Advanced photographic methods in studying ship graffiti from medieval churches in Nessebar

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ABSTRACT

This article discusses the application of advanced computational photographic techniques in recording and surveying graffiti from medieval and post-medieval churches in the historical town of Nessebar on the Bulgarian Black Sea coast. Reflectance Transformation Imaging (RTI), Close-range photogrammetry, and Gigapixel panorama photography were used in a project for the documentation and research of historical graffiti in four churches in Nessebar. The project aims to create a complete record and database of these important historical monuments according to modern standards making the most of advanced technical opportunities for scientific documentation. The authors demonstrate the advantages of these techniques in the recording and the study of the graffiti in greater detail than was possible before, as well as in the assessment of their state of preservation and the opportunities for their publication and presentation at high standards. In order to evaluate the performance of the methods during the analysis process, the novel dataset of ship graffiti was compared to earlier research studies.

Keywords: ship graffiti, Reflectance Transformation Imaging (RTI), Close-range Photogrammetry, Gigapixel panorama photography, medieval churches, Nessebar

INTRODUCTION

Since 2018, a team of archaeologists from the Bulgarian Center for Underwater Archaeology (CUA), the Archaeological Museum in Nessebar, the National Archaeological Institute with Museum at the Bulgarian Academy of Sciences (NAIM – BAS) and the Balkan Heritage Foundation (BHF) have undertaken a project aimed at recording historical graffiti, mostly of ships, from four medieval and post-medieval churches in Nessebar, a UNESCO World Heritage town on the Bulgarian Black Sea coast (Fig. 1). The project has been financially and technically supported by the Ministry of Culture, the BHF, and the CUA. Its ultimate aims are:

– to create a complete record and database of these important historical monuments according to modern standards and advanced technical capabilities for scientific documentation.



Fig. 1. *The map of Nessebar showing the locations of the churches with the number of documented ship graffiti in each of them*

- to assess the graffiti's state of preservation and conservation.
- to generate the graffiti's presentation and communication with the public through publications, exhibitions, and an online database, accessible free of charge.
- to offer broader and more objective perspectives in studying a relatively understudied discipline, namely seafaring and shipbuilding in the western Black Sea during the post-medieval period.

The advanced computational photographic techniques used so far are Reflectance Transformation Imaging (RTI), Photogrammetry, and Gigapixel Panorama Photography. They facilitate capturing small-scale details of the graffiti and the visualization of elements barely visible by a naked eye. In addition, the precise documentation supports the scientific analysis of the monuments and gives various opportunities for their visualization and presentation.

MATERIALS AND METHODS

The Graffiti in Nessebar Churches

Several hundred historical graffiti have been registered in four medieval and post-medieval churches in Nessebar. These are St. Spas (Church of the Holy Saviour/The Holy Ascension of the Lord, 17th century), St. Stephen (built in the 11th century and reconstructed in the 13th, 16^{th,} and 18th centuries), St. Todor (built in the 13th, and reconstructed in the 18th century), and St. John Alitourgetos (13th – 14th century) (Fig. 2). The biggest group of ship graffiti numbers over 300 and it is also the most studied (Villain-Gandossi 1979; Овчаров Н. и др. 2019; Georgieva,



a) St. Stephen (11th century, reconstructed in 13th, 16th, 18th centuries) b) St. Spas (17th century)



c) St. John Alitourgetos (13th – 14th century) d) St. Todor (13th – 14th century, reconstructed in 18th century)

Fig. 2 *Nessebar medieval churches where ship graffiti were documented with advanced photographic methods in the current study*

Prahov 2020). Another group represents personal names and years, but so far, these graffiti have not been studied at all. According to the depicted years, they can be dated mainly to the 19th century. There are also single graffiti of heraldic symbols on St. John Alitourgetos church, dated by early researchers to the 14th century (Овчаров Н. 1992). Several graffiti of animals (horses, birds, a goat) in St. Spas and St. Stephen churches, graffiti of buildings in St. Todor, as well as schematic anthropomorphic images in St. Stephen church could be associated chronologically with the larger group of ship graffiti. The graffiti were notched on various places on the inner and outer façades of the buildings, on murals (St. Spas and St. Stephen) or on separate stones (St. Todor, St. John Alitourgetos). Most of the ship graffiti were incised on the decorative rectangular frames (panels) of the low murals level in St. Spas and St. Stephen churches (imitation of the semi-precious stone plates decorating the luxurious late antique churches) and in the second level with floral decorative elements which are at human head height (1.6 – 2 m). This level is still quite suitable for notching the images. Most of these panels are carved with several ship images, which are sometimes organized in logical compositions. Many of the ship graffiti, and almost all graffiti of names and years, are depicted on the upper murals level with the figural images of saints and scenes from the New Testament. Many of these overlap one another, as is the case with the eastern wall of St. Stephen's narthex where several dozens of ship graffiti are densely covered with later notched names, years and still unidentified incisions. The high-

est incised graffiti are those of names and years, some of them at more than 3 meters in height, which is an obstacle for their documentation. In general, the ship graffiti are located at a height between 1 and 3 m, most of them between 1 and 1.8 meters (Fig. 3). The graffiti of names and years are located at a height between 1.5 and 4 m, with most found between 1.8 and 3 m. This shows a somewhat topological chronology of earlier – lower level, and later – higher level graffiti. An exception is a group of precisely incised ship graffiti on St. Stephen church's exterior façade that is located at 3 – 4 m height on the east-facing wall, now under the roof, which once belonged to the western wall of an upper floor that resembled a gallery (Рашенов 2006, 17). These are some of the most representative and largest depictions of this group.

So far, the research has focused only on the group of ship graffiti since they represent an important historical source of information for seafaring, shipbuilding traditions, and the worldview of the population in Nessebar and that of the Western Black Sea coast in the post-medieval period. The ship graffiti were dated by N. Ovcharov (Овчаров Н. 1992), on the basis of their typological characteristics and the information for the building, reconstruction, and wall-painting of the churches, between the 17th and 19th centuries. This was a period when the Western Black Sea coast and most of the Balkan Peninsula were part of the Ottoman Empire. Only the graffiti from St. John Alitourgetos could be dated to an earlier period (13th – 14th century).

