Analysis of Lacunae and Retouching Areas in Panel Paintings Using Landscape Metrics

Frederico Henriques[1] and Alexandre Gonçalves[2]

[1] Escola das Artes / CITAR, Universidade Católica Portuguesa, Porto, Portugal
[2] Dep. Civil Eng. & Arch. / ICIST, Inst. Sup. Técnico, Tech. Univ. Lisbon, Lisboa, Portugal
frederico.painting.conservator@gmail.com, alexg@civil.ist.utl.pt

Abstract. This paper explores a novel use of Geographic Information Systems and Landscape Metrics in the characterization of lacunae and retouching areas on panel paintings. The aim is to understand some spatial properties of original and non-original areas and contribute to the documentation of conservation and restoration treatments with valuable information. The study uses an orthophoto of the analysed artwork in a GIS program to produce polygons with a direct visual interpretation, corresponding to the major colour zones, the lacunae and the retouching areas. Over these areas landscape metrics are applied and interpreted. The result is a useful set of values describing spatial properties and relations between lacunae, retouching areas and the unaffected zones in the painting. These quantified parameters extend the traditional qualitative diagnosis reports on the state of conservation of artworks and contribute to support the evaluation of conservation and restoration projects.

Keywords: Painting, conservation and restoration, lacunae, retouching, GIS, landscape metrics.

1 Introduction

1.1 General Introduction

The interpretation of the state of conservation of artworks is an issue in conservation and restoration. Its documentation is generally made by empirical observations, sometimes supported by analytical methods that help to qualify and characterize the major pathologies [1][2]. It is thus possible to classify and quantify important items in the diagnosis process, such as tears in linen paintings [3], or the area of lacunae, overpaints, detachments, cracks and other detectable features in the artwork surface.

However, there are other spatial properties in the distribution of pathologies that might be interesting to evaluate the complexity and feasibility of an intervention in the artwork. The production of these properties requires the application of spatial analytical methodologies, such as the evaluation through Landscape Metrics, suggested and described in this work.

Although the method of Landscape Metrics is only used in the characterization of land-use planning and analysis, and specifically in scenarios of territorial evolution, in this work a correlation with such spatial analyses of land surface is used to bridge the

M. Ioannides (Ed.): EuroMed 2010, LNCS 6436, pp. 99–109, 2010.

application of the same concept into the analysis of the pictorial surface. Despite the evident difference in the metric scale between the two fields of study, we assume that there is a similarity between land use classes and the elements in the painting surfaces. An explanation of this is related with the pictorial surface, which can be seen as a fragmented territory where, at a specific location, a value (land use/colour or pathology) might be assigned.

The purpose of this study is to evaluate and interpret the application of Landscape Metrics as an analytical methodology that helps to clarify some questions arising in conservation: how extent are significant lacunae/retouching areas in a painting; what their average size is; how irregular their geometry is; what is the spatial pattern of their distribution; and if a tendency to locate in specific chromatic areas is noticed.

1.2 GIS, Spatial Analysis Operations and Landscape Metrics

A geographic information system (GIS) is a computer based information system that enables the capture, modelling, storage, retrieval, sharing, manipulation, analysis and presentation of geographically referenced data [4]. There are several types of models associated to information: databases with georeferenced information (such as addresses), raster (such as images) and vector models (points, lines and areas). A raster image file is a grid of cells, also designated as an array of pixels, structured with columns and lines and with a value associated with each cell [5]. Spatial analysis is a field of study which concerns the manipulation of spatial information and the extraction of spatial relations and properties. The analysis answers questions about the geographic features, such as distance, adjacency, interaction and neighbourhood-induced characteristics between events or spatially distributed objects.

Landscape metrics (LM) are a set of spatial analytical measures and indicators widely applied in territorial analysis. LM has been used to understand the landscape structures in ecology, landscape architecture and land use planning [6]. Several of such metrics allow a quantitative description of spatial patterns, helping the decision makers to define, with respect to the natural environment, agricultural, rural, coastal and transportation policies. Some examples of its application are the 3D LM methodologies used to support forest structure discrimination, mapping and monitoring of the National Park Bavarian Forest [7], the spatial analysis of land occupation in Mainland Portugal [8] and the analysis of vegetation dynamics in Amazon forest [9].

