The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-2-2023
29th CIPA Symposium "Documenting, Understanding, Preserving Cultural Heritage:
Humanities and Digital Technologies for Shaping the Future", 25–30 June 2023, Florence, Italy

A PHOTOGRAPHIC DOCUMENTATION WORKFLOW FOR DIGITIZATION OF CULTURAL HERITAGE: THE 14 CENTURY CHURCH OF SV. NIKOLA IN KALOTINA, BULGARIA

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KEY WORDS: Documentation, Photogrammetry, RTI, Architectural Heritage, 360° Photography, Medieval Bulgaria

ABSTRACT:

The church of Sv. Nikola, dated to the mid-14th century, is an important medieval cultural heritage monument with vivid fresco iconography located in the village of Kalotina, Bulgaria. The church consists of a small narthex and a larger naos with an apsidal wall. Much of the decorative details are beginning to degrade which makes the need for documentation of the current state important for preservation. Due to its remote location, public access is limited for both visitors and researchers. During the recent campaign, a workflow was designed with the purpose of obtaining complete documentation of the church. The workflow aimed to be low-cost and relatively quick. Complete photographic documentation was conducted including close-range photogrammetry of the interior and exterior of the church, Reflectance Transformation Imaging (RTI) of a selection of the graffiti within the frescoes, and 360-degree HDR panoramas. Additionally, a field survey of the surrounding area was performed by archaeologists and a geodetic survey which was used for the georeferencing of the photogrammetric 3D models. This detailed workflow developed for this project serves as a case study of a methodology for complete documentation of immovable cultural heritage.

1. INTRODUCTION

The medieval church of Sveti Nikola (Saint Nicholas) keeps historically important wall-paintings. The church is located in the modern village of Kalotina, Bulgaria near the Bulgarian-Serbian border and has survived centuries of turbulent history and now is the subject of archaeological and architectural research as well as conservation. It is one of few preserved medieval churches in modern-day Bulgaria with a depiction of the ktetor's aristocratic family of the Second Bulgarian Empire. Despite its historical significance, the protection of the monument is challenged by various administrative issues and deterioration of the building and its frescoes. This paper will present a protocol for complete documentation of an immovable cultural property using the case study of the Church of Sv. Nikola.

From 2008-2013 small scale campaigns were undertaken at the church with students but no complete documentation was done. In 2020, a team led by the Balkan Heritage Foundation carried out a full-scale investigation of the ecclesiastical monument, its surface and surroundings, wall-paintings, and graffiti using a non-destructive digital toolset. The project aimed to address research questions related to the edifice and create a digital portfolio and database for the church, but also to facilitate the administrative procedures in the sake of protection of the site and related to its statute. This is especially important for monuments such as the Church of Sv. Nikola as it is not accessible to the public as a tourist monument due to its remote location.

For this project, a series of digital documentation methods were employed including a geological ground survey of the church and surrounding area, close-range photogrammetry, Reflectance Transformation Imaging (RTI), and 360-degree high dynamic range (HDR) panoramas. From the photogrammetric 3D model, scaled orthophotos of each interior and exterior wall of the church were produced and digitized in 3D to identify the two main phases of fresco decoration and the architectural construction and restoration phases. The fading frescoes are covered with graffiti. Inscriptions that could be deciphered were photographed as still images, and those that were not legible were additionally documented using RTI. The 3D model represents a complete representation of the site which can be manipulated by the user. Finally, a virtual tour was created using the 360° HDR panoramas.

Independently, each of these methods serve a scientific purpose, but together they provide a robust dataset for analysis and interpretation of the features and decorations of monuments. The digital documentation methods used in this project can be used for both scientific research by collaborators locally and abroad, but also allow immovable cultural property to be presented to the general public worldwide.

2. STUDY SITE

The church of Sveti Nikola dates to the 14th century AD and was originally constructed under the Ottoman Empire during the rule of Ivan Alexander of Bulgaria (Gerov & Kirin, 1993. The village of Kalotina is located along the Diagonal Road that connected Belgrade with Constantinople. The foundations of the small church measure 8.6 x 4.4 m and the interior consists of a single nave, narthex, and apse facing the east (Figure 3).

