ADVANCED METHODOLOGIES FOR SURFACE ANALYSIS : METHODS, COMPARISON AND MONITORING OF THE MOSAIC SURFACE FLOOR OF THE ST. MARK'S BASILICA IN VENICE

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ABSTRACT

This paper describes the phases of the research[1] conducted to generate a high resolution model of the mosaic floor of St. Mark's Basilica in Venice. In order to perform accurate and effective scheduled maintenance, competently executed by the personnel of St. Mark's Basilica, it is necessary to get over the dichotomy that is generated between the site system cost and the time for the realization of the participations of restoration. Use of high resolution digital orthophotos makes it possible to reduce both of the introduced aspects. The research finds, beyond the methodologies used for the realization of the interventions, the models of comparison of altimetric control data temporal series of interventions on the floor executed since 1980. It finds a comparison between complex surface models realized to leave: from the data originating from historical levelling, control data realized with digital level Leica NA3003, from point gains with digital photogrammetric autocorrelation by means of high resolution photos taken with a Rollei DB44 camera,
laser scanner survey conducted with a Leica HDS 3000.

1. INTRODUCTION

The term "mosaic" is used to describe the decoration of an architectonic surface using small stones, fragments of terra cotta or glass, laid side by side and firmly secured onto a layer of plaster to form a flat surface decorated in geometric or figurative patterns. The term has an uncertain etymology but it likely derives from the Greek word for muse (μουσα), which appears in Roman literature in the Scriptores Historiae Augustae, attributed to Spartiani on the life of Pescennius Niger, in a passage in which the portrait of the emperor is called *pictum de musio*. The exact instructions for creating a floor mosaic, left to us by Vitruvius (VII, i) and Pliny (Nat.hist., XXX VJ,186-7), are documented in a large quantity of original records. Preparation of the mosaic ground must be done on a completely level, dry and sound surface. The first layer was the "statumen", tightly-packed pebbles and rock; on top of this layer was 25 cm of mortar of three parts fragments of terracotta and one part lime called "rudus", and finally the nucleus, the 12 cm layer of three parts smashed tiles and bricks and one part lime cement. The surface of the tesserae embedded into a top layer of plaster was polished and in turn made compact and resistant by a final layer of marble dust, sand and lime. A general rule was that artists would procure the materials for the tesserae of their mosaics primarily on the site where the work was executed; foreign materials had to be used for colours that couldn't be found in local stones. In the finest mosaics of the great art cities, artists used fragments of stone and marble imported for use in architecture. We begin to find glass tesserae in the oldest mosaics, but in St. Mark's, constructed in the 1st millennium, there is the influence of the method that began at the end of antiquity, namely the "carpet" mosaic (fig. 1) where the entire floor is scattered with geometric patterns such as squares, rectangles, diamonds, octagons, hexagons, semicircles and a range of subjects in every geometry, pagan-style birds and animals with a new symbolic significance attributed to them by Christian ideals. Skipping a few centuries and following the customs of religious Byzantine architecture, the mosaicists of St. Mark's respected the principle of division between the earthly part (floor-walls) and the celestial part (vaults and domes) whose intention and function are distinguished by the various facing materials used on the walls. The upper part of the building displays a visibly celestial and metaphysical appearance lent by the gold leaf mosaics while the lower area underscores earthly qualities due to the massive quantity of marble on the walls and the floor, a veritable 2,100 m^2 "carpet". Side by side in the floor of St. Mark's Basilica we find *opus sectile* (marble tiles of several colours laid to form geometric shapes) and *opus tessellarum* (marble and glass tiles laid to create floral or animal motifs) with a net predominance in St. Mark's of the former over the latter. Both techniques date back to antiquity, as shown. In St. Mark's Basilica, evidence of the great wealth of the doges is displayed in the wide use of precious marbles as well the skilled craftsmen who, in all probability, were brought to Venice from Constantinople or Byzantine Greece, as were the architects and mosaicists. The floor was created using various panels, of different sizes, with geometrical and figurative motifs; other surfaces in brightly lighted areas, such as the areas under the Pentecost and Ascension cupolas, are faced with great slabs of Greek Proconnesio marble, one of the first marbles ever to be cut into sheets.
The patterns are organized in a regular and methodical way and the location is as symmetrical as possible. In this strictly geometrical layout, we find symbolic animals and floral motifs depicted at the edges. Particularly visible for the chromatic beauty and elegance in the execution are two pairs of peacocks in the right, or southern, nave, preserved virtually intact and object of the first 3D tests at a 1:1 scale.

