Edge Detection Algorithms in Mapping the Condition and Historic Phases of the Last Judgment Mosaics in Torcello/Venice

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Abstract. Whenever innovative survey techniques allow gathering detailed information about fixed building interiors, establishing the conditions, authenticity or the structural problems of historic built in mosaics rests a quite complex process. This paper analyzes the reliability of digital post processing techniques to support distinguishing among application methods, original and remade areas, and for detailed damage assessment. The results are destined to form an interdisciplinary repository regarding the Byzantine mosaics of Torcello as hearth of the Veneto-Byzantine mosaic school of the 13th c.

Keywords: Image Post Processing, Digital Repositories, Byzantine Mosaics of Torcello.

1 Introduction

Whenever nowadays more and more innovative survey techniques allow gathering detailed information about fixed building interiors, establishing the conditions, authenticity or the structural problems mining the stability of historic built in mosaics rests a quite complex process. A standardized method for the sector is still lacking, and the use of new technologies is limited and/or not scalable without the involvement of well-trained human experts. Among the large number of internal and external factors that hinder technically documentation and investigation of ancient interior mosaics *in situ*, in first place should be mentioned the high refractive index of the vitreous materials and the heterogeneity of the mortar bed that make useless the application of classical nondestructive methods as spectral and IR thermal visualization or sound tomography. Considerable drawbacks cause also the great dimensions and difficult to access positions.

The present paper focuses on this problematic and on the potential of digital image processing for its solution in the context of the opened 2018 and still ongoing second restoration campaign of S.Maria Assunta cathedral in Torcello, Venice, part of the

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UNESCO world patrimony[1]. After the introduction to the historic background of the monument, and the challenges its study and conservation hide, in the second part are outlined the limits of the approaches adopted to the moment. The third section analyses the reliability of digital image processing techniques to support distinguishing among application methods, original and remade areas, and for detailed damage assessment. The last section informs about the next step of this research: an interdisciplinary digital repository regarding the Byzantine mosaics of Torcello as hearth of the Veneto-Byzantine mosaic school of the 13th c, whose works are spread in Italy (Venice, Rome, Florence, Palermo, Messina), in Greece (Fokida, Chios, Daphne), in Turkey (Istanbul) and Germany (Potsdam, Friedenskirche).

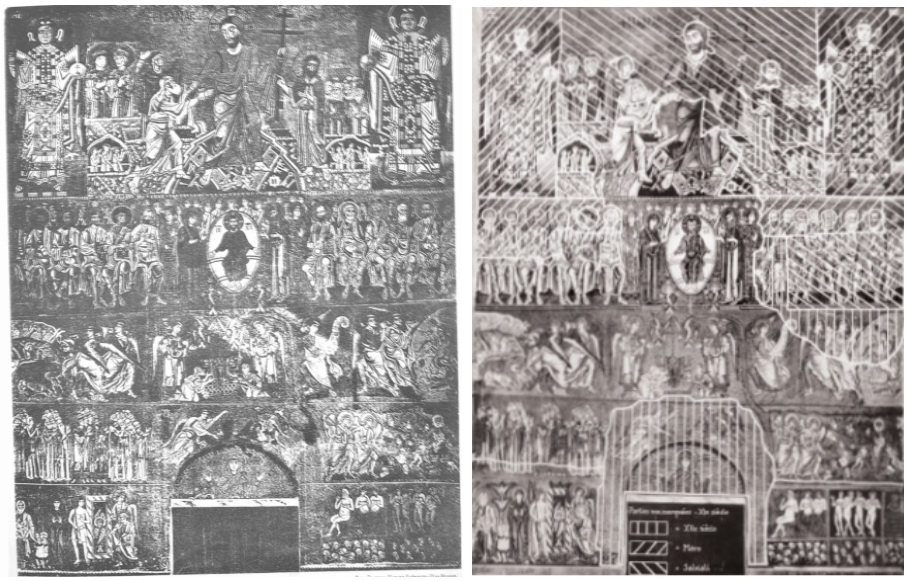

Fig. 1. Left: the earliest known photo of the west wall, a photo incision by Sherer Nabgolz & Co, Moscow, published 1884 by (Pokrovskij, 1887, p. 290) that precedes with decennials the earliest Italian photo of these mosaics by Giorgio Naya, Alinari, 1915. Right: a scheme of the restorations of the Torcello mosaics by (Andreescu, Torcello III, 1976, p. fig. 1).

