Digital Image Processing in Weathering Damage Analysis and Recovery Treatments Monitoring

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Abstract. Scientists and conservators, involved in cultural heritage documentation management, have to furnish not only qualitative but also quantitative description of the assessment of state of conservation that is incomplete without a realistic estimation of degradation conditions. Scientists and technicians, involved in analytical analysis, are able to satisfy these needs through stone or paints sampling analysis, often destructive when approaching a monument. The paper refers to the application of the Digital Image Processing and non-invasive damage analysis (ICAW technique) employed to verify in qualitative and quantitative way the decay of stone and rock paintings.

Keywords: Digital Image Processing, Non Destructive Technique, Salt damage, Recovery treatments, Monuments Conservation.

1 Introduction

Non destructive techniques (NDT) were widely applied on cultural heritage. The non invasive analysis of weathering damages and the non destructive monitoring of degradation evolution, especially in case of recovery treatment, brought to the development of the ICAW technique (Integrated Computer Analysis for Weathering, F. Zezza 1989). This technique, widely applied in several Mediterranean Basin monuments, covers entirely the most critical aspects of monuments conservation, permitting a non destructive Digital Image Processing of the weathering conditions, the time monitoring evolution of degradation, and the non invasive monitoring of the efficiency and the limits of recovery treatments. The methodology was applied to stone building, sculpture and paints, and permits to lead and to orient the recovery treatments. ICAW was born for a new cultural heritage documentation approach; it is able to avoid, or at least to limit, the laboratory invasive sampling, under the awareness that the future scientific development of monuments quantitative documentation must be related to the available non invasive technology. The non destructive technique (ICAW) here presented is an answer to the pressing needs of conservators, nowadays always more engaged into a wide global sharing knowledge on cultural heritage.

2 Digital Image Processing and Cultural Heritage

An efficient diffusion and multidiscipline exchange of global know-how in the areas of cultural heritage could be reached through modern information and communication

M. Ioannides (Ed.): EuroMed 2010, LNCS 6436, pp. 71–84, 2010.

technology (ICT) focusing on multimedia technologies. Every data diffusion, however, could not elude from an accurate documentation on the knowledge we need to share (M.Ioannidis, 2003). The assessment of state of conservation is an essential aspect that has to precede knowledge diffusion. On the other hand, the state of conservation is incomplete without a realistic estimation of degradation conditions, obtained through analytical analysis that suffers several operating limitations when approaching a monument. Answering this needs implies that scientists and conservators must work together to focus on the most non invasive technique applicable to the cultural heritage under investigation, due to the uniqueness of the assets they are treating.

For these reasons non destructive technique (NDT) finds wide applications worldwide to satisfy the analytical assets description essential for conservation and maintenance of the monuments (F.Mallouchou-Tufano, Y.Alexopoulus 2003, C.Borg, 2004, A. Adriaens, 2004). On-site and remotely sensed data collection are particularly indicated where the collection of samples, also micro-destructive, finalized to laboratory analysis, could be damaging for the monument, especially in case of architectural elements or delicate paints. Moreover the punctual results by samples analysis, necessary for a preliminary quantification of the damage, are often non-representative of the entire asset. Instead, the remotely sensed techniques, especially in the pre-diffusion cultural assets documentation steps, seems to be more appropriate to obtain a global and areal evaluation of the monuments characteristics. A fundamental aspects of every physical evaluation on a monument is also the time monitoring control of the parameters adopted. These on site remotely sensed techniques, thanks to their relatively easy repeatability, due to the absolute non invasive operations and relatively low onerous logistic and economical efforts, seems to be preferable for these aims.

Between non destructive on site techniques, Digital Images Processing are widely applied, and involve techniques that range from laser-scanning to infra-red visualizations or colorimetry. Between images analysis, the ICAW technique was successfully applied on monuments conservation description. Integrated Computerized Analysis for Weathering (ICAW, F. Zezza 1989) is a non destructive technique, employable in situ, which offers the possibility of determining the state of conservation of stone material exposed to atmospheric agents, both of natural and anthropogenic origin, and to evaluate the rate of weathering in time, describing quantitatively the decay distribution on the studied surfaces. ICAW, performed in several monuments of the Mediterranean basins for his absolute non-invasive applicability to describe the state of conservation, was progressively implemented considering different environmental conditions and different building material (e.g. F.Zezza 1996, 1997, 2002), proving to be particularly useful to monitor the decay distribution in time, both before and especially after recovery treatments, of paints, monuments, architectonical elements, sculpture and historical buildings. This innovative and unique technique, able to avoid invasive sampling analysis, or in the worst cases to limit them, is directly useful for the cultural heritage documentation and knowledge sharing.

