Colour measurement procedures on outdoor 3D artworks: a case study

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Colour in the Cultural Heritage field is one of the parameters currently used to document artworks appearance, to support and to monitor conservation / restoration procedures on them. Studies dealing with colorimetric measurements aimed to document and support interventions on works of art have to be correctly programmed, since they have to be performed before, during, and after any interventions. However, one of the main drawbacks of surveys based on colorimetric analysis is linked to the repeatability and reproducibility of the measurements. Indeed, the definition of reliable methods for identifying the location of investigated areas is essential, particularly when the analysis has to be repeated on the same spots at a later date. This fact is of extreme importance and it is not an easy task to achieve mainly when chromatic variations have to be monitored on 3D artworks, such as statues and/or ornamental stones. In this paper we will report a study on colour measurements performed during a biennial diagnostic survey on the Ratto della Sabina (1583), a marble sculpture by Giambologna, placed outdoor under the Loggia dei Lanzi in Piazza della Signoria, Florence. The diagnostic survey, performed in the 2011-13, was aimed at evaluating the most appropriate protective treatment of the marble and was coordinated by Magnolia Scudieri, SSPSAE of Florence, and Mauro Matteini with the technical support of Alberto Casciani. This study illustrates the main results of the colorimetric analysis, with a focus on methodological issues, such as the repeatability of colour measurements due to the modelling of the figures, the access to the areas to be investigated, and the weather conditions. Finally, limits and advantages of the application of this technique on the study of 3D artworks will be described.

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Introduction

The colour of outdoor stones is never stable in time since they are easily attacked by atmospheric agents, thus undergoing different kinds of reactions. The degradation of stone evolves over time, and can be accelerated by different agents (chemical, physical and/or biological). In particular water, acidic substances and atmospheric particulate favor chemical degradation; the action of wind and thermal shocks facilitates mechanical disruption, while the activity of micro-organisms, algae and fungi are the basis of biological degradation [1-2].

Since the colour of a stone object largely affects its aesthetic aspect, it is important to define protocols for measuring the colour of the surface in a given time, in order to monitor possible colour changes, and to choose the best conservation treatments, if needed. Colorimetric analysis, widely used in several applicative areas, including the art conservation field, may offer an adequate solution to this problem. This method allows determination of the colour parameters of an object by measuring the visible spectral reflectance of the object itself. The measurements are carried out non-invasively using portable colorimeters or spectrophotometers, supported by sophisticated software which allow a rapid and reproducible determination of the colour parameters of interest [3-10]. Colorimetric measurements campaigns aimed at documenting and supporting conservation interventions on works of art have to be correctly programmed, since they need to be performed before, during, and after any interventions. However, one of the main drawbacks of surveys based on colorimetric analysis is connected with the repeatability and reproducibility of the measurements. This fact is of extreme importance and it is not an easy task to achieve, especially when chromatic variations have to be monitored on 3D artworks, such as statues or ornamental stones. In this paper we will report a study on colour measurements performed during a biennial diagnostic survey on the *Ratto della Sabina* (1583), a marble sculpture by Giambologna, that is located outdoors, under the Loggia dei Lanzi in Piazza della Signoria, Florence (Figure 1).

The sculpture underwent restoration in 2001. Since then, it has been constantly monitored with diagnostic surveys for the purposes of assessing its real condition and identifying the best cleaning/protective treatments. The last monitoring program took place in the years 2011-2013 and was coordinated by Magnolia Scudieri, of the former Soprintendenza Speciale per il Patrimonio Storico, Artistico ed Etnoantropologico e per il Polo Museale della città di Firenze – now affiliated to the Polo Museale Regionale della Toscana, and Mauro Matteini, with the technical support of the conservator Alberto Casciani. In the framework of this survey, which included several analyses (such as photographic documentation, Fourier Transform Infrared Spectroscopy, Micro-photogrammetry and water absorption measurements), IFAC-CNR team carried out a campaign of colorimetric measurements to support the conservation intervention by measuring the colour variations associated to the cleaning tests. This work reports the main results of the colorimetric analyses, with focus on the methodological issues that have been tackled, such as the problem of repeatability of colour measurements due to the modelling of the figures, the difficult access to the areas to be investigated, and the influence of weather conditions.

