2020 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Trento, Italy, October 22-24, 2020

Geophysical investigations, digital reconstruction and numerical modeling at the Batia Church in Tortorici (Messina, Sicily): preliminary results

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***Abstract* – The paper presents the results of scientific investigations carried out at the Batia Church located in the small village of Tortorici (Messina, Sicily). We performed several geophysical surveys and reconstruct 2D and 3D digital models of the monument. Finally, we present the structural analysis and numerical simulation with the aim of study and evaluate seismic vulnerability of the structure. The analysis consists in collecting data with noninvasive portable instruments to characterize local site effects as well as dynamic properties of the structure.**

I. INTRODUCTION

The church of the Annunciation or "Batia", located in the village of Tortorici (Messina, Figure 1), was built on the current site in 1757 at the behest of Bishop Gaetano Galbato. It is Called "Batia" because of the abbey of the Clares for noble girls. The abbey was attached to the church complex. The Mass was celebrated in the church until 1963 when, due to its bad state of conservation, it was definitely closed. In the late 1990s it was recovered and it now used for cultural activities. Inside the church, there are several important paintings and statutes dated in the period from 1500 to 1700. This paper presents the main results obtained by mean of geophysical investigations, digital photogrammetry and numerical modelling of the structure to be used to plan and support the different future restoration phases as well as plan potential retrofitting measures.

II. GROUND PENETRATING RADAR INVESTIGATIONS

Investigations of historical monuments using non-invasive geophysical techniques are of great scientific and social interest. In this regard, the Ground Penetrating Radar (GPR) has proven to be particularly suitable thanks to its ease of use and high-resolution capabilities, particularly at relatively low depths, which are usually of interest for monuments and cultural heritage sites. GPR can potentially offer much clearer images inside a monument than outside, due to the usual smoothness of the floor or walls, the lack of grass and the absence of wind as well as other environmental disturbances. Non-invasive investigations in monuments can help to identify and characterize buried cavities (both natural or man-made for example created during the construction of tombs or crypts), fractures in works of art, in a masonry wall or in a column or identify gradients of humidity that can be fundamental for the stability of a structure, and / or features hidden as closed doors in the wall and no longer visible and so on [1, 2, 3]. The non-invasive investigations also offer information on the history of the monuments, possible architectural changes and changes in use, as well as restoration works that took place in the past and / or can detect the absence of foundations of pre-existing structures.

Fig. 1. Location of the Tortorici village within Sicily (southern Italy). The inset shows the external iew of the church.

The church has been investigated through the use of orthogonal and grid B-scans having a spacing of 20x20 cm. The data were acquired with a RIS MF Hi-Mod system equipped with a dual antenna at 200 and 600 MHz [1]. The data was processed using the commercial reflexw code following a standard processing made of zero timing, background removal, depth gain, filtering and migration. After the processing (on the Bscan signs), the Bscans were put together to obtain plan images at different depths. The 600MHz antenna is able to better resolve the most superficial anomalies, while there is greater penetration depth with the 200 MHz antenna. Figure 2 shows the results of the investigations on the part relating to the central altar (top part) and the nave (bottom part).

In particular, there is a central anomaly corresponding to a funeral site and a lateral anomaly at the left exit that leads to the cloister. This could be due to works that took place over time, but it is not easy to interpret. The anomaly could be linked to a filling to fill a potential height difference. The main anomaly that is found is represented by the long spot on the left side that runs parallel to the longitudinal wall and placed in front of one of the two entrances to the church. It is certainly a superficial anomaly, but it would not seem to be due to the presence of underground services. It is believed to be a trace of a previous foundation. Finally, there are various other minor anomalies, but nothing seems to be very significant.

III. PHOTOGRAMMETRIC DIGITAL RECONSTRUCTION

The modern technological solutions offer great opportunities of having complete geomatic surveys in several environments as well as in Cultural Heritage sites [4, 5, 6, 7, 8]. Photogrammetry can be defined as a science to obtain reliable information about the spatial properties of land surfaces and objects, without physical contact.

