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Preserving the contemporary mural "*Musica Popolare*" by Orticanoodles in Milan, Italy: Deterioration processes and protection performance of commercial coatings

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ABSTRACT

This study aims to investigate the possibility of protecting real street artworks in urban outdoor conditions. Specifically, this paper focuses on a testing experimental work carried out on the mural "Musica Popolare" (2016) in Milan by Orticanoodles and includes: *i*) the assessment of the state of conservation through in-situ and micro-invasive techniques; *ii*) the set-up of an in-situ testing protocol to assess the compatibility and efficacy of protective treatments; *iii*) the one-year monitoring testing campaign. This study investigates the deterioration processes of the paint and evaluates the protective performances of various commercial coatings, which were previously tested under laboratory conditions. Notably, the mural experiences three distinct exposure conditions (fully exposed, partially exposed, and sheltered) allowing for a comparative evaluation of their effects. The coatings performance was evaluated by using a testing protocol including: portable digital microscopy, VIS reflectance spectroscopy, glossmetry, and vertical water contact angle measurements. After one year of natural ageing, the monitoring results indicate that acrylic-based coatings offered only limited protective action of the painted surface, ensuring a moderate colour retention but an insufficient protection towards liquid water. In sheltered areas, the application of protective coatings had a negative effect, making the treated surfaces more unstable than the original paintings without significantly improving water repellency (WCAs). An increase of particulate matter (PM) adhesion to the surfaces was also observed. Contact angle measurements indicated that only the fluorinated coatings achieved and maintained good water repellency over the one-year period. However, none of the tested coatings provided satisfactory protection over the monitoring period, highlighting the need for more innovative and effective preservation strategies for these artworks.

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Introduction

Contemporary murals are becoming an increasingly noticeable form of artistic expression, mainly localized in urban public spaces. It is evident that these artworks, whether they are spontaneous or commissioned, embed social, artistic, and historical values, and therefore are clear evidence of civilization [1–3]. Nonetheless, protecting street artworks presents new challenges due to the use of modern synthetic materials, often applied without proper substrate preparation and exposed to outdoor conditions that differ significantly from those of historical mural paintings [1]. Scientific research in this field is growing, with the aim of: *i)* characterizing materials and deterioration mechanisms [4–12], *ii)* testing in lab and in-situ the effectiveness of protective coatings [13–17], and *iii)* developing guidelines for the long-term protection and safeguard of these important contemporary artistic expressions. Due to their intrinsic nature, modern paints exposed to outdoor conditions can be highly prone to color and material fading, which may occur in a very short span of time, even within one or few years [4–6,18,19]. Aged mural paintings usually exhibit deterioration phenomena such as color fading, whitening, color changes, craquelure, cracking, powdering, exfoliation, and salt efflorescence