2. Monitoring of the Basilica

Since the late 1980s, the Procuratoria di San Marco (*Protectorate Board of St. Mark's*) decided to monitor eighty different control points on the load-bearing structure, mainly on walls not faced with marble (crypt and façade intrados) and

[1] This research is in part financed with PRIN-2002 and 2004. The survey campaign has been carried out with the contribute of F. Prandi, G. Monti, L. Taffurelli, S. Morandi.

above the marble wall facings, using high precision levelling. This was done to periodically monitor the structural movements, in view of the undulation of the top layer of floor mosaic.

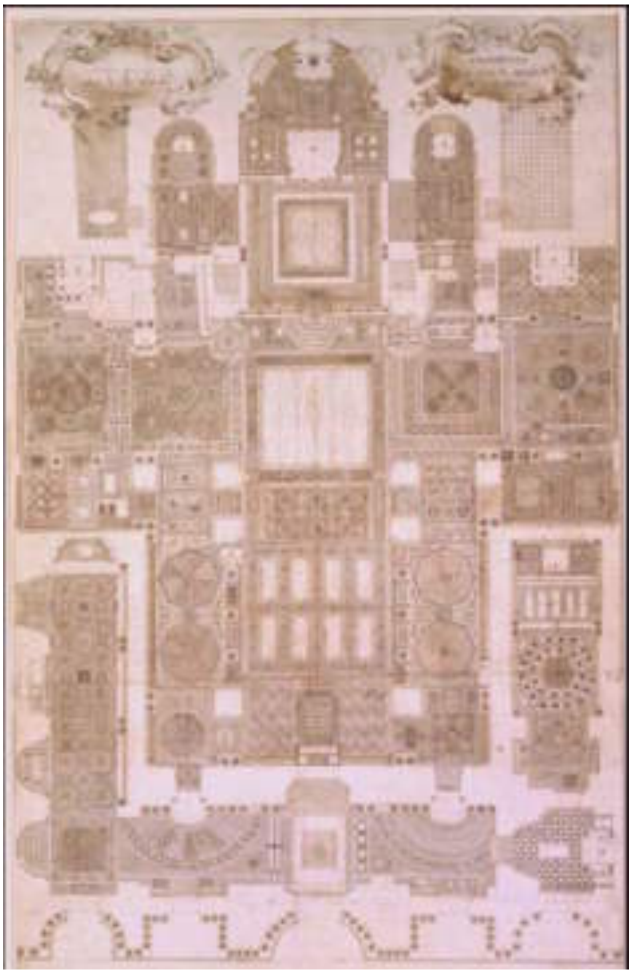

Figure 1. Sanguine pen drawing of the old mosaic floor of St. Mark's, work of Antonio Visentini

The movements are caused by past interventions, such as overloads relating to overlapping the wood and iron on the Byzantine domes done in the 13th century, as well load changes due to different settling of the sand screed of the subfloor and the foundations, the continuing effects of small terrestrial shocks, tide levels, flooding, and finally, subsidence that involved the entire northeastern Adriatic. Quarterly controls were conducted for several years to differentiate movements related to the effects of seasonal tide cycles from structural movements using a reference point located in the crypt.
Monitoring is currently done annually. Over the years it was found that the Basilica moves largely due to seasonal changes, but the annual cycle is stable and the visible undulations of the floor cannot be correlated to movements in the Basilica (fig. 2, V.T. 89/04). After discounting abnormal movement due to certified causes (damage), the magnitude of the shifting varies from point to point and has not exceeded 1.5 mm in 15 years.
Over the last few years, the floor has been monitored and inspected in more than 1,000 points using precision level techniques (fig. 3). Its movements are quite sensitive to the upward thrust effects of tides (lagoon flooding). The undulations in the floor play an important role in the mosaic restoration processes.