Depiction of ship graffiti in holy places, such as churches and monasteries (buildings or rock cut temples), mosques, shrines, and sanctuaries, is a widespread phenomenon in the Mediterranean and its hinterland (Artzy 1999; Champion 2015; Demesticha et al. 2017; Meinardus 1972; Michail 2015).

In Bulgaria, late medieval or post-medieval ship graffiti are also known from inland, *e.g.* from the church of Holy Forty Martyrs in Veliko Tarnovo Dermendjiev, Koseva (Дерменджиев, Косева 2000), the church St. George in Kyustendil (Mitov 2018), Imaret Mosque in Plovdiv M. Champion (Овчаров Н. 1987), and Aladzha rock cut monastery near Varna (Todorov 1981).

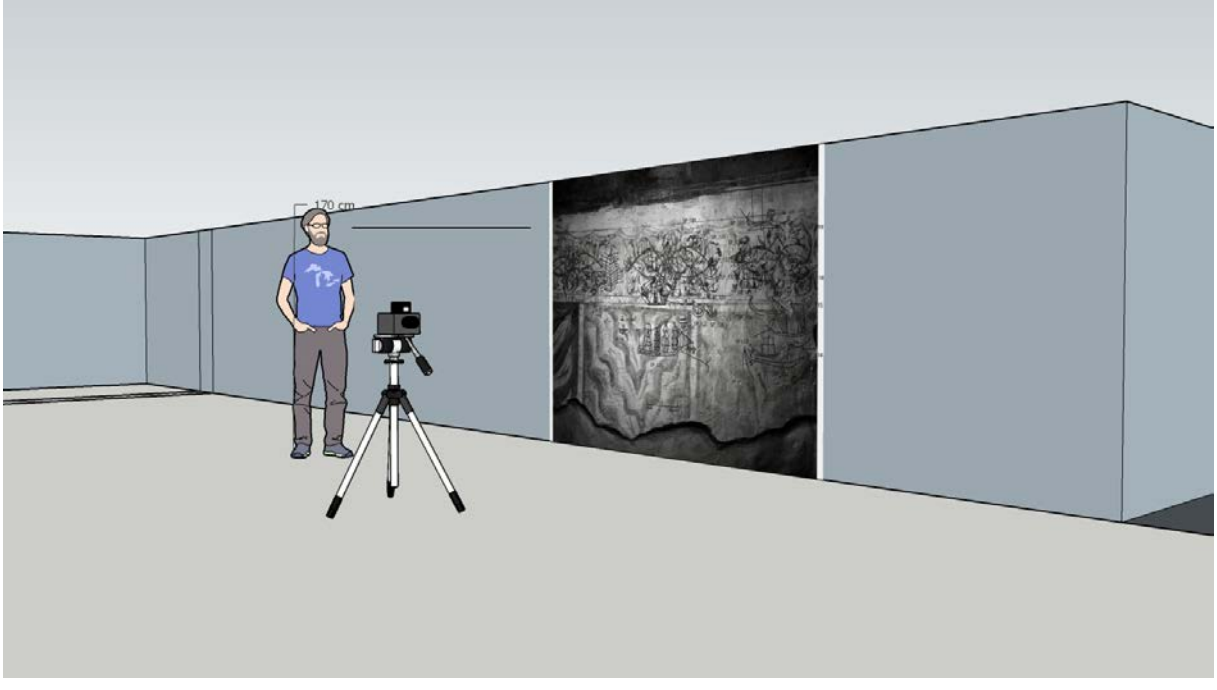


Fig. 3. *The most common location of ship graffiti in the interior of the churches is at human eye level*

A separate group of ship graffiti are the medieval ones discovered in the medieval Bulgarian capital cities of Pliska and Preslav, and the ones in Nikopol on the Danube which were dated to the 10th century (Ovcharov D. 1977; Овчаров Д. 1981).

The origin and reasons for incising ships in various, mostly sacred, places are still not conclusively known. The most plausible and widely accepted hypothesis considers them 'ex-voto' representations (Artzy 1999; Demesticha et al. 2017; Michail 2015). Champion 2015 suggests that these carvings were left by medieval religious mariners inside the holy temples, and compares this practice with the British tradition known as 'church ships', according to which wooden ship models were left hanging from the churches' roofs as votive offerings for safe return from a voyage (Champion 2015, 345). Such practice was also common in other countries. In his work N. Ovcharov (Ovcharov N. 1993, 8 – 9) interprets ship graffiti as 'snapshots or photographic pictures of the things that had excited the people's minds, as well as representation of objects (i.e. ships) that were 'worshipped by seamen and fishermen' (Овчаров Н. 1992, 8 – 9).

It is not clear if the graffiti in Nessebar had been notched in the period when the churches were still functioning or after their abandonment. However, the quantity of the graffiti, seriously damaging the wall paintings, suggests the latter. The tradition of notching objects or names in churches contradicts the canons of the Church and would not have been tolerated by the clergy.

The ship depictions in Nessebar are a schematic but often accurate and correct representation of a ship's or a boat's hull and its rigging system. The details and the shapes of the hulls, masts, sails, riggings, anchors, their position, and other specific details show that they were notched by people whose life was closely connected with the sea, and who knew the seafarer's craft.

The ship graffiti in Nessebar are an important source of historical and anthropological information about shipbuilding, seafaring, and the life and worldview of the marine communities along the Western Black Sea coast. They complement the relatively poor data from the written historical sources and the archaeological record for the region from the 17th – 19th century. Despite the importance of Nessebar's graffiti as cultural heritage monuments, they have not yet been comprehensively documented and published nor studied; consequently, they have not been the subject of research. C. Villain-Gandossi (1981) analyzed and published 64 ship graffiti from St. Stephen and four from St. John Alitourgetos, along with photographs and technical drawings of some of them (Villain-Gandossi 1981, 405 – 420). N. Ovcharov (Овчаров Н. 1992) published more than 200 drawings (imprints) of single ships or compositions of several ships along with drawings (imprints) of them in his monograph dedicated to seafaring along the Western Black Sea coast from the 14th – 19th century. His fieldwork for copying the graffiti covered three of the churches. These were St. Spas, St. Stephen and St. John Alitourgetos (Овчаров Н. 1992). The graffiti in St. Todor church were only recently discovered (Georgieva et al. 2019).