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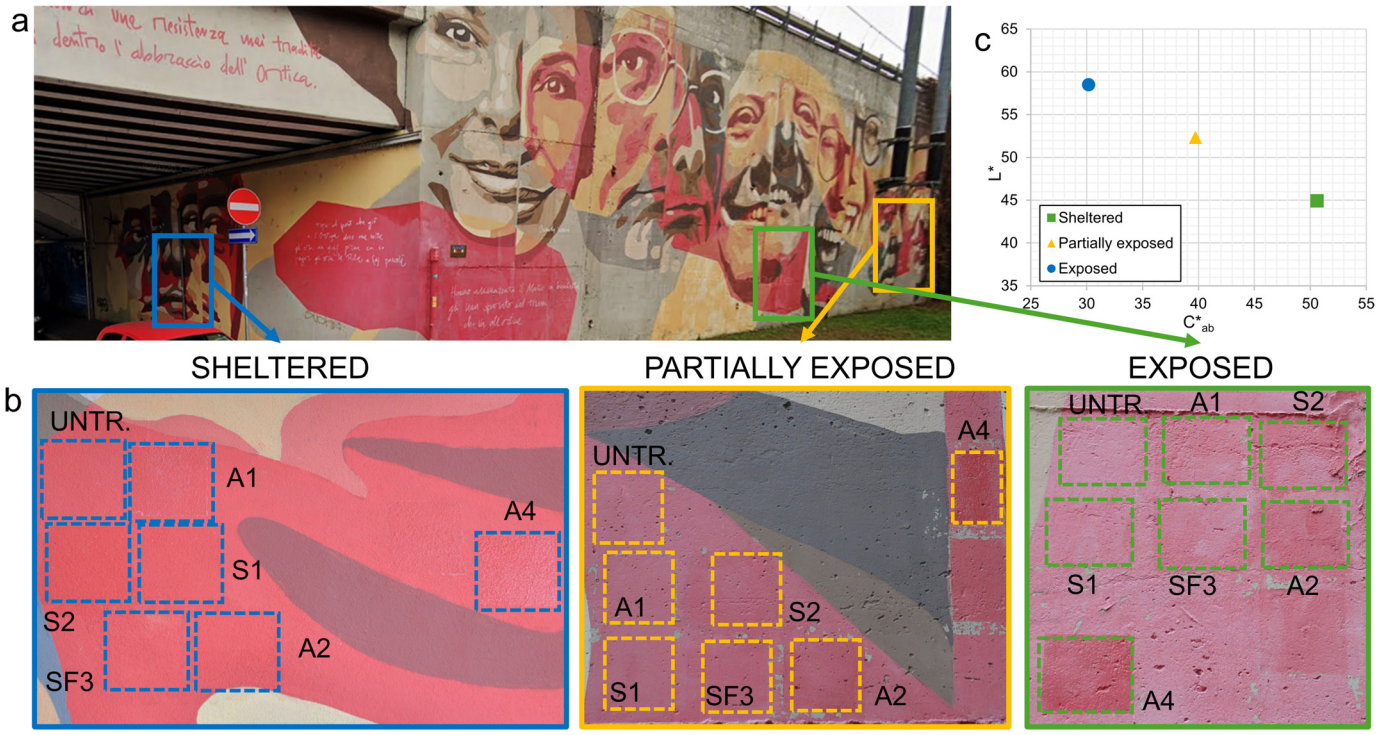

Fig. 1. a) The "Musica Popolare" mural; b) application areas of the protective coatings across the three selected sections of the mural; c) colorimetric differences among the three areas.

[1,18,20]. Recently, a multi-scale and multi-technique non-invasive methodology has been proposed for the in-situ investigation and monitoring of street art murals, combining portable point analyses with hyperspectral and multispectral imaging, and supported by micro-destructive laboratory techniques. This integrated approach, which was also applied to the same case study discussed in the present work, proved effective for material identification and conservation assessment of urban artworks [21]. Despite the vulnerability of these surfaces, the use of protective coatings remains uncommon and poorly considered by various actors. A recent Italian project [22] has revealed the interest among restores, conservators and artists about the suitability and durability of current protective products available on the market. Artists' choices are primarily guided by cost and aesthetic considerations, though awareness of the impact of paint chemistry on durability is increasing.

This paper explores the possibilities of protecting real painted surfaces of outdoor murals employing a range of different commercial products, originally developed for the protection of historical architecture. The selected case study is "*Musica Popolare*" by Orticanoodles (Fig. 1a), a mural located in the Ortica neighborhood of Milan, on the side wall of a railway overpass and inside the tunnel below it (45°28′19.5″N 9°14′31.0″E). The artwork is dated to 2016 and is part of the Ortica Memoria project (OrMe), a series of murals designed to preserve and celebrate the cultural and musical identity of Milan through public art [23]. This represents an interesting case study, as the painted surfaces are exposed to atmospheric agents in different ways: A south-east facing area fully exposed to sunlight and rainfall, a south-east facing area partially exposed to sunlight, and a completely sheltered section inside a road tunnel, protected from both sun and rainfall though potentially exposed to higher concentration of PM and gas pollutants because of the partially enclosed location. These distinct exposure conditions allow for the evaluation of protective coatings under different environmental scenarios on the same type of painting materials and substrate.

Research aims

This research explores the possibility of ensuring effective protection to enhance the durability of these artworks in urban outdoor conditions. Specifically, this paper presents an experimental study on the *Musica Popolare* mural in Milan (Italy), focusing on:

(i) The assessment of its state of conservation through in-situ and micro-invasive investigations.
(ii) The set-up of an in-situ testing protocol to evaluate the compatibility and efficacy of protective treatments.
(iii) The monitoring of the painted surfaces to assess the durability of the applied protective treatments.