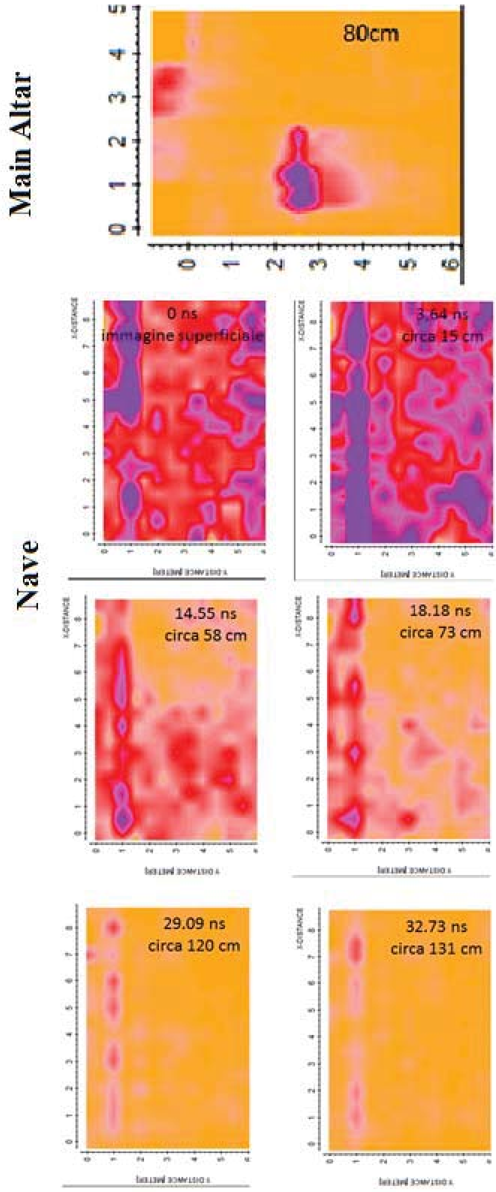

Fig. 2. Main results of the GPR investigation.

Photogrammetry is a relatively new technique for accurate digital capture of 3-dimensional objects. The photogrammetric process consists of several phases of processing (see [4] for details). Various markers have been placed throughout the area of interest (mainly on the ground) and the relative spatial coordinates have been detected through accurate measurements. To create the model presented in Figure 3, approximately 1500 images were acquired during two separate campaigns. The images were collated at different distances about 70% overlap forward and 60% overlap sideways.

Fig. 3. High resolution photogrammetric model (internal and external) of the church of Batia. In the figures below the yellow areas represent the highlighted anomalies of the geophysical investigation.

The development of the 3D model was carried out with free and open source licensed software such as VisualSFM, Meshlab and Blender. The final model (obtained by fusing the internal an external part) is perfectly scaled and measurable with a millimeteric precision. Furthermore, the results of geophysical investigations have also been included in the digital model. The digital model has also been uploaded to a computer platform that can be consulted remotely and can be used for the enhancement of the artifact as well as for the creation of special content for documentary purposes.

IV. NUMERICAL MODELLING (PRELIMINARY RESULTS)

Starting from the digital model obtained from photogrammetry, a 3D numerical model of the church of Batia was built and everything was transferred to the commercial code ANSYS that works on finite elements (FE) using the macro modeling technique. To build the FE model, 8 knot isoparametric solid elements (Solid65) were used to model the masonry walls and the structure. Figure 4 shows the static analysis for only its own weight showing the vertical displacements and the compressive tension state. The results of the experimental campaign of geophysical investigations in addition to the visual inspection allowed to evaluate the mechanical properties (specific weights and modulus of elasticity of the masonry) of the materials used and estimated also by comparing literature data. Subsequently, the parameters necessary to simulate the behavior of the material will be set on the basis of the available experimental results (first experimental frequency identified with environmental vibration measurements).