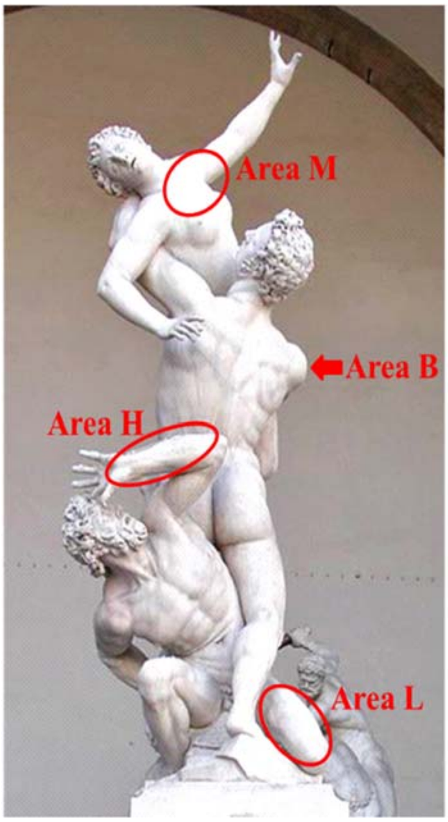

Figure 1: Ratto della Sabina by *Giambologna.*

Materials and methods

The "Ratto della Sabina" by Giambologna

The *Ratto della Sabina* sculpture was executed between 1579 and 1583 by the Flemish artist Giambologna (Jean de Boulogne, 1529-1608). The statue (4.1 m in height), which is carved from a single block of marble, depicts three figures and represents a scene of the legendary abduction of the Sabines. The sculpture portrays an old Sabine man kneeling and defending himself from a younger Roman male, who stands astride him and holds a struggling Sabine woman in his strong arms. These three figures create a complex sculptural group with a dynamic spiral composition that offers multiple points of view. This artwork has always been on public display under the Loggia dei Lanzi where it was exposed, together with other important sculptures, at the behest of the Grand Duke of Tuscan in order to create an open air museum. Thus, for centuries, the statue has been at the mercy of the aggressiveness of the atmospheric agents, such as wind, rain and pollution.

The survey program encompassed investigation and monitoring of eleven areas with different orientations and, thus, differently exposed to the environmental agents. Different analytical techniques were used in order to define the most appropriate treatment by evaluating the effectiveness of different cleaning treatments. Among these areas, the four that showed the most representative results from the point of view of colorimetric analysis were selected for this study and are described below.

Area B -This area was chosen on the right arm of the young Roman (Figure 2A). It was involved in a previous treatment (in 2003) that used Wacker290 on sub-areas 1 and 2. Sub-area 3, instead, had never been treated. Five measurement points were identified as reported in figure.

Area H - This area was selected on the left arm of the old Sabine man in a slight rounded area strongly affected by washout. Six measurement points were identified (Figure 2B).

Area L - This area was chosen on a completely flat surface of the left thigh of the old Sabine. Five measurements point were identified (Figure 2C).

Area M - This area was selected on the bosom of the Sabine woman in a flat area still affected by washout. Two measurement points were identified (Figure 2D).