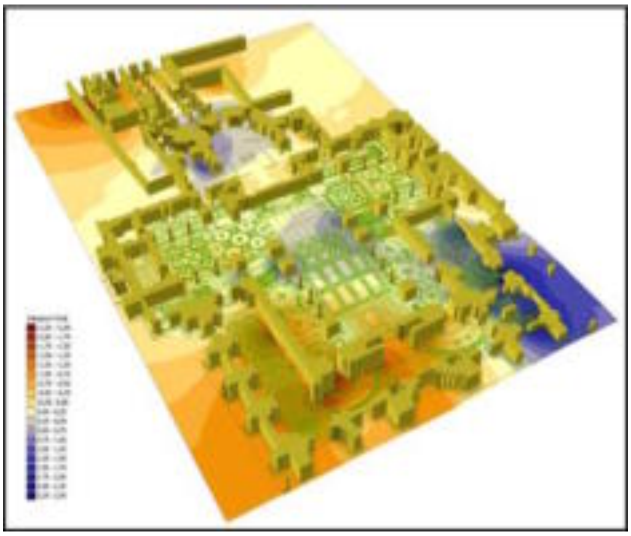

Figure 2. Control of the Basilica. Total variation of the structure in the period 1989-2005

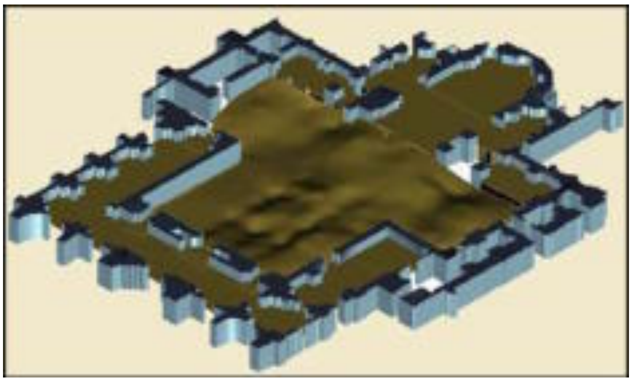

Figure 3. DTM of the floor, calculated on 1000 level points

3. Survey and representation of the mosaic layer

The floor mosaic lies on the subfloor of St. Mark's Basilica, affected in turn by its uneven qualities. Mosaic art had long been considered an art of little value in antiquity. Until it was recognized with an artistic value comparable to other forms of representation (painting and sculpture), mosaic restoration meant merely making improvements to the surface, modifying borders and apparatuses. The undulation of the floor was eliminated and the mosaic layer was lifted and reworked, sometimes following the original design, but it may have been changed to meet the style and techniques of the period. In the 16th and 17th centuries, great painters influenced the work of mosaicists, who merely reproduced paintings in mosaic, using a "cartoon" to transfer the drawing onto the wall. Large canvases by Paolo Uccello, Tintoretto, Veronese, Andrea del Castagno, Mantegna and Titian were used as the basis to recreate mosaic floors in poor conditions. In the mid 1800s, the efforts of St. Mark’s “proto” Pietro Saccardo -encouraged by John Ruskin and Alvise Zorzi to strictly respect its history -developed the concept of conservation in mosaic restoration and maintenance and attempted to identify the best method to represent and maintain the complexity of the monument in all of its forms. The search for a method to immediately describe the undulation, in view of a use on site, led to a preference for 3D representational models that were gradually improved upon until achieving the current execution of the digital 3D orthophoto on a 1:1 scale. The comprehensiveness, low-cost, precision and rapidity achieved in the survey of a 40 m^2 portion of floor extended application of this method to all 2,100 m^2 of mosaic floor surface of St. Mark's.

4. 3D digital orthophoto — Test area

The 3D digital orthophoto is obtained with:

- images taken with a Rollei DB44 Metric photogrammetric camera at 16 million pixels (0.009 mm), with calibrated f/40 lens at a height of 2.1 m
- support of the blocks on topographically-determined control points,
- solution of the blocks by TA to bundle adjustment
- construction of the DTM for matching images.