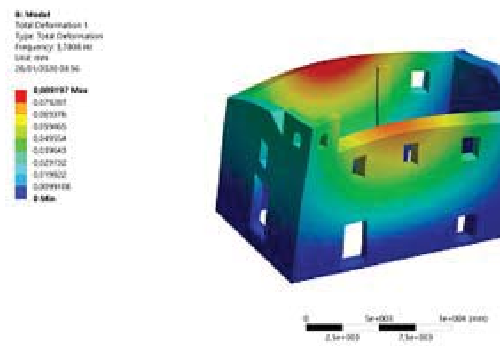

Fig. 4. First modal shape computed numerically

Based on this approach, the average elastic modulus has been estimated at around 1200 N / mm2, which is closer to the values already used in other works and suggested by the standards for the stone masonry scheme. The Poisson ratio was assumed to be 0.2; however, changing this value to 0 or 0.49 did not reveal any change in the form of the mode and the corresponding frequency variation was less than 1%, well below the level of uncertainty. Figure 4 shows the first numerical modal shape of the church of Batia obtained with the identified numerical model. We computed also the five superior modes. The first two are known as bending modes (almost pure translations) along the two main directions of the structure: the first way mainly involves the translation in the Y direction, while the second way involves the translation in the X direction. The third way of vibrating represents motion torsional, while the higher modes are called higher bending modes. The identified FE model was used to assess (currently preliminary) the seismic vulnerability of the structure. To this end, linear time history (TH) and nonlinear static (pushover) analyzes were performed. In particular, in the absence of a specific in situ investigation aimed at evaluating the non-linear behavior of the masonry material, and being an expensive non-linear calculation of the TH analysis, the FE model was used to perform linear parametric TH analyzes in which the results of different seismic sequences are compared. An estimate of the non-linear response of the masonry church was instead performed by the pushover approach, in which specific hypotheses were made on the non-linear behavior of the masonry.

AKNOWLEDGEMENTS

The authors thank the Mayor of Tortorici, Emanuele Galati Sardo, for supporting this project. This paper was partially supported by the Joint R&D Bilater Project "Noninvasive investigations for enhancing the knowledge and the valorization of the cultural heritage" funded by the University of Malta and the National Research Council of Italy (Biennal Programme 2018-2019).

REFERENCES

[1] Persico R., D'Amico S., Matera L., Colica E., De Giorgio C., Alescio A., Sammut C. V., Galea P., 2019. GPR Investigations at St John's Co-Cathedral in Valletta, Near Surface Geophysics, 17, 213–229 doi: 10.1002/nsg.12046

[2] Persico R., Matera L., D'Amico S., Borg R.P., Galea P., 2016. Integrated GPR and passive seismic investigations in cultural heritage sites: case studies in Malta. Proceedings of Grond Penetrating Radar 2016, Honk-Kong, June 13-16, 2016, IEEExplore, DOI:10.1109/ICGPR.2016.757260

[3] Persico R., D'Amico S., Pajewski L., Perez Gracia V., 2016. Ground-penetrating Radar Prospection at the Jesuits' Church in Valletta, Malta. Near Surface Geoscience, We 22 A17

[4] S.D'Amico, M.Saccone, R.Persico, V.Venuti, G.V.Spagnolo, V.Crupi, D.Majolino, "3D survey and GPR for cultural heritage. The case study of SS. Pietro and Paolo Church in Casalvecchio Siculo", Kermes, vol.107, 2017, pp. 11-15.

[5] S.D'Amico, V.Crupi, D.Majolino, G.Paladini, V.Venuti, G.Spagnolo, R.Persico, M.Saccone, "Multidisciplinary Investigations and 3D virtual model at the Archeological Site of Scifi (Messina, Italy)", Proceedings of the 9th International Workshop on Advanced Ground Penetrating Radar - IWAGPR 2017, 2017.

[6] V.Crupi, S.D'Amico, F.Longo, D.Maiolino, R.Persico, M.Saccone, G.V.Spagnolo, V.Venuti, "Indagini multidisciplinari e rilievo 3D fotogrammetrico presso il sito archeologico di Scifi (Messina)", Proceedings of the 35th National Meeting Gruppo Nazionale Geofisica della Terra Solida, ISBN: 978-88-940442-7-0, 2016, 553-557.

[7] R.Persico, S.D'Amico, L.Matera, E.Colica, C.De Giorgio, A.Alescio, C.V.Sammut, P.Galea, "GPR Investigations at St John's Co-Cathedral in Valletta", Near Surface Geophysics, vol.17, pp.213-229.

[8] V. Venuti, B. Fazzari, V. Crupi, D. Majolino, G. Paladini, G. Morabito, G. Certo, S. Lamberto, L. Giacobbe, "In situ diagnostic analysis of the XVIII century Madonna della Lettera panel painting (Messina, Italy)", Spectrochim. Acta A Mol. Biomol. Spectrosc., vol.228, 2020, Article ID 117822.

[9] D'Amico S., Imposa S., Panzera F., Lombardo G., Betti M., Muscat R., Borg R., Grassi S., 2017. Evaluating dynamic behavior of historical buildings through ambient seismic noise measurement and numerical modelling. Proceedings of IMEKO International Conference on Metrology for Archaeology and Cultural Heritage, Lecce, Italy, October 23-25, 2017