The medieval wall paintings depict various scenes from the bible and portraits of saints (Figure 2). The depiction of aristocratic family as the donors for the church has figures of a couple with two children and the dedication inscription references the Tsar

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(Gerov & Kirin, 1993). There are two phases of wall paintings present with the earlier dating to the 14th century (Panayotova, 1966). Remains on the exterior southern facade of the church suggest the exterior was partially decorated in wall paintings but much of this decoration has since been lost.

The surfaces of the wall paintings are also covered in graffiti and inscriptions, some of which are contemporary with use of the church in the 14th century and some dating to after the church was abandoned (Андреев, 2004). A collection of the later graffiti on the surface of the wall paintings preserves a period of migration during the Crusade of Varna. The preserved graffiti dating to this period include depictions of a crusader, a priest, equestrians, hunting scenes, as well as Cyrilic inscriptions.

Some of the wall paintings have been moved to the National Archaeological Institute with Museum - Bulgarian Academy of Sciences (NAIM-BAS) in the 1940’s in order to preserve them while the ones remaining are in dire need of conservation and restoration. The church currently does not have protection status which has led to the rapid deterioration of its architecture and decoration. Stability and humidity problems arise from surface erosion, lack of drainage systems, and extended exposure to the elements in the past due to the roof having previously collapsed.

Figure 1. Modern Condition of the Church of Sv. Nikola.

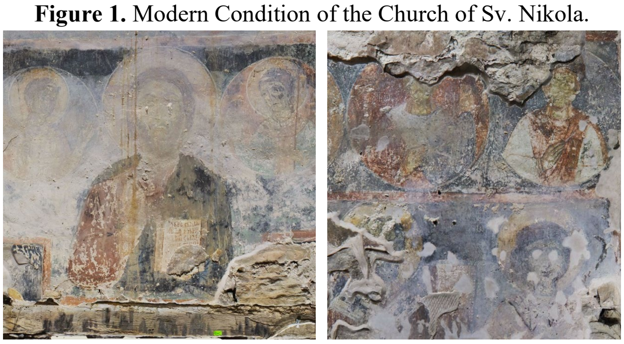

Figure 2. Wall Paintings Inside the Church.

3. METHODOLOGY

3.1 Ground Survey

The geodetic/ground survey was used to position the church within the Bulgarian state coordinate system (БГС2005-UTM and Datum EVRS 2007). The instrument used was Distomat Wild Heerbrugg DI1600 with a Carl Zeiss Theodolite 020 B. The instrument had an expected accuracy of 1-3 cm due to the limitations of the local control network. The photogrammetric models were scaled and georeferenced using markers placed on the exterior and interior of the church walls which were measured using the survey instrument.

The church itself is located at the edge of the village on the slope of a hill. The terrain is dipping to the south toward a narrow road and rising to the north toward a forested area (Figure 3). A portion of the church is underground, particularly on the north side where almost half of the foundation is below ground, and the access is limited due to the encroaching foliage.

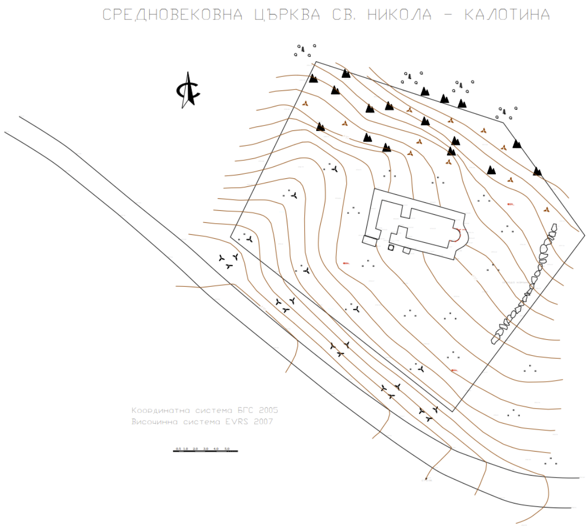

Figure 3. Survey Ground Plan of the Church with Terrain.