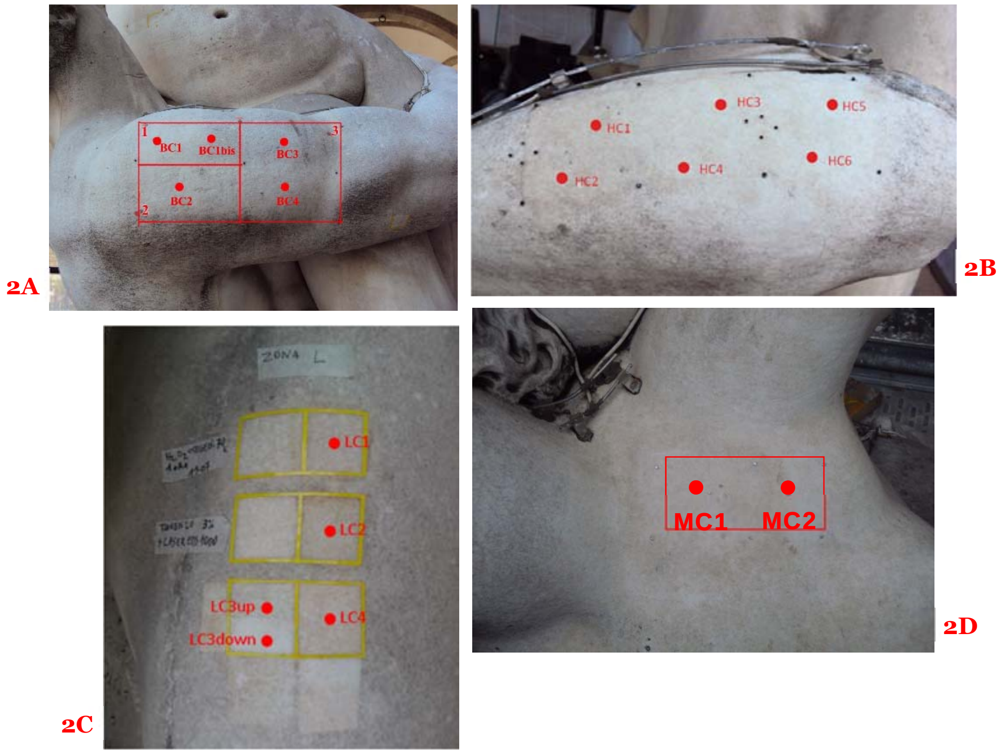

Figure 2: Investigated areas – 2A: Area B. Sub-areas (1, 2, 3) and measurement points (BC1, BC1bis, BC2, BC3, BC4); 2B: Area H. Measurement points (HC1, HC2, HC3, HC4, HC5, HC6); 2C: Area L. Measurement points (LC1, LC2, LC3up and LC3down, LC4); 2D: Area M. Measurement points (MC1,MC2).

Cleaning tests

The cleaning process plays a primary role in the aesthetic recovery of artifacts, including stone statues. Indeed, due to the degradation processes, alterations and the formation of a film of dirt or an incorrect restoration can change the colour of the stone surface over time, resulting, in the worst cases, in a loss of readability of the artwork. Although cleaning is often a much needed operation, it is extremely delicate one. An unsuitable intervention may irreversibly damage the artwork by promoting the loss of material, or by making it more susceptible to degradation factors. The cleaning treatments are usually chosen according to the nature of the stone and its state of conservation, the type of substances to be removed and the distribution of the dirt over the surface. Depending on their nature, the cleaning procedures can be divided into chemical, mechanical or physical methods, and can be applied alone, sequentially or selectively on predetermined areas.

Chemical treatments include the use of various cleaning products (water, deionised water, organic solvents, etc.) [11-12]. Mechanical methods, instead, are based on the removal of dirt using special tools such as scalpels or micro-sandblasters, all to be used on firm stone.

Among the physical methods, the most used is the laser cleaning, which is based on the photomechanical reaction induced by the interaction between the light beam generated by a high intensity pulsed laser and the layer of dirt [13-19].

For the statue *Ratto della Sabina*, several treatments were tested in order to select the best cleaning method. Particularly, tests were carried out by using:

- Deionised water (Area B, Area H, Area L);
- Ion exchange resin (Area H, Area M): ammonium oxalate (5%) solution;
- Laser (Area L; Table 1).