The orthophoto achieved in this way, with ground resolution of 0.5 mm, can record the arrangement and conditions of every tesserae of the mosaic and at the same time, provide information on the level of the entire floor.

The first area tested was the peacocks, using an orthophoto printed onto a transparency at a 1:1 scale to see the level of geometric matching and develop the chromatic matching, whose results were very satisfactory. The next step was survey of the area located in the right arm of the transept opposite the entrance to the Camera del Tesoro, inaccessible to visitors due to the restoration works underway to repair the deterioration that compromised the mosaic surface (fig. 4).

The system used is similar to aerial photogrammetry: the camera is mounted on a trolley at a distance of 2 meters from the object, enabling coverage to the ground of 4 m^2 for every photogram for a total of 27 images, divided into three strips. Based on the coverage of each photographic image and their overlapping, the planned distribution of the support points surveyed topographically with a completely motorized TCRAI 103 station and with a high precision Leica NA3003 digital level to limit the positioning error of the points to a few millimetres and less than one millimetre in quota. There were a total of 70 support points, nine per image and distributed evenly to form a 85 x 75 cm grid of the survey area. All were realized in the calculation to orient the images by aerial triangulation for bundle adjustment, obtaining a hyper-determined and controllable model.

In this phase (May 2004), APEX PCI 7.0 software was used to realize the orthophoto and the 3D model and subsequently, the ArcGIS 8.1 and ArcINFO 8.0.2 (ESRI) suite was used to view and manage the information contained in the DTM.

The 27 images were imported into the APEX system in Tif format without compression to obtain the best resolution necessary for an orthophoto at 1:1 scale. Thus, the software handled a large amount of data because every image averaged 48.7 MB, for a total of 1.25 GB of information. The programmes used to view all the images at the same time use the "image pyramid" with eight levels of gradually decreasing resolution, according to the degree of zoom activated.

Construction of the DTM was set on a very dense mesh of nodes (15 x 15 mm) whose programme measures the quotas on the images and uses interpolation to determine the spaces between the points, so that the surface is uninterrupted and as close as possible to reality. The match between the DTM and the real progress of the mosaic depends on the grid on which it is created. A satisfactory equilibrium can be achieved between the calculation times and the size of the grid. It is also possible to establish the level of smoothing of the surface and insert break-lines where needed.

In this test area, the mosaic displayed major deterioration with swelling and abnormal breaking in the surface, due to elevated tension between the elements making up the support layer of the tesserae. These swells are due to chemical reactions in the mortar with the sea salt rising to the surface from the subfloor, leading to a rapid deterioration in its conditions after years of use.

The positioning error was negligible and the maximum error between the topographic quotas of the support points and the points measured on the model after triangulation and after creation of the DTM are less than one millimetre. After creating the DTM, ArcGis and Arclnfo can extract all the information that concern the altimetric progress, such as the most significant sections, by designing templates that - in this case - were compared directly on site with the surface of the floor to check the accuracy of the model. A print out on non-warping transparent paper was placed on top of the mosaic tesserae and the match turned out to be very accurate.

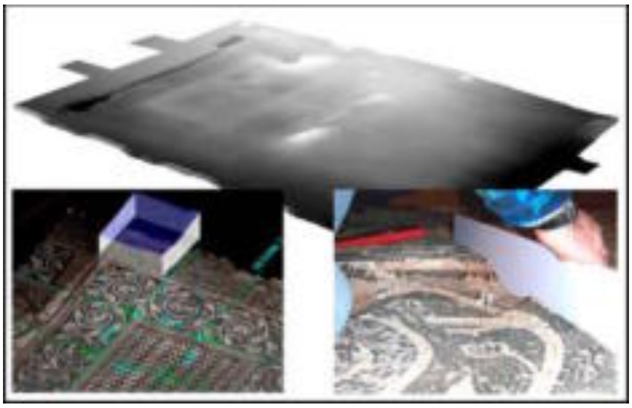

Figure 4. 3D model of the floor (DTM) to restore

5. Digital 3D orthophoto of the entire mosaic floor

The excellent feasibility, utility of the orthophoto for restorers and the ability to extract profiles automatically from the photographed surface extended the use of photogrammetric images across the entire floor. A team of three or four researchers, with the help of the personnel at the Procuratoria, planned the research between September 2004 and April 2005, taking into account religious festivals and peak tourist flows. Most of the work was done after closing hours of the Basilica.