Material and methods

Five commercial protective coatings (labelled as A1, A2, S1, S2, SF3) were selected, characterized and tested in a previous experimental lab study on mock-ups [16,24]. They were applied by brush on red-painted areas of the mural (approximately 10 × 10 cm), as these were the most affected by color fading. In this study, an additional protective coating (A4), characterized as an acrylic copolymer MA-MMA-nBA-2EHA-EMA [6], was also applied to the mural by spray. The characteristics of the selected products, according to the technical datasheet, and the method of application to the mural, are reported in Table 1.

The coatings were prepared following the respective data sheets (i.e., diluted 30 % in ethyl acetate and then 15 % in isopropanol for A2, diluted 10 % in distilled water for S1 and, as they were supplied, for A1, S2 and SF3). The coatings A1, A2, S1, S2, SF3 were applied by brush using the same procedure as in the laboratory experiments [16], ensuring that approximately the same amount per square meter (g/cm^2) was used for each coating, i.e., 0.3 g for A1 and S2, and 0.15 g for A2, S1, and SF3, satisfying the minimum quantity specified in the technical datasheets. To follow this pro-

Table 1
Summary of the selected protective coatings, with abbreviation, class of product, declared chemical composition (from technical datasheet of the suppliers) and method of application.

Abbr.	Class of product	Product	Supplier	Chemical composition from technical datasheet	Application method
A1	Acrylic	MTN PRO Synthetic Varnish	Montana Colors (Barcelona, Spain)	Water based acrylic	Brush
A2	Acrylic	Paraloid B72	Rhom & Haas (CTS, Italy)	Acrylic resin copolymer MA-EMA	Brush
A4	Acrylic	T1000 Varnish gloss	Montana Cans (Germany)	Acrylic-based	Spray
S1	Silane	Hydrophase Acqua	Phase Restauro (Italy)	Alkyl alkoxy silane with catalyst	Brush
S2	Silane/Siloxane	Lotexan	Keim (Germany)	Micromolecular silane/siloxane	Brush
SF3	Fluorosilane	Nano Silo OR	CTS (Italy)	Water dispersion of fluoro-silane at nano scale	Brush

A more detailed characterization of the coating is available in literature [6,16].

cedure, each liquid coating was weighted before and after the mural application. According to the different viscosity of each coating, from two to four surface treatments were applied with horizontal and vertical direction of the brush. On the other hand, the coating A4, commercialized in a spray can, was applied as supplied by spraying the product twice at a distance of 25 cm from the wall, ensuring full coverage of the squared area. After application, the coatings were left to dry in environmental conditions for approximately 24 h before the testing. Images of the treated areas are reported in Fig. 1a and b.

Before the coating's application, analyses were performed to characterize painting materials both in-situ and in laboratory after micro-sampling. Optical microscopy (Leica DM6 3D, Leica Microsystems, Milan, Italy with an objective of 20× – 50×, and LASX software 5.1.0.25593) was used to assess the surface morphology and the stratigraphy of micro-samples on polished cross-sections. μ-FTIR spectroscopy (Thermo Nicolet iN10 MX, Thermo Fisher, 128 scans, resolution 4 cm^{-1}) was performed on micro-samples in transmission and ATR mode (Ge crystal tip) to analyse the paint's chemical composition. Raman spectroscopy (Thermo Scientific DXR3 Raman, laser 532 nm wavelength, 10 mW real output power and 50 μm aperture, 2 cm^{-1} of resolution) was carried out to identify some pigments and fillers. SOPrano library [25,26] and bibliographic references [27] were used for the identification of the pigments.

In-situ characterization was carried out by portable instruments and an in-situ testing procedure. To evaluate the compatibility before (t_{pre}) and after application (t_0) and after one year (t_1) of outdoor natural ageing, morphological observations were carried out by using digital microscopy (Dino-Lite Premiere AM7013MT, color CMOS sensor and white LED illuminator).

VIS reflectance spectroscopy (Spectro-colorimeter CM-2600d Konica Minolta, Japan; D65 light source at 10°, spot size of 8 mm) evaluated color changes by 15 measurements per area,). CIELab and $CIELCh_{ab}$ color space were used to elaborate the measurements and calculate ΔE_{ab} values [28,29].

Gloss measurements were achieved through a glossmeter multi-gloss 268, Konica Minolta, Japan. 15 measurements per area were carried out at an angle of 60° [30,31], and the obtained values, in Gloss Units (GU), were averaged.