3.2 Photogrammetry

Photogrammetry has only become commonplace in archaeological documentation in the past decade despite being a method developed and used in architectural documentation since the late 19th century (Albertz, 2007; Grussenmeyer et al. 2002; Dallas, 1996). Photogrammetry, the process of extracting 3D information from images, provides a number of possible output files that can be used as is or inputted into secondary programs for further scaled analysis or documentation. On its own, photogrammetry can be accurate to less than a millimeter when executed properly. However, the limiting factor in many architectural photogrammetry projects is not the photogrammetry itself, but the instruments used and achievable accuracy of the ground control points, whether they are measured with scale bars or survey instruments such as Total Stations or GNSS receivers. Georeferencing the models using ground control points is integral for the models to be used for measurement and to place them in their correct location in the real world whether through CAD software or within a GIS.

At the church of Sv. Nikola in Kalotina, a complete georeferenced 3D model of the interior and exterior of the church was created for this project. Prior to the photography of the church itself, the camera and lens were calibrated in order to have an initial solution to the distortion model of the interior orientation of the camera. All camera and lens combinations have inherent distortion that can be mathematically represented (McGlone & Lee, 2013). This calibration sequence was performed on the corner of the church where there is high texture and large variation in depth. A total of 18 images are taken at six positions in a pyramid and at each position three images are taken: one in the horizontal orientation and two at each of the portrait orientations. The settings are locked in the camera prior to future photography (focus, f-stop, ISO, and focal length) to maintain the calculated distortion values. The calibration sequence was processed in Agisoft Metashape and the results consist of eleven solved interior orientation parameters that represent the distortion of the lens that can be applied to subsequent photogrammetric models (McGlone & Lee, 2013; Remondino & Fraser, 2006). Pre-calibrating the camera is a fundamental, yet often overlooked, quality control measure in photogrammetry as it ensures that rigorous attention is paid to the internal mechanisms of the camera and that the software is not stretching the calibration to fit the model. It is particularly important with projects with large image sets as having the interior orientation parameters solved can significantly reduce the processing time for the initial alignment of the model as the software does not need to simultaneously solve for these values.

The photography for the church was done in two sessions, one for the exterior and one for the interior. When planning this project, our desired accuracy was taken into account when setting up the photography. In order to obtain the desired level of detail for the fine decoration and graffiti, the threshold of 0.5 mm was set. Using the camera settings we can determine the expected accuracy of the photogrammetry alone, and the georeferenced accuracy we can optimally achieve which is limited by the control network and survey instrument.

The exterior was photographed using a Nikon D500 21 megapixel crop sensor DX DSLR camera with a 24 mm Nikkor lens (36 mm equivalent) in terrestrial strips. The interior was photographed using the same camera and 24 mm lens but instead used a fan geometry for the images which is superior for confined indoor spaces. The fan geometry is an outgrowth of the method of using panoramic photos taken from multiple image stations (Luhmann, 2010). Prime lenses are the ideal and proper type of lens for professional photogrammetry as they have a fixed focal length, and you can be certain that there is no change in this important calibration parameter throughout the photography. With this camera and lens combination, a ground pixel size of 0.25 mm was calculated yielding an expected accuracy of under 1 mm for the photogrammetric model. The accuracy of the control network and resulting georeferencing for this project was approximately 2 cm.

For the interior and exterior components, a total of almost 1000 images were taken (Figure 4). Both models were georeferenced using measurements from the ground survey. Small green targets were placed on the surface of the wall in a random distribution and measured using the survey instrument.