The importance of S.Maria Assunta cathedral in Torcello and its mosaics can be explained firstly with their relation to the antiquities of many other European countries, once part or in strong relation with the Byzantine empire, which are interested to deepen existing knowledge on their history in more technically profiled sectors in order to reach more balanced, scientifically solid and coherent concepts. The mosaics on the western wall are unique for the unprecedented in Byzantine art composition of the Descent into Hell, combined with the Last Judgment (Lavrent'eva, 2014, pp. 105-158). And if the presence of the Last Judgment scene there can be considered traditional (the Last Judgment on the western wall of the main building of the temple or in the narthex

[1] http://whc.unesco.org/en/list/394

is found in many churches of the middle Byzantine period: in St. Stephen (9th c) (Pelekanidis S., 1985, pp. 6-21, fig. 4, 5, 7) and Panagia Mavriotissa (Castoria, end of 11th - beginning of 12th century) (Pelekanidis S., 1985, pp. 66-83. fig 14-18)(Pelekanidis S., 1985, p. 66-83. Fig. 14-18), Panagia ton Chalcheon (Thessaloniki, 1028) (Brenk, 1966, pp. 119-122, fig. 3), (Tsitouridou, 1985), in the Athenian Zion (Georgia, end of 11th century) (Virsaladze, 1984, pp. 13-14, fig. 10.2), in the St. Nicholas Cathedral (Veliky Novgorod, after 1118) (Lifchiz, Sarab'ianov, & Zarevskaja, 2004, pp. 489-495) etc.), the Descent into Hell in the Byzantine system of temple decoration was traditionally part of the festive cycle. It could be located in the narthex or in the naos, often in the dome area with Christmas, Baptism and Crucifixion, or only paired with the Crucifixion (as in the mosaics of the catholicons of the monasteries of Hosios Lucas in Fokida (1030-1040-ies), Nea Moni in Chios (1049-1055), the Assumption of the Virgin in Daphne (1100 circa) (Kartsonis, 1986, pp. 214-221, fig. 81-86), but never on the western wall together with the Last Judgment.

As the major part of the mentioned original Byzantine mosaic decorations has been lost, the vast composition of the Last Judgment in Torcello[2], in whose lower registers are still conserved intact Byzantine works, offers to restorers and scientists a rare possibility to can look inside into the various artifacts' structures/tissues to study their constituents, technique, and technology. Their digital documentation, the organization, updating and complementation of the acquired data in an interdisciplinary digital repository constitutes the main scientific goal of the work reported here. Its other actuality stays in the selection of the most adapted digital filters for the image processing of the collected images in support to their integrated study and analysis.

2 The Limits of the Investigative Approaches Adopted in the Past

The study of the mosaics of Santa Maria Assunta in Torcello goes back to the second half of the 19thc and is reflected in an extensive body of publications reported by (Lavrent'eva, 2014, pp. 40-54), where methodological guidelines of the research follow each other for two main periods.

The first stage can be characterized by the desire of scientists to determine the origin of the mosaics of all three areas of the Basilica and the cultural appurtenance of their masters on the basis of few stylistic "clues" (Lavrent'eva, 2014). The mosaics on the western wall were dated from 9th to 13th century and attributed to Western masters from Veneto or Ravenna with the exception of O. Demus who retained them the work of a Greek artel (Demus, 1988, p. 28).