Today, the technological advances in the methods for cultural heritage documentation gives wider and more objective perspectives for the presentation, communication, study, and interpretation of graffiti. Their publication and presentation according to the modern standards and technical opportunities will encourage further studies of the barely known discipline of seafaring in the western Black Sea during the post-medieval period.

Computational Photography Methods

In the field documentation of the graffiti from Nessebar several photographic methods were used. These were as follows: Reflectance Transformation Imaging (RTI), Close-range Photogrammetry, and Gigapixel panorama photography. Several software products were rou-

tinely used to process the generated images (models), including Adobe Creative Cloud package, Cloud Compare, Agisoft Metashape, RTI Builder and Viewer, ImageJ, and D-stretch plugin.

Reflectance Transformation Imaging (RTI)

Recording with RTI was the principal method applied in this project. RTI is a computational photographic method for documentation, exploration, and visualization of the surfaces of various cultural heritage monuments. The technique makes it possible to examine, document, and visualize surface details, even those invisible to the naked eye (Mudge et al. 2006; Palma et al. 2010). This method uses a series of photographs (best practice suggests approximately 60 images) of an object taken with a stationary camera and flashlight, pointed from different angles and at the same distance. Specialized software called RTI Builder combines the images through the Polynomial Texture Mapping (PTM) or Hemispherical Harmonics (HSH) fitting algorithms. The resulting output is a single RTI file that presents the detailed surface morphology of the object in an interactive manner. The model, manipulated via the RTI Viewer software, allows the object to be viewed by the researcher from a different angle of illumination, *i. e.* through shading enhancement methods and at the desired magnification. The software also offers other options for viewing and presentation, thus producing 'increased photorealism' of an object (Caine and Magen 2011; Malzbender et al. 2001) (Figs. 4 a, b, c, d, e, f). A processed image with a clear enough visualization of all details in the frame can then be further edited and exported for graphical illustration (Fig. 4f).

RTI is a widely available technique since the software package RTI Builder and the associated RTI Viewer are open-source developed and provided by Cultural Heritage Imaging (CHI, NG, USA) along with manuals and instructions for their use (http://culturalheritageimaging.org/Technologies/RTI/). The necessary equipment is a camera, lens, tripod, external flash



Fig. 4a. *RTI shot of a panel from the south wall of the church St. Spas without enhancement. Here the fresco is also visible, which can sometimes confuse the researcher during analysis of small-scale details*



Fig. 4b, 4c, 4d. *RTI models of a panel from the south wall of the church St. Spas with the use of 'Specular enhancement' method. Some areas of the shotsare quite illuminated, which could prevent the researcher from presenting evenly the small-scale details of the picture. This is the most common limitation of RTI*



Fig. 4e. *RTI model of a panel from the south wall of the church St. Spas with the use of 'Normals visualization' method. Here the texture of the fresco is excluded in order to facilitate analysis of the small-scale details. In order to achieve better results in this case, the high-resolution setting is very important. The method works quite well when the object's surface has high relief*

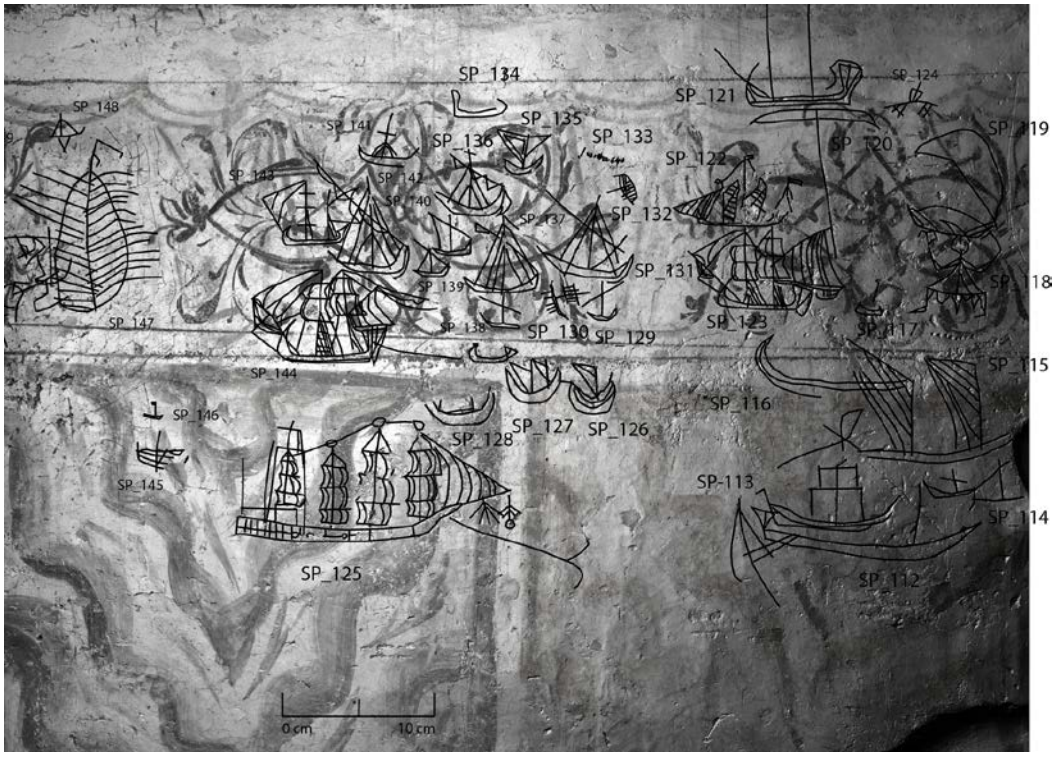


Fig. 4f. *A RTI model of a panel from the south wall of the church St. Spas is used as a background in the creation of a technical drawing, thus allowing the researcher to present all details of the scene precisely and correctly*

with a remote transmitter, computer, and a black sphere with a polished surface. The sphere is placed next to the artifact or monument within the image frame. The reflection of the flash on the sphere, recorded on any picture, provides RTI Builder with the necessary information about the location of the flash, which is then used in the construction of the model (Fig. 5).