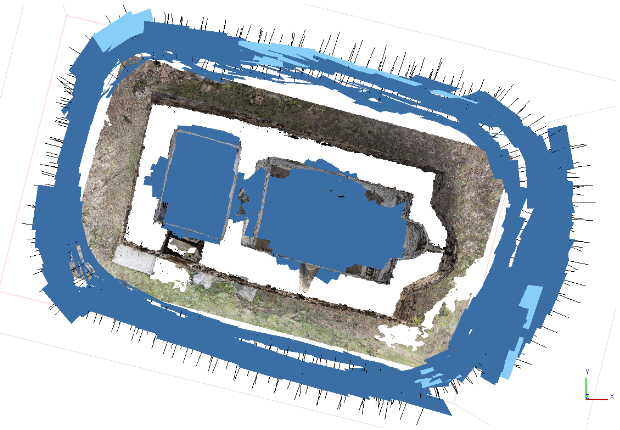

Figure 4. Nadir View of Merged 3D Model Showing Camera Positions.

The images were processed using Agisoft Metashape with the fixed calibration. The two sets of images were initially aligned and scaled separately in different image chunks and after alignment, the two models were merged together using the control point information in each. Prior to the chunks being aligned, the exterior model had an overall scaled accuracy of 1.2 cm and the interior of 1.6 cm. These values aligned with the expected accuracy of the geological measurements. The 3D textured model can be a digital alternative that can provide an interactive experience of heritage through the use of 3D glasses or by developing the model for virtual reality experiences (Figures 5-6).

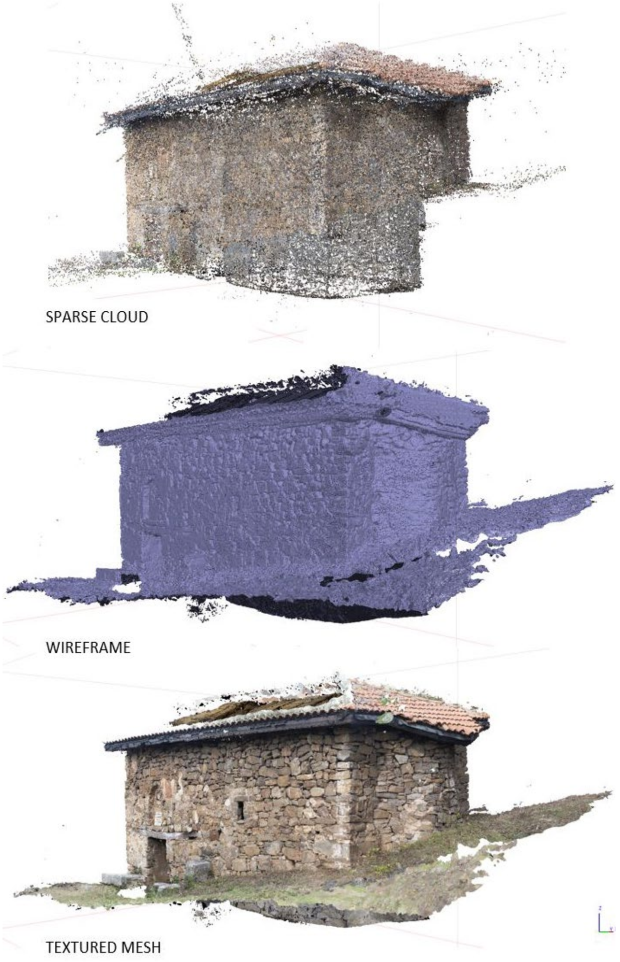

Figure 5. View of the Exterior of the Merged Model from the South-East.

Figure 6. Interior View in the Naos of the Model (top: Wireframe; bottom: Textured Mesh).

The mesh of the merged 3D model was composed of over 4 million vertices and over 8 million faces. From the 3D model, georeferenced and scaled orthophotos were generated of the four exterior walls and ten interior walls of the church. This 3D model served as the base for subsequent measurements, cross sections, and digital drawings of the features and details of the construction and decoration of this important cultural monument.