3 Methodology

The ICAW analysis (Integrated Computerised Analysis of Weathering, F. Zezza 1989) consists in a digital image processing complemented by NDT techniques. The basics lie in the level of restitution of light energy from the surfaces exposed: the initial analysis of the image is addressed to establish the chromatic characteristic of the stone depending on colour, structure and state of conservation of the material; in this way the stone surface corresponds to different levels of returned light.

Illustration, quantitative evaluation of damage and information can be reached through a methodological approach which gives back in an objective way the scientific rating of stone damage. The ICAW technique, fixing the rate of weathering through the degree of stone decay considered both as digital images of the weathering forms and related buried structure, allows detecting the weathering on surface and in depth.

The process to determine the weathering forms and the thickness of the decayed layer consists in the transformation of the pictorial images into digital images and in the employment of ultrasonic pulses (Fig.1).

With reference to the exposed surfaces, the quality of the image must allow to perceive the properties of the object. In digital image processing a black and white image (pictorial image) may be considered as a continuous dimensional function in two variable planes x and y able to supply a representative value of the luminosity for every pair of coordinates. This f(x,y) function is representative of a certain distribution of luminosity in a planar domain internally connected and without singularity. Each image pixel will contribute through a different level of grey with which it is associated, to the formation of a digital image, these individual spatial samples (pixels) are represented by a value (Lg) indicating the level of luminosity relative to an appropriate scale. As regards the tonal range associated to images processed in false colour, the 256 gradations allowed for each of the three basic colours used (red, blue and green), practically a limitless number of combinations. As fig 2 shows in schematic form, the grey levels histograms reflect both the restitution of light energy determined by the chromatic variations of the rock (fig.2) and the textural and structural properties of the stone (exfoliation, lamination, fossils, fissuring, graded bedding etc.). The stone decay, as degree, is showed in abscissa by the interval of grey levels which tend towards 0 increasing in width.

Considering the variations of luminosity recorded in a series of images of rock of different colour and composition as well as different states of conservation, and supplying histograms from freshly quarried rock to severely damaged stone, it is possible to make the following observations: a) the gradual move towards the start of the abscissa, or rather towards the dark shades of grey, of the intervals relative to images of fresh of weathered stone; b) the dispersion of luminosity levels due to the presence of structures of organic or inorganic origin; c) the increase of the dispersion of these levels accompanied by a wider interval of the grey levels in which are included those of severely weathered stone and those of the fresh one.

The ICAW technique can be applied to assess above all the deterioration degree of buildings materials and paints. In addition the ultrasonic measurements, through the indirect method, allowed to detect changes in physical conditions of the stone material and to calculate the depth of decayed layer with their laying and interrelations. The decay patterns which can be obtained in relation to the distance-time diagrams represent the buried structures. The surfaces on which the technique is applied are generally flat. However, during the processing of the time-distance diagrams (homeosurface or indirect method), it is considered that the irregularity of the damaged stone surface corresponds to different levels of light returned from different parts.

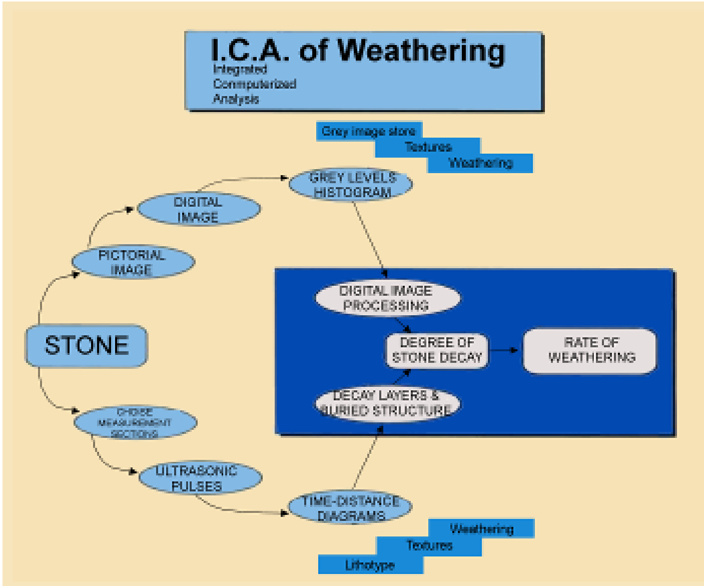

Fig. 1. ICAW technique: analytical approach to detect the rate of weathering (from F.Zezza 1996)