1.3 Case Study

The case study involves the application of GIS-based tools to extract LM values for the lacunae and retouching areas in a wood painting made by an unknown Master, probably of 16th century Portuguese origin. The iconographic representation is attributed to *St. John the Evangelist* because his specific attributes are represented: the figure wears a red drape, and a winged snake emerging from the chalice is present. The panel has a *Castanea sp.* support with 4 cm thickness, tangential cut in a single ca. 145 cm high by ca. 51 cm wide plank and is painted with the common material (pigments, dyes and binders) of the production in the 16th century. Photographs of the painting were taken during the conservation and restoration treatment, after removing varnish and repaints and before the filling and retouching operations.

2 Methodology

2.1 Generic Description

The first operation in the methodology was to acquire digital photographs of the artwork. These images are processed with a close-range photogrammetric program which creates an orthophotograph combining the original imagery. This operation is followed by the use of a GIS to extract features (corresponding to the visually identified most significant colour patches and pathologies). Then the metrics are applicable. These steps are described in detail in the following sections.

2.2 Image Capture and Orthophotograph Processing

Photographic records of the painting were made in digital mode with a 5.0 Mpixel camera, *Sony Cybershot F-717*™. Digital images in JPEG/EXIF 2.2 image format were used to create an orthophotograph with close-range photogrammetry software.

This operation can be presented in three stages: a calibration to determine the geometric characteristics of the camera and to set parameters for it; the use of a set of images from different viewpoints to produce, by bundle adjustment, a digital surface model (DSM) with four points located at the vertices; and the production of an orthophoto [10]. In all the steps of the exercise *Photomodeler 4.0*™ software was used.

An orthophoto image is a document that might be produced from perspective photos, in which all perspective-related distortions have been removed. It is similar to obtain a photograph of a surface where the camera is placed perpendicularly to this surface at an infinite distance. Because orthophotographs are planimetrically correct, they can be used as base maps for direct measurements of distances, angles, positions and areas [11]. Orthophotographs are also used as a base for measuring spatial properties, since the distortion ("barrel effect") of the photographic lens and the relief of the represented surface are considered.

Despite the fact that the panel planks present a negligible warp, an orthographic photo was produced to minimize errors in the measured spatial properties. The orthophoto produced was a TIFF format file with 542 columns by 1519 rows (823,298 pixels), three bands, uncompressed size of 2,26 MB using 8 bits pixel depth.

2.3 Data Processing in GIS

After the orthophotograph production, the image was georeferenced in a GIS program, *ArcGIS*™, version 9.3, from ESRI®. In this operation a metric scale is assigned and the image is subject to a georeferentiation, with local coordinates being applied. The image layer has a fixed pixel size of 0.095 cm, an empirical value considered to be adequate to represent with detail the artwork. Following this, polygons were drawn to delimit the main regions of colours in the painting and the lacunae/retouching areas.

Eight areas were created in a layer to characterize the zones of *light red drape*, *dark red drape*, *sky*, *flesh*, *winged snake*, *earth pigments* (covering the ground and the figure's hair), *chalice* and *water* (Fig. 1). Lacunae or retouching areas were edited manually and represented in a distinct vector layer, but could also be produced by the application of automatic classification (e.g., via supervised classification). The main reason for the manual classification was the ability to interpret by visual inspection the most adequate of the eight zones for each lacunae/retouching area. Both datasets of lacunae/retouching areas were then converted to the raster format, producing grids with the same detailed resolution as the orthophoto (0.095 cm), which facilitates eventual overlay operations with the original image, within the GIS.

LM analyses could also have been performed with vector data, and the choice of the data model depends on the intended type of metric indices. If the operator chooses to analyse raster datasets, the choice of the spatial resolution influences most metrics, so an adequate value should be selected. After the conversion (lacunae/retouching area and regions of colours) both raster layers were added to result in a single grid with a combination of all data. This dataset represents all the various combinations of pigments and presence or absence of lacunae or retouching, such as "light red drape" or "lacunae on light red drape".

