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Powdered cellulose microblasting: a useful technique for dry-cleaning the reverse side of canvas paintings

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Abstract

This study evaluates the effectiveness of microblasting with powdered cellulose for the dry-cleaning of canvases. Various surface cleaning tests were conducted by microblasting on the reverse of canvas paintings and the results were compared to those obtained with traditional dry-cleaning techniques using erasers and sponges. To assess cleaning effectiveness and potential changes on the support, the treated surfaces were examined both before and after cleaning using optical microscopy (OM), scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM–EDX), confocal laser microscopy with surface roughness measurements, and spectrophotometry. The results from this comparative evaluation suggest that microblasting with powdered cellulose is a feasible technique for removing soiling on canvas and that it does not affect canvas structure or its topography. Furthermore, powdered cellulose leaves fewer particles of residues on the surface after cleaning, and these residues are chemically stable and compatible with the canvas support. Thus, the technique also avoids the potential negative long-term effects of eraser and sponge residues of particles that may remain on the canvas when these traditional systems are used.

Keywords: Dry-cleaning methods, Canvas paintings conservation, Powdered cellulose microblasting

Introduction

With the passing of time, the versos of paintings tend to accumulate dust, soil, or grime deposits on the canvas, both above and between fibres and on the preparation layer in the case of open weave canvases. This soiling is a source of humidity retention and may favour the growth of microorganisms that can alter the artwork [1].

Cleaning is a very delicate and irreversible intervention, because of the risk of damage to the treated surfaces. For paintings, the most common techniques used by conservators are chemical (free or gelled water and solvents) and mechanical (dry-cleaning). Both techniques have advantages and drawbacks and the decision regarding which one to use depends on the nature of soiling to be removed.

In the case of paintings, free or gelled solvents are seldom used to clean the canvas due to the many risks associated with wet cleaning. Some canvases shrink dangerously when they come into contact with water, causing paint layers to flake [2], and some grounds and paint layers may be solubilized by solvents [3]. These wet methods are mainly used to remove lining adhesives in cases in which dry-cleaning is not effective or is contraindicated [4].

However, to remove common dirt accumulated over the years on the verso (the subject of this paper) the method chosen is always a dry one [5].

The dry-cleaning methods currently used to remove this surface dirt from the back of canvases may entail a risk because they are based on different mechanical processes that involve manual pressure and friction.

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The literature on the methods for the dry-cleaning of canvases and on the alterations that they may cause on the verso of easel paintings is very scarce. Indeed, little scientific attention has been given to these issues.

The literature published to date is limited and generally reports the use of erasers, sponges, brushes, scalpels and other systems to clean the verso of paintings both in papers that describe a particular conservation treatment [6–8] or in general reference sources on the conservation of paintings [5, 9–11].

Vacuum cleaning seems to be the least harmful method, and it is usually performed as the first step of a dry-cleaning treatment. Very often it is combined with the action of a soft brush to enhance the results. However, this method has little or no effect in canvases with engrained soiling deposits, where dirt has become cemented due to biological, physical and chemical processes [1, 12, 13].

Cleaning with erasers and sponges has been mainly studied for the conservation of paper works [14–18], painting surfaces [19–26], and textiles [27–30], although a few studies have focused on canvas [31] or included canvas support samples in the experimental section [26].

The main advantage of using erasers or sponges for canvas cleaning is the ease of their control: cleaning can be stopped when necessary and fragile areas, or areas that do not need cleaning, can be left untreated. Both erasers and sponges show good results for the removal of dirt between fibres to the naked eye; they are also low-cost techniques that do not require special equipment for their use.

However, the mechanical action of these techniques may entail movement or crushing of fibres, thus modifying their structure, weakening their resistance and causing breakages or material loss. Moreover, product residues extraneous to the canvas composition may remain between the fibres and on the surface. This could result in changes in the surface roughness, potentially affect its absorptive properties, also regarding airborne grime [26], and the long-term stability of the canvas [31], since erasers and sponges contain abrasive materials, sulphur, hydrochloric acid, plasticizers, drying oils, etc. [16, 21, 30, 32]. All erasers and sponges tested as cleaning agents of canvases in the previous literature have been found to entail alterations [26, 31]. Among erasers, vinyl-based ones seem to involve less changes [31], although phthalates included in their composition pose particular concern [17, 23, 31].

Another dry-cleaning technique is microblasting. This is currently used for the treatment of heritage assets, mainly in architectural heritage, but previous scientific studies have reported positive results on paper works [33–35] and paintings [36]. Microblasting consists in the projection of abrasive particles driven by pressurized air to break the bonding between surface deposits and the substrate by impact, cutting or friction based on the kinetic energy formula [$KE = ½m \times v^2$] where m is abrasive mass and v velocity (related to pressure) in classical mechanics. Their application parameters are described in the scientific literature, the most influential being pressure, distance, angle, time, nozzle, particle-flow, and specific abrasive properties. Selecting the correct abrasive to be used and adjusting the main parameters can therefore modify the effects on the surface [37].

In this study, microblasting of powdered cellulose is tested as an alternative dry-cleaning technique for canvases in cases where soft brushing and/or vacuum cleaning is not efficient. The research pursues two main goals: to identify any changes in the structure and topography of the canvas, and to determine whether any residues of particles are left behind once the cleaning is finished. Also, the results of the cleaning must be at least as good as those obtained with other dry mechanical cleaning techniques currently used by conservators.

Cleaning tests were conducted with some of the most common methods used by conservators (erasers and sponges) and by microblasting powdered cellulose on samples of new and old canvas, naturally and artificially soiled. To compare and evaluate the results, confocal microscopy, SEM–EDX microscopy, optical microscopy and spectrophotometry were used to determine the removal of dirt, the amount of residues of particles left, and changes to the surface topography after treatment.

Materials and methods

Materials

The materials used included two linen canvases with similar characteristics and properties but with a different condition state for comparison: a new canvas (as a mock-up) and an old one. Linen was chosen because it is a type of canvas that has been used throughout the history of painting [38].

The new canvas, by Piera®, has a fine plain weave 100% linen fabric, with a density of 12 by 13 threads per square centimetre and a white universal acrylic coating on the front. The canvas was stapled onto a pine wooden stretcher of 46 cm × 38 cm (standard size “8F”) with a mortise joint.

The old canvas, naturally aged, is an original oil painting approximately 50 years old with similar characteristics to the mock-up. It has a fine plain weave linen canvas, with the same density as the new one (12 by 13 threads/cm^2) and a commercially applied white coating on the front. The stretcher in this case has a size of

35 cm × 27 cm (standard size "5F") and a mortise and half miter joint. The canvas is in poor condition, displaying dirt all over, yellowed fibres, uneven tension, folds and small tears. This painting has no patrimonial value, and so was used in this study as a sacrificial old canvas sample.

For comparative evaluation, a layer of artificial dirt was applied by brushing on one half of the reverse of the new canvas. The artificial soiling was prepared following Ormsby et al. [39] but omitting the liquid components (oils and solvent), and it was applied with a brush [40]. This artificial dirt contained carbon black (2 g), iron oxide (ochre) (0.5 g), silica (1.75 g), kaolin (20.0 g), gelatin powder (10.0 g), soluble starch (10.0 g) and cement (type I) (17.5 g).

The mock-up and the old original painting were chosen because in both cases vacuum cleaning was ineffective, even in combination with a soft brush.