3.3 Digital Drawing

Architectural documentation on heritage sites is mandated in Bulgaria as it gives a unique perspective to the materials, construction techniques, and existing pathologies. While manual drawing is slowly becoming more rare as we move toward fully digital forms of documentation, the resulting documentation products remain similar. Manual drawing in comparison to digital drawing is extremely time consuming and arguably less accurate than drawing digitally using the scaled and georeferenced 3D models and their exports (Jones & Bevan, 2019). Using the 3D model and resulting orthophotos, an updated top plan (Figure 7) as well as two sets of annotated digital drawings were created for all of the interior and exterior walls of the church as per the requirements of the ministry. The first set included the high resolution orthophotos with dimensions along the sides and bottom to identify the overall size of the walls themselves as well as the size of features such as windows and doors (Figures 8-9). The second set were detailed drawings showing the construction phases, building materials, and layers of frescoes (Figures 10-11).

The drawings were completed using AutoCAD Map 3D which allowed the true scale to be maintained through the entirety of the process which limits any loss of information. This allows for inspection of the details of the architecture in real world size as well as both zooming in for detail and plotting to scale for printing and publishing purposes. The layers for the detailed drawings included stone, tufa, brick, wood, mortar, first fresco phase, second fresco phase, and cracks with the notation and legend in Bulgarian language. The scalable digital products allowed for high detail and precision during the vectorization process. During a previous campaign in 2014, stone by stone drawings of the exterior of the church were completed so the resulting orthophotos from this new project served as a baseline to check the earlier drawings. These comparisons serve to identify change and the procession of decay in the exterior facades.

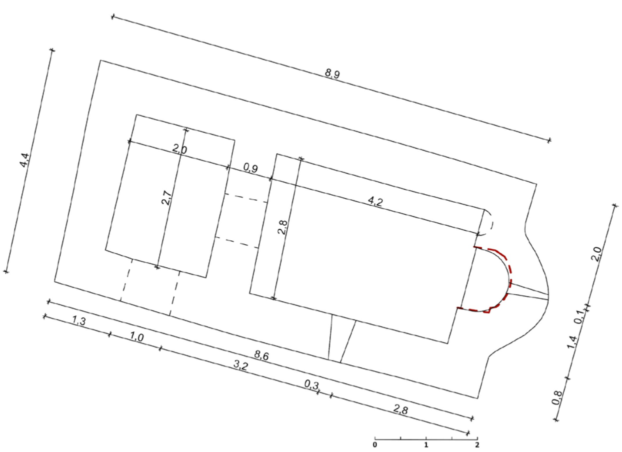

Figure 7. Updated Top Plan.

Figure 8. Orthophoto of Exterior South Façade.

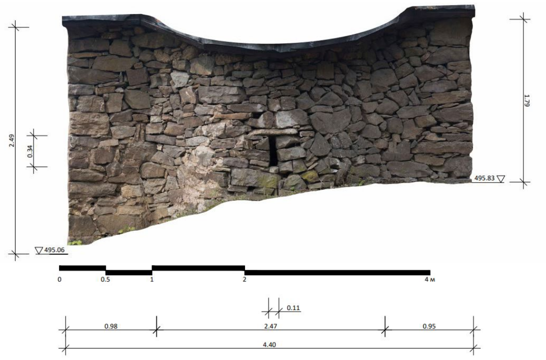

Figure 9. Orthophoto of Exterior East Facade with Dimensions.

Figure 10. Orthophoto of Interior North Naos Facade.

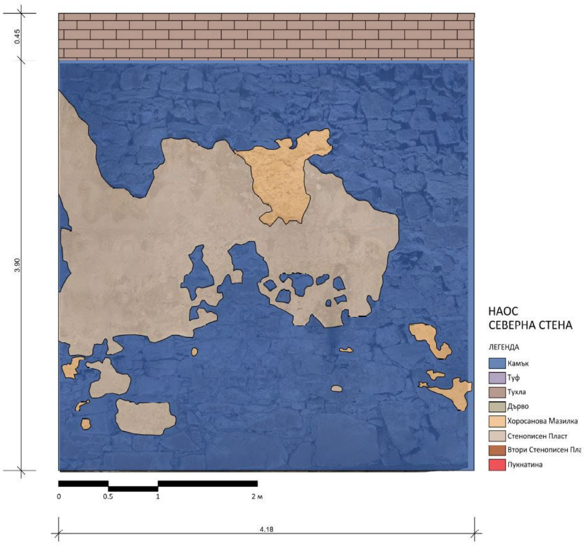

Figure 11. Drawing of Interior North Naos Facade.