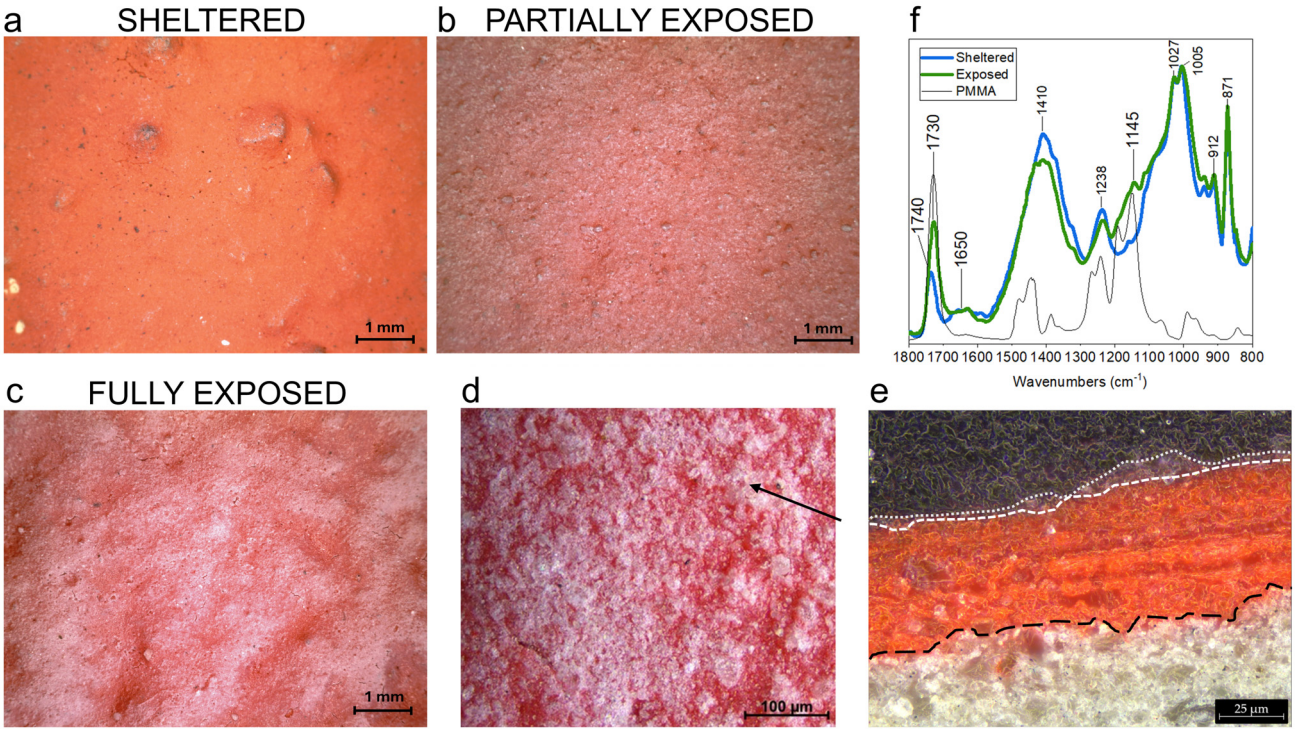

Fig. 2. a-c) Digital microscopy images of the surfaces in the three untreated areas; d) optical microscopy image of the exposed surface (20×); e) optical microscopy image of the cross section of the sample coming from the fully exposed area (50×), dotted lines highlight the different layers in the stratigraphy; f) μ-ATR FTIR spectra of the surfaces of sheltered and exposed areas and PMMA reference spectrum. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