Therefore, the different grey intervals indicate the stone properties, the weathering forms and the state of conservation of the material. The intervals of grey levels content, interpreted as above and collected in different block of colour, outline as digital maps the weathering in an objective way.

Daily, monthly and seasonal data can be elaborated to produce digital images and maps of different kinds of substrates before and after treatment application, or simply to monitor the natural decay condition. Also, before and after treatment, the areal distribution of the decay patterns with the surface change forms can be detected;

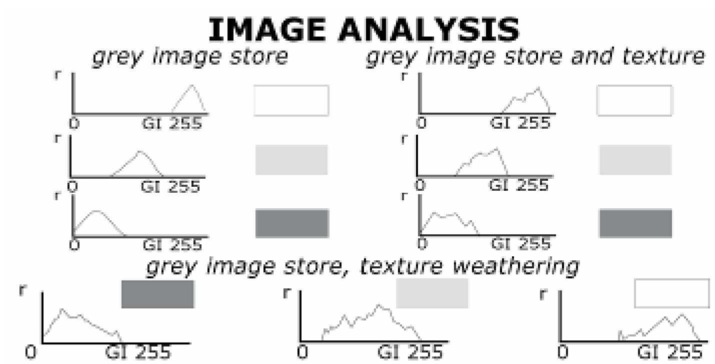

Fig. 2. The grey levels histograms allow to identify chromatic variations, textural characteristics and weathering degree of building material (from F.Zezza 1989)

therefore, in case of recovery treatments, using image analysis, it is possible to obtain a micro-morphological evaluation of the untreated and treated surfaces.

4 Weathering Damage Analysis

4.1 Assessment of the State of Conservation

In fig.3 is assessed the deterioration degree and the thickness of the weathered layer of the marble portal (Cathedral of San Nicola, Bari) built in XII century. For the ancient marbles the ultrasonic measurements show the overlap of different weathered layers as the reproduced example (fig.3), referred to the marble of the Temple of

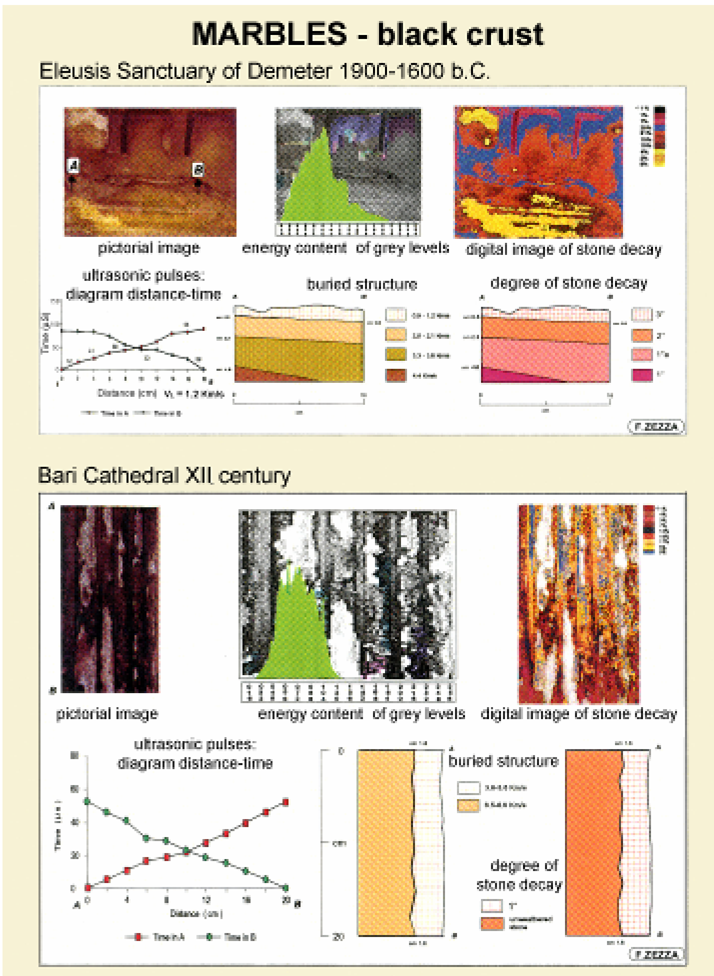

Fig. 3. Damage assessment determined by ICAW: qualitative and quantitative evaluation of the weathering (damage categories), from F.Zezza 1996