For microblasting, cleaning powdered cellulose Arbocel® was used following previous research done on other cellulose supports [41]. This comprises 98% cellulose, with average fibre lengths of 40 μ, pH 7 ± 1 and bulk weight of 220 g/L.

Although there is a wide range of materials for dry cleaning of paintings, in this study we selected only those previously cited in the literature as agents used in the back of canvases to eliminate adhered dirt, when soft brush and/or vacuuming is not efficient.

A selection of three very often used ones was done: Art Sponge®, smoke sponge made of vulcanized rubber latex [42]. Akapad® Soft sponge made of styrene butadiene rubber, vulcanized castor oil and antioxidant NG-2246 [43], and Milan® 430 eraser made of synthetic rubber [44].

The use of smoke sponges as a material for cleaning the canvas of paintings is mentioned in the international reference bibliography [25], in professional workshops around the world [45–47], in worldwide reference institutions [48–50] and in academic documents [51, 52].

Akapad sponges have also been referenced as a possible cleaning material for the verso of paintings in sources of similar origin [9, 53–58].

Erasers appear less referenced in some countries, although their use on canvas is clear in current bibliography of international relevance [20]. However, this material is recurrent in the Spanish and Latin American bibliography on cleaning the canvas of paintings, showing a widespread use both in professional workshops [59, 60], and in relevant institutions [61–65]. They are also recommended in national reference monographs [10] and mentioned in documents from the university environment [53, 66–69]. Among them, Milan gum is widely and especially used [53, 70, 71] and this is why it was considered appropriate to include it in the study as a comparison reference.

Cleaning methods

Cleaning tests were carried out at the Conservation facilities of the Faculty of Fine Arts of the University of Barcelona which have climate control (20–24 °C temperature and 50–60% humidity).

A Melinex® grid reference with 16 windows was created to locate the sample areas. Four cleaning tests were done with each product (Arbocel®, Milan®, Akapad® and Art Sponge®), analysed by a different technique (SEM–EDX, spectrophotometry, surface microscopy and confocal microscopy) (Fig. 1).

As vacuum cleaning and soft brushing alone were not effective for the case studies, cleaning was carried out in

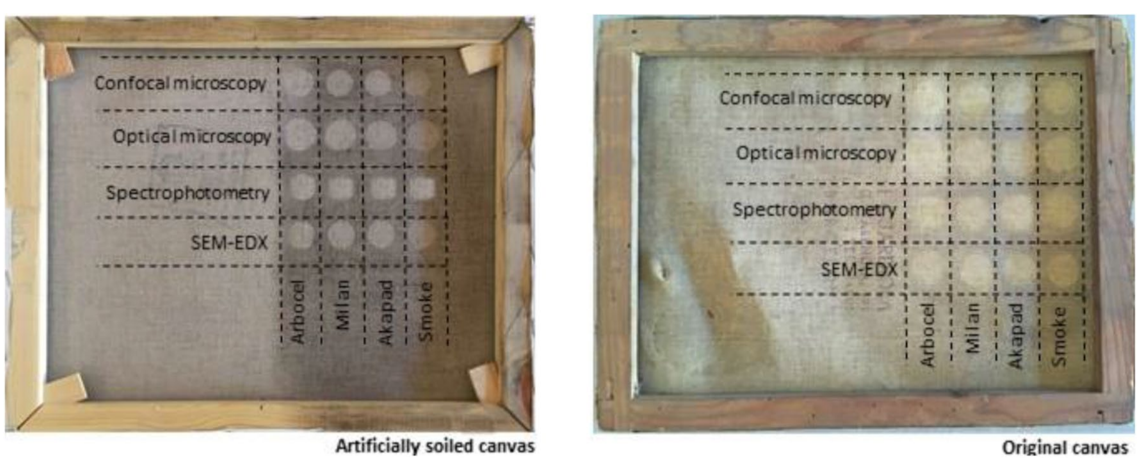


Fig. 1 Melinex® grid reference placing the sample areas on the artificially soiled canvas (left) and the old canvas (right), (16 windows)

two phases more. The second phase entailed cleaning the artificial and natural dirt by means of powdered cellulose microblasting (Arbocel®), Milan® rubber, Akapad®Soft sponge and Art Sponge® (cleaning parameters Table 1). And the third phase consisted of removing product residues of particles with a soft brush and a HEPA vacuum cleaner.

For microblasting tests, Arbocel® BE600-30PU cellulose of 30 µm from J. Rettenmaier and Söhne was used as the abrasive. Cellulose fibres were blasted with a footswitch operated microblasting CTS5/B, with a straight tungsten carbide nozzle of 0.7 mm diameter. Other equipment used included a silenced compressor of 1.5 CV and a dehumidifier filter to reduce the humidity of the compressed air and the clumping of the cellulose. The treatment was made in a sandblasting cabinet Box CTS4 with an environmental dust collector. The cleaning parameters were selected according to previous data in literature [34, 37] and were tested before doing the cleaning tests to detect if some changes were necessary.

Cleaning tests with sponges and erasers were conducted for 5 s by gentle rubbing in the warp and weft direction, applying slight pressure, as performed in the dry-cleaning treatment. The canvas was analysed with optical microscopy; in all cases notable cleaning results were achieved within 5 s, without mechanically damaging the canvas. This is the standard procedure a conservator would use to monitor the cleaning methodology during conservation treatments.

Evaluation techniques

To evaluate changes in the canvas topography, degree of cleaning and the residues of particles remaining on the support, optical microscopy (OM), scanning electron microscope (SEM–EDX), confocal laser microscopy (CLM) and spectrophotometry were used. These techniques facilitate useful information in the evaluation of mechanical cleaning methods such as possible texture changes, fibre alteration, colour variation, presence of dirt or cleaning products residues.

Analyses were carried out before and after cleaning the old canvas and before applying the artificial dirt, after its application, and after cleaning the new canvas. One spot of each cleaning product was made for each analytical technique (Fig. 1). Testing different sites allowed to compare among destructive (SEM–EDX) and non-destructive techniques (OM, CLM, spectrophotometry). Also, this approach enabled to select sites adapting the working area of each technique, according to instrumentation geometry (8 mm diameter for spectrophotometry, 1.5 cm diameter for OM, 5 mm^2 for SEM–EDX samples and CLM). As reported in the results and figures, the area analysed is sufficiently homogeneous to minimise variations, as shown in figures.

Optical microscopy

Optical microscopy was conducted by using the Dino-Lite® microscope with $\times 60$ and $\times 200$ magnification lens processed with DinoCapture® software. Analysis of surface morphology at $\times 60$ and $\times 200$ magnification allows to detect possible texture changes or fibre alteration, determining accurately the effects and the effectiveness of the different cleaning tests.

Scanning electron microscopy (SEM)

Morphological analysis of untreated and treated samples was performed with a FEI ESEM QUANTA 200 in the low vacuum mode (LowVac). Analyses were conducted with a chamber vacuum at 130 Pa with an accelerating voltage of 20 kV and a working distance (WD) between 9.4 and 10.4 mm. Images were taken by using the backscattered electron detector.