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3.4 Reflectance Transformation Imaging

Reflectance Transformation Imaging (RTI) was first developed in 2001 by Hewlett-Packard (HP) Labs and has since been promoted by Cultural Heritage Imaging (CHI) who maintains the software and basic user guides (Cultural Heritage Imaging, 2013). RTI, a pseudo-3D photographic technique used to enhance fine details of surfaces using digital relighting methods, is a well established computational photographic method for documenting inscriptions and graffiti (Mudge et al. 2006). Unlike photogrammetry, RTI is not a 3D technique and it is not a tool to perform accurate measurements, but it does measure surface normals for each pixel of the area photographed and creates a pseudo-3D result. With the help of the information stored in the surface normal field, we can create the so-called "normal map". This way we can perform a dynamic relighting of the image in specialized software (RTI Viewer) and then apply many enhancing filters, such as Specular Enhancement. If used with high-resolution DSLR cameras, the ground sample size for each normal measurement can be less than 50 microns. At this scale, RTI can reveal very fine disruptions in a surface, such as shallow incisions, which are hard, or impossible, to observe with the naked eye on various monuments and artifacts in numismatics, epigraphy, rock art, fine arts, etc. (Earl et al. 2010; Mudge et al. 2006; Raykovska et al. 2015; Georgieva et al. 2022). In addition to the high-detailed image of the area of interest, it also provides a perfectly lit image for the archive.

The purpose of this documentation project was to observe the results from 2008-2013 campaigns and to continue with the areas which were not originally photographed or required improvement. For the photography we used a Nikon D500 with a 60mm macro and a 100 mm macro lens depending on the size of the panels. A complete list of all inscribed graffiti at Sv. Nikola was compiled and epigraphers checked each inscription on the walls with the existing documentation (Figure 12). Inscriptions that could be deciphered with the naked eye were photographed as still images, and those that were not legible were documented using both still images and RTI.

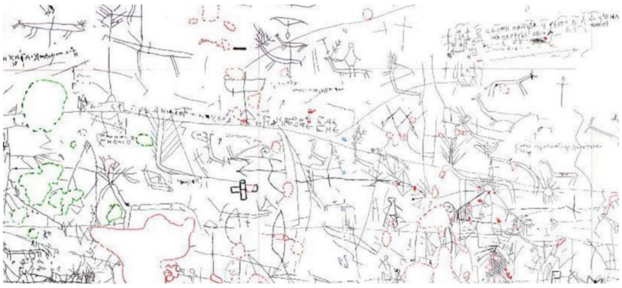

Figure 12. Sketch of Graffiti on West Facade of Narthex.

In total, RTI was done on nine graffiti from the interior of the narthex of the church and one from the exterior. Due to the location of the interior graffiti four RTI panels were captured and processed on site using RTIBuilder (Version 2.0.2). The four panels on the interior of the narthex represent groups of inscriptions (panels 5-7; 11; 15-16; 18-19-29) (Figure 13). The Specular Enhancement filter helps to reveal the incisions of the graffiti, but also the marks of the brushstrokes. One RTI was shot on the south exterior wall, next to the entrance to the Narthex (Figure 14). It captures a very deteriorated inscription, which was almost impossible to find, even using the detailed description of its location, published by Christo Andreev in 2004 (Андреев, 2004). The result from the RTI proves that the inscription did exist, although big parts of it are lost due to the decaying of the limestone.

Figure 13. Interior RTI Panel 5-7. (top: colorized RTI image; bottom: graffiti enhanced with the specular enhancement filter).

Figure 14. Exterior RTI of Inscription. (top: colorized RTI image; bottom: graffiti enhanced with the specular enhancement filter).