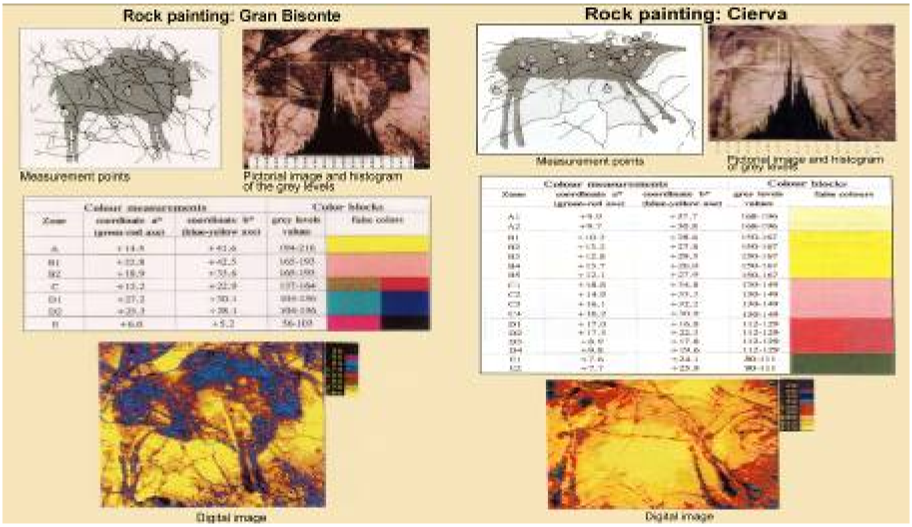

Fig. 4. Chromatic coordinates, grey levels histogram and digital image analysis (ICAW) used to determine the fading of 'Bisonte' and 'Cierva' paintings, Altamira Cave, Spain, (from F.Zezza 2002)

Eleusis dated between 1900-1600 B.C., indicates. The quantitative evaluation of stone decay degree depends by the damage indexes that express the rating of the weathering: their calculation is related to ultrasonic velocities which in turn mark the strength classification and the values of indexes as compactness, porosity and imbibitions of the building material (F.Zezza, 1996).

Stone decay degree and damage indexes reveal the overall need of preservation measures for stone monuments or individual stones structures.

The colorimetric measurements performed in the CIELAB system, collected in selected points of the paintings, can be converted into computerized maps. The technique, applied to determine the conservation state of the Palaeolithic paintings in Altamira Cave (Spain), refers to the surface extension of weathering. Colour changes due to chemical processes of dissolution, neoformation salts, biological and anthropogenic processes (F. Zezza, 2002), indicate a significant degree of weathering. Therefore, the determination of the colour parameters and their monitoring in time is extremely important to assess the state of conservation of the paintings.

The colorimetric determinations provide reproducible mathematical information that allows the verification, by comparative means, of the effects produced by the action of the natural and anthropogenic pollution, like the occurrence and the superficial distribution of black crusts. The extrapolation of punctual values into processed image involves the transformation of chromatic coordinates in the corresponding grey levels considering the values of the chromatic coordinates as a criterion for the definition of zones of distinct colour (fig.4). This method, which investigates the visible optical spectrum images, lends itself to detailed examination of the images in the near infrared spectrum.

4.2 Weathering Damage Time Monitoring

To be able to document the state of conservation in time is fundamental for monuments conservation practice and for the correlations concerning decay, anthropogenic interventions and environmental conditions. The assessment of these processes can be based on NDT techniques. The control of the evolution in time of decay processes or that of the effectiveness of the treatment is extremely important to define the plan of maintenance interventions or to improve the environmental conditions.

The ICAW methodology, basing on its non invasive approach and on its logistic repeatability, allows controlling the evolution in time of the decay processes. The fig. 5 reproduces, as examples, the results of some comparative analysis regarding the fading which affects the paintings of the Altamira Cave.