Numerous RTI projects have been implemented for documentation and exploration of various monuments and artifacts in numismatics, epigraphy, rock art, fine arts, wood carving, metal, ceramics, paper art and craft, architecture and more (Caine and Magen 2011; Earl et al. 2010; Mudge et al. 2006).

In the course of graffiti RTI recording in the Nessebar's churches, the two DSLR cameras and lenses used were Nikon D750 and Nikon D500 with 60 mm and 105 mm macro NIKKOR lenses. They were mounted on a tripod and controlled by a wireless transmitter for greater stability. The cameras were synchronized with the external flashes – either "Nikon Speedlight SB-800" or "Godox". The shooting distance varied between 1 – 2 m, thus providing sufficient detail and resolution of the images. The positioning of the camera and the composition of image frames was in accordance with the graffiti compositions on the walls (Fig. 6). The single graffiti and some more representative and important ones were recorded separately. When several graffiti were incised close to one another, the composition of the pictures aimed to include the entire group of epigraphic monuments. If this was impossible, the graffiti were combined in several groups. The biggest challenge was to compose the shooting frames on the wall areas



Fig. 5. *Black polished sphere used in capturing a scene compiles all reflected flash lights*

with high concentrations of graffiti of ships or names and years, some of them overlapping one another (e.g. the narthex of St. Stephen church with numerous graffiti of ships, names and years, and the upper wall painting register in St. Spas and St. Stephen churches with a concentration of graffiti of names and years as well as some ships). At this stage of fieldwork, priority in the documentation was given to the ship graffiti. The recording of complex scenes of several interconnected graffiti of ships, boats, ropes, and anchors depicted over larger areas on the walls presented another challenge. In these cases, we attempted to include all interrelated graffiti when possible, given the size of these complex compositions. If necessary, the camera distance was increased, but this reduced the image resolution. RTI recording of graffiti in the corners of the churches or in some niches or window holes was also quite difficult due to obstacles with the positioning of the camera and the flash at the necessary distance and with the illumination of the graffiti from each side. Another serious challenge was to record the highest graffiti on the walls. In these cases, the camera tripods were set on platforms, and the flash was fitted on a long telescopic monopod. For the documentation of the exterior ship graffiti located under the roof of St. Stephen church, a stable metal scaffolding was used (Fig. 7). When graffiti were incised too high on the church walls or in some small niches, the application of the RTI technique was unsuitable due to technical restrictions. In these cases the documentation was replicated using close-range photogrammetry.



Fig. 6. *Precise framing of a panel from the south wall inside the church St. Spas. Positioning of the camera at an accurate distance of 1.50 m in accordance with the size of the scene*



Fig. 7. *Capturing of the highest located graffiti in the yard of church St. Stephen with the use of scaffolding*

Photogrammetry

With its wide range of applications and techniques, photogrammetry has become commonplace in cultural heritage documentation over the past decade. Photogrammetry is a useful tool for the documentation of small features such as graffiti through the extraction of line drawings to scale from the 3D models. However, the dense 3D models can also be used for detailed analysis and interpretation. Like RTI, photogrammetry is a non-invasive recording method that can be executed quickly and accurately in the field, with further processing to enhance the details done off-site.

During the 2020 season of this project, close-range photogrammetry was done on one of the exterior graffiti of the church of St. Stephen and on five panels on the exterior of the church of St. John Alitourgetos. This included three on the east wall and one each on the north and west walls. The on-site photography was done using a Nikon D750 24 megapixel full-frame DSLR camera and a Nikkor 100mm FX lens. The photos were taken from a distance of about 1 m, which provided a ground sample distance of 0.05 x 0.05 mm. Therefore, one pixel in the image represents 0.5 x 0.5 mm in space. The estimated *a priori* accuracy of 0.3 mm provides the limit of detail which can be seen and detected in the models. The models were built in Agisoft Metashape (v1.5.4) and scaled using a scale card visible in the images. On average, the panels of St. John were between 30 and 50 sq cm, and the resulting point clouds had on average 5 million vertices.

Numerous post-processing methods can be used to enhance 3D models to visualize and enhance graffiti. A common method in the literature is to import the models into mesh analysis software such as MeshLab (Prada & Wordsworth 2018; Lopez et al. 2019) or 3D Studio



Fig. 8. *Results of photogrammetric processing of an exterior panel on the west wall of the church of St. John Alitourgetos before and after the algorithms were applied*

