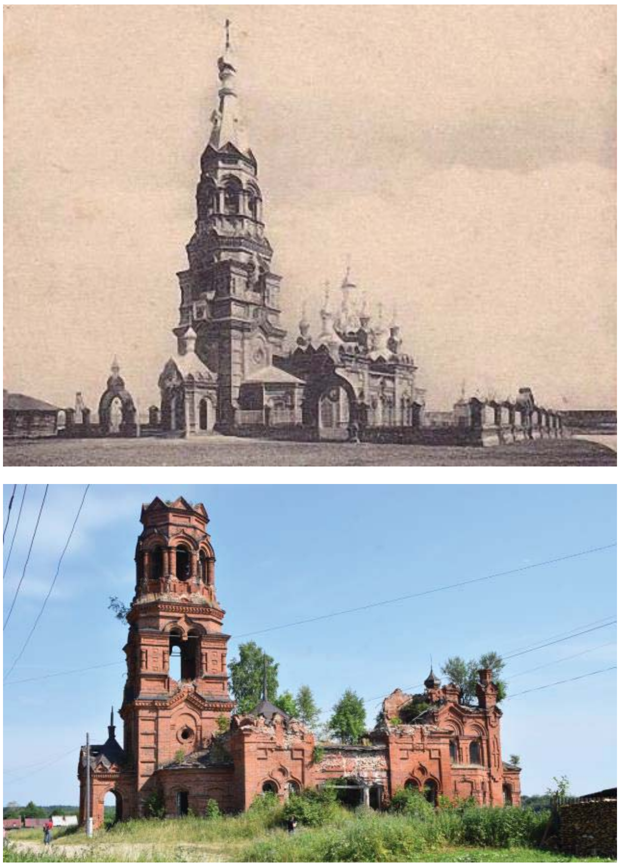

Fig. 2. Blagoveshchenskaya Church, or Church of the Annunciation in the village of Pokcha: historical documentation (before 1917) and conservation in 2018.

In 2018 the architectural complex is in an obvious state of neglect. The rubble of the roofing systems of the main span, wooden and vaulted, have collapsed occupying the environment of the central nave: over time they have been covered by earth and vegetation creating a natural ridge, which reduces the access to the church only to the portions of narthex and apse. The connection to the bell tower, once permitted by the central nave through the gallery and the refectory, has been demolished and it prevents documenting the state of conservation of the elevated rooms, externally still conserved. The complex is also totally devoid of control and regulation services for the presence of people and animals, often occupying the narthex environments that, consequently, are deteriorated by the presence of herds in transhumance during the summer season.

IV. STRATEGIES OF ANALYSIS FOR THE DIGITATION OF THE RUINED SHAPE

The documentation of the current state of Blagoveshchenskaya Church has highlighted the need to experiment integrated approaches of acquiring the survived "shape" to understand the preservation of the architectural "ruin", centring the analysis on the main structures of the building and on their security for the recovery intervention [10].

The morphological analysis of masonry structures was organized and simplified during the digital measurement and acquisition processes, organizing a decomposition of the spatial constructive units that semantized the architectural apparatuses of environments, linking them to the global volumetric macrosystem at the end of the digitization process. Furthermore, the internal inspection of the masonry sections, in their fracture or collapsed portions, has allowed the cognitive integration of the structural envelope, reliably reconstructed in the shape of its architectural “skin”, to which materials and constructive information can be referred.

The documentation approach thus highlights the need for a renewed attention to the methodologies of acquisition and representation of the formal properties of the complex itself, in particular in terms of their correspondence and integration, and encourages the possibilities offered by digital transposition as an enhanced opportunity for reconstruction and use of archaeological and architectural data. The adoption of a double level of acquisition, static from the ground with Terrestrial Laser Scanner (TLS) and mobile aerial with drones for photogrammetry (UAV), ensures total coverage and, despite of different instruments, defines a compatible procedure of integration of these data in the common format of point clouds.

A number of 73 TLS scans have been realized to collect all external surfaces and to spatially connect the complex distribution of internal environments. The quality of scans

Fig. 3. Vectorial and materic sections of Blagoveshchenskaya Church and of the main ruin vaulted central environment

has been performed at almost 2 mm of laser spot spacing till 5m height, and of almost 5 mm in the upper surfaces. The quality of TLS acquisition for the bell tower and the central dome has been favoured by the presence of the inner natural hill over the ruins of the roof, permitting a higher level of instrument position from the ground.

The UAV photogrammetric campaign has been organized with a flight plan mission set from the central top of the complex at a level of 50 m from the ground in the mode “point of interest”. Within this procedure, a photogrammetric campaign has been conducted through the aerial camera with a conical acquisition around the monumental complex, descending to a height of 15 meters above ground and developing 329 shots in 20 minutes of flight. This has given the opportunity to conceive a wide area of overlapping between TLS and UAV resulting point clouds, both on vertical and horizontal built surfaces, in order to optimize their referencing in an integrated sparse database of morpho-metric characters.