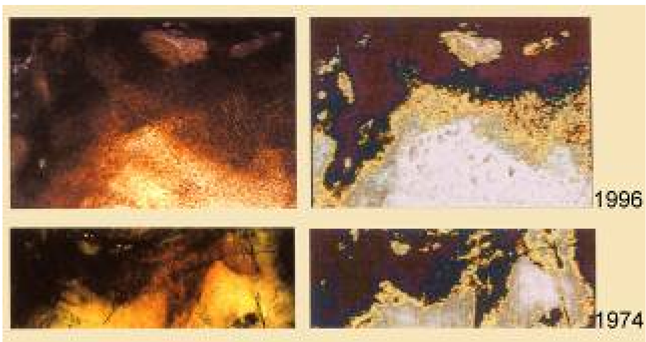

Fig. 5. 'Cabajo' painting of Altamira Cave (Spain). Fading monitoring in time by digital images collected on 1974 (bottom) and 1996 (top), from F.Zezza 2002.

The same ICAW methodology can be suitable to evaluate the threshold that indicates the risk to lose a painting due to fading as the fig.6 related to the paintings of the Grotta dei Cervi (Badisco, Italy) shows. Therefore the computerized analysis of the damage can be positively employed to plan the maintenance interventions.

4.3 Recovery Treatments Monitoring

Conservative interventions. The comparison of digital images elaborated before and after treatment application enables the evaluation of the effectiveness in time. For example, the computerized mapping utilized for the control of the conservative treatments effectiveness carried out for the 'Basilica of San Nicola' in Bari, Italy (fig.7), highlighted the existence of black crusts before the intervention (areas in blue, fig.7a, June 1986). The church portal digital image after treatment showed the total removal of black crusts (fig.7b). After six years the digital image has been able to reveal the reappearance of new weathering forms (areas in blue and dark green, fig.7c).

In particular, the digital images revealed a worsening of marble properties with the reappearance of black crusts and the reopening of cemented fractures, as well as the intercrystallyne decohesion.

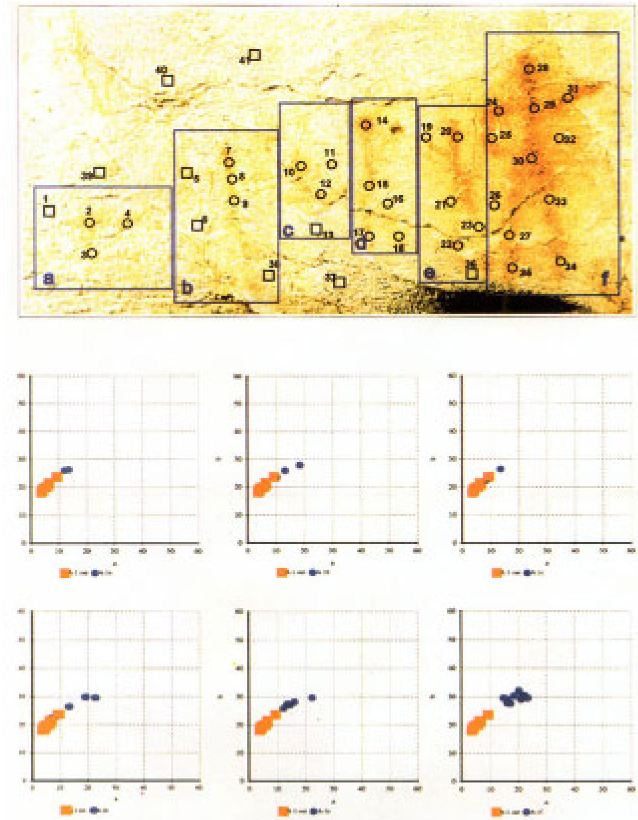

Fig. 6. Fading threshold evaluation for Grotta dei Cervi, (Badisco, Italy), from F.Zezza 2003

Fig. 7. Assessment of treatment by ICAW technique: monitoring in time of the Basilica of Bari, Italy. State of conservation: before treatment (8a, 1986), after treatment (8b, 1986) and after 6 years from treatment (8c, 1992,) from F.Zezza 1996.