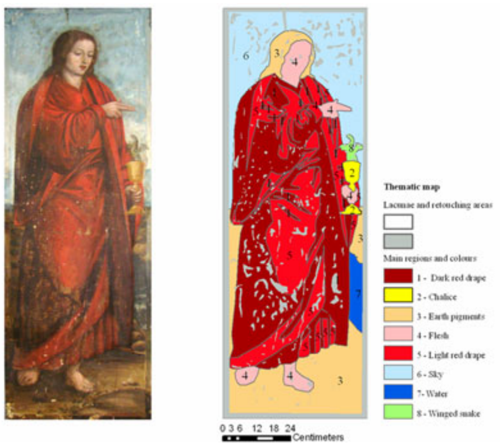

Fig. 1. Orthophotograph of the *St. John the Evangelist* panel painting and the corresponding thematic map of lacunae, retouching areas and main colours

2.4 Application and Interpretation of Landscape Metrics

LM are available to *ESRI® ArcGIS™* users as an extension named *Patch Analyst* (version 0.9.5) (and also *Patch Analyst for Grids*) developed for version 9.1 or later by the Geomatics Services Group, Ontario Ministry of Natural Resources. The use of the extension is straightforward and requires only the identification of the raster layer with the classified cells.

To apply the landscape metrics there are six categories of statistics in Patch Analyst: *Area Metrics*, *Patch Density and Size Metrics*, *Edge Metrics*, *Shape Metrics*, *Diversity & Interspersion Metrics* and *Core Area Metrics*.

Landscape metrics are classified into three types, relating with the level at which they apply to: *patches* (individual homogeneous regions), *classes* (set of all patches with the same classification), and *landscape* (all the elements): *patch-level metrics* are defined for individual patches, characterizing their spatial properties. In most applications they are used basically in the calculation of other level metrics, such as the average patch area for a class of in the entire landscape; the computed values for each individual patch may have little interpretive value [12]; *class-level metrics* describe the geometric properties of all patches assigned to the same type or class. Examples are the average values of patches for a specific class, such as the average area, perimeter, and number of distinct neighbour classes, among others; and *landscape-level metrics* describe properties for the entirety of the tessellation of classes/patches in the landscape, reflecting its geometric and topological quantitative properties.

Not all these metrics share the same importance or significance in the particular analysis of a painting. For instance, patch-level metrics will only apply if an individualization of the patches makes sense, which is not the case of the patches in the painting, since no individual value is assigned to it. Class-level metrics express for each colour and type of pathology its geometric and dispersion properties. Landscape-level metrics provide general quantifications on the distribution of the classes (colours and pathologies) in the painting.

The following metrics were selected: *Class Area* (CA), *Number of Patches* (NumP), *Mean Patch Size* (MPS), *Patch Size Coefficient of Variance* (PSCoV), *Patch Size Standard Deviation* (PSSD), *Edge Density* (ED), *Landscape Shape Index* (LSI), *Mean Nearest Neighbour Distance* (MNN) and *Total Core Area* (TCA), because they directly represent properties that might be useful in the characterization and interpretation of the extent and spatial distribution of pathologies.

CA is an area metric, useful to assess the extent of each pathology and defined colour region in the painting, providing valuable information for the diagnosing process.

NumP directly expresses the number of patches in each class. This number is a measure of the landscape configuration which gives an insight on the level of division or fragmentation in each class. It is defined by dividing the class area by the total area of the landscape.

MPS is a measure that informs on the average covered area per class, which gives an insight on the heterogeneity of size in relation with class. It could also be compared between colours and between areas of the same pathology.

PSSD and *PSCoV* are the standard deviation and the coefficient of variation of patch areas, where PSCoV = PSSD/MPS.

ED is the total length of the boundary between patches with different classes divided by the total class area, and gives a measure that expresses the level of fragmentation of each class.

LSI is interesting in expressing, for each class and for the total landscape, the total value of the boundary lengths of its patches divided by the square root of their total area. It is a measure of the average irregularity of each class: the higher the value of LSI, the less circular are the patches. Such measure is useful when applied to patches representing pathologies, since irregularity may be related with a higher volume of retouching work in conservation and restoration interventions. This metric expresses the dissimilarity between the sizes of patches, per class.

ED is the total length of the boundary between patches with different classes divided by the total class area, expressing the level of fragmentation of each class.

MNN is a measure that expresses the isolation of patches, since for each patch the distance to its nearest neighbour in the same class is calculated. For all patches in the same class, the average value of this measure is calculated.

TCA is a shape and core measure. Core areas are comprised of pixels that are entirely surrounded by pixels of the same type. TCA estimates the total area, per class, occupied by these pixels.