The second period started end of 1970s and was facilitated by the scaffold constructed in occasion of the first restoration campaign of the Torcello cathedral when

[2] H 15 m x W 9.41 m = 141.15 m^2 surface area

also a detailed analogue photographic documentation was provided. During this restoration[3] I. Andreescu found in situ evidence to refer the initial part of the mosaic ensemble to the time around 1100, and to attribute it to a Byzantine workshop (Andreescu, Torcello I-II, 1972); (Andreescu, Torcello III, 1976); (Andreescu, Les mosaïques, 1981). Basing on historic sources, she drew up a detailed chart of the mosaic repairs and fakes of the western wall (Fig.1, right), of the southern chapel and the main apse (the initial stage of decoration around 1100— "the first workshop", medieval remakes of the late 12th century — "the second workshop", fragments of the restoration of Modern times). Dating the original ensemble in the time around 1100 for long remained a priority (Andreescu, Torcello I-II, 1972) however, in her later works she, relying solely on the results of chemical analysis of tesserae, prefers to date more broadly the mosaics of the western wall and the southern chapel in the second half of the 11th c (Andreescu-Treadgold, I primi, 1997, p. 89); (Andreescu-Treadgold & Henderson, How does, 2009) for the following reasons:

- The glass *tesserae* of Torcello were used in mid 11th century in Greece and Constantinople (e.g., in the images of Constantine IX and his wife Zoe next to Christ in the south gallery of S. Sophia in Constantinople).
- In later mosaics (John, Irina and Alexios Komnenos in front of the Mother of God, ibid. 1118-1122.) the *tesserae* are quite different in chemical composition, comparable only with mature 12th century works (the mosaics of the "second workshop" in Torcello or in the cathedrals of Sicily). (Andreescu-Treadgold, I primi, 1997, pp. 101, note 12).

Chemical analysis is certainly becoming a priority in the study of historic mosaics, but it cannot be used alone for a precise dating (within one century): the production of glass smalts in the Byzantine period is relatively little-studied and our knowledge about - not homogeneous, hence it can help only to distinguish the characteristic compositions of *tesserae* from different epochs[4]. Moreover, it is worth considering that the mosaics in S. Sophia used by Andreescu as reference certainly have been more times remade, therefore they cannot be a decisive argument in favor of the dating of these in Torcello (Stoyanova, Il mosaico con il volto della Vergine nel Museo Civico medievale di Bologna: originale, copia, replica o falso?, 2015, p. 129). In the same time, such important factor as the mortar bed and its deformations as sign of remakes or damage has never been considered to the moment in the dating of the Last Judgment mosaics. Insufficient attention has been paid also to the purely art technical peculiarities as regularity of the mosaic pattern, the relation between *tesserae* and mortar bed level, etc. Thus, whenever the second stage in the exploration of the mosaics in Torcello has been marked by an appeal to the technical and technological aspects of the mosaic decoration which has become a priority to the moment, it couldn't shift to an integrated, scientifically solid approach. In overall, the most substantial obstacle for the objective attribution of the Torcello mosaics continue to be the numerous restoration interventions and replaced original mosaic pieces.

[3] The first and second restoration were directed by Giovanni Cucco (Procuratoria of St Mark church, Venice). In the 1980-ies his work was assisted by Paolo Mora (ICCROM).

[4] For example: early Christian mosaics, mosaics of the 9th-12th centuries, later 20th c.

3 Methodology, Results and Discussion

In occasion of the second conservation & restoration campaign of the mosaic decoration started October 2018, experiments were carried out by the restorers to the end to overwhelm the limits of former approaches. They match in first place objectivity and precision in the empirical evaluation of original and remade areas, and in second - the reliability of digital image processing operators to support automated distinguishing between application methods, and for detailed damage assessment. The method is based on the comparison among the issues of the empirical condition survey and theoretical study - from one side, and from the other - of the high resolution digital documentation elaborated to the purpose and the digital models extracted from it.

3.1 Condition Survey

In ancient mosaic decorations built in architectural ambient, the condition survey (CS) is a complex process whose function is to lay out damages or their symptoms not directly perceivable from the visible appearance, as well as to clear their dependence from the architectural configuration and other local factors. It is an essential phase in the scientific documentation and in long term monitoring of less or more rapid deformations of the originals occurring in response to the building or ambient conditions.