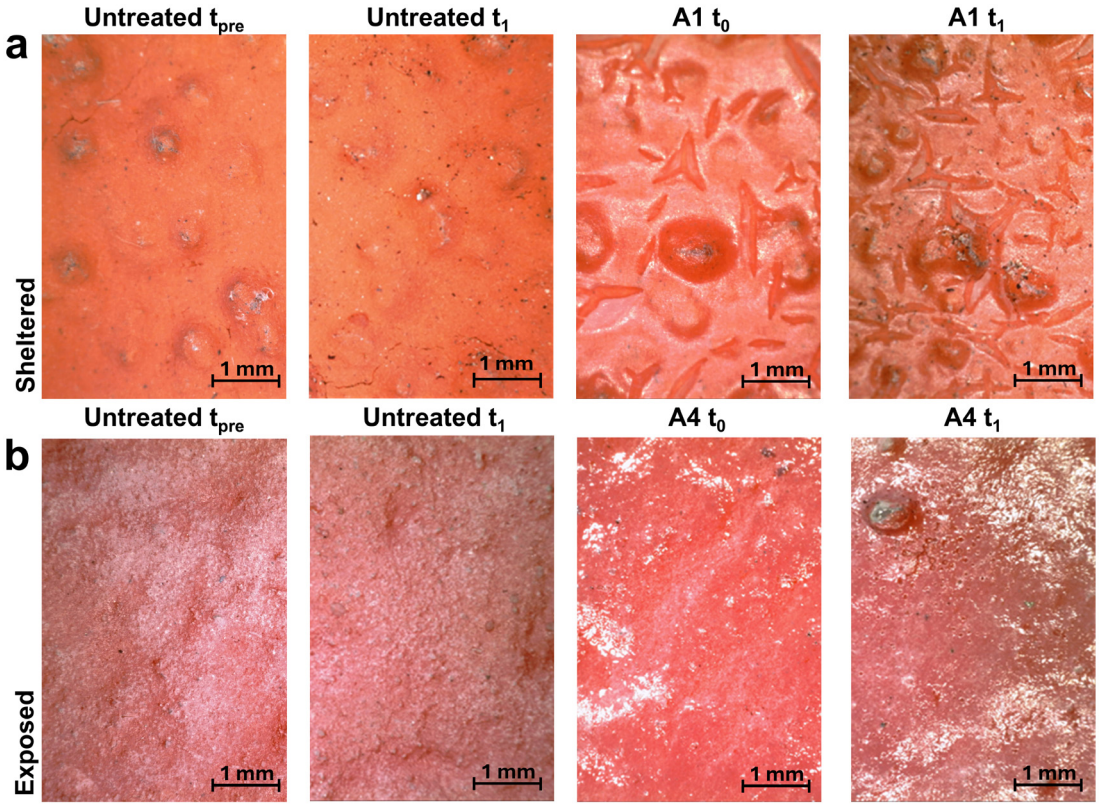

Fig. 3. Digital microscopy images of: a) sheltered area treated with A1 and b) exposed area treated with A4. For both cases the digital images of the untreated and treated surfaces are shown before the treatment and after one year of natural ageing. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

To evaluate the protective effectiveness, water absorption measurements were carried out by using the contact sponge testing method (3 mL of wetting demineralized water, 3 min of contact with surface, area of the sponge 23.76 cm^2) [32,33] and in situ vertical contact angle measurements (WCA) by a portable instrument (MSA – Mobile Surface Analyzer, Kruss, Germany), with 5 μL water droplets. WCA values (6 measurements per area) were obtained using KRÜSS Advance v.1.16, applying Young-Laplace fitting method, and ImageJ software [34]. All the in-situ measurements were conducted taking care that the surfaces were not directly subjected to solar irradiation. Two monitoring intervals were considered (supplementary figure 1): Δt_0 (t_0-t_{pre}) representing the time elapsed between the two surface characterizations before (t_{pre}) and 24 h after (t_0) coating application; and Δt_1 (t_1-t_0), representing surface changes after one year of natural ageing after coating application. Protective factors (PF) were determined only for coatings that effectively reduced color fading, comparing ΔEt_1 of treated (tr.) and untreated (untr.) areas in the same time interval (using eq. 1 in Supplementary Figure 1) [35].

Results and discussion

Materials characterizations and state of conservation of the mural

The visual inspection of the mural clearly reveals that the surface morphology and state of conservation vary depending on the exposure conditions of each area. (Fig. 1). Both from direct digital microscopy observations of the painted surface onsite, and from optical microscopy observations of micro-samples' surfaces, it was possible to detect an increasing roughness and crumbling of surface painting film, passing from the sheltered to the fully exposed areas (Fig. 2a, b and c). Moreover, on fully exposed surfaces, higher magnification revealed the presence of dispersed whitish particles, identified as polymeric binder (Fig. 2d). The whitish superficial layer can be observed in the cross section of the exposed surface with an average thickness of 5 μm (Fig. 2e). Despite the evident presence of these white grains on the surface, in the cross sections the whitish layer of the deteriorated polymeric binder, on top of the red painting, is hardly visible (Fig. 2e). The thickness of the red painting layer showed a high variability depending on the different color fields and location.