The previously mentioned Landscape Metrics were applied to the classified grid. Results are presented in Tables 1 and 2. The classes are: *dark red drape* (DRD); *chalice* (Ch); *earth pigments* (EP); *flesh* (Fl); *light red drape* (LRD); *sky* (Sk); *water* (Wa); and *winged snake* (WS). A dagger (†) following a class name is a correlated area of lacunae.

Table 1. Area Metrics (*) and Patch Density & Size Metrics (**)

	CA*	NumP**	MPS**	PSCoV**	PSSD**
DRD	241,304	33	7,312	76,231	36,572
DRD†	20,537	185	111	28,741	210
Ch	7,060	2	3,530	6,897	1,598
EP	125,893	3	41,964	16,269	44,791
EP†	37,537	31	1,211	71,759	5,701
Fl	31,893	5	6,379	8,264	3,458
Fl†	959	14	68	20,073	90
LRD	156,540	40	3,914	49,694	12,759
LRD†	8,132	93	88	25,886	148
Sk	123,931	5	24,786	18,267	29,705
Sk†	48,228	66	731	88,421	4,240
Wa	12,722	1	12,722	0	0
Wa†	4,481	1	4,481	0	0
WS	3,223	2	1,612	14,438	1,527
WS†	699	16	43	11,210	32

Table 2. Edge Metrics (*), Shape Metrics (**), Diversity & Interspersion Metrics (***) and Core Area Metrics (****)

	ED*	LSI**	MNN***	TCA****
DRD	3,918	834	4,229	221,900
DRD†	1,516	392	11,888	13,551
Ch	94	131	43,417	6,575
EP	961	291	305,310	120,616
EP†	730	197	28,760	33,088
Fl	403	188	127,010	29,931
Fl†	79	128	14,121	621
LRD	3,088	681	2,364	141,461
LRD†	716	245	16,782	4,810
Sk	1,391	370	4,400	116,486
Sk†	1,432	321	8,493	40,352
Wa	108	134	1	12,091
Wa†	83	123	1	3,943
WS	128	137	2,000	2,619
WS†	79	129	4,989	337

The total area of the pictorial surface has 823,740 cells. Using this value as a basis, the statistical analysis is mainly focused in the lacunae areas. The number of cells is given by Patch Analyst as the *Total Landscape Area* (TLA) metric.

The *CA* metric indicates that the largest areas of the original paint layer are the figure's drape, namely the dark red and light red. The sky and earth pigment zones also evidence a significant value. The largest area of lacunae is in the sky and earth pigment regions. To that extension a decisive contribution from the peripheral overpainting, shaped as a frame, in the panel's outer edge.

In the zones of original painting, specifically in both red-hue drape areas, the value of the *NumP* metric is higher. For the lacunae distribution, the highest number of patches is noticed in the areas over the dark red tints, followed by the presence over the light red and sky areas. In the earth colour zones of ground and the figure's hair a lower number of lacunae patches is observed. In the remaining regions the value is negligible. *NumP* is an interesting parameter in the moment of performing a chromatic reintegration as it is directly related with the number of lacunae. In these cases, the higher the number of lacunae, the largest the quantity of matching colours needed and most prolonged the operation is. The fact of the highest values show up in specific regions might express an index on the required amount of work. In the case study, the highest values are noticed in both *drape* regions and in the *sky* (Fig. 2). As such, lower values will translate into less work, and this is verified in the *winged snake* and *flesh* regions.

The *MPS* metric has higher values in the *water*, *earth pigments* and *sky*. For the lacunae in the *St John the Evangelist* panel, a high value occurs in the border since there is a large and continuous area of overpainting (see Fig. 1), significantly raising the average patch size in some classes. Without this specific area, the highest value of this metric would occur in the *dark red drape* and *light red drape* classes, and the lowest in the *winged snake*.

Fig. 2. Detail of lacunae and overpaint regions in the *dark red drape* and *sky* zones. The represented areas were defined with manually edited polygons, and later the information was converted to the raster format.

PSCoV estimates the variance in the region size. As referred, it expresses an assessment directly proportional to the standard deviation of size and inversely proportional to the average size. As such, it suggests a classification on the level of asymmetry on lacunae size. In the artwork it is noticeable that the regions of lacunae over *earth pigments* have the largest difference and those of *red drape* (both *light* and *dark*) are very similar.