In Torcello, during the second restoration campaign as in the first, the CS was performed *in situ* detecting point-by-point the entire surface, and identifying by means of auscultation, with the help of stethoscope and a tuning fork, the areas of degradation focusing on:

- Support type, its structure and preparation.
- Chemical and morphological composition of mortar (fillers and binders).
- Structure of mortar- and of mosaic-layer.
- Application technique(s).
- Presence of non-original inserts or of restoration integrations and their characteristics; mosaics realized in different techniques, in different periods.
- Eventual mycological contamination in the ground and in the mosaic layer.
- Presence of aging symptoms (crackles) and their typology.
- Status of conservation of the single strata.
- Art-technical and art-technological characteristics and their relation to a determined epoch, school, master.

The main objective was to elaborate an updated digital scientific documentation in support to the conservation, material characterization, virtual reconstruction, dating and attribution of the different phases in the execution of the mosaic as component of S. Maria Assunta' interior decoration.

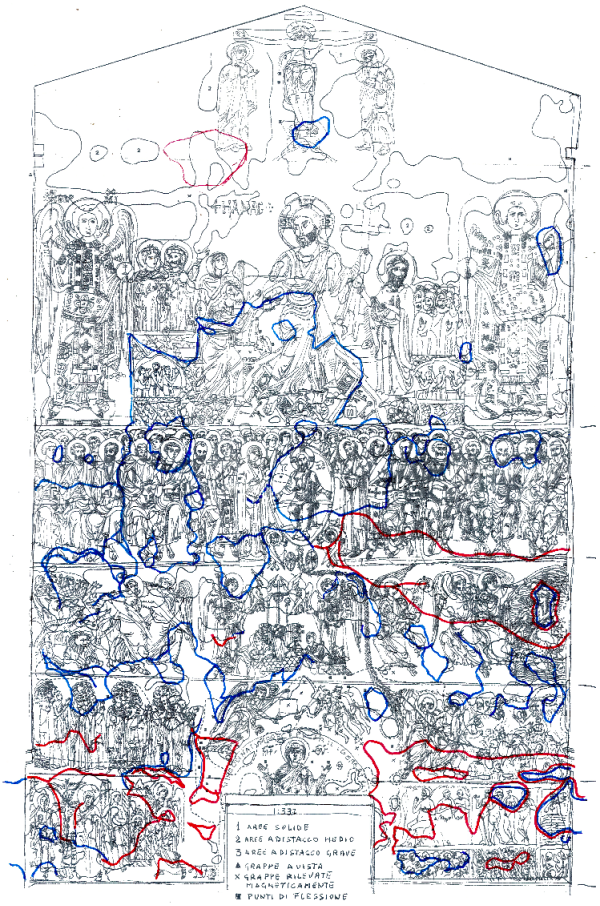

Fig. 2. One of the Condition Survey Maps, October 2018. Areas circumscribed in red indicate "pronounced detachment", those in blue – "minor detachment" between the masonry and the *rinzaffo* or between the *rinzaffo* and mortar bed of the *tesserae*. Chart – G. Cucco and the Author.

In assessing the type of perceived acoustic response it was possible, with a certain approximation, to define the general situation. The areas were detected metrically and reported, in their geometric configuration, on graphic maps of appropriate scale in order to can have a global view of the situation and the possibility to compare the maps form October 2018 with this made in 1979 and with related maps of the architectonic structure. The comparison evidenced that the mosaic on the west wall, even after the last consolidation in the 1980-ies, continued to be damaged by water infiltration both from the soil and from the roof. The infiltrations of meteoric water from the roof contributed to the formation of crystallization cycles between masonry and plaster and between plaster and mosaic support. The mosaic mantle presents aspects of modest degradation, not always denounced by swelling. They are constituted by the lack of adhesion between the mosaic surface and the masonry support; between the mortar bed and the

underlying plaster of lime and by detachments, much more extended, between the latter and the masonry. In the lower registers the damage is also due to the capillary rise of salt water.

3.2 Digitization

In the occasion of the second restoration campaign was undertaken a detailed digital documentation of the wall mosaics together with upgrading of historic, technical, analytical, and other related data subdivided in three main levels and following sublevels:

Historic/documental sources: historic descriptions, drawings, prints, maps, publications, documentation of the Torcello cathedral and related Byzantine mosaic complexes.