V. OPPORTUNITIES OF 3D INTEGRATED MODELLING FOR SHAPE AND STRUCTURE

The integration of the products of digital survey protocols applied on the site [11], from both terrestrial and aerial metric and image acquisition tools, was complementary completed through the differentiated visual stations, able to guarantee information on basement, exterior and interior parameters, as well as monitoring data on the roof components and elevation units. Focusing on the central pavilion vault, half-destroyed during the electrical accident, the documentation, finalized to the restitution of a complete structural shape, has involved the detection both of the vault from the intrados, visible also in its constructive thickness, and also of the extrados levels, occupied by the ruins of the octagonal masonry tholobate at the base of the wooden roof.

The finalization of the integrated database of Pokcha complex has defined a virtual system of the preserved form, directing the attention on the metric-spatial correspondence of information obtained from TLS database and UAV photogrammetry, calibrated at the different reliability of space reconstruction characteristic of the instruments. In particular, a morphological reference and registration has been developed on the scale of each structural unit of the built complex: for the pavilion vault, the two type of data have been aligned on perimetrical boundaries and façades, considering the deviation accuracy of discreate surfaces and target control points. Then, a segmentation of the overlapped point cloud has been provided, deleting the overlapped areas of points and maintaining the TLS quality of data on the intrados surfaces and both TLS and UAV on the coverage surfaces.

The subsequent modelling action has followed the integration of instrumental point clouds experimenting an overall mesh triangulation strategy, finalized to the generation of a Reality-Based model capable of preserving the structural irregularity through the mediation of numerical polygonal surfaces.

Particular methodological considerations have been developed for the mesh triangulation of the integrated TLS and UAV sparse database. In order to perform an HD Mesh Construction, a correct correspondence of points normal was necessary, and it required the processing of UAV point cloud in order to support the optimization of poly-faces orientation in the mesh. Other processes of filtering of the point cloud, in particular regarding the presence of openings’ grids and extensive vegetation, have been implemented to better expose the surface of the structural domain under the decay and nature levels of the ruin site.

The triangulation phase of the final integrated database has highlighted some portions of missing morphological information, due to building masonry areas covered by vegetation during the survey campaign (removed in the point cloud with the filtering process). These parts have been integrated with a fitting of mesh holes according the geometric primitives derived from the mesh model.