Interpretations of Area and Patch Density & Size Metrics are only based on the size of lacunae/retouching areas and not on the many complex shape-related characteristics that might complicate an intervention, such as the proximity and interspertion between zones. Thus, other indicators, such as the metrics presented in Table 2, are needed to complement the analysis:

ED analysis documents the extension of the lacunae borders. As listed in Table 2, the highest values belong to the *dark red* and *light red drape* lacunae areas, which suggest a longer division line between adjacent regions.

The *LSI* metric is a parameter on the lacunae typology: if it shaped like a circle it has a high value, and if it is very irregular the opposite occurs. The highest values are in the *dark red drape*, *sky* and *light red drape*. This analysis also suggest to provide useful information to the conservator-restorer as in the chromatic reintegration operations, besides the matching colour operations, the sinuous shape of the lacunae is the most demanding technical challenge. In practice, it is in these zones that the conservator-restorer's skills and capacities are put to the test. In such irregular zones, in mimetic-type interventions, it is often necessary to execute small and sensitive brush strokes in the border areas between lacunae and the original chromatic layer, to dissimulate the intervention. In the interventions of intentionally non-dissimulate characteristics (*ringranatura*, *tratteggio, selezzione cromatica* and *astrazione cromatica*), there is the need to thoroughly respect the border lines between the original layer and the lacunae subject to the chromatic reintegration [13, 14, 15]. The above mentioned *ED* metric also can be considered in the analytical considerations on the required level of expertise.

The *MNN* metric expresses region separation. On one hand it gives a quantification on the isolation level, and on the other hand indicates a measure on the concentration of lacunae. The highest densities and proximity of lacunae occurs in the *sky* and *winged snake* classes. The larger the value of the lacunae density, the larger is the difficulty of an intervention. However, the fact of the lacunae being too close to each other might translate into an operational added value. This is valid in the sense of the proportionality between the proximity of lacunae and a lower number of matching colours required in the intervention. In practice, a colour produced in the palette, with some small adjustments, can be used sometimes as an homogeneous cover for several close lacunae.

TCA metric indicates, for each class, which is its core area. In the table, the large lacunae regions on the border are noticed to have an impact on the high values of this metric. The interpretation is similar to some of the previous metric indicators, and expresses the ease of intervention in these regions.

The entirety of lacunae can also be considered as a single entity, without classifications by regions of colours. Table 3 displays the values of some metrics for the merged lacunae patches. Note that adjacent patches might be combined in a single continuous patch, and the total number of patches (317) is less than the count of lacunae patches in Table 1 (406).

Table 3. Landscape metrics (LM) of the lacunae patches without division by colour regions

Metric	Value
CA	120,573
NumP	317
MPS	380
TCA	79,019

CA indicates that lacunae occupy 14.6% (120,573/823,140) of the entire surface of the panel painting. The number of patches where chromatic reintegration is required is 317, with a mean size of 380 units. Table 3 does not list some LM shown on previous tables since the set of statistics of a single class of lacunae patches did not suggest to be capable of providing additional useful information. However, the unused LM might be considered in the qualitative analysis of collections of artworks by the same artist, or in a set of pieces with aesthetic or style similarities.

3 Conclusions

This paper presented a novel application of spatial analysis operations, namely Landscape Metrics (LM), to the characterization of surface phenomena in paintings. The variety and complexity of LM proved to be very helpful in assessing and describing the shape characteristics of painting detectable features, such as lacunae or overpainting areas, and might be extended to other cases. Such techniques, usually applied in territorial analysis, can also be applied in very distinct domain of conservation of paintings, being useful in the quantitative diagnosis needed in the documentation of artwork conservation status and in the support of the chromatic reintegration phase.

The interpretation of some Landscape Metric parameters, after georeferencing an image of the artwork, supports the use of this quantitative approach, extending human perception in the capability of evaluating important elements, such as lacunae/retouching areas and main colour-regions characteristics, and improving the quality of the diagnostic procedures made by the conservator-restorers.

Some LM are easily interpretable and correspond to important measurable characteristics: for instance, *CA, NumP*, *ED* and *LSI* metrics suggest being good indicators of the skill required in the intervention of chromatic reintegration. Very useful information on the number of lacunae to reintegrate, on the fragmentation level and on the variety and irregularity on their shapes is expressed by these metrics.