Area L	Laser treatment
LC1	H_2O_2 (70%) 1 h (No laser)
LC2	Tween 20 (3%) + laser EOS 1000
LC3up	laser LQS (5 Hz, F_{max} 0.41 J/cm^2 on wet surface) +laser LQS@532 nm, 5Hz, F_{max} 0.2 J/cm^2 on wet surface)
L3down	laser LQS (5 Hz, F_{max} 0.41 J/cm^2 on wet surface) + laser LQS@532 nm (5Hz, F_{max} 0.6 J/cm^2 on wet surface)
LC4	laser LQS (5 Hz, F_{max} 0.6 J/cm^2 on wet surface)

Table 1: Description of the laser treatments on Area L.

Experimental

Measurements of the chromatic parameters were carried out with the spectrophotometer Minolta CM-2002 model. This instrument measures reflectance spectra in the 400-700nm range with an acquisition step of 10 nm. Measurements were acquired using a diffuse lighting geometry, 8° angle of view and exclusion of the specular component. The colorimetric data reported in this work are the average of five consecutive measurements (with an error calculated as the maximum deviation) and were calculated in the CIEL*a*b* 1976 colour space [20-22]. For each measurement, the instrument was positioned on the same spot (Ø 8 mm) on each area, and removed immediately after. The instrument was provided with its own white reference (100% reflective) for calibration. Masks of reference were created, using paper sheets previously perforated and delimited, in order to reposition the instrument in exactly the same point before and after the cleaning tests. The colour measurements were performed following the timetable reported on Table 2.

The colour differences were calculated on average values as Δ(L*a*b*) and ΔE_{76} in order to compare the obtained data with those acquired in previous diagnostic campaigns. Furthermore, since other colour-difference formulas have been defined in the years, the ΔE_{00} colour differences were also calculated applying the CIEDE2000 formula [23-24].

Area B / Date	Colour measurements / treatments
T0 (9 June 2011)	BC1, BC2, BC3, BC4 before treatments.
T1 (16 June 2011)	BC1 and BC3 not treated. BC2 and BC4 after cleaning with deionised water.
T2 (12 March 2012)	BC1 and BC3 after one year of environmental exposition for comparison with BC1bis (never treated).
T3 (13 March 2013)	BC1, BC3 and BC1bis after one year of environmental exposition.
T4 (18 March 2013)	BC1, BC3 and BC1bis after cleaning with deionised water.
Area H / Date	**Colour measurements / treatments**
T0 (16 June 2011)	HC1, HC2, HC3, HC4, HC5, HC6 before treatments.
T1 (23 June 2011)	HC1, HC2, HC3, HC4 after cleaning with ammonium oxalate. HC5 and HC6 not treated.
T2 (13 July 2011)	HC1, HC2, HC3, HC4, HC5, HC6 to evaluate the repeatability of the measurements.
T3 (12 March 2012)	HC1, HC2, HC5, HC6 after 8 months of environmental exposition. HC3 and HC4 after cleaning with deionised water.
T4 (19 March 2012)	HC1, HC2, HC5, HC6 for check. HC3 and HC4 after cleaning with ammonium oxalate.
T5 (13 March 2013)	HC1, HC2, HC3, HC4, HC5, HC6 after one year of environmental exposition.
Area L / Date	**Colour measurements / treatments**
T0 (13 July 2011)	LC1, LC2, LC3up and LC3 down, LC4 before treatments.
T1 (13 July 2011)	LC1, LC2, LC3up and LC3 down, LC4 after the laser cleaning.
T2 (12 March 2012)	LC1, LC2, LC3up and LC3 down, LC4 after eight months of environmental exposition.
T3 (13 March 2013)	LC1, LC2, LC3up and LC3 down, LC4 after one year of environmental exposition.
Area M / Date	**Colour measurements / treatments**
T0 (12 March 2012)	MC1 and MC2 before treatments.
T1 (19 March 2012)	MC1 after cleaning with ammonium oxalate. On MC2 not treated.
T2 (13 March 2013)	MC1 and MC2 after one year of environmental exposition.