Laser cleaning control. The analytical techniques currently used to evaluate the laser cleaning effects are based on stereomicroscopic and polarizing observations, XRD analysis, FTIR and SEM-EDAX analyses, artificial ageing tests and further colorimetric measurements. For some monuments and particularly for those of great esteem to control the laser cleaning effects it exists objectively the difficulty to collect the stone material directly by the exposed surfaces or to have at disposal samples of size suitable to carry out the wide spectrum of the tests which are useful to validity of the reached results.

To supply the data concerning the structural properties of the stone materials, the weathering and the micro-morphology of the surfaces and, in the specific case, the effects of the laser cleaning, the non-destructive computerized analysis can be applied. To assess the results of the laser cleaning concerning the preliminary application performed on samples of Penthelic marble utilized for the Blocks of the Parthenon West

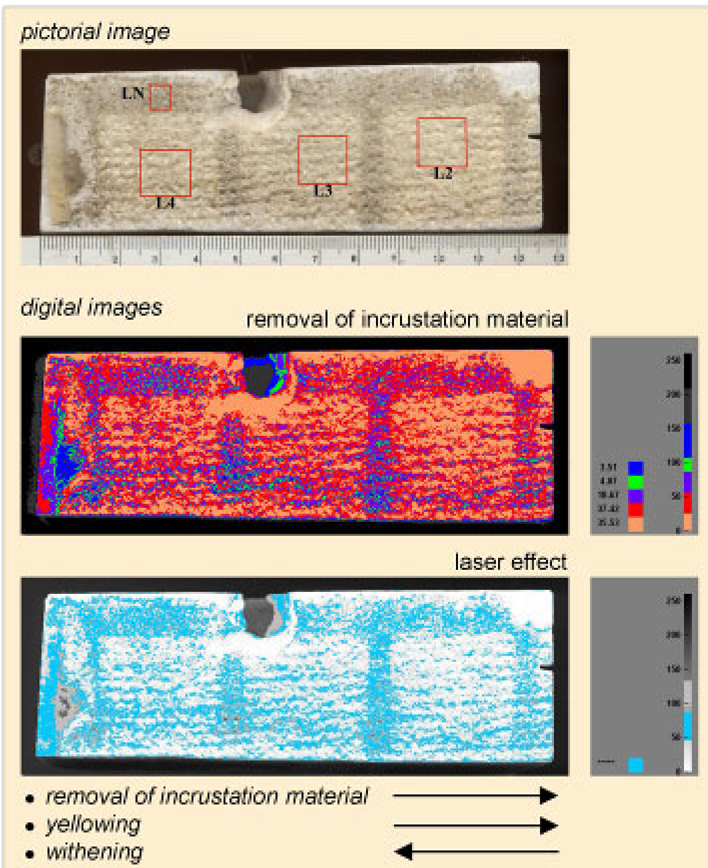

Fig. 8. Digital image analysis: chromatic variations of a Penthelic marble sample, after removal of incrustation material, treated with different infrared (IR) and ultraviolet (UV) radiation combination at relatively low energy fluencies

Frieze, the author has developed, in collaboration with the Department of Surface Conservation of the Monument of YSMA, under the auspices of the Committee for the Conservation of the Acropolis Monument, some demonstrative applications of the ICAW technique.

The tests regarded a fragment of a Penthelic marble slab which, within the experimental stage, was also utilized for the quantitative and qualitative tests to evaluate the effects of the preliminary applications of the cleaning methods above mentioned initially performed on newer marble additions (dating to the 1960's) from the West Frieze.

Three cleaned areas (L2, L3, L4, fig.8) have been interested by a simultaneous action of two discrete laser – based removal mechanism, characterized by different parameters as: i) the infrared (IR) and ultraviolet (UV) radiation combination at relatively low energy fluencies, ii) the number of pulses and iii) energy density (P.Pouli, V. Zafiropulos, 2003). The digital images analysis regarding the effects of removal of the incrustations (fig.8) clearly shows that the selected area L3 is located between two opposite conditions, the former (area L4) characterized by lower removal of crust with whitening effects, the latter (area L2) with higher removal of crust and yellowing effects.

On the other hand, the digital image analysis has been focused on the control performed accordingly to the following criteria selected within the laser cleaning techniques: i) to allow the widest possible preservation of the noble patina which preserves details of the relief; ii) do not cause direct or indirect damage to the substrata; iii) do not generate by –products; iiii) to consider the chemical and mineralogical structure of the marble, the state of decay as well as the stratigraphy of the incrustation.