Mosaics of the east and of the west wall: iconography, chronology, prototype(s), application techniques, cultural provenience of the masters.

Fig. 3. The figure represents an example of parallel detachment between the brickwork and the *arriccio* (←) and between the *arriccio* and the mortar bed(→).The image was taken from the base of the mosaics, after the removal of the marble cornice.

Status of preservation: types of materials used, construction techniques (from design to application), organization of the work, history of restoration interventions, results of scientific analyses of selected samples, degradation due to environmental agents, CS-maps.

For the digital photos of the mosaics were used highly sensible ocular and non-ocular (stereo) magnifiers and endoscopes. For reasons of property and for the unpublished novelties acquired during this campaign, this digital repository for the moment will rest

off-line and will be accessible only with permission. At any rate it constitutes a modern, unprecedented documentation of the Torcello mosaics, a precondition for a new step in their study which is impossible with the analogue pictures used in the past. As the scaffold hindered the acquisition of the entire mosaic surface from near distance, after its demolition macro images (Stoyanova, Stoyanov, & Pavlova, Non Algebraic , 2018, p. 126) will be taken with the help of drones.

3.3 Mapping of Mortar Bed Deformation

A factor of primary importance considered in mosaic authentication and attribution by human experts is the surface smoothness and the relation between *tesserae* and mortar level. This relation is indicative of the application technique (direct or indirect). The peculiarities of the mortar bed reveal to the trained eye the professionalism and working technique of the masters, art-technical and art-technological characteristics of the mosaic art work; they help to assess the status of conservation and to individualize the presence of later interventions. The experience demonstrates that the symptoms of natural aging affecting over time the physiochemical (facture, brilliance, colour) and stratigraphic / spatial consistence of a mosaic work, due to their complexity, result the most difficult to imitate and, properly for this reason, constitute a reliable reference point for material characterization and attributions: much more than the chemical composition of glass *tesserae* which are easy recyclable. An intact mortar bed certifies the originality of the mosaic work, while a deformed one is sign of later modifications and/or of replaced originals.

To the end to distinguish automatically the original from the secondary areas in the realization of the mosaic and their precise extension, the direct from the indirect technique of application, among levels of artistic quality and degrees of preservation; to localize presence of damage, its typology, etc., we carried out some tests with existing Edge detection filters (Management Association, 2018, p. 1015). Edge detection is a common image processing task which detects and extracts the discontinuities in image brightness, in our case as indicator of discontinuity of the surface smoothness which corresponds to the boundaries of tesserae within the analyzed mosaic piece. For the above listed single or interdependent variables, the most computationally simple and broadly applicable among the existing edge detection filters resulted the Gradient directed algorithm, the Gaussian differences, and the Sobel-Feldman algorithm. They demonstrated satisfactory practical performance and reliability as well as close correspondence to the results obtained during the CS carried out by experienced restorers.

Gradient directed algorithm. For regularized estimation and selection of surface smoothness and colour, a threshold gradient directed regularization approach was applied. As known, gradient operators usually contain smoothing processing and calculate the magnitude and/or gradient direction using the center differences which makes them practical to use larger window size in the partial derivatives. Moreover, using more gradient directions provides possibility for a much finer measurement to study the patterns of the distribution of the gradient directions. (Fig.4,1st line, right) shows the result

of its application on a digital mosaic photo, comparable to the paper imprints taken manually from mosaics.