The strips followed the instructions provided by the test area in the coverage and support points. The overall number of photograms acquired at a scale of 1:50 provide a ground pixel of 0.5 mm. A total of 1909 photograms were taken, plus necessary integrations, and the number of support points was 2,240, much higher than necessary but indispensable for making appraisals on the precision possible by decreasing the number of control points and keeping them as linking points. Rectification of the narthex began in the north area, 103 photograms on 190 support points, since it was more subject to movement of the mosaic in recent years.

The images were handled using the updated Socet Set 5.2.0 software by BAE Systems and Bingo and viewing with the ArcGis and Arclnfo suite.

The boundaries between the floor and risers that appear in the perimeter models at the walls, columns and otherwise must be accurately determined. This is done by observing the models through a stereoscope and marking off the space where the points should be that form the DTM and the 3D orthophoto.

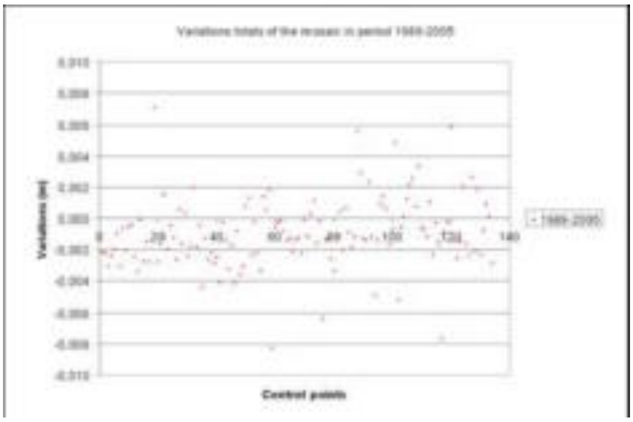

Figure 5. Total variation of the narthex floor in the period 1989-2005

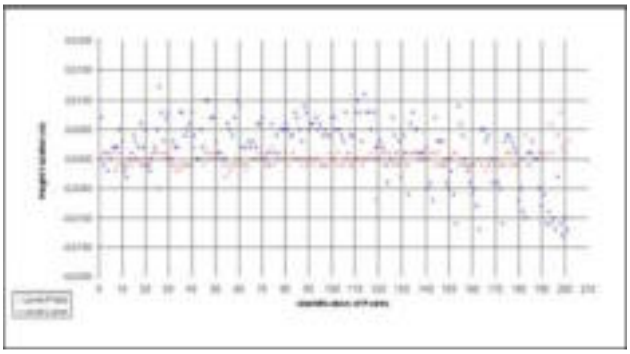

Figure 6. Photogrammetric control points. In ordinate are given the values of the remainders between of level height and DTM generated by photogrammetry and laser system.

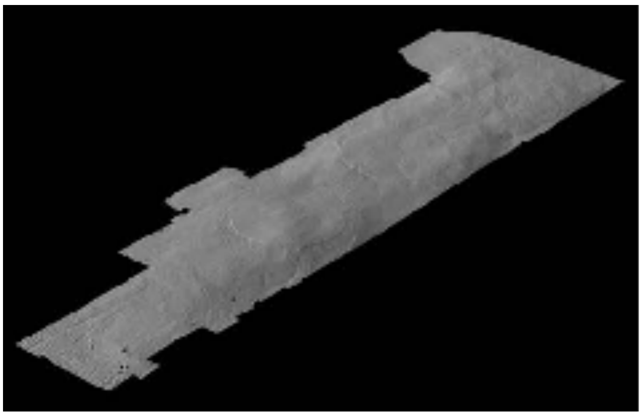

Figure 7. DTM generated by Leica HDS 3000

Figure 8. Comparison between the level height of the 2005 and extracted height from the data laser scanner (historical points)