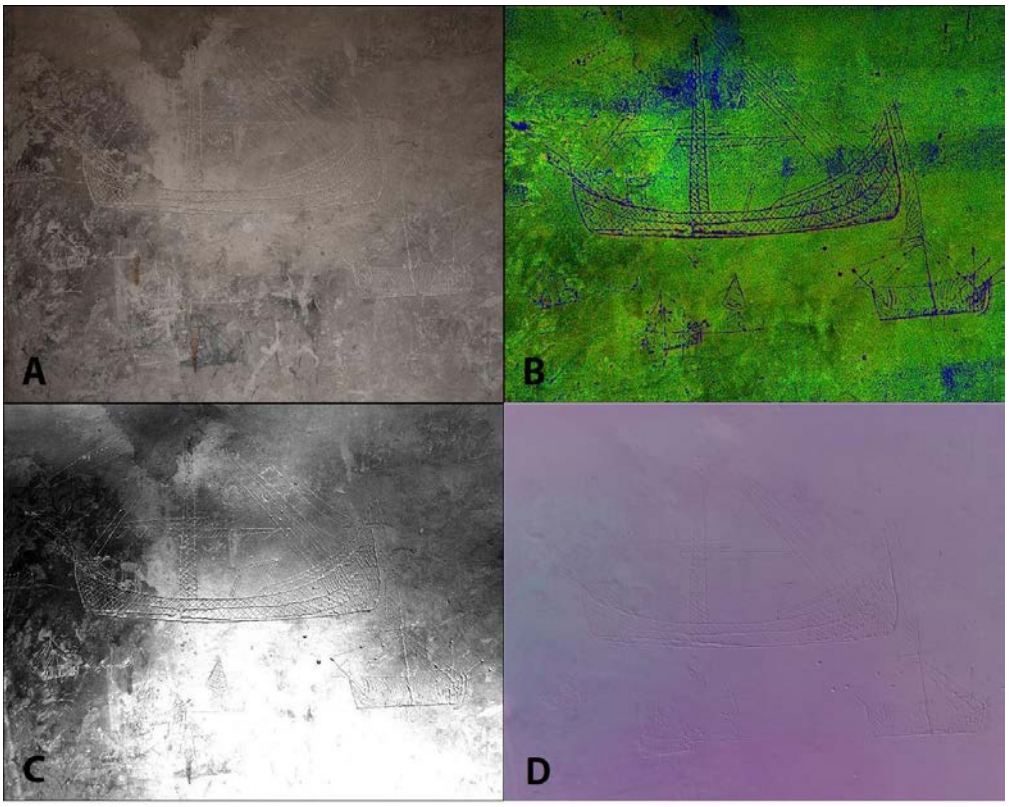


Fig. 9. *Comparison of results from photogrammetry and RTI processing on an exterior panel at the church of St. Stephen: (A) RGB orthophoto; (B) photogrammetric results; (C) RTI results; (D) normal map*

Max (Bertocci et al. 2018), where an artificial raking light can be introduced to the model that mimics the effect of RTI using the normal maps. Other methods include the use of computer algorithms such as the Multivariate Alteration Detection (MAD) algorithm, which is used to highlight changes in surfaces (Abate et al. 2019).

For this project, the models were exported as .obj files and then imported into Cloud Compare (v2.7.0), an open-source 3D point cloud program, for further processing. The .obj files

were opened in Cloud Compare and two algorithms were run on the point clouds. These were PCV (ambient occlusion) (Tarini et al. 2003) and Poisson Surface Reconstruction developed by Kazhdan et al. (2006). PCV uses the normals of the point cloud to compute the illumination from a theoretical sphere of light at each point of the cloud. The resulting scalar field is applied to the point cloud and can be modified to increase contrast to enhance features. Poisson Surface Reconstruction generates a triangulated mesh from a point cloud with normals. Similarly to PCV, the resulting scalar field can be adjusted to refine the visibility of features (Fig. 8). In this way, models of both methods, photogrammetry and RTI, used to document the large panel on the exterior of the Church of St. Stephen, were compared in post-processing (Fig. 9).

360-degree Photography and Gigapixel Panorama

Virtual tours and virtual reality experiences are quickly becoming a common marketing trend in heritage. An increased number of museums, galleries, and historical sites are presenting themselves to the world through these new media. The experience of being able to explore, wonder, and play in these online environments while learning, conveys innovative power and an opportunity to provide unrestricted access to these museums and sites without putting the heritage at risk. The Smithsonian Museum in the United States has a virtual tour of the past and present exhibits available on their website, and this allows the public to view these important artifacts of the past even after exhibits have ended. The British Museum offers virtual tours through Google Street View as well as having an online catalog. Archaeological and heritage sites themselves have not been left out of this movement. Some more notable examples include the virtual tour of Stonehenge by English Heritage (2017), the Acropolis virtual tour by the Acropolis Restoration Service (2014), and the virtual tours of five Egyptian sites, including tombs not open to the public by Harvard University (2020). Around the world, it is becoming a necessity to have an online presence.

A 360º virtual tour of the St. Stephen church was completed during the 2020 season to promote this important monument and create a virtual visualization that can be used by researchers and the public from all over the world. In total, nine 360º panoramas were created, each with a 500-megapixel resolution (Fig. 10). This corresponds to six panoramas in the *naos* and three panoramas in the *narthex*. The panoramas have been combined into a virtual tour



Fig. 10. *360-degree panorama of the naos in the church St. Stephen*



Fig. 11. *Gigapixel panorama on the narthex of St. Stephen church which serves as a map of the graffiti models*

which can be accessed at: https://360.gigascan.bg/360/360GigaScan/VRTours/StStephen.html. The tour includes all of the panoramas taken, and when the tour is online, it can be used to promote the museum and encourage more visitors to the site itself. The next goal concerning the public communication and presentation of the graffiti is their incorporation in the virtual tours for the distance tourists and the researchers.

Moreover, such data is a digital archive, which preserves the knowledge and conditions of the site at a certain point in time, such as in the museum setting. It can also be used as a research tool by academics who are unable to access the site physically. In this way, researchers can, for example, track any regress at the site in order to make plans for conservation and reconstruction. In addition to the 360º virtual tour, a Gigapixel panorama was created of the entire eastern wall of the narthex in the church of St. Stephen, where the graffiti were documented (Fig. 11). This high-resolution image serves as a map to locate all the RTI panels. Due to its high detail, this is an excellent archival document containing information on the condition of the frescoes at this specific point in time.

Gigapixel images have a resolution equal to or greater than 1,000 megapixels. To properly stitch a panoramic image (both for 360º and gigapixel images), the camera and lens have to rotate around a no-parallax point, which corresponds to the entrance pupil of the lens. Rotation around this point eliminates the effect of parallax, which is the movement of two distant objects relative to one another when viewed from different angles. In this project, we employed two devices from Dr. Clauss Bild- und Datentechnik GmbH. These were the Rodeon piXplorer for the gigapixel panorama and the piXplorer 500 for the 360º photography. A Nikon D500 camera with a 105 mm lens was attached to the Rodeon piXplorer.