3.5 360 Degree HDR Photography

Recently, 360-degree High Dynamic Range (HDR) photography has become an excellent archival tool for heritage documentation. HDR photography involves taking images from the same stable camera position with multiple exposures, often 3-7 images based on the variance in lighting conditions. The images are then processed together to create a single image with even lighting across the entire scene despite changes in lighting, such as the effect of overexposed areas at windows or underexposed areas in the shadows. Due to its high resolution and the ability to capture the entire light range in the photographed area, it is a representation of the condition of the heritage and its elements at the specific point in time. The panoramic images are combined together into a virtual tour, which can be updated at any time and compared to newer sources as conditions change.

Other than an excellent documentation tool, this specific photography method can help to popularize immovable cultural heritage and promote it to the public, which is an essential part of its preservation (Castagnetti et al. 2017; Seaton & Raykovska, 2020). Many galleries and museums are now using virtual tours and virtual reality to attract more visitors. The virtual tour can incorporate information about the site, history, architecture, and restoration (Argyriou et al. 2020). The graffiti can also be represented as a part of a gallery, and the 3D model could be linked in too. A good virtual tour could serve as a complete guide for the online visitors, as well as for academics and researchers.

At the church of Sv. Nikola in Kalotina, the complete 360 degree solution from Dr. Clauß Bild- und Datentechnik GmbH - piXplorer 500 was used. The resulting panoramic images from each camera station cover 360 degrees in the horizontal axis and 180 in the vertical creating a full spherical panorama. At each camera station 406 images are taken producing a final resolution of the stitched HDR panorama of ~500 megapixels, which is more than enough to represent the condition of the church. Additionally a color checker passport was used, to guarantee accurate color representation of the frescoes. The images were processed in Kolor’s Autopano Giga package and the final virtual tour produced in Kolor Panotour (Figure 15).

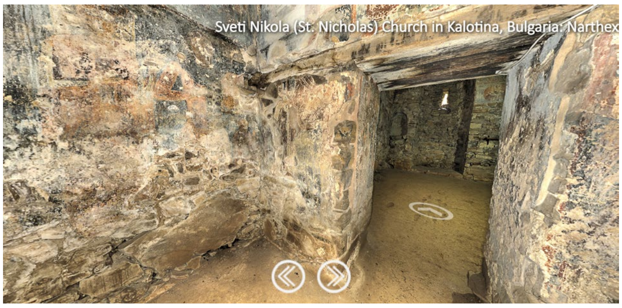

Figure 15. View of the Virtual Tour View from the Narthex. (https://360.gigascan.bg/360/360GigaScan/VRTours/Kalotina.html).

4. RESULTS & CONCLUSION

The results from the ground survey, high resolution 3D model, and RTI allow this team and future researchers to study and analyze the unique features of the architecture and decoration of the church at real world scale without the need to be physically present at the site. One week of documentation work in the field can be used for current and future analysis of the state of the monument as well as promote interdisciplinary collaboration in the future. In addition, the 360 degree tour and 3D model can be uploaded online and be used to present and promote the remote site to the general public. The final package of digital products included a complete 3D model of the interior and exterior of the church exported as both an OBJ mesh and an XYZ point cloud, 14 annotated drawings of the dimensions and features of the facades, 12 RTIs of previously illegible graffiti and inscriptions, and a 360-degree virtual tour. Alongside the documentation outlined in this paper, all documents related to the Church have been collected and archived or digitized. These documents include publications, journals, reports, maps, and images dating back to the foundation of the monument. All of these resulting products will be used by researchers for the purpose of developing a complete catalog of all historical, decorative, epigraphical, and architectural aspects of the Church of Sveti Nikola.

The combination of the digital tools applied in this project provide an example of a robust workflow that can be employed on any site in relatively low time and cost compared to other documentation methods such as manual drawing or laser scanning. Repeating aspects of this workflow could add an additional dimension in monitoring of these cultural heritage monuments that are in immediate need of conservation and protection.

ACKNOWLEDGEMENTS

The authors would like to thank the Balkan Heritage Foundation, Dr. Angel Angelov from the National Ethnographic Institute with Museum, and Dr. Stanislav Stanev from the Bulgarian Academy of Science Institute for Art Studies. We would also like to thank the Bulgarian Ministry of Culture who provided funding for this project.

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