Figure 9. Comparison between the level height of the photogrammetric check points and the extracted height from the lattice (generated from the data laser scanner)

Figure 10. Comparison between the level height of the photogrammetric check points and the extracted height from the photogrammetric DTM (generated by automatic image matching)

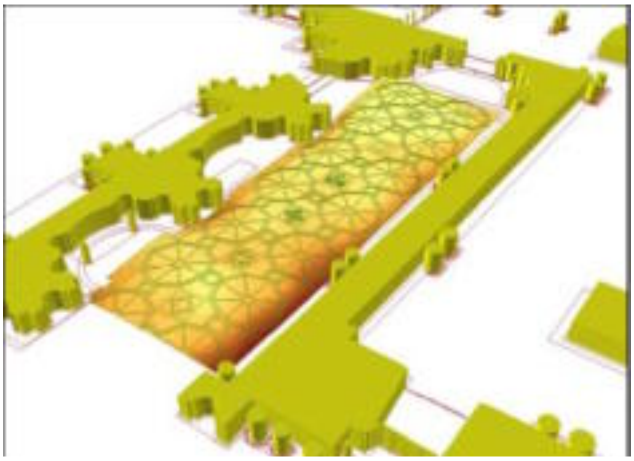

Figure 11. 3D model of the floor generated by automatic image matching (Z factor = 3x)

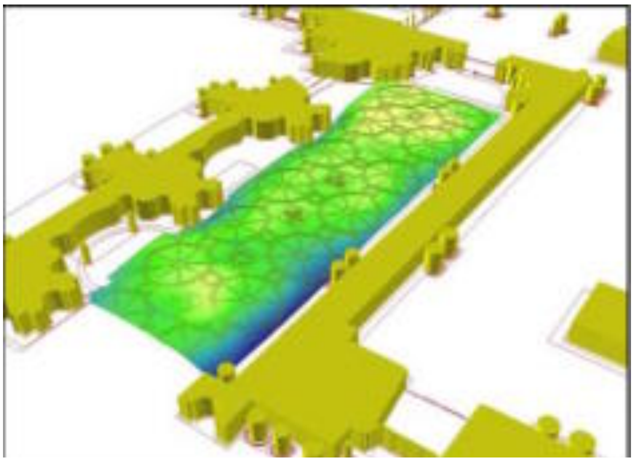

Figure 12. 3D model of the floor generated by lattice with laser scanner system (Z factor = 3x)

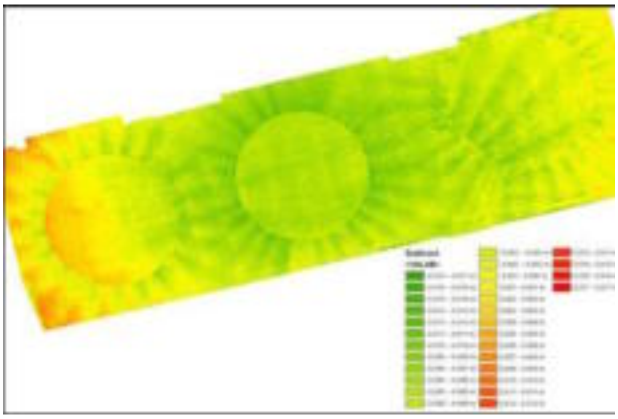

Figure 13. Raster calculator from ArcInfo: the image represents the difference between the DTM photogrammetric and laser

A Leica HDS 3000 laser scanner was used in the narthex to compare with DTM from automatic image matching and to have the risers. The intention is to obtain a realistic and precise representation of the entire floor inside the Basilica, represented by a model in elevation consistent with the floor and the sections at the 1:50 scale.