Color Decorrelation Stretching (D-Stretch plugin)

Colors are generally represented in digital imaging by a three-component vector, such as the commonly used Red, Green and Blue components of the RGB, which is the default of most digital imaging systems. Color Decorrelation Stretching is a technique for enhancing contrast in non-standard color spaces, such as XYZ and LAB. Since the 1980s, this technique has been increasingly applied to terrestrial sites and is recognized as one of the most important tools for documenting rock art (Brady, Gunn 2012, 629). With the creation of the D-Stretch plugin for ImageJ, a scientific image processing toolkit developed by the US National Institutes of Health, these complex algorithms can now be easily manipulated by non-specialist users. Color Decorrelation, and D-Stretch in particular, has yielded spectacular results in the digital reconstruction of degraded, faded, and damaged wall paintings at Angkor Wat in Cambodia (Tan et al. 2014), but it also gave great results in the survey of the frescoes in Balsha in 2015 (Bevan et al. 2015, 146).

D-Stretch takes similar colors that are perceptually hard to distinguish with a naked eye and redistributes them evenly throughout the entire color space. The algorithm performs an inverse transformation to bring these stretched colors back to the original, native RGB space, but with different hue variances (Harman 2008). This new decorrelated representation of the original colors, though does not restore the original pigments. The new image may be technicolored in quite an artificial way (Fig. 12) (Bevan et al. 2015, 146).

RESULTS

The advanced photographic techniques (mostly RTI) made it possible to capture the graffiti in Nessebar's churches in great detail and visualize subtle relief elements, some invisible to the unaided eye, to uncover previously unknown graffiti or parts of them.

Graffiti from the church St. Spas

In the nave of the church St. Spas, a total of 174 ship graffiti were recorded with RTI. After applying the technique and analysis of the images with various surface enhancement



Fig. 12. *Representation of a ship graffito from St. Stephen church with Normals Visualization effect (up) and with DStretch Plugin (down)*

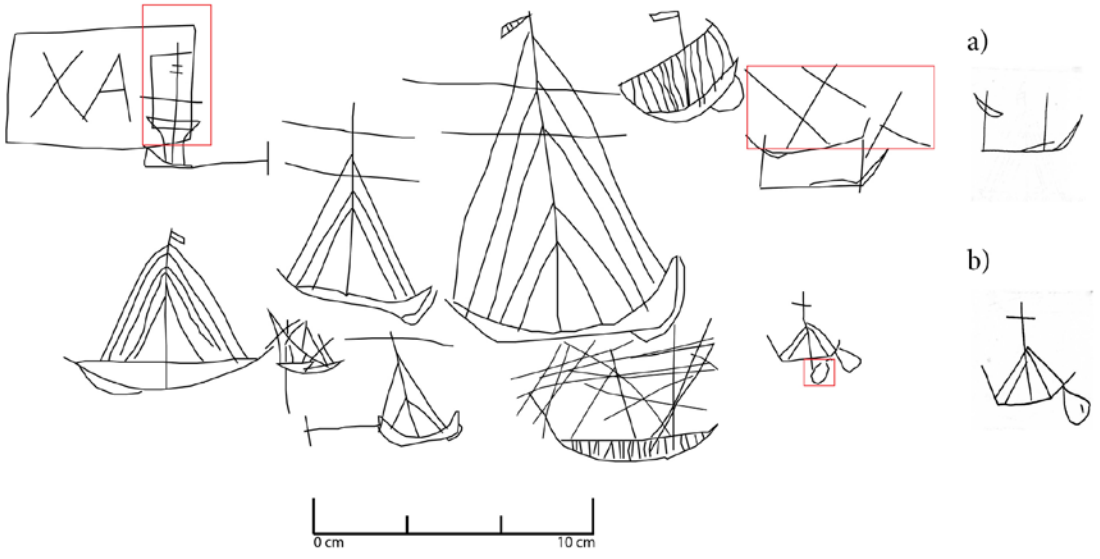


Fig. 13. *New elements of some ship graffiti were found (framed in red) during comparative analysis with the technical drawings from N. Ovcharov's catalogue (1992): a) ship graffito No 61; b) ship graffito No 62*