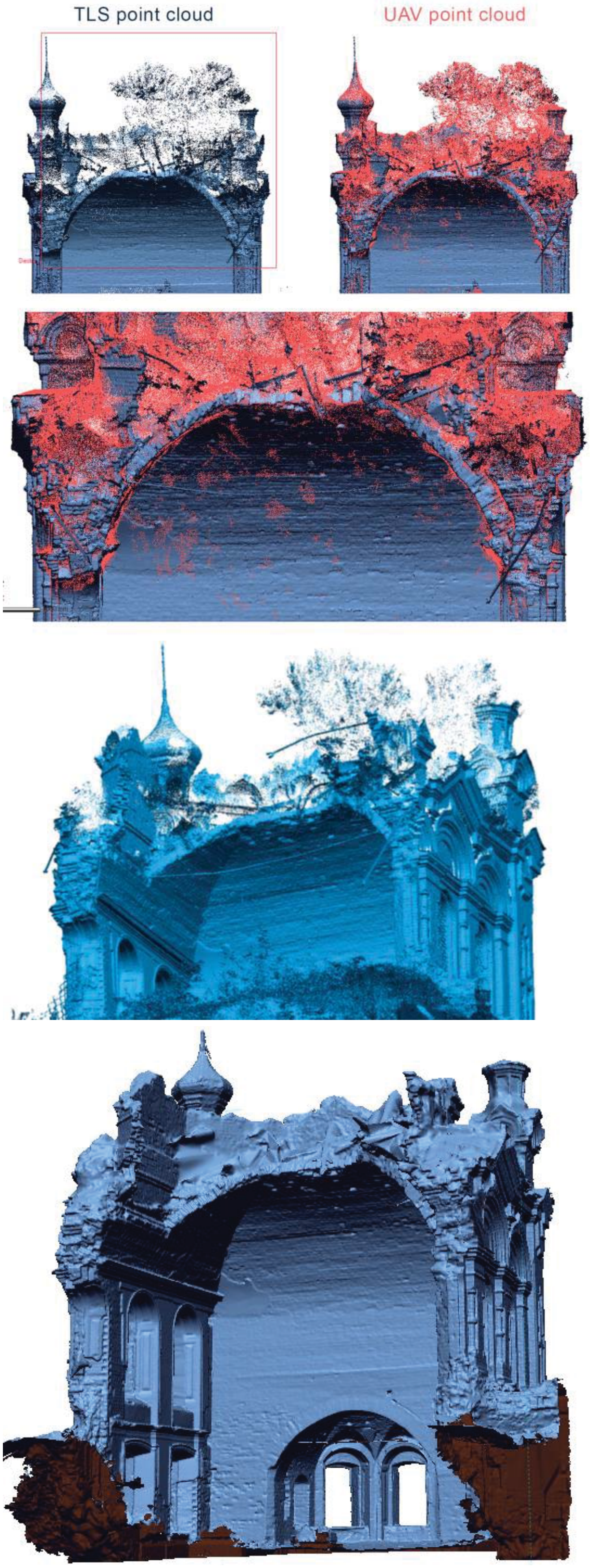

Fig. 4. Integration between TLS and UAV point cloud and management of alignment reliability, optimizing the final integrated database to derive the HD mesh model.

VI. CONCLUSIONS

The need for a formal approach to the re-drawing analysis and intervention on Endangered Historical Sites directs the operational experimentation of morphological-structural representation on two research targets [12]:

- The planning of a documentary strategy able to acquire the totality and particularity of the architectural detail, in all its typological variants (masonry, metal parts, wall coverings) and collocation (main environments, underground, in elevation, coverage levels).
- The convenience of transferring these detailed systems into suitable morpho-metric products, capable of experiencing information and analytical opportunities of historical masonries through graphic representation.

This objective directs methodologies and products to prefer a three-dimensional approach to documentation and visualization of the building, directly from data of digital survey. The interactive orbitational approach and the parametric comparison thus become the means dedicated to qualitative and quantitative structural assessments, aware of the interactions that the historical architecture can establish between its individual preserved components and, referring to restoration, with its intervention design.

The presented study case defines a primary phase of research directed to the generation of an overall model of Blagoveshchenskaya Church. Thus, this strategy will support the decomposition and meshing for "structural cells" of the entire complex, defined for minimal spatially identifiable and statically defined units in which the architectural system of the ruin can be subdivided.

In this way, the semantized structure will permit an easier management in the possibility of analysis of his deformed shape and considering the direction of computing of reliable mesh models into structural simulation platforms for the monitoring of evolving damages in endangered heritage. [13]

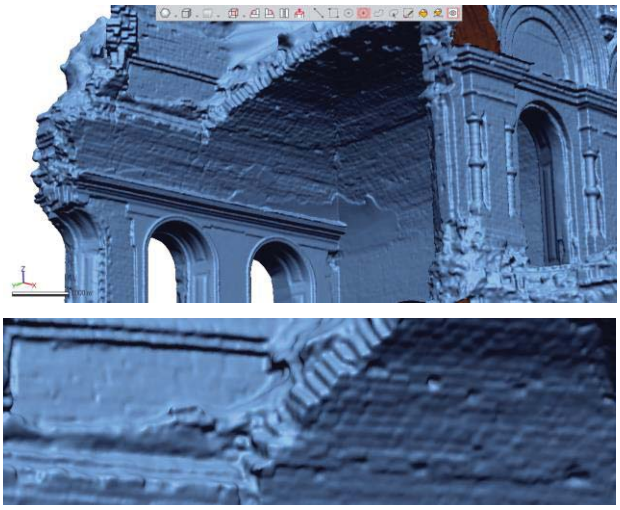

Fig. 5. Details of the shape quality in the HD mesh of Blagoveshchenskaya Church structural model.

ACKNOWLEDGMENTS

The documentation of Upper Kama Region is part of a wider program of activities carried out, since 2013, by DAda-LAB - University of Pavia (coordinator prof. S. Parrinello) and Perm National Research Polytechnic University (coordinator prof. S. Maximova). The digital survey campaigns in 2018 and 2019 have been conducted by Parrinello S., Picchio F., De Marco R., Dell'Amico A. Part of the graphic elaborates of the contribution were developed inside the course of "Architectural survey & restoration" (prof. S. Parrinello, prof. G. Minutoli) of the Double Degree Italian Chinese course in Building Engineering and Architecture of University of Pavia.

PROMETHEUS project is funded by the EU program Horizon 2020-R&I-RISE-Research & Innovation Staff Exchange Marie Skłodowska-Curie. It sees the collaboration between three Universities (University of Pavia, Italy, Polytechnic University of Valencia, Spain, Perm National Research Polytechnic University Perm National Polytechnic University Research, Russia) and two companies (EBIME, Spain, SISMA, Italy).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 821870.

The editorial responsibility of the paragraphs is recognized to: S. Parrinello for paragraphs 1 and 6, R. De Marco for paragraph 2, 3, 4, and 5.

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