Samples of 0.5 cm^2 were taken from both paintings by cutting the canvas with a scalpel. Each sample of around 0.5 cm $\times$ 0.5 cm was placed flat in a different stub and

Table 1 Cleaning parameters used in the tests

Technique	Material	Equipment	Parameters
Microblasting	Arbocel® BE600-30PU Granulometry: 30 µm Fibre length: 40 µm Bulk weight: 220 g/L pH: 7 ± 1	CTS 5/B with cabinet and environmental dust collector Nozzle Ø 0.7 mm Compressor Dehumidifier filter	Pressure: 20 kPa (2.9 psi) Angle: 70° Distance: 50 mm Time: 5 s
Hand friction	Milan® 430 eraser (in block)		Friction warp and weft direction Time: 5 s
	Akapad® Soft sponge		Friction warp and weft direction Time: 5 s
	Art Sponge®		Friction warp and weft direction Time: 5 s

was subsequently mounted in the SEM holder, before being introduced into the microscope vacuum chamber.

Sample morphology was observed between × 100 and × 1000. Images with a field of view of 0.9 mm × 1.25 mm were taken at × 500 magnification for the new canvas and at × 332 magnification for the old canvas. All images contain a scale bar representing 500 µm, for reference. Determining the canvas surface morphology before and after cleaning allows the identification of possible texture changes and a more precise assessment of the effectiveness of the cleaning systems tested.

Energy-dispersive X-ray spectroscopy (EDX)

Energy dispersive X-ray analyses were performed for elemental characterization of the samples by using the Silicon Drift Detector (SDD) Thermo Scientific™ Fisher UltraDry™ with a crystal active area range of 30 mm^2 coupled to the ESEM Quanta 200 scanning electron microscope. The software control used was the PathFinder Alpine.

Analyses were conducted with an accelerating voltage of 20 kV to evaluate cleaning results and to identify the elemental composition of the cleaning products (Arbocel®, Milan® rubber, Akapad®Soft sponge and Art Sponge®) and soiling.

Elemental analyses were performed on 10 to 20 points of images at × 500 magnification, generating a spectrum of each point where the main elements are detected.

Spectrophotometry

A Konica Minolta CM 2600d spectrophotometer with a range of 400–700 nm and a measuring interval of 10 nm was used to determine cleaning chromatic differences. The optical geometry of reflection is 10°, the measuring area Ø 8 mm, and the results are expressed according to CIELAB 1976 system with reference to illuminant D65.

The CIELAB coordinate values evaluated correspond to the averages of 30 measurements by repositioning the spectrophotometer on the spot before each measurement so as to increase the representativeness of the results. The chromatic values were obtained using the CM-S100w 3.20.0002 Spectra Magic software and processed in a spreadsheet to obtain the differences in each of the three coordinates (ΔL^*, Δa^* and Δb^*) before and after cleaning in each of the 1.5 cm diameter spots analysed.

Confocal laser microscopy with surface roughness measurements

Primary profiles and surface tests were performed in accordance with studies which have used surface area roughness (Sa) to evaluate cleaning effectiveness [72, 73]. SENSOFAR PLμ 2300 and Nikon × 20 magnification lens were used to obtain surface roughness measurements, conducted with the SensoSCAN300 software.

Images of soiled and cleaned surfaces at × 20 and mean values for the area field roughness parameters [74] were taken from three different sub-areas of 5 mm^2. However, because soiling always fills up surface valleys and reduces original roughness, these data were not considered representative of the original surface.

Height parameters Sa (arithmetic mean height), Sq (root mean square height) and Sz (maximum height of peaks -Sp- and valleys -Sv-) were selected to compare area roughness in the different cleaned surfaces. Nevertheless, as Sa and Sq may be similar even if the surfaces are different, functional material and void volume parameters of Vmp (peak material volume), Vvv (valley void volume), Vmc (core material volume) and Vvc (core void volume) were included to clarify the evaluation.

Results and discussion

Optical microscopy

Artificially soiled canvas samples

In the new canvas, images were taken at 60 and 200 magnifications of the same cleaned sample, soiled with artificial dirt and cleaned with the four cleaning techniques tested, in order to establish whether they remove the artificial dirt and modify the texture by removing the canvas fibres, and/or whether residues of particles of the cleaning materials are observed.

The images in the first column in Table 2 show the untreated, unsoiled reverse of the painting. The white coating layer can also be seen between the weft and the warp. The image at 60 × shows that originally the threads were not perfectly twisted and that some fibres were slightly raised and disordered. The images in the second column reinforce this idea, once the sample has been impregnated with artificial dirt.

The third column shows the result of each cleaning test. No significant displacement of fibres were observed by using optical microscopy at × 60 and × 200, a magnification range usually performed while cleaning treatments are carried out. However, as shown in the next sections -especially in SEM–EDX results and CLM-, higher magnifications are required to explore this further. Dirt was removed without leaving almost any residue by using Arbocel® powdered microblasting and Art Sponge. In contrast, some black particles of soil remaining on and between the canvas were identified in the samples cleaned with Milan® eraser and Akapad® Soft.

Old canvas samples

The results of the old canvas cleaning tests are shown in Table 3. For each cleaning technique, the spot is

Table 2 Reverse of the artificially soiled canvas at × 60

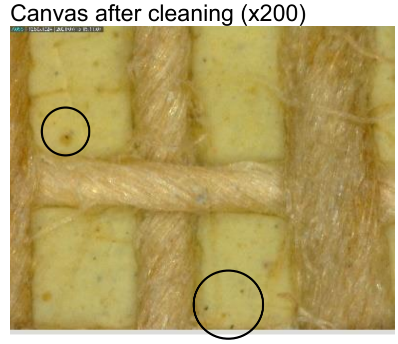
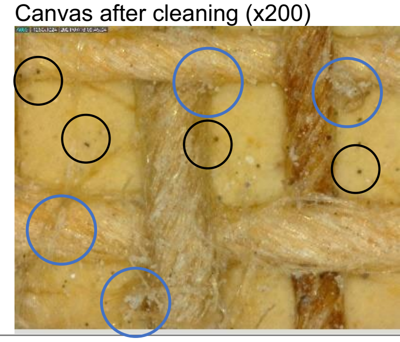
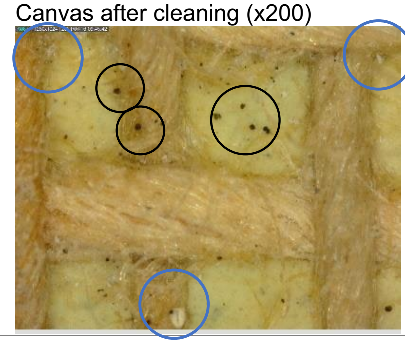
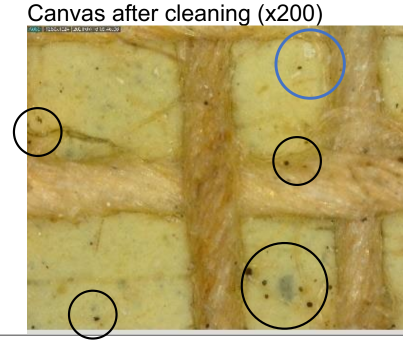
New canvas cleaning results		
Canvas before cleaning	**Canvas with artificial dirt**	**Canvas cleaned with Arbocel®**
		
Canvas before cleaning	**Canvas with artificial dirt**	**Canvas cleaned with Milan®**
		
Canvas before cleaning	**Canvas with artificial dirt**	**Canvas cleaned with Akapad®Soft**
		
Canvas before cleaning	**Canvas with artificial dirt**	**Canvas cleaned with Art Sponge®**
		

Spots before without and with artificial dirt, and after cleaning tests. Black dirt particles are circled

presented before and after cleaning in which dirt residues of particles can be detected, when present, as well as the residues of particles of the cleaning materials.