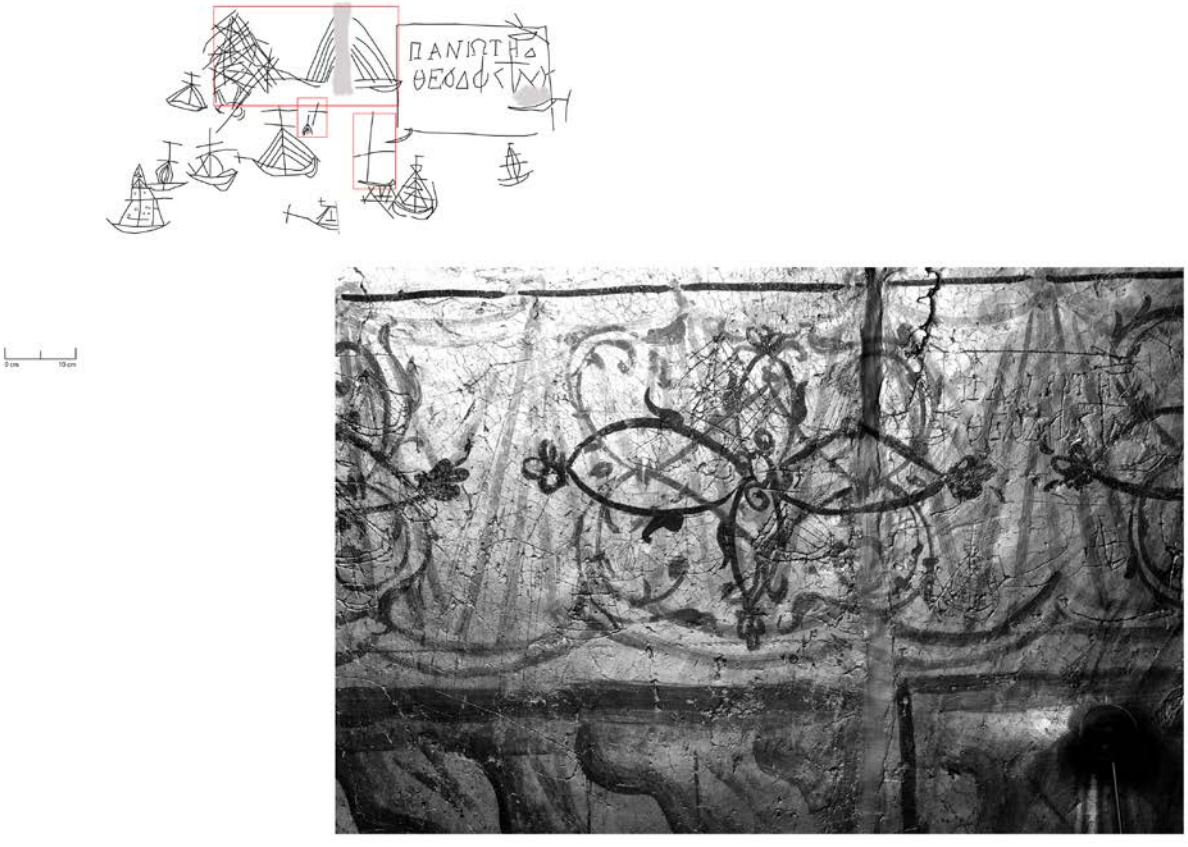


Fig. 14. *Some elements of the graffiti have been erased with paint during conservation of the murals in the past. This is a sign that these monuments have been neglected at the time. Framed in red are elements registered during the current project*

methods, we registered previously undocumented details of some of the graffiti (Fig. 13), as well as 35 ship graffiti that are not included in the publications from the second half of the 20th century. Several ship graffiti have been partially covered and even filled in with paint in previously undertaken conservation procedures against the constant erosion of the murals inside the church (Fig. 14). In his catalog accompanying the monograph, N. Ovcharov presented 139 ship graffiti from the church St. Spas (Овчаров Н. 1992).

During the current survey, 10 of these ship graffiti were not discovered. Five of them seem to have been presented on the sides of the south entrance but are lost today. Ship graffiti from the north wall of the nave presented in N. Ovcharov's catalog under the numbers 50, 51, 52, 89 were not discovered in the course of our work. A graffito under the number 134 in his catalog from the south wall was also not found.

Graffiti from the church St. Stephen

We recorded 153 ship graffiti overall in the church St. Stephen using RTI, 114 in the nave and altar, 24 in the narthex, and 15 on the western wall outside. Many of the graffiti are somewhat schematic representations of ships with fewer details. Some seem half-erased or incomplete. Only a few of the surviving graffiti resemble depictions of both ships and boats in detail. These are mostly the graffiti of ships on the western wall outside the church, where preservation is good. However, their future preservation may be endangered due to their constant exposure to various weather forces. The application of the RTI method in the *narthex* of the church was considered successful to a certain extent. The whole eastern wall, which today is covered with a roof, was incised with hundreds of graffiti of all types, consisting mainly of inscriptions of names and years, as well as some vessels. Most graffiti seem to have been incised very lightly on the plaster and are at present almost erased and illegible. Most graffiti at this location were covered with paint during the conservation of the wall paintings. It is not inconceivable that some graffiti were completely filled in with paint, which demonstrates that the cultural heritage value of these monuments has been neglected until now. The overlapping of numerous graffiti and the large area covered made it problematic to compose and position the frame for the RTI recording (Fig. 15). For this reason, the whole wall was recorded in 46 separate, overlapping RTI models. The compositional arrangement of the camera was aligned with the identified ship graffiti, although it is possible that we missed some parts of graffiti during the setting of the camera's position.

Graffiti from the church St. Todor

The graffiti on the outer façade of the church St. Todor were registered and documented for the first time during season 2018. In total, 20 graffiti were registered and documented. There were three from the south wall, two from the east, nine from the north, and six from the west. They are located on individual stones, and most of them are in a very poor state of preservation. The graffiti are eroded, with the main details of the drawing either barely noticeable or completely erased. Five graffiti are of ships, two of buildings, and the rest are years and Greek letters. Three of the ship graffiti (two from the south and one from the east walls) are turned upside down, suggesting they are not in their original position (Fig. 16). This assumption is supported by the fact that the southern and eastern walls were rebuilt in the 18th – 19th centuries, probably reusing the stones with graffiti originating elsewhere.