The color measurements showed increased whitening from the sheltered area to the two exposed areas, with the area fully exposed to sunlight exhibiting the most significant change: a marked decrease of C^* coordinate and increase of L^* is observed. The Color differences (ΔE) between the fully and partially exposed areas compared to the sheltered area are 17.16 and 14.60, respectively (ΔE were calculated as the color difference between untreated areas of the exposed sections compared to the untreated area of the sheltered section). The exposure to the atmospheric conditions caused a drastic color fading, with a strong decrease of the red tone (a^*).

Raman analysis confirmed the presence of the presence of calcite (thanks to the typical peak at 1086 cm^{-1}), TiO_2 anatase phase (144 cm^{-1}) and revealed the use two synthetic organic pigments: Naphthol AS red pigment PR112 (1580,1552, 1484, 1461, 1448, 1392, 1375, 1358, 1282, 1230, 1206, 1161, 1109, 1061, 1039, 967, 812, 745, 725, 680, 614, 571, 527, 527, 439, 430, 345 cm^{-1}) and Diarylide yellow pigment PY83 (1596, 1400, 1334, 1254, 663 cm^{-1}) [27]. μ-FTIR analysis identified the paint as a vinyl-acrylic-based paint with calcite and kaolinite as fillers. Indeed, the bands at 2513, 1795, 1410, 871 and 711 cm^{-1} are ascribed to C–O and C=O stretching carbonate bonds of calcite [5], while those from 3695 to 3620 cm^{-1} and at 1027, 1005, 938, 912, 795 and 699 cm^{-1} allowed to identify the presence of kaolinite [8,36]. The strong carbonyl peak at 1740 cm^{-1}, along with the C–H bending vibra-

Table 2
Colorimetric results after the application of the coatings ($\Delta E\ t_0$) and one year after outdoor exposure ($\Delta E\ t_1$). The cells are color-coded according to the ΔE intervals: dark green if $\Delta E<1$, light green if $1<\Delta E<2$, yellow if $2<\Delta E<3.5$, red if $3.5<\Delta E<5$, and dark red if $\Delta E>5$). The protective factor (PF) is calculated only for coatings that reduce color fading compared to untreated areas at t_1.

		ΔE_{t0}	Stand. Dev.	ΔE_{t1}	Stand. Dev.	PF t_1
Sheltered	A1	2.13	± 2.34	2.30	± 1.38	
	A2	2.36	± 1.84	1.15	± 0.78	
	A4	4.69	± 1.89	2.36	± 1.21	
	S1	2.13	± 0.78	3.00	± 0.54	
	S2	5.04	± 1.45	4.85	± 0.67	
	SF3	1.42	± 0.56	2.08	± 0.21	
	Untr.	/	/	0.82	± 0.35	/
Partially exposed	A1	2.88	± 0.28	2.41	±0.43	37%
	A2	4.37	± 1.74	6.75	± 1.32	
	A4	6.14	± 0.58	2.31	± 0.23	40%
	S1	1.20	± 0.21	2.08	± 0.15	46%
	S2	2.57	± 0.58	2.32	± 0.78	40%
	SF3	3.07	± 1.39	2.19	±1.45	43%
	Untr.	/	/	3.85	± 0.78	/
Fully exposed	A1	10.18	± 3.78	3.33	± 2.12	50%
	A2	12.15	± 3.67	8.90	± 2.87	
	A4	13.64	± 3.86	2.24	± 2.56	66%
	S1	3.76	± 0.56	3.83	± 0.32	42%
	S2	6.50	± 1.84	3.37	± 1.65	49%
	SF3	6.59	± 2.86	4.71	± 2.34	29%
	Untr.	/	/	6.61	± 0.62	/

tions bands at 1434 cm^{-1} and 1374 cm^{-1}, as well as the bands at 1240 cm^{-1} and 1024 cm^{-1} associated with C–O and C–C stretching vibrations respectively, are commonly considered as indicative of a vinyl-based paints [37]. μ-ATR FTIR spectra (Fig. 2f) acquired from samples taken from both the sheltered and exposed surfaces revealed, in the latter, the appearance of bands related to acrylic binder (1145 cm^{-1}), the formation of unsaturation in the polymeric chains (1650 cm^{-1}) [37,38], and a shift of carbonyl band from 1740 cm^{-1} to 1730 cm^{-1}. Material characterization is consistent with IR spectra reported in previous literature [4] and further supported by HPLC MS/MS results obtained from micro-samples of the same mural, as reported in a very recent study [21]. These findings suggest that the whitish grains are residues of the deteriorated acrylic binder which, becoming brittle, started a process of surface crumbling and powdering. It is likely that the binder mixture is undergoing changes due to photo-oxidation, resulting in the accumulation of deteriorated acrylic polymer on the surface. This allows hypothesizing that the binder has deteriorated to such an extent that the inorganic fillers (calcite and kaolinite) of the paints have been previously completely lost and/or washed away, leaving on the surfaces only the residues of deteriorated acrylic matrix.