The dry-cleaning technique with the best results is microblasting with powdered cellulose, as canvas is free of residues of particles, both from the cleaning material and from the dirt.

Table 3 Reverse of the old canvas

Old canvas cleaning results		
Arbocel®		
Canvas before cleaning	Canvas after cleaning (x60)	Canvas after cleaning (x200)
		
Milan® rubber		
Canvas before cleaning	Canvas after cleaning (x60)	Canvas after cleaning (x200)
		
Akapad®Soft sponge		
Canvas before cleaning	Canvas after cleaning (x60)	Canvas after cleaning (x200)
		
Art Sponge®		
Canvas before cleaning	Canvas after cleaning (x60)	Canvas after cleaning (x200)
		

Spots before and after (× 60 and × 200) cleaning tests. Black dirt particles residues are circled in black. Cleaning material residues are circled in blue

In contrast, the spots cleaned with Milan® eraser and Akapad®Soft sponge contain some dirt particles and a large amount of residues from the rubber, trapped between the fibres of the canvas and the gaps between the weft and the warp. The spot cleaned with the Art Sponge® also presents some dirt residues, although fewer cleaning material residues were identified.

Regarding the morphology of the cleaned spot surface, some changes are observed in the canvas cleaned with dry traditional techniques. After cleaning, fibres are quite disordered and somewhat deteriorated (folded and broken) (see column 3 of Table 3). In contrast, microblasting with powdered cellulose kept the original texture of the canvas, resulting in a better twisted thread.

SEM–EDX

Scanning electron microphotographs of the uncleaned and cleaned samples were studied to evaluate possible changes to the fibres at high magnification.

In addition, the main elemental composition of the canvas samples was studied by EDX analysis in order to identify chemical elements related to possible particles of residues from the cleaning agents or artificial soiling in the treated samples. Thus, EDX results of the different cleaned spots were compared with the EDX microanalyses of the cleaning agents and artificial soiling (Table 4).

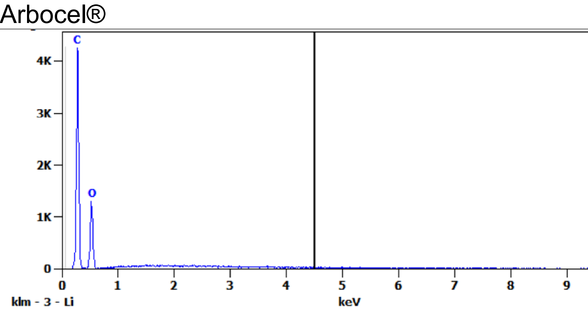
Cleaning materials and artificial soiling

By means of EDX microanalysis, the main chemical elements present in the four cleaning materials and the artificial soiling were identified, obtaining 10 spectra of a flat sample 4 mm in diameter (Table 4). Although some of the elements are present in both cleaning systems,

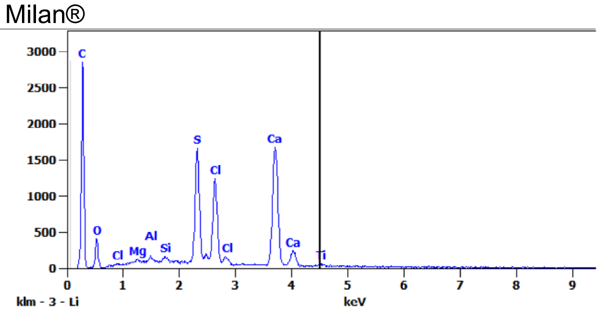
Table 4 Spectra of the chemical elements found in the cleaning materials and artificial soiling

EDX microanalysis of the cleaning materials

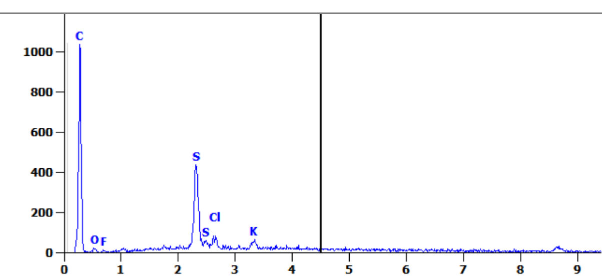
Arbocel®



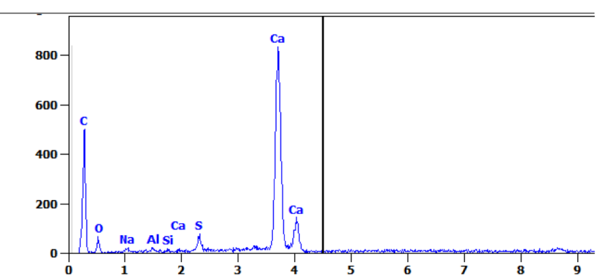
Milan®



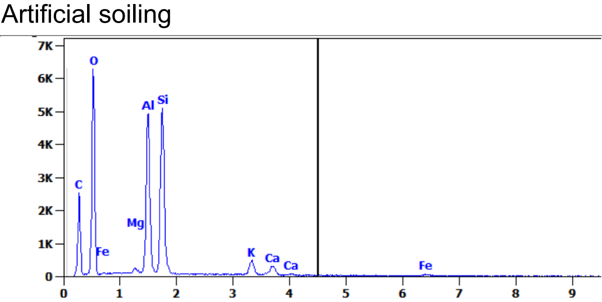
Akapad®Soft



Art Sponge®



Artificial soiling



soiling and/or substrate, combination of this information with SEM visualization of particles in samples enabled to detect possible remaining residues after the cleaning treatment.

In the case of Arbocel®, since it is composed of cellulose ($C_6H_{10}O_5$), only C and O appear prominently in the EDX spectra. As this is also the main component of canvas, in the case some soiling particles would remain after the cleaning treatment, they would be easily identified by EDX. Evaluation of possible residues of Arbocel® in the canvas after the treatment was undertaken by SEM visualization, as morphology and dimensions of Arbocel® are different from textile cellulosic fibres (see an example of an Arbocel® particle on a textile thread in Table 6).

As for Milan®, Cl, S and Ca appear significantly, being Cl and S an identification key of cleaning agent residues that may remain in the treated samples, as these two elements are not present in soiling (see Table 5, figure c). Traces of Al, Si, Mg and Ti are also identified. C and O is also abundant.

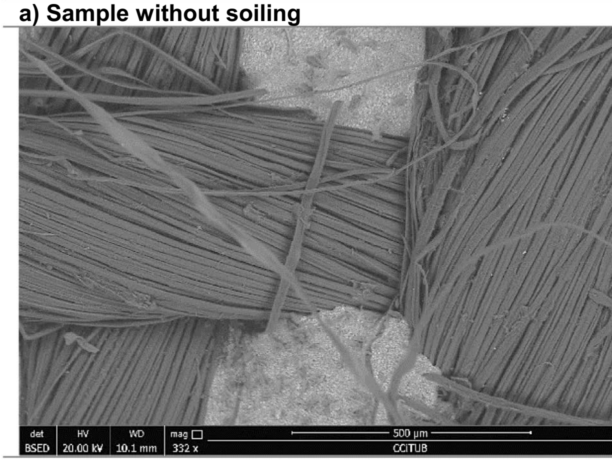
Akapad®Soft sponge presents C and O as the most abundant elements in the spectrometry. In addition, other elements such as F, Cl, K, S, Si are observed, the last two probably being derived from the vulcanization process. Small particles containing S and Cl are indicative, in threads of samples treated with this sponge, of cleaning material residue, as these elements are not present in the non-treated canvas, nor in the soiling.

Art Sponge® is composed of vulcanized natural rubber, so the spectrometry mainly shows C and O, followed by Ca and S, the former used very likely in the form of $CaCO_3$ as a filling system and S as a component of the vulcanization process. Zn, Al, Si and Na are also found to a lesser extent, probably used as additives. Presence of particles containing S and large amounts of Ca in the samples treated with Art Sponge® is a sign of cleaning material residue.

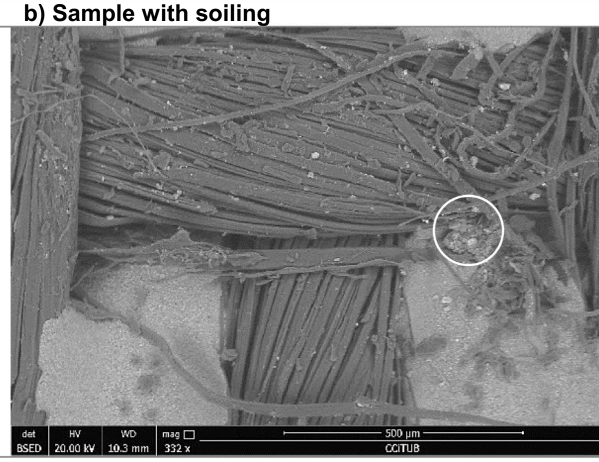
Artificial dirt was also analysed in order to distinguish it from the possible traces of the cleaning materials. The elements observed in the spectra are C and O, Fe (due to iron oxide), Si (silicates, kaolinite and clay), Al (kaolinite and clay), Ca ($CaCO_3$ from cement) and traces of K and Mg (mineral salts of the gelatine). Thus, particles in

Table 5 SEM–EDX analysis of the artificially soiled canvas

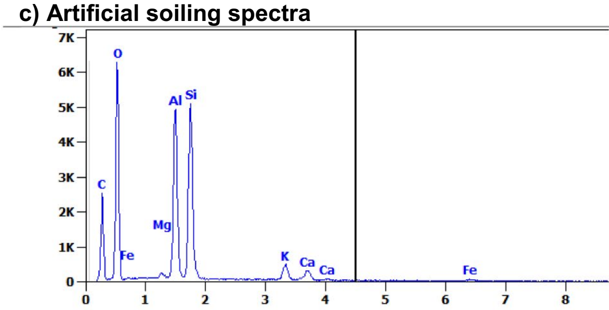
a) Sample without soiling



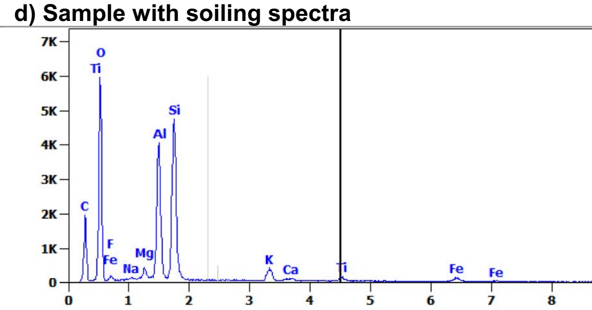
b) Sample with soiling



c) Artificial soiling spectra



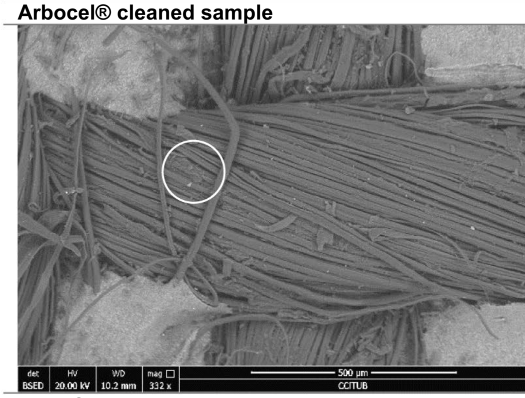
d) Sample with soiling spectra

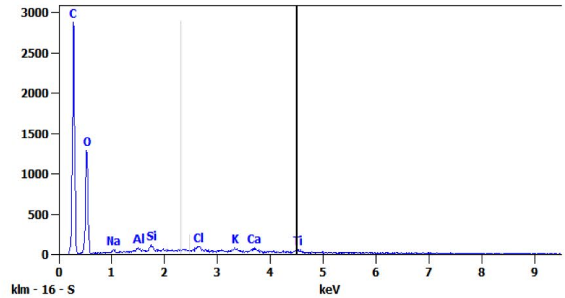


The circled area of image b (sample with soiling) has been analysed by EDX and the resulting spectra is shown in image d, being similar to the artificial soiling spectra (image c)

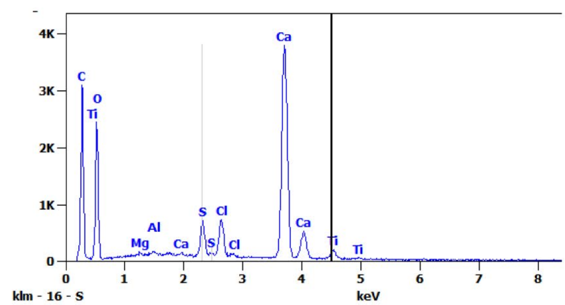
Table 6 SEM–EDX analysis of the cleaned samples

Arbocel® cleaned sample

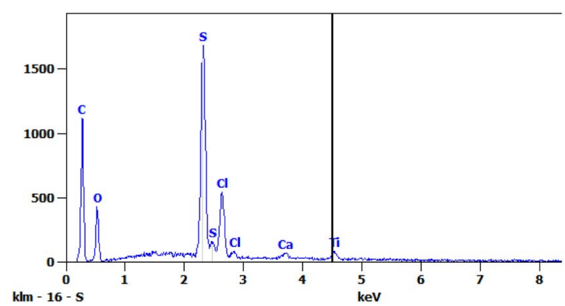




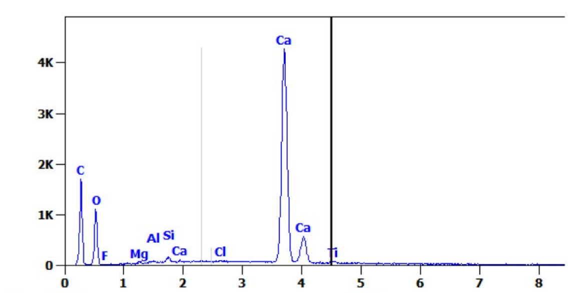
Milan® cleaned sample



Akapad® cleaned sample



Art Sponge® cleaned sample



The circled area was analysed by EDX and the resulting spectra are shown samples with artificial dirt, showing high amounts of Al and Si, accompanied with Fe and Mg are a clear indication of soiling residues.

Artificially soiled canvas samples

As shown in Table 5, artificial soiling can be easily identified in SEM images by EDX characterization. Samples with artificial dirt present soiling particles deposited between fibres and some fibres appear disordered.

In contrast to the similarities in the results obtained using the three traditional cleaning systems observed by means of the optical microscope at ×60 and ×200, in the SEM–EDX analysis the presence of particles of dirt and cleaning material residues is seen to differ with each cleaning material (Table 6).

In the sample cleaned with microblasting powdered cellulose most of the dirt particles were removed and no particles of material residues remain on the surface. This is also confirmed in the spectra (Table 6). In this sample, a few residues of Arbocel® are identified (see the particle in the circled area, image on the top). No changes or damages of the canvas were visible and we could not detect any soil particles remaining in the sample.

In the sample cleaned with Milan®, fibres were removed, folded and some of them are broken. The spectrum shows the presence of characteristic chemical elements of dirt such as Mg, Al, Si and a large amount of Ca, S and Cl, components identified in the spectra of Milan® eraser (see Tables 4 and 6) which were not present in the new canvas without the artificial dirt.

The sample cleaned with Akapad®Soft sponge has a very rough appearance. The EDX microanalysis, shows a large quantity of the main components of the sponge, S and Cl (see Tables 4 and 6).

Lastly, the sample cleaned with Art Sponge® has a less modified appearance. The spectra indicate traces of dirt particles and highlight the presence of Ca, a characteristic chemical element observed in the microanalysis of the smoke sponge (see Tables 4 and 6).

Old canvas samples

As in the artificially soiled canvas, in the old sample the particles of residues of the dirt and the cleaning materials vary according to the cleaning technique used, as shown in Table 7.

The first image (Table 7), the dirty canvas, shows a homogeneous appearance, in which the dirt is spread over the entire surface and deposited between the fibres.

In the Arbocel® cleaned sample, the dirt has mainly been evenly removed. Between the fibres, there are some traces of dirt and small deposits that, due to their appearance, seem to be traces of the canvas priming. This is also confirmed in the spectra. Fibres remain twisted and there is no significant movement.

In the case of the sample cleaned with Milan® eraser, as found in our previous analysis, a large amount of particles of residue from the eraser itself is found, as well as dirt particles that have not been removed. The spectrum again shows the presence of characteristic chemical elements of dirt such as Mg, Al, Si and a large amount of Ca, component identified in the spectra of Milan® eraser (see Table 4).

And finally, the two samples cleaned with sponges, Akapad® Soft and Art Sponge®, present similar results in so far as dirt and particles of residues of the sponges are observed trapped between the fibres of the canvas. The EDX microanalysis, shows the presence of characteristic chemical elements of dirt and a large quantity of the main components of the sponges, S and Ca (see Table 4).

Morphologically, in samples cleaned with manual techniques, the texture of the canvas was changed: the fibres were removed and some of them were folded or broken.

Spectrophotometry

Table 8 shows the results of the spectrophotometry analysis, which can also be seen in Fig. 2.

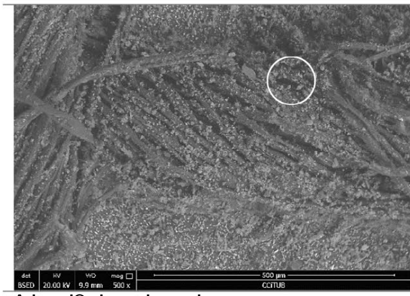
The four cleaning methods used in this study entail a substantial change in L* (D65), increasing the luminosity of the old canvas in all cases; that is, there is a cleaning effect. Values in b* (D65) are also modified by all the cleaning procedures, indicating an increase in the yellow hue. Changes in the a* (D65) coordinate are considered irrelevant.

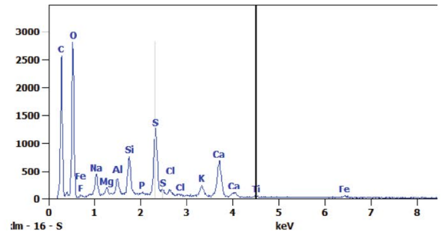
The increase in L* (D65) can be explained by the removal of dirt, dark in tone, resulting, therefore, after cleaning, in spots of greater luminosity. However, considering that the tone of the materials used for cleaning is lighter than the old canvas (yellowish due to the oxidation of cellulose) an increase in L* (D65) could also come from the particles of residues of the cleaning materials. It seems reasonable to suppose that this is the case, at least in part, of spots treated with Milan® and Akapad®Soft sponge, where a high presence of cleaning residue particles and a lower degree of cleaning were observed in optical microscopy and SEM–EDX analysis.

Removal of dirt particles (dark in tone) increases the visibility of the fabric's yellowish colour. Therefore, an increase in b* (D65) in all spots after cleaning was expected. However, here as well these results may have been affected by the presence of particles erasers residues and sponges (clearly identified by optical microscopy and SEM–EDX) as all of them exhibit a yellowish tone or nuance. Therefore, the greater increase in b* (D65) after using these agents does not necessarily correlate with a greater degree of cleaning; rather, it may reflect the visual

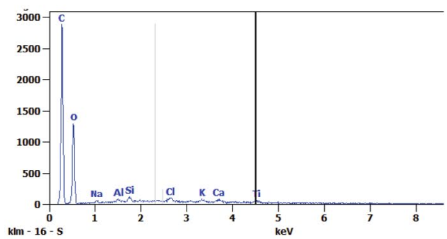
Table 7 SEM–EDX of the old canvas samples

Dirt canvas sample

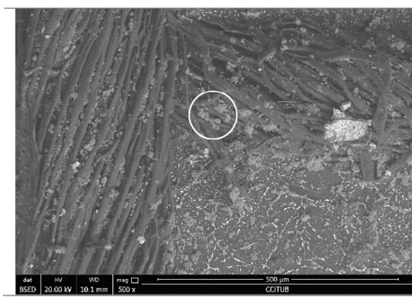


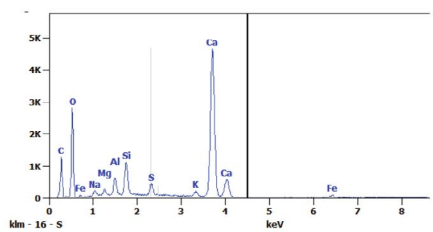


Arbocel® cleaned sample

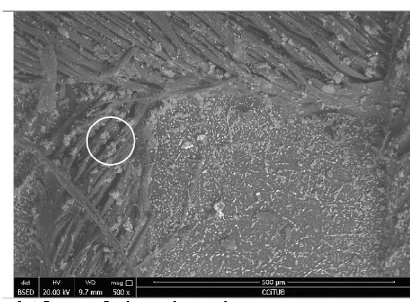


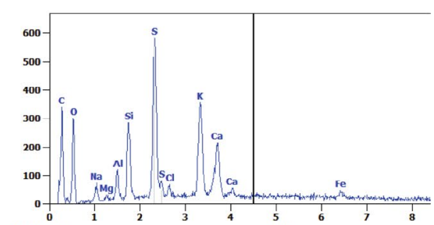
Milan® cleaned sample



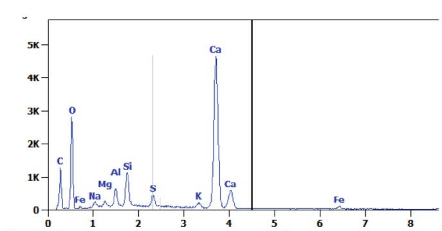


Akapad® cleaned sample





Art Sponge® cleaned sample



Images at × 500. The circled area was analysed by EDX and the resulting spectra are shown

Table 8 Spectrophotometry results in the old canvas

	Mean L*(D65)	Std. dev. L*(D65)	Mean a*(D65)	Std. dev. a*(D65)	Mean b*(D65)	Std. dev. b*(D65)
Before Arbocel®	55.41	0.06	5.38	0.10	21.44	0.12
After Arbocel®	62.07	0.10	5.36	0.17	25.95	0.11
Changes Arbocel®	**6.65**		**− 0.02**		**4.51**	
Before Milan®	54.77	0.21	4.75	0.13	19.56	0.19
After Milan®	60.26	0.16	4.51	0.08	24.14	0.11
Changes Milan®	**5.50**		**− 0.24**		**4.58**	
Before Akapad®Soft	54.58	0.30	4.58	0.13	19.68	0.23
After Akapad®Soft	59.99	0.23	4.79	0.07	25.63	0.15
Changes Akapad®Soft	**5.40**		**0.21**		**5.95**	
Before Smoke Sponge	54.91	0.47	4.68	0.16	21.33	0.37
After Smoke Sponge	59.41	0.16	4.66	0.07	26.35	0.21
Changes Art Sponge®	**4.50**		**− 0.02**		**5.02**	

Changes in L*(D65) and b*(D65) after cleaning the old canvas (emphasised in bold). The various shades of greyrange from more luminosity (lighter grey) to less luminosity (darker grey) in the first graph and from less yellow(light grey) to more yellow (dark grey) in the second

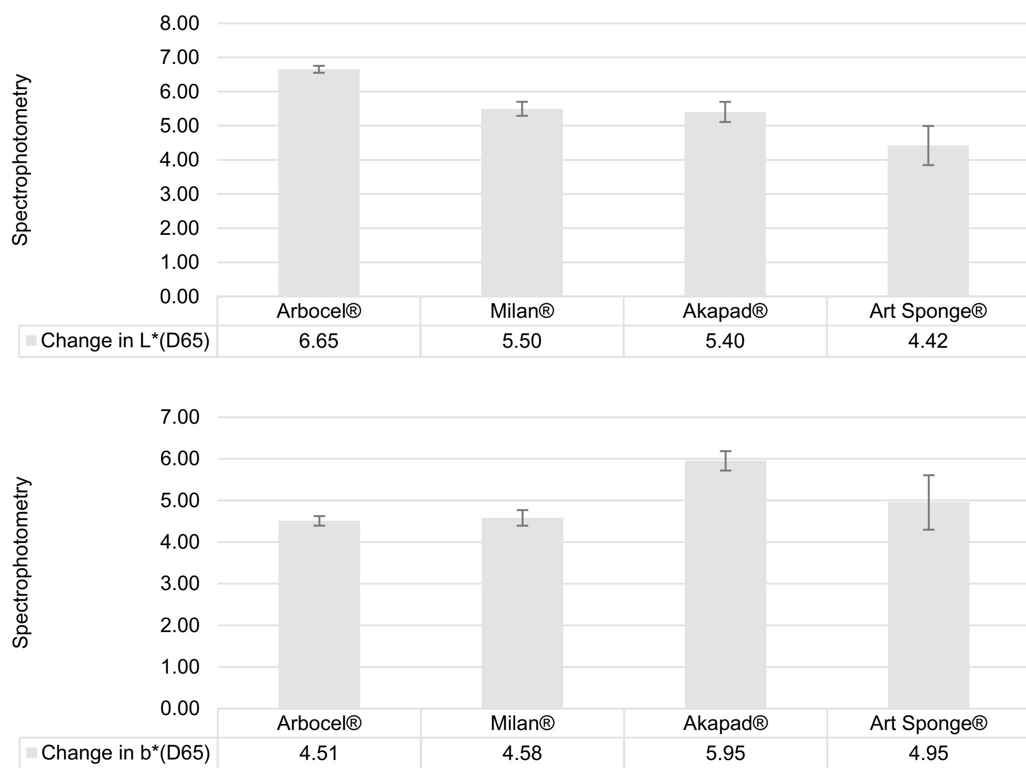
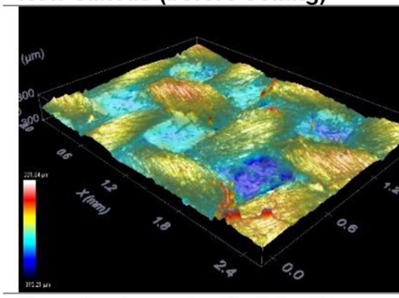
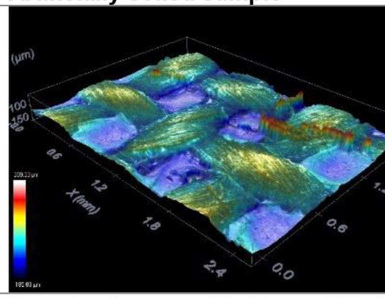
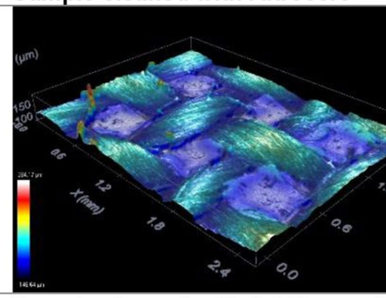
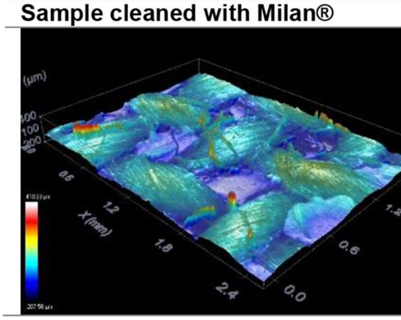
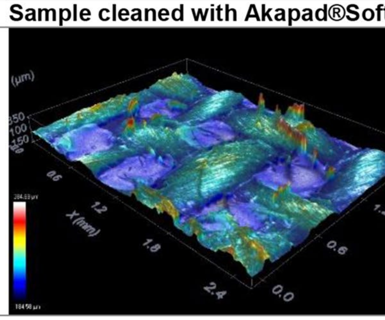
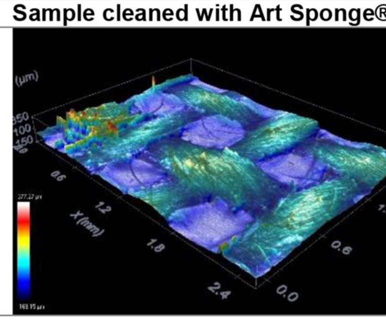


Fig. 2 Changes in L*(D65) and b*(D65) after cleaning the old canvas. The various shades of grey range from more luminosity (lighter grey) to less luminosity (darker grey) in the first graph and from less yellow (light grey) to more yellow (dark grey) in the second

change exerted by the particles of residues of cleaning materials in the asset. Thus, spectrophotometric results must be regarded in combination with electronic microscopic data to see the whole picture. In this study, spectrophotometry provides evidence of changes in colour that occur in samples derived from the cleaning effect and the possible remaining particles of residues (both soiling and/or cleaning agents), all this has been observed before with SEM and EDX.

Table 9 Confocal microscopy results

New canvas (before soiling)	Artificially soiled sample	Sample cleaned with Arbocel®
		
Sample cleaned with Milan®	**Sample cleaned with Akapad®Soft**	**Sample cleaned with Art Sponge®**
		

3D images showing the topography of the artificially soiled canvas

Confocal microscopy

The topography of the canvas before and after cleaning is shown in the following confocal microscopy 3D images. These reveal lifting and movement of some fibres, removal of dirt and deposits of particles of residues of cleaning agents.

Artificially soiled samples

The first image in Table 9 shows the three-dimensional image of the new canvas surface, before applying the artificial dirt. Comparing it to the second image, we see that the application of the dirt with a soft brush reduced the maximum height of the fibres, slightly modifying the topography—from a height between yellow and blue to one between blue and green. In both images, some fibres appear raised, and are higher in the soiled canvas.

Certain differences are observed after cleaning: the sample cleaned with Arbocel® shows some raised fibres and fewer dirt particles of residues in the gaps between warp and weft compared to the others; in the second sample, cleaned with Milan® eraser, fibres appear raised in a new position, and residues of particles appear between the gaps of the canvas structure (dark blue); the third sample, cleaned with the Akapad®Soft sponge, shows many raised and displaced fibres and particles of residues in the interstices; lastly, the sample cleaned with the Art Sponge® also presents raised and moved fibres, although there are fewer particles of residues between the warp and weft gaps.

Old samples

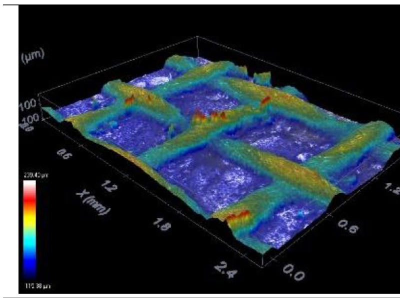
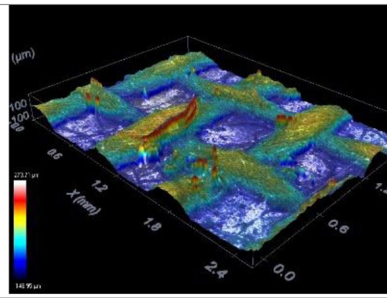
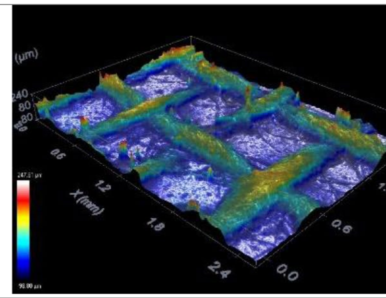
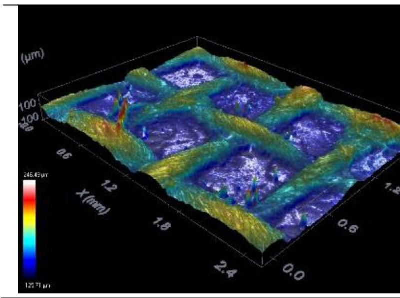
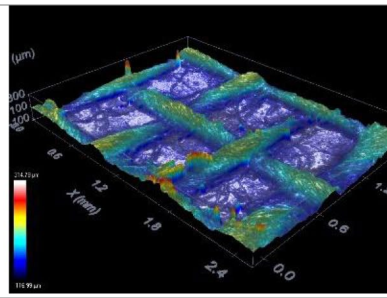
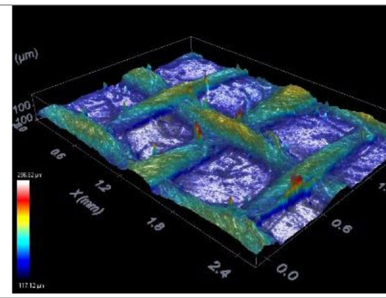
The topography of the old canvas samples is shown in 3D images in Table 10. In all the samples (uncleaned and cleaned), some fibres appear raised (in red). This confirms that the texture of the canvas is not significantly modified with any of the cleaning methods, although, as seen in optical microscopy and SEM, traditional cleaning systems displace the fibres due to mechanical action.

As for the gaps between weft and warp, the difference in dirt and residue deposits before and after cleaning is significant. In Table 10 there are two images of the same dirty canvas in two different locations; in both, large deposits of accumulated dirt (dark blue) are visible and fibres are barely distinguished.

In the sample cleaned with Arbocel®, the dirt accumulated between the weft and the warp was removed, with the ensuing emergence of valleys. On the other hand, in the samples cleaned with traditional systems, part of soil has been removed, but traces of dirt or particles of residues accumulated in the boundary of each concavity between threads are identified. The Milan® eraser appears to be the one that leaves the most deposits (either dirt or residues of cleaning agents) followed by the Akapad®Soft sponge and lastly by the Art Sponge®.

Area roughness analysis shows differences between tests (Fig. 3). On all treated surfaces Sa and Sq increase because cleaning eliminates the smoothing of the

Table 10 Confocal microscopy results

Old canvas (before cleaning) 1	Old canvas (before cleaning) 2	Sample cleaned with Arbocel®
		
Sample cleaned with Milan®	**Sample cleaned with Akapad®Soft**	**Sample cleaned with Art Sponge®**
		

3D images showing the topography of the old original canvas

uniform soiling layer accumulated on the reverse of the canvas.

Compared with the soiled surface, Sq of Milan, Akapad® and Art Sponge® are only slightly higher (± 1 μm) and Sa (± 2.5 μm). The highest increase in total height corresponds to Arbocel® (Sa ± 4 μm; Sq ± 3 μm) indicating that cleaning is more effective because more soiling is removed (as can be seen in 3D images). Sz, a parameter related to the absolute values of Sp and Sv, presents similar behaviour but in this case the Akapad® value is higher, thus indicating a significant lifting of some fibres, as can be seen in confocal images.

As regards volume parameters, Vmp and Vvv are quite similar in all the tests, suggesting that peaks and valleys remain relatively unchanged after treatment; only Alkapad® shows a higher increase. Analysing the core volume, both Vmc and Vvc have similar behaviour to Sa and Sq. However, the Vvc/Vmc ratio seems to reflect a more likely response to surface treatment, indicating that Milan, Akapad® and Art Sponge® slightly modify the soiled surface. To explain these results, the particles of residues of the product used remaining on the canvas surface and the soil modify the average of voids in the analysed area must be taken into account. The higher the values, the cleaner the surface might be; in this case Arbocel® obtains the highest values.

Conclusions

After the results, powdered cellulose microblasting can be considered as a feasible dry-cleaning technique for removing surface soiling on canvases: SEM and confocal microscopy analyses confirm that this procedure applied with the selected cleaning parameters did not cause damage to the surface or any textural alteration of the canvas within the context of the current evaluations. Conversely, in our study, the use of erasers and sponges with the described application method slightly modified the samples' topography by displacing and lifting the fibres.

Erasers and sponges left residues of particles clearly visible with a scanning electron microscope on the fibres and within the warp and weft gaps, even after vacuuming the surface. The SEM–EDX results suggest that powdered cellulose can be easily vacuumed from the surface, as no detectable particles of residues were left on the samples after cleaning. In addition, if any particles of residues remain, this material is chemically compatible with the canvas. Although microsblasted cellulose is mechanically much weaker than textile threads, further research will be conducted in order to investigate if, in the event of few particles remaining in the canvas, this poses any risk. Regarding the ability to remove surface dirt, the SEM–EDX results show that samples microblasted with cellulose and those cleaned with Art Sponge® are virtually free of soil deposits,