All the presented statistics depend on the initial delimitation process of the lacunae and/or colour zones over the orthophotograph, which was performed via manual vectorization and visual inspection. Very small patches were not considered in this exercise, but all the interpretations and assumptions of the significance of Landscape Metrics in the characterization and diagnostic of surface phenomena on artworks were not affected by our generalization. The application of the proposed methodology could be detailed and further assessed with the use of high resolution digital imagery. The possible use of the *velatura* technique, which might be executed in the chromatic reintegration, was also not considered in the evaluation of the patches detected in the analysed painting.

The process of analysis is not fully automatic. It depends on the intrinsic characteristics of the artwork, and on the initial photo-interpretations, to identify on surface the main patches. The accuracy and quality of the presented methodologies strongly depend on the expertise of the GIS operator in perceiving and modelling phenomena and transmitting his interpretation of the statistical data produced and expressed by the Landscape Metrics.

Acknowledgements. This work has been supported by "Fundação para a Ciência e a Tecnologia" and "Programa Operacional Ciência e Inovação 2010" (POCI 2010), co-funded by the Portuguese Government and European Union by FEDER Program. This research was also supported in part by the "Fundação para a Ciência e a Tecnologia" training grant SFRH/BD/42488/2007. The analysed painting is property of Zarco Antiquários, Lda., and we thank the opportunity to use images of the conservation-restoration treatment. We also appreciate the collaboration of Ana Bailão, conservator-restorer of paintings, on the technical information about the state of conservation of the panel painting.

References

1. Letellier, R.: Recording, Documentation, and Information Management for the Conservation of Heritage Places. Guiding Principles, vol. I, http://www.getty.edu/conservation/publications/pdf_publications/recordim.html
2. Eppich, R., Chabbi, A.: Recording, Documentation, and Information Management for the Conservation of Heritage Places. Illustrated Examples, vol. II, http://www.getty.edu/conservation/publications/pdf_publicatio/recordim.html
3. Henriques, F., Gonçalves, A., Bailão, A.: Tear Feature Extraction with Spatial Analysis: A Thangka Case Study. Estudos de Conservação e Restauro 1, 11–23 (2009)
4. Worboys, M., Duckham, M.: GIS. A Computing Perspective. CRC Press, Boca Raton (2004)
5. Longley, P.A., Goodchild, M.F., Maguire, D.J., Rhind, D.W.: Geographic Information Systems and Science. John Wiley & Sons, Chichester (2001)
6. Leitão, A.B., Miller, J., Ahern, J., McGarigal, K.: Measuring Landscapes. A Planner's Handbook. Island Press, London (2006)
7. Blaschke, T., Tiede, D., Heurichb, M.: 3D Landscape Metrics to Modelling Forest Structure and Diversity Based on Laser Scanning Data. In: Thies, M., Koch, B., Spiecker, H., Weinacker, H. (eds.) Proceedings of the ISPRS working group VIII/2 'Laser-Scanners for Forest and Landscape Assessment' Freiburg, Germany, October 3-6, vol. XXXVI-8/W2, pp. 129–132 (2004)
8. Couto, P.: Análise Factorial Aplicada a Métricas da Paisagem Definidas em FRAGSTATS. Revista Investigação Operacional 24, 109–137 (2004)
9. Watrin, O.S., Venturieri, A.: Métricas de Paisagem na Avaliação da Dinâmica do Uso da Terra em Projetos de Assentamento no Sudeste Paraense. In: Anais do XII Simpósio Brasileiro de Sensoriamento Remoto, INPE, Goiânia, Brazil, pp. 3433–3440 (2005)
10. Waldhäusl, P., Ogleby, C.: 3-by-3 Rules for Simple Photogrammetric Documentation of Architecture. In: Fryer, J.G. (ed.) Close Range Techniques and Machine Vision. Symposium of Commission V of ISPRS, IAPRS XXX/5, Melbourne, Australia, pp. 426–429 (1994)

11. Wolf, P.R.: Elements of Photogrammetry, 2nd edn. McGraw-Hill International Editions, Singapore (1983)
12. Smith, M., Goodchild, M., Longley, P.: Geospatial Analysis - a comprehensive guide. 3rd edn., `http://www.spatialanalysisonline.com/output/html/LandscapeMetrics.html`
13. Casazza, O.: Il Restauro Pittorico nell'Unità di Metodologia. Nardini Editore, Florence (1981)
14. Bergeon, S.: Science et Patience ou la Restauration des Peintures. Éditions de la Réunion des Musées Nationaux, Paris (1990)
15. Althofer, H.: La questione del ritocco nel restauro pittorico. Il Prato, Padova (2002)