6. CONCLUSIONS

This work aims to obtain a detailed understanding of the current situation of the mosaic floor, to provide a more powerful tool for restorers to use in their job.
The repertory of information will be structured on a GIS georeferenced in three spatial dimensions in order to obtain the information necessary for the restoration project.
This operation, which was possible to realize only during the cognitive phase at the start of the works using the traditional techniques, with the new methods studied and proposed can be extended with continuity to the entire floor surface, conserving the data in an historic archive to analyse at a subsequent date. Together with metric digital images, integration of the geometric models extrapolated with the most modern instrumentation in times and costs compatible with available resources represents the most advanced frontier in research in many fields of application, in particular for the areas related to cultural assets.
Study and management of the data must be and will be organized in a GIS that will include several types of geometric, topographical, and historic information concerning all the contents that can be useful for conservation of the asset. Future objectives involve optimization of the methods used for St. Mark's, a unique example, with a view to building a flexible and effective method to reduce the current cost of survey in the broad sense, and as a result of new representative and quantity means, the costs of maintenance.
The possibility to draw templates of the altimetric profiles automatically makes it possible to conserve the real object through models.
This work began and at a good point is not limited to the areas of research finalized at a particular case - which describes St. Mark's - but creates the assumptions whose scientific and traditional methods can provide reciprocal support and advantages.

REFERENCES

Achille, C., Brumana, R., Fregonese, L., Monti, G., Monti, C., Savi, C., Vio, E., 2002. Il pavimento musivo della Basilica di San Marco. L 'ortofoto 3D alla scala 1:1 come palinsesto virtuale di un sistema informativo, ASITA, Proceedings of the 6th National Conference on Geomatics for the Environment, Territory and Cultural Heritage, Perugia, Italy, pp. 29-34.

AA.VV., 2004. Ortofoto digitale 3D a scala naturale del pavimento musivo della Basilica di San Marco a Venezia, Cultural Heritage and Polytechnic of Milan, in the journal of the Polytechnic of Milan, Milan, Italy.

Adam, J. P., 2003. L'arte di costruire presso i Romani, Longanesi & C., Biblioteca di Archeologia, Milan, Italy, vol. 10.

International Symposium on Real-Time Imaging and Dynamic Analysis, mt. Archives of Photogrammetry and Remote Sensing, Hakodate, Japan, Vol. XXXII, part 5, pp. 920-926.

Brumana, R., Achille, C., Balletti, C., Fregonese, L., Guerra, F., Savi, C., 1998. The St. Marcus' Basin in Venice (Italy): The Basilica, the plaza and the sea water. The proposal of GIS model built Arclnfo to relate the archives of information in order to manage the conservation and the maintenance of the Basin, ESRI Convention, San Diego, USA, www.esri.com/library/userconf/proc98/proced.htm pagg.l4.

Enciclopedia dell'arte, Istituto della Enciclopedia italiana, voce

Mosaico, Vol 5.

Favaretto, I., Da Villa Urbani, M., 2003. Il Museo di San Marco, Marsilio, Venice, Italy.

Giussani A., Monti C., 1999. Il controllo statico della Basilica di San Marco, in Scienza e tecnica del restauro della Basilica di San Marco: atti del Convegno internazionale di studi (Venezia, 16-19 May 1995), edited by Ettore Vio and Antonio Lepschy, ed. Istituto veneto di scienze, lettere ed arti, Venice, Italy.

Marini, G., 2003. I mosaici della Basilica di Aquileia, CiscrA, Aquileia, Italy.

Monti, C., 1985. Basilique de San Marco à Venise: traveaux de mèsure pour le controle statique, Atti dei Convegno del Symposium International des mésures des déformationes avec les méthodes géodésiques, (Invited paper), Katowice, Poland.

Monti, C., Galeazzo, G., 1999. Il rilievo fotogrammetrico della Basilica, in Scienza e tecnica del restauro della Basilica di San Marco: Proceedings of the International Symposium (Venezia, 16-19 May 1995), edited by Ettore Vio and Antonio Lepschy, ed. Istituto veneto di scienze, lettere ed arti, Venice, Italy.

Monti, C., Brumana, R., Achille, C., Fregonese, L., Savi, C., 1998. Basilica di San Marco, Piazza e GIS, Journal of the Department of the Territory, Rome, Italy, n.3, pp. 51-76.