As Tab.1 shows, different aspects of the laser cleaning method have been considered for the elaboration of the computerized images of the treated surfaces.

Table 1. Laser cleaning effects on treated surfaces

A. Removal of crusts	
	1) chromatic variations 2) homogeneity of the treated surface 3) preservation of the noble patina
B. Evaluation of the aggressiveness	
	1) fissuring 2) decohesion 3) loss of crystals 4) loss of material 5) cratering 6) by-products
C. Roughness	1) deviation of the profile by mean line

The degree and the efficiency of the laser cleaning method (figg.9-10) have been tested taking into account the cases (E. Papakonstantinou, 2003) evaluating the points A, B and C outlined in Tab.1:

- loose deposits (of soot and dirt particles) on the marble substratum
- black crusts (homogeneous compact crust and dendritic crust) on the marble surface
- black crusts on the monochromatic surface layer (beige layer)
- black crusts on the monochromatic surface layers (orange-brown layer with beige layer traces)

Fig. 9. Parthenon West Frieze Block – BIII

Fig. 10. Laser cleaning of the West Frieze Block - BVIII

Fig. 11. Pictorial and digital images of the West Frieze - Block III before and after laser cleaning treatment

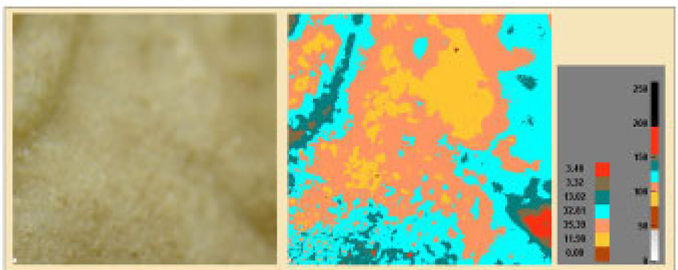

Fig. 12.

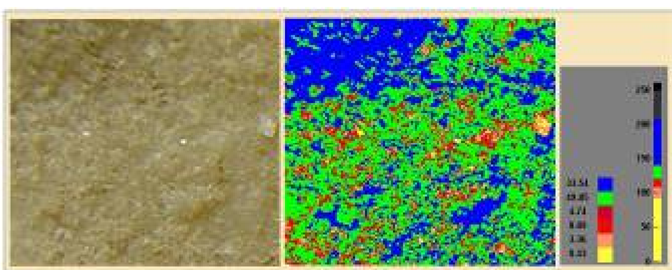

Fig. 13. Laser cleaning control: pictorial and digital images showing crystals broken (fig.12, yellow and beige colour) and cratering (fig.13, yellow and beige colour); in the last case the micro-morphology of the surface can appear also as consequence of a coalescence of laser spots

The comparisons of the pictorial and digital images certificate the homogeneity of the treatment which has preserved the monochromatic surface layers, verifying the good effectiveness of the cleaning process (fig.11). The black crusts have been removed as well as the loose deposits. The homogeneity of the orange colour indicates that the block surface has not suffered, in this case, chromatic variations, indicating the good cleaning result obtained by operators. The presence of the yellow colour is linked with washed zones during the exposition of the marble to the weathering and the blue-red colour indicates traces of monochromatic layers or primary and secondary structural characteristics (i.e. veins, cracks) of the Penthelic marble.

Preliminary tests can allow improving the treatment. Further details of digital image analysis areas, enlarged 22x (fig.12) and 8x (fig.13), indicate the possibility to avoid loss of material induced by crystal broken or cratering. By this point of view, the digital image analysis constitutes a control on-line of the laser cleaned objects.

5 Conclusion

ICAW image analysis improves the quality and the quantity of cultural heritage documentation and appears nowadays a new goal to safeguard monuments and to document the state of conservation.

The technique offers the possibility to avoid invasive sampling, often non representative of the entire monuments surface studied, and the possibility of a constant time monitoring remotely sensed, low demanding in term of cost and logistic efforts. ICAW found many application in several EC projects concerning the conservation of monuments and recovery treatment monitoring, from 1989 up to now, concerning stone, paints and sculptures, and suggests the best conservation approach for museums pieces.

These kinds of knowledge within an efficient exchange and sharing of know-how in the areas of cultural heritage, represent one of the next future scientific challenges, in an integrated collaboration operating system.

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