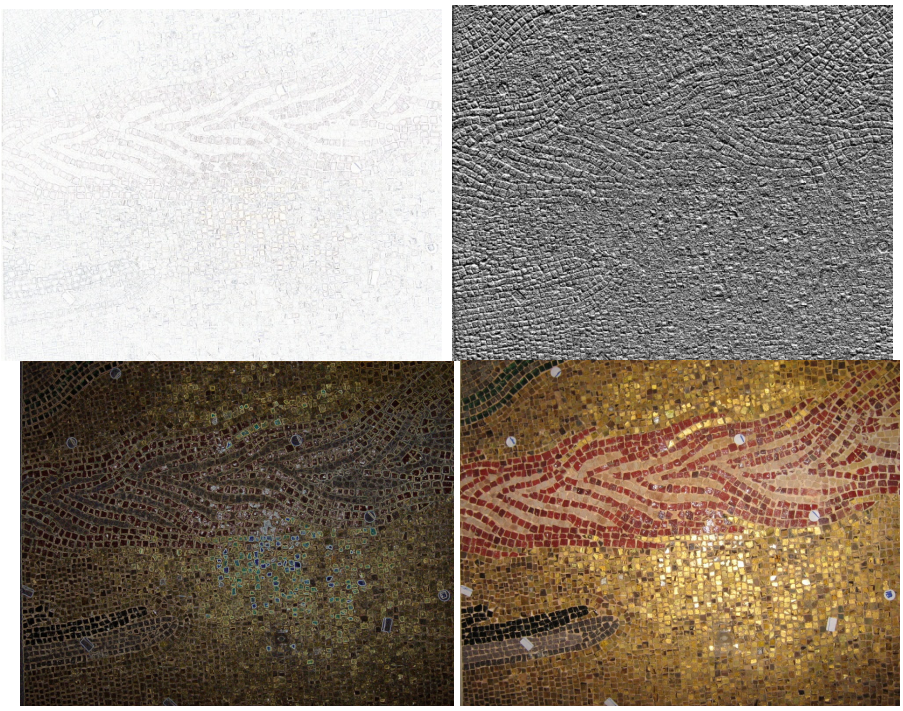

Fig. 4. 1st line, left: the result of the Gaussian differences operation; right – of the Gradient directed algorithm.2nd line, left: the computation of the Sobel-Feldman operator on the same image (2nd line, right) documenting original (top) and restored (bottom) parts. The aggregates in blu/green indicate interstices higher than the smalts, typical for a direct, non professional application. In fact, they exactly correspond to areas restored in 1758.

Gaussian differences. As a feature enhancement algorithm, the difference of Gaussians was utilized to increase the visibility of edges of the Torcello digital images (Fig.4, 1st line, left). The thickness control of this operator reveals very useful in visualization the relation between tesserae and mortar bed level. Whenever a wide variety of alternative edge sharpening filters operate by enhancing high frequency detail, the Difference of Gaussians algorithm was preferred because it removes high frequency detail that often includes random noise, rendering this approach one of the most suitable for processing images with a high degree of noise: the high refractive index of gold smalts in our case. A major drawback to application of the algorithm is an inherent reduction in overall image contrast produced by the operation (Lindeberg, 2015).

Sobel-Feldman algorithm (horizontal and vertical). Angularity and surface texture of aggregated tesserae are important morphological characteristics of a mosaic and have

great influences on its performance. In respect to Scharr, Prewitt, Roberts Cross and other gradient operators, the Sobel-Feldman special direction-dependent edge detection resulted the more adapted for the mosaics and was employed to obtain the out-lines of the aggregated tesserae. The image at (Fig.4, 2nd line, left) illustrates the result of a Sobel–Feldman filtering: a coloured 2D map of the gradient at each point, with the areas of high gradient (interstices higher than the tesserae) visible as white lines.

Fig. 5. Left: Normalized x-gradient from Sobel–Feldman operator; right: Normalized y-gradient from Sobel–Feldman operator of the same image (Fig.4, 2nd line, right)

Besides the micro imaging tests, very useful for the assessment of the entire wall mosaic resulted a digital model produced in a precedent 3D documentation campaign when the entire Last Judgment has been scanned using a device based on Frequency Modulated Coherent laser radar Technology, the Leica Geosystems LR200 system (Fig. 6) (Balzani & Callieri, 2015, pp. 6, fig. 4). Thanks to an improved time-of-flight solution, the frequency modulation of the optical signal of Leica LR200 has allowed sampling accuracy of around one or two orders of magnitude higher than the one of standard time-of-flight solutions. The reliefs visible on the grey scale digital model (Fig.6, left) extracted from it, exactly correspond to the areas were original mosaics have been replaced with new ones (Fig.1, right). Obviously, these changes in the surface inclination are due to the irreversible changes in the mortar bed caused by the extrapolation of old and application of new mosaic pieces.