Monti, C., Achille, C., Brumana, R., Fregonese, L., Savi, C., 2002. 3D models generation from laser scanner data to support digital orthophoto 3D: the mosaic surface of the floor of S. Marcus Basilica in Venice, Commission V Symposium, Proceedings ISPRS WG V/4 — Close-range imaging, Long-range vision, Corfù Greece, pp.423-428.

Tomaselli F., 2002. Evoluzione delle tecniche del restauro dei mosaici tra XVIII e XIX secolo, in “Atti di Bressanone”, Bressanone, Italy, pp. 8-22.

Vio, E., 2001.Lo studio della basilica di San Marco attraverso nuove rappresentazioni, in I nuovi metodi d’indagine e comunicazione della storia dell’architettura, Sinai publishers, Milan, Italy, pp. 115-120.

Vio, E., Lepschy, A., 1999. Science and Technique of restoration of the St. Mark’s Basilica, Proceedings of the international symposium of studies of Venice (16-19 May 1995), ed. Istituto veneto di scienze, lettere ed arti, Venice, Italy.

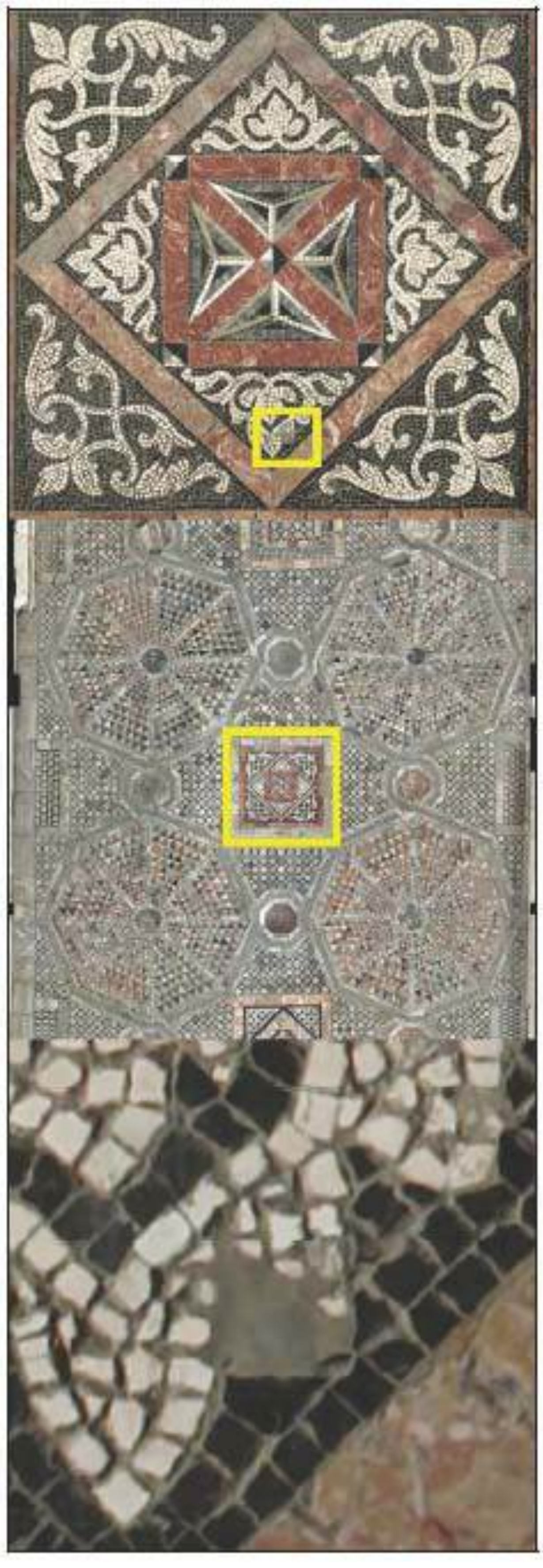

Figure 15. The orthophoto of narthex with particular (scale 1:10 and 1:1)