Table 2: Timetable and schematic description of the colorimetric surveys carried out in the period 2011-2013 on the Ratto della Sabina, Loggia dei Lanzi (Florence).

Results and discussion

Measurements of the chromatic parameters were carried out over time, on the same areas of the surface of the sculpture in order to point out the chromatic alterations and support curators and conservators in choosing the best conservation treatments.

The main drawback that first appeared in the colorimetric survey was connected to the difficulty in guaranteeing the repeatability of the measurement, namely the possibility of exactly reproducing the same measurement conditions in time.

The masks previously prepared were placed between the surface of the statue and the colorimeter in order to perform measurements without any direct contact with the sculpture and to provide some reference points for repeating the measurements in the same areas in time. In spite of this expedient, the rounded shape of certain surfaces of the statue (e.g. the arms) made it sometimes difficult to precisely re-position the instrument.

The climatic conditions also influenced the measurements: the abundant rain in the days prior to the diagnostic survey (on March 2013, T5) and the intense humidity strongly influenced the state of the marble surface. This resulted in very wet surfaces, despite an attempt to cover the sculpture with cellophane sheets during the rain and to dry the areas of interest using a hair-dryer. The surface moisture of the marble affected the colorimetric measurements, particularly as regards the variations in the L* parameter, which, presented on the wet surfaces values lower than those recorded on the dry ones. This result was also confirmed by laboratory tests performed on wet marbles specimens. Below, the results of the colour survey for each area are reported.

Area B – Before the cleaning intervention, sub-areas 1 and 2 treated with Wacker290 in 2003 (BC1, BC2) appeared clearer and more yellowish as compared to those never treated (BC3, BC4). After the cleaning treatment with demineralised water on BC2 and BC4, an increase of the lightness occurred in both areas, while a decrease in the yellow component was observed in the pre-treated one. However, no significant colour changes were recorded in the two uncleaned points (Table 3).

Area	L*					a*					b*				
	T0	T1	T2	T3	T4	T0	T1	T2	T3	T4	T0	T1	T2	T3	T4
BC1	83.2	83.2	83.5	78.1	81.3	0.7	0.7	0.5	0.6	0.6	10.5	11.1	10.2	9.3	10.0
BC2	79.3	83.9	---	---	---	0.8	0.4	---	---	---	10.9	9.9	---	---	---
BC3	75.5	76.1	74.5	72.2	74.0	0.5	0.6	0.7	0.7	0.8	7.3	7.7	8.1	7.2	8.0
BC4	70.8	80.2	---	---	---	0.8	0.6	---	---	---	8.3	8.6	---	---	---
BC1bis	---	---	73.6	72.1	72.3	---	---	0.8	0.7	0.8	---	---	9.3	8.3	8.9

Table 3: Area B – Averaged colorimetric values (L, a*, b*) for each measurement point before (T0) and during the diagnostic survey.*

It must be kept in mind that the surface of this area was exposed to washout, but in a uniformly way. The right portion of the treated sub-area was not exposed to rain differently than the left one. This inhomogeneous exposure to water prevented an objective interpretation of the data. Based on this fact, one year later the first survey, it was decided to choose a new measurement point, named BC1bis, located in a less exposed point of the treated sub-area 1, in order to obtain a more reliable comparison with respect to the untreated subarea on the right (BC3). Furthermore, considering the difficulties in repositioning the instrument on the BC2 and BC4 points (due to the rounded modelling of the arm), these points were not considered in the following measurements surveys.

After one more year, the colour variations recorded were very modest, with a slight decrease in the L* parameter, perhaps due to the deposit of fine particulate. After a slight cleaning with deionised water a recovering of lightness occurred that was more pronounced on the BC1 point.