In-situ monitoring of protective coatings

In the sheltered painted area, after the application of acrylic-based coatings (A1 and A2, but particularly for A1), the surface of the coating film showed a network of fine cracks already at t_0, observed by portable digital microscopy (Fig. 3a), most probably related to bad adhesion of the coating to the painting substrate during drying. Other coatings did not significantly alter the surface morphology. A4 induces an evident increase in the gloss (Fig. 3b), for all the three tested areas, probably imputable to the different method of application of the coating. In the more degraded and porous areas, particularly those that are partially or fully exposed, all protective coatings, except A4, are absorbed without significantly altering the morphology of the painted layer. Digital microscopy observations (Fig. 3a) of the coated sheltered areas after one year from the application (t_1) reveal an increase in the deposit of particulate matter (PM) for all coatings. No increase in PM deposit was observed in the exposed areas, according to the fact that these areas are exposed to the action of rain.

Colorimetric measurements agree with visual and digital microscopy observations and results are reported in Table A. After coatings application ($\Delta E\ t_0$ in Table 2), in the sheltered areas, the protective layers induce slight to moderate color changes. Coating A4 ($\Delta E\ t_0 = 4.69$) and S2 ($\Delta E\ t_0 = 5.04$) cause the most noticeable color changes, while SF3 shows the least initial impact ($\Delta E\ t_0 = 1.42$), indicating a better aesthetic compatibility with the original painted surface. In the fully exposed area, all the coatings induce a strong color change with $\Delta E\ t_0$ values ranging from 6 to 13, except for S1, which shows the lowest $\Delta E\ t_0$, around 4. In the partially exposed areas, the coatings show an intermediate color change after treatment, with the application of A4 that produce the highest $\Delta E\ t_0$ value (6.14). It should be noted that in the case of the fully exposed and deteriorated surface, even SF3 induce a strong color change.

After one year of natural ageing ($\Delta E\ t_1$ in Table 2), in partially and fully exposed areas, the untreated painted surfaces have undergone an important color change, especially in the fully exposed area where ΔEt_1 is around 7. In the fully and partially exposed sections, all coatings provide a modest protection towards the red painted surface, except for A2 that, in the fully exposed and partially sheltered areas, showed a ΔEt_1 higher than the untreated surfaces (8.90 and 6.75 respectively). In any case, the coatings provide only a modest protection with protective factors ranging between 30 and 65 %. It should be noted that in the fully exposed area, also the fluorinated SF3 coating induces a noticeable color change after one year of natural ageing (4.71). In the sheltered section, all protected areas faced a slightly higher color change than the untreated area. This is possibly also associated to the increased accumulation of atmospheric PM on the coated areas.

In sheltered areas, gloss values for A2 and A4 decrease by approximately one-unit (from 1.3 to 0.5 and from 5.1 to 4.1, respec-

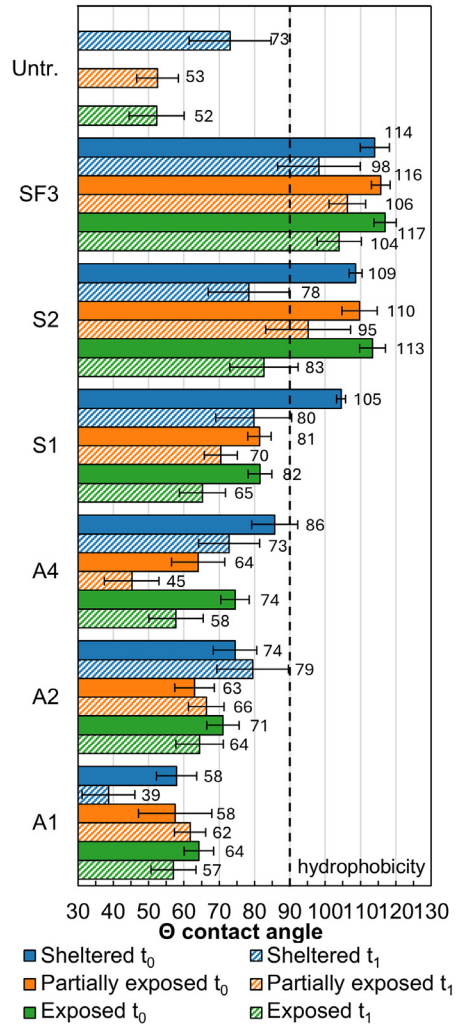

Fig. 4. Water contact angle (WCA) of the untreated and coated areas after the application at t_0 (solid colour) and after one year at t_1 (hatched fill), in the three different areas: sheltered (blue), partially exposed (orange), fully exposed (green). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

tively), whereas A1 (G t_1 = 2.0), S1 (G t_1 =0.7) and S2 (G t_1 = 0.7) coatings remain stable (ΔG absolute value <0.5). In partially sheltered areas, A1 still shows stable values (around G t_0 = 4.0, with ΔG (t_1-t_0) = −0.5), while A2 and A4 values decrease by 1 and 0.8 units, respectively (from 2.4 to 1.4 and from 8.7 to 7.9 respectively). Si based coatings (S1, S2, SF3) show a modest gloss increase after one year (around G t_0 = 1, with ΔG (t_1-t_0) equal to −0.8, 0.7, 2.3 respectively), with SF3 showing the largest ΔG (t_1-t_0) value (2.3). In fully exposed areas, A1, A2, S1 and S2 show stable gloss values (from 3.4 to 3.3, from 2.1 to 1.7, from 1.5 to 2.0, from 1.3 to 2.0 respectively), while A4 and SF3 a modest increase (ΔG (t_1-t_0) = +1.5, having G t_0 equal to 8.7 and 1.5 respectively). Overall, A4 is maintaining the highest gloss, while SF3 shows the most noticeable increase over time. Gloss measurements are reported in Supplementary Table 1.

The results from the contact sponge measurements (Supplementary Table 2) demonstrate that the paint layer itself acts as a barrier, that inhibits the penetration of liquid water into the porosity of the cementitious plaster, as also observed in the laboratory experiments [16]. In fact, the in-situ capillary water absorption tests did not allow the detection of differences between treated and untreated surfaces, especially in the sheltered and partially exposed areas, where the painting layer is still in rather good conditions. The contact sponge method is, actually, adapted from the application to stone materials to the painted surfaces, but the sensibility of the onsite methodology is not enough to detect the small decrease in water absorption, and the measured values fall within the error range of the measurement.

Vertically oriented Water Contact Angle (WCA) measurements have been carried out with portable instrument onto the three different sections. The results are summarized in Fig. 4. As it can be easily observed, in the untreated sheltered area, the painting itself shows a WCA of about 70° (a value compatible with a vinyl-acrylic resin). In the untreated exposed areas, the deterioration of the painting film determines lower WCA values, around 50°. After treatment, only S2 and SF3 achieve water repellency as indicated by WCA values higher than 90°. All the other coatings only slightly increase the contact angles if compared to untreated conditions. After one year of outdoor exposure, only SF3 maintain its protective effect (i.e. WCA above 90°).

Conclusions

In the mural considered, three sections with different exposure conditions showed different levels of deterioration. The protection of these differently weathered surfaces allowed to point out different performances of the same treatment depending on the state of conservation and exposure conditions. Overall, after one year of natural ageing in outdoor conditions, the acrylic coatings showed a modest protective action of the painted surface: A1 and A4 provided the best color protection in all conditions (with PF between 40 % and 60 %). In the case of A1, adhesion issues were observed due to the immediate formation of a micro cracks after application. For all acrylic-based coatings surface water repellency was comparable, or below, the threshold values of untreated surfaces. Silane and siloxane-based coatings (S1, S2, SF3) showed moderate color changes in one-year monitoring (with a PF between 30 and 45 %). In sheltered areas, applying protective coatings has a negative impact, as the treated surfaces show an increased color change and adhesion of atmospheric PM, without a significant improvement in water repellency (WCA). Contact angle measurements showed that only SF3 coating achieved and maintained a good water repellency (around 100°) after one year. None of the coatings provided a satisfactory protection action during the one-year monitoring, indicating that there is clearly a demand in developing innovative and more effective protection strategies for these artworks. There is, indeed, a need to develop new, specifically designed materials capable of protecting street artworks from solar photo-oxidation while ensuring a better and durable surface water repellency.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.culher.2025.08.004.

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