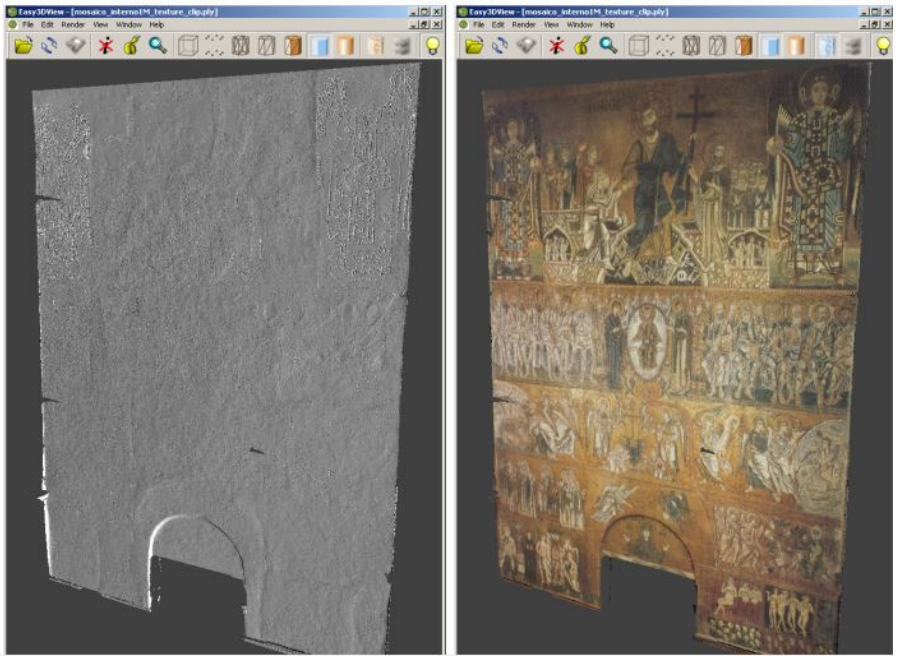

Fig. 6. The average inter-sampling distance used for the scanning of the entire west wall with Leica LR200 is around one centimeter (i.e. the typical one used with time-of-flight devices).

4 Conclusions and Future Work

The digitization of the Last Judgment mosaics and their post processing allowed to distinguish in greater detail the different phases of restorative interventions and delineate with more precision their extension. The results showed that repairs and fakes of the mosaics on the western wall have been carried out in much more phases than those indicated on the chart designed by Andreescu (Fig.1, right), sometimes interesting also older interventions, hence their map needs fundamental upgrading. Respectively the attributions and other related interpretations of the single areas needs revision and a profound analysis on a more variegated and complete referential base. Therefore our future work is focused on the digitization of the mosaics on the east wall, to the end to accomplish the initiated interdisciplinary digital repository and make it possible to create deep analysis, based on the information, gathered from the related to Torcello Byzantine fresco and mosaic decorations on the Balkans (Ohrid, Skopie, Sofia, Fokida, Chios, Daphne), in Istanbul, Kiev, and from those belonging to the Veneto-Byzantine mosaic school of the 13th c located in Italy (Venice, Rome, Florence, Palermo, Messina) and Germany (Potsdam, Friedenskirche).

On the subject have already been organized two workshops with the mosaic restorers of Potsdam, Friedenskirche[5] concerning iconography, stile, working and application techniques, relation between type of detachment and mosaic support or chemo physical characteristics of employed materials, between the regularity of the surface and the period in which the mosaics have been applied etc.

In a further stage the work on the repository will continue with implementation of service for automatic sharing of artefacts (Kaposi, et al., 2013), (Márkus, Kaposi, Szkaliczki, Luchev, & Pavlov, 2015), (Luchev, et al., 2016), (Nagy, et al., 2016) and full collections (Pavlov, Paneva-Marinova, Goynov, & Pavlova-Draganova, 2010) in other digital libraries (Pavlova-Draganova, Georgiev, & Draganov, 2007) (Pavlova-Draganova & Pavlov, 2011), (Márkus, Kaposi, Szkaliczki, Luchev, & Pavlov, 2015) (Márkus, et al., 2017)

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