Area H - Colour measurements performed after a treatment with ammonium oxalate (T1) showed, in the treated points (HC1, HC2, HC3, HC4,), a slight general tendency to yellowing (not visible to the naked eye) and a decrease in lightness (except for HC3; Table 4).

Area	L*						a*						b*					
	T0	T1	T2	T3	T4	T5	T0	T1	T2	T3	T4	T5	T0	T1	T2	T3	T4	T5
HC1	79.9	78.7	79.3	73.3	75.8	68.9	1.2	1.6	1.6	1.6	1.5	1.7	11.7	12.2	12.2	12.3	12.2	11.0
HC2	81.9	79.7	79.9	76.2	75.0	76.0	1.2	1.9	2.0	1.9	1.9	1.9	12.4	13.6	13.2	14.3	13.8	12.6
HC3	80.7	82.3	82.1	80.3	79.3	72.8	0.2	0.6	0.6	0.6	0.6	0.9	9.1	10.0	10.0	9.7	9.9	9.8
HC4	82.1	80.8	80.8	81.1	79.7	75.6	0.6	0.9	1.0	0.8	0.9	1.0	9.8	10.8	10.7	10.2	10.5	9.8
HC5	81.3	81.2	81.5	73.7	74.7	71.2	0.3	0.3	0.3	0.7	0.7	0.6	9.1	9.6	9.7	9.0	8.7	9.0
HC6	82.9	81.6	80.7	76.1	76.4	74.5	0.3	0.5	0.3	0.7	0.8	0.7	9.1	9.8	9.8	10.0	10.4	9.0

Table 4: Area H – Averaged colorimetric values (L, a*, b*) for each measurement point before and during the diagnostic survey.*

However, since the rounded modelling of this area made difficult to perform measurements, it was decided to repeat again the analysis after ten days (T2), in order to validate the repeatability of the procedure and the reliability of the acquired data. The values obtained were completely congruent with the previous ones ($\Delta E_{T1-T0}=\Delta E_{T2-T0}$ except for HC6; Tables 5-6). The control measurements carried out on HC1, HC2, HC5 and HC6, after 8 months of environmental exposure (T3), showed a general tendency to turn gray. Instead, the L* values measured in the HC3 and HC4 points, cleaned with demineralised water, resulted to be the same L* values of 2011 ($\Delta L^*_{T3-T0}<1$), probably thanks to the cleaning intervention to which they were subjected. A treatment with ammonium oxalate, on the same points, induced a slight graying of the surface ($\Delta L^* \approx 2$).

The decrease in the L* value at T5 was mainly due to the wet surface because of the abundant rain fallen before the measurements acquisition.

D65/10° Area di misura	ΔE_{76} (T1-T0)	ΔE_{76} (T2-T0)	ΔE_{76} (T3-T0)	ΔE_{76} (T4-T0)	ΔE_{76} (T5-T0)
HC1	1.3	1.3	1.9	1.3	4.7
HC2	2.0	2.0	2.4	2.9	6.8
HC3	2.0	2.0	1.5	2.0	5.1
HC4	1.7	1.7	1.2	2.5	6.5
HC5	0.7	0.8	7.6	6.6	10.1
HC6	1.5	2.3	6.9	6.7	8.4

Table 5: Area H – ΔE_{76} colour differences before and during the diagnostic survey.

D65/10° Area di misura	ΔE_{00} (T1-T0)	ΔE_{00} (T2-T0)	ΔE_{00} (T3-T0)	ΔE_{00} (T4-T0)	ΔE_{00} (T5-T0)
HC1	1.0	0.7	4.8	3.0	8.1
HC2	1.9	1.7	4.2	5.0	4.2
HC3	1.4	1.3	0.7	1.2	5.7
HC4	1.2	1.2	0.8	1.8	4.6
HC5	0.3	0.4	5.4	4.7	7.3
HC6	1.0	1.6	4.8	4.7	5.9

Table 6: Area H – ΔE_{00} colour differences before and during the diagnostic survey.