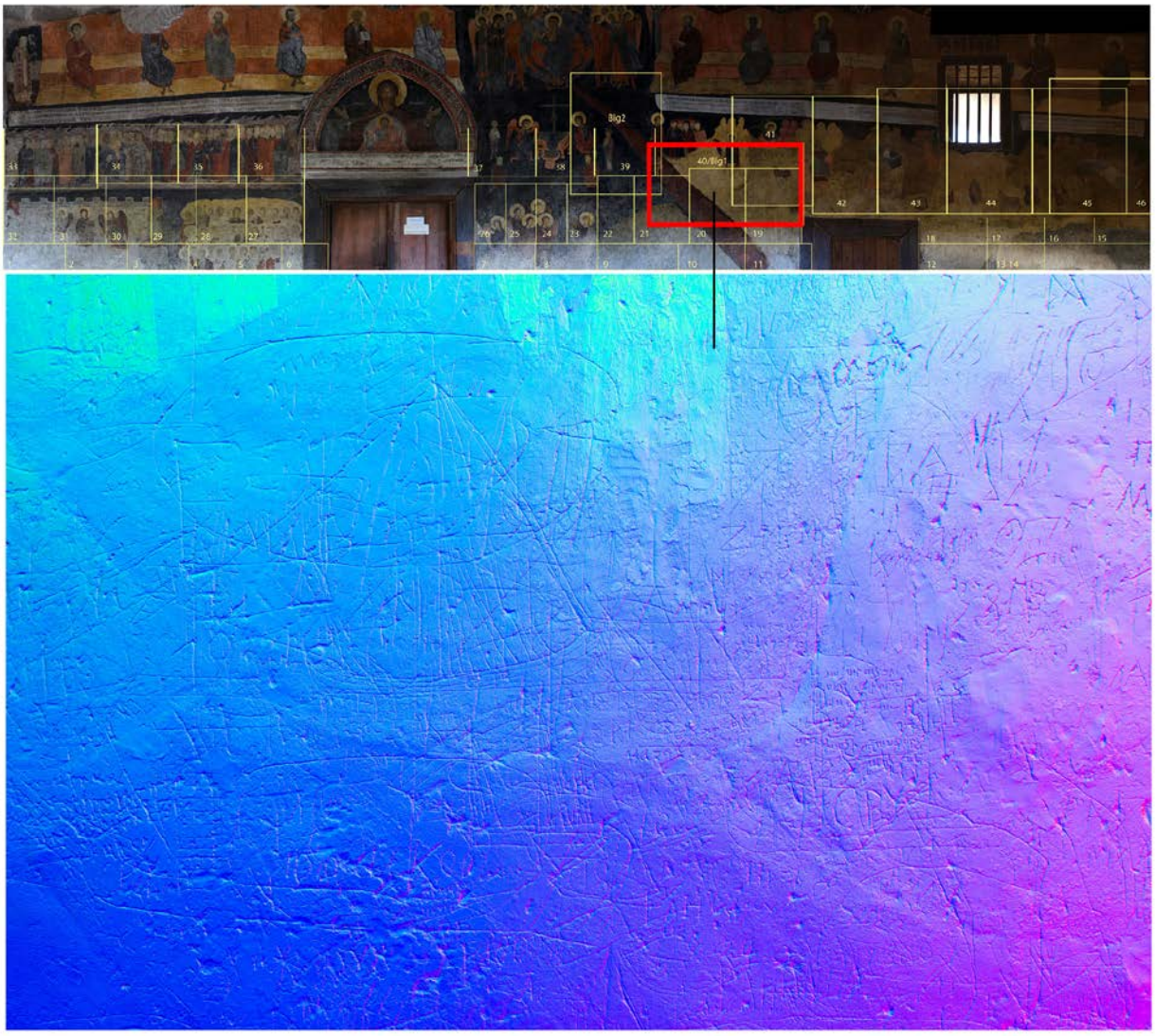


Fig. 15. *The overlapping of graffiti on large areas on the church of St. Stephen's narthex is an overwhelming challenge for framing*

Graffiti from the church St. John Alitourgetos

Four graffiti of ships, six different inscriptions, and one heraldic symbol in total were documented with photogrammetry on the façades of church St. John Alitourgetos. The graffiti are under the same environmental risks as those on St. Stephen exterior walls, and deterioration of the incisions is already visible as a result of stone erosion processes. The high-resolution photogrammetric models of the most eroded graffiti (a ship graffito from the east wall and inscriptions from the west wall) show that even the most advanced methods are incapable of recovering details that have been irreversibly lost over the centuries.

DISCUSSION

The application of the computational photographic techniques allowed the research team to document the ship graffiti according to the modern technical capabilities and standards for cultural heritage documentation work, as well as to uncover new, previously undocumented graffiti or part of them.



Fig. 16. *Standard photographic shots of graffiti on St. Todor church which show that three of the ship graffiti are positioned upside-down*

The current results demonstrate that RTI is a method that can be used for both analysis of small-scale details and the dissemination of high resolution photographs for academia and the public. The availability of such materials allows their further analysis and enhances their use by scholars. Compared with the photogrammetric method, we consider RTI enhancement tools more suitable for analyzing the ship graffiti's complexity, as they contain multiple shading positions. This is a necessity for the visualization of details from any angle. In this respect, it is a unique two-dimensional method that has many characteristics of a three-dimensional one. However, an uneven distribution of light, causing shadowing of some details across an image, can be considered a limitation, especially when the image is intended for wide dissemination.

This limitation could be minimized with the use of some graphical enhancement tools as well as with the *Normals Visualisation* algorithm. Nevertheless, while RTI can provide more information than the photogrammetric workflow for detecting small incisions in the stone, the photogrammetry is more compact, as well as being time and cost-efficient. We propose that the photogrammetric workflow can be used to highlight areas of interest that require further investigation, specifically when RTI is unsuitable for use, such as in areas where accessibility is a constraint.

CONCLUSION

Between 2018 and 2020, most of the historical graffiti in Nessebar were documented and a digital archive of these monuments was submitted to the National Institute for Immovable Cultural Heritage, "Ancient Nessebar" Museum, the Centre for Underwater Archaeology at the Bulgarian Ministry of Culture and to the National Archeological Institute with Museum at the Bulgarian Academy of Sciences. The availability of the archive will also allow graffiti's further analyses and use by scholars.

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Модерни фотографски методи за изучаване на графитни изображения на кораби от средновековни църкви в Несебър

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РЕЗЮМЕ

Статията е посветена на прилагането на модерни фотографски техники при документиране на графити от средновековни църкви в град Несебър. Рефлексно-преобразувателна фотография, фотограметрия и гигапикселова панорамна фотография бяха използвани при документиране на графитни изображения на кораби в църквите „Св. Спас", „Св. Стефан", „Св. Йоан Алитургетос" и „Св. Тодор". Целта на проекта е за тези важни исторически паметници да се създаде архив и цялостна база данни, отговарящи на съвременните стандарти и технически възможности за научна документация. Авторите демонстрират предимствата на тези техники при подробното проучване на графитите, при оценката на тяхното физическо състояние и възможностите за публикуването и представянето им според съвременните стандарти. За да се оцени ефективността на модерните методи, беше направен сравнителен анализ с графити на кораби, документирани при изследвания от XX век.

Ключови думи: графитни изображения на кораби; Reflectance Transformation Imaging (RTI); Close-range Photogrammetry; Gigapixel panorama photography; средновековни църкви; Несебър