Application of 3D Technology for the Documentation of Late Medieval Wall Paintings in the Church of St. George in Lovran, Croatia

Zlatan Novak, mag. ing. geod. et geoinf.
Vektra d.o.o.
Varaždin, Croatia
zlatan.novak@vektra.net

Kristina Krulić, dipl. conservator-restorer
Department of Wall Paintings and Mosaics
Croatian Conservation Institute
Rijeka, Croatia
kkrulic@h-r-z.hr

Abstract— **In recent years there has been a lot of interest in the application of 3D spatial data acquisition techniques such as 3D laser scanning and photogrammetry. Among the most demanding and challenging tasks in the protection of cultural heritage is the drawing up of detailed 3D documentation of wall paintings.**

The application of new technologies in conservation research and the documentation of late medieval wall paintings in the sanctuary of the church of St. George in Lovran is a process conducted periodically, depending on the financial and technical abilities at a given moment, and represents the first example of a comprehensive documentation of a national cultural heritage monument.

This project shows how a combination of cutting-edge technologies in 3D spatial data acquisition was applied to document this remarkable historical piece of art.

***Index Terms*— documentation of wall paintings, 3D laser scanning, photogrammetry, orthophoto, microscanning**

I. INTRODUCTION

The church of St. George is among the oldest architectural structures in the historical centre of Lovran, situated on the east coast of the Istrian peninsula in Croatia. Owing largely to its well-preserved cycle of late medieval wall paintings in the sanctuary, dating between 1470 and 1479 [1], the church has the status of a protected national cultural heritage.

The architectural structure of this late medieval sanctuary is unique because of its rectangular architectonic base, topped with a painted, star-ribbed vault. It was largely this characteristic that prompted the search for new solutions by documenting this cultural monument, as traditional methods of documentation (hand measurement and photography) failed to provide results of a satisfactory precision.

In order to draw up a coherent 2D (two-dimensional) documentation of the pre-existing condition of the wall paintings, with the help of a 3D (three-dimensional) model, "unrolled" 2D measurable orthophotos were made of the curved surfaces of the star-ribbed vault, as well as orthophotos of all the plane surfaces of the sanctuary [2]. The technological characteristics of the wall paintings, with such details as an impressed and incised drawing and the thickness of the brushwork were documented by microscanning. This was also a way to partially try to document the incised inscriptions and graffiti that were barely visible to the naked eye, which were written in Latin and Glagolitic letters. These texts had subsequently been carved onto the wall surface. The most frequent among them are the biblical quotations and various years, which are clearly important when dating the wall paintings [3].

These procedures were preceded by a detailed 3D laser scanning of the whole church, and by using this information all of the segments necessary for conservation documentation were later individually revised.

II. WORKING METHODS AND TECHNOLOGY

A. 3D laser scanning and the drawing of the pre-existing state of architecture

3D laser scanning is based on the so-called LIDAR (Light Detection and Ranging) technology of using laser beams to determine distance [4]. As exemplified by this project, the system used was also equipped with an integrated high-resolution HDR (High Dynamic Range) camera that makes it possible to paint each of these points with its actual colour. The same technology was used to make a 3D model of the whole church, Fig. 1, including the sanctuary, Fig. 2, in order to produce a precise and detailed architectonic survey of the pre-existing condition of the facade and the interior.

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Fig. 1. 3D colorized point cloud of the church exterior

Fig. 2. 3D colorized point cloud of the church interior

Fig. 3. Architectural 2D drawing with the orthophoto of the wall paintings

B. Texturising the 3D model and the creation of the orthophotos

The most demanding part of the documentation process concerned the wall paintings whose complexity and level of detail presented a major challenge in terms of using the technology available.

A phase shift 3D laser scanner, Z+F IMAGER 5010C, represents the fastest and most precise method of collecting spatial data in the protection of cultural heritage. However, wall paintings sometimes call for us to take a step further, i.e. to venture into the field of microscanning, in other words to use special hand-operated systems for 3D scanning and photogrammetric methods, in order for a 3D model to be presented with as much detail as possible in terms of textures and actual colours.

The phase shift 3D laser scanner was used as a basis for all of the subsequent 3D scanning. With the help of the precisely measured surface of the walls, vaults and ribs in the shape of a polygonal 3D model, a foundation was created in order for a high-resolution and precision projection of wall paintings to be transferred to these surfaces in virtual and measurable 3D surroundings. This project combined almost all of the methods of the static acquisition of spatial data by using cutting-edge short and mid-range 3D technologies.

Along with the phase shift 3D laser scanner, a photogrammetric microscanner (Artec MHT) was also used, together with a calibrated camera (Nikon D200). Photos were orthorectified and combined to make up a whole with the help of a 3D model [5], in order to create the precise, virtual, and measurable palpability of the wall paintings, Fig. 3.

Orthophoto is the name for a measurable photograph, i.e. a group of photographs that when combined make up the whole. In order for it to become measurable, one must first carry out a photogrammetric mathematical process that is based on the so-called inner and outer orientation of photographs. When applied in a more professional manner, for scientific research or conservation work, one needs to use more sophisticated programs and 3D devices, as the emphasis here is put not only on visualization and presentation but also on the precise documentation of an ensemble (such as the sanctuary of the church of St. George in Lovran), Fig. 4.

Fig. 4. 3D polygonal model of the vault with textures

What was unique about this task was that a precise 3D polygonal model of all of the elements of the vault and the triumphal arch were created by using spatial 3D laser scanning, in order to be able to later paint the same surfaces precisely in space with the actual high-resolution colours using microscanning and photogrammetry.

The detailed orthophotos of the walls were created using the Mencisoftware z-map photogrammetric application. This software was used for its ‘’z-blend’’ function that enabled precise mosaicking of many orthophotos. It also has the ability for precise camera calibration, and single photo orthorectification, combining the high resolution photographs and high resolution point cloud. PolyWorks, Geomagic, Acute3D, MeshLab, CloudCompare and Agisoft PhotoScan were software used to build the 3D model, to colour the vault segments and to decimate the triangles, maintaining the high accuracy of the polygonal model.

C. The “unrolled” single-plane projection of the vaulting fields

Once the wall painting was projected onto a 3D plane that matched the actual one, Fig. 5, it was possible to use further innovative methods to present the wall painting or some portion of it in particular plane projections, but also in “unrolled surfaces” on a 2D plane, Fig. 6, Fig. 7.

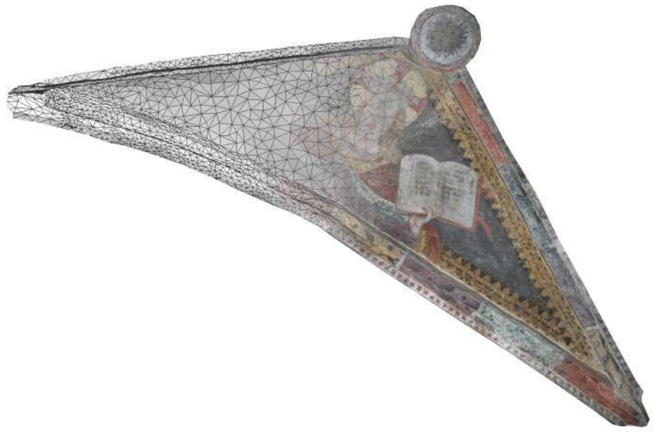

Fig. 5. 3D polygonal model of the part of the vault with the detailed textures of the wall paintings

Fig. 6. *Unrolled* 2D measurable orthophoto of the wall painting from the vault

Fig. 7. *Unrolled* 2D measurable orthophoto of the wall painting with marked position in the architecture plan

The mathematical method that was used refers to the plane projection of a number of smaller segments of the vault. The size of the segments projected onto their own plane is so minute that their projection does not cause the actual dimensions to diminish, i.e. it has minimal effect on the actual dimensions per length of an individual vaulting field. The size and number of the vault segments that are partitioned and projected onto the smaller planes depends on the precision necessary. In other words, the actual dimensions of the wall painting itself. Finally, all of these portions that are projected onto the smaller planes are put together into an ensemble to make up a so-called depiction of the vault in a single-plane projection.

The combination of PolyWorks and Agisoft PhotoScan software together with custom programming was used to define smaller projection segments of the vault.

Fig. 8. 3D polygonal model scanned with the 3D microscanner, Z-scanner 800

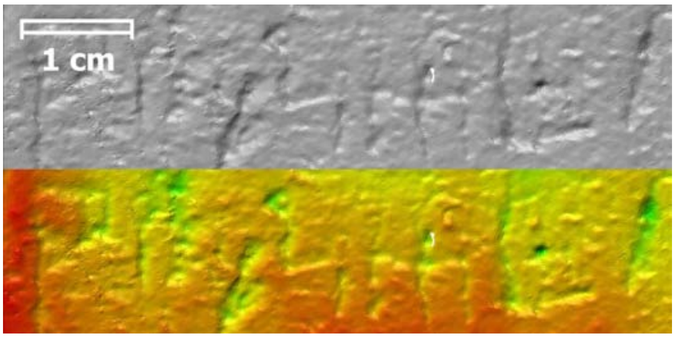

Fig. 9. 3D polygonal model scanned with the 3D microscanner Z-scanner 800 (the smallest detail recognition – graffiti)

D. Microscanning of the details

In order to obtain a very detailed 3D model depicting the small details and relief, a method of 3D microscanning was used. This method is much more precise than the classic photogrammetry when it comes to tiny reliefs on the very surface of the wall. The hand-operated 3D microscanner (Z-Scanner 800) with a combination of photogrammetric and laser technology was used. Its unique technical approach enables 3D scanning below the level of one millimetre in that the scanner can move while operating and can be referenced based on details on the very surface that is being scanned. The result of microscanning is the visible 3D texture of the surface of the wall painting. What can be seen is the technological characteristics of the wall painting such as the thickness of the brushwork, the imprinted and incised drawing, Fig. 8, (the details in the relief such as the halos, moulded directly in the plaster), as well as the incised inscriptions and graffiti, Fig. 9.

III. CONCLUSION

The methods applied shortened the duration of the research field work and enabled the creation of comprehensive conservation documentation on the condition of the heritage object in all of its segments. Such an approach, the documenting of a single building from macro to micro level proved very useful in terms of further analysis of it, valorization and presentation. The documentation thus obtained is used primarily for the purpose of creating a database regarding the condition of the wall paintings, specifically for the mapping of the technique characteristics, the deterioration and the treatments conducted. In addition, there can be no doubt that it will become the basis for further research, the development of renovation projects and the presentation of this cultural heritage.

IV. ACKNOWLEDGMENT

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