Area L – The comparison between measurements performed before (T0) and after the selected cleaning treatments (T1) showed that the conservation treatments induced a significant increase in the lightness for all the areas ($\Delta L^*>6$), due to a reduction in the graying of the surface (Tables 7-8).

Furthermore, an increase in the b* coordinate ($\Delta b^*>3$), corresponding to an increase of the yellowness of the surface, was registered in all points with the exception of LC3down, where the maximum clearing up was also calculated ($\Delta L^* \approx 16$).

Area	ΔE_{76} (T1-T0)	ΔE_{76} (T2-T0)	ΔE_{76} (T3-T0)	ΔE_{76} (T4-T0)
LC1	7.6	9.0	7.7	4.8
LC2	8.9	12.1	9.7	4.9
LC3up	10.0	7.3	4.1	1.7
LC3down	16.2	12.9	8.5	4.9
LC4	7.8	6.0	3.0	2.5

Table 7: Area L – ΔE_{76} colour differences before and during the diagnostic survey.

Area	ΔE_{00} (T1-T0)	ΔE_{00} (T2-T0)	ΔE_{00} (T3-T0)	ΔE_{00} (T4-T0)
LC1	5.6	6.6	5.8	3.4
LC2	6.5	8.9	7.3	3.8
LC3up	7.6	5.6	3.4	1.9
LC3down	11.8	9.5	6.6	4.2
LC4	5.4	4.3	2.2	1.7

Table 8: Area L – ΔE_{00} colour differences before and during the diagnostic survey.

After 8 months (T2), the major colour changes were recorded on LC2 and LC3down, the least on LC4. In particular, the slight yellow tone occurred in the different subareas after laser cleaning, regressed in all areas, and mostly in LC2 ($\Delta b^*_{T2\text{-}T1}$=-2.4). Furthermore, the three sub-areas (LC3up, LC3down and LC4) treated with the LQS laser, underwent a decrease in lightness, reasonably attributable to a graying caused by a deposit of particulate. For the two sub-areas treated with hydrogen peroxide (LC1) and Tween 20 + Laser EOS1000 (LC2), instead, an unexplained increase in lightness was found.

Area	L*				a*				b*			
	T0	T1	T2	T3	T0	T1	T2	T3	T0	T1	T2	T3
LC1	68.3	75.0	76.7	75.7	2.0	2.9	2.2	2.2	10.9	14.2	13.8	12.7
LC2	68.6	76.8	80.6	78.3	1.6	2.0	1.0	1.1	10.5	13.7	11.3	10.5
LC3 up	69.5	79.3	76.6	73.4	1.7	0.2	0.4	0.5	10.9	12.1	11.3	10.6
LC3 down	69.5	85.5	82.1	77.4	1.7	-0.7	-0.3	-0.1	10.9	10.0	9.1	8.5
LC4	73.8	80.5	79.3	76.7	0.9	0.8	0.6	0.5	9.5	13.4	12.0	10.3

Table 9: Area L – Averaged colorimetric values (L, a*, b*) for each measurement point before and during the diagnostic survey.*

<u>Area M</u> was added in 2012 in order to carry out a further treatment with ammonium oxalate (in addition to that one already performed on Area H) on a flat surface of the sculpture, which was exposed to corrosion and easily accessible by instrumentation. Two subareas were here identified: the left part (MC1) was treated with ammonium oxalate, the right one (MC2) was not.

Although the cleaning treatment was applied only on MC1, the colorimetric analysis showed similar chromatic variations in both points (Tables 10-11). The most reasonable explanation for this unexpected result is that, during the intervention, the ammonium oxalate solution applied on MC1 had partially spread in the contiguous MC2 point causing this outcome.

Area	L*		a*		b*	
	T0	T1	T0	T1	T0	T1
MC1	82.7	77.9	0.2	1.0	9.8	10.7
MC2	82.1	77.0	0.3	1.0	10.5	10.8

Table 10: Area M – Averaged colorimetric values (L, a*, b*) for each measurement point before and during the diagnostic survey.*

Area	ΔL* (T1-T0)	Δa* (T1-T0)	Δb* (T1-T0)	ΔE* (T1-T0)	ΔE00 (T1-T0)
MC1	-4.84	0.8	0.9	5.0	3.5
MC2	-5.10	0.6	0.3	5.1	3.6

Table 11: Area M – ΔL^*, Δa^*, Δb^*, ΔE_{ab} and ΔE_{00} colour differences [T0: before cleaning test; T1: after cleaning test] on MC1.

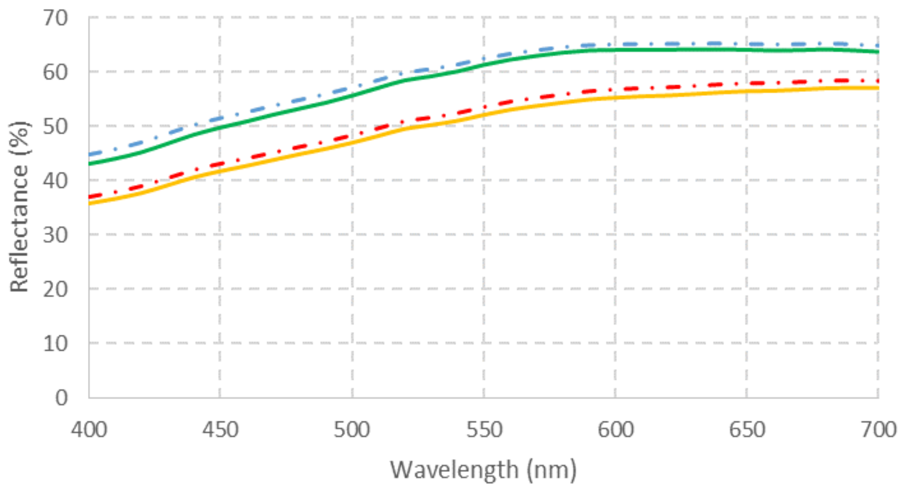

Figure 3: Spectral features of the two investigated points, MC1 and MC2, before [T0] and after the [T1] cleaning test (M1_T0: blue dash-dot line; M1_T1: red dash-dot line; M2_T0: green solid line; M2_T1: yellow solid line).

The observed colour differences, which are principally due to the reduction of the L* parameter after the treatment, are easily explained by observing the spectral features of the two investigated points (Figure 3) before and after cleaning. Indeed, an average intensity decrease is observed, without any variation of the spectral shape.

Conclusions

This work illustrates selected results of the colorimetric measurements campaign carried out in the framework of a wider survey performed on the sculptural group *Ratto della Sabina*, located in Piazza della Signoria in Florence. The importance of this artwork, together with the special complexity of the modeling of this statue, makes this case study representative of the peculiar questions related to the use of colorimetry to monitor the degradation of outdoors 3D artworks.

In the analysed case, the obtained data showed the extreme importance of defining a protocol to ensure repeatability of measurements over long time periods. Among the factors to be considered, the role of the atmospheric conditions, which introduce a further source of variability, since may temporarily affect the colour surface, deserves particular attention. The comparability of data acquired on the same areas at different times is the essential ingredient to guarantee the reliability of data. For these reasons, during the long term campaign carried out on the *Ratto della Sabina*, some of the data acquired had to be discarded. However the remaining data could be used to evaluate the effectiveness of the cleaning procedures and were indeed used as support in the choice of the best conservation treatments. In particular, the best results were reached by means of laser cleaning (with an evident increase of the lightness), although in some cases laser induced a yellowing of the surface (increase of the b* parameter). Moreover, colour measurements performed few months after cleaning evidenced a tendency to darkening of the stone (decrease of L* parameter). This tendency was maybe due to the sedimentation of dust and atmospheric particulate on the surface, especially on the areas not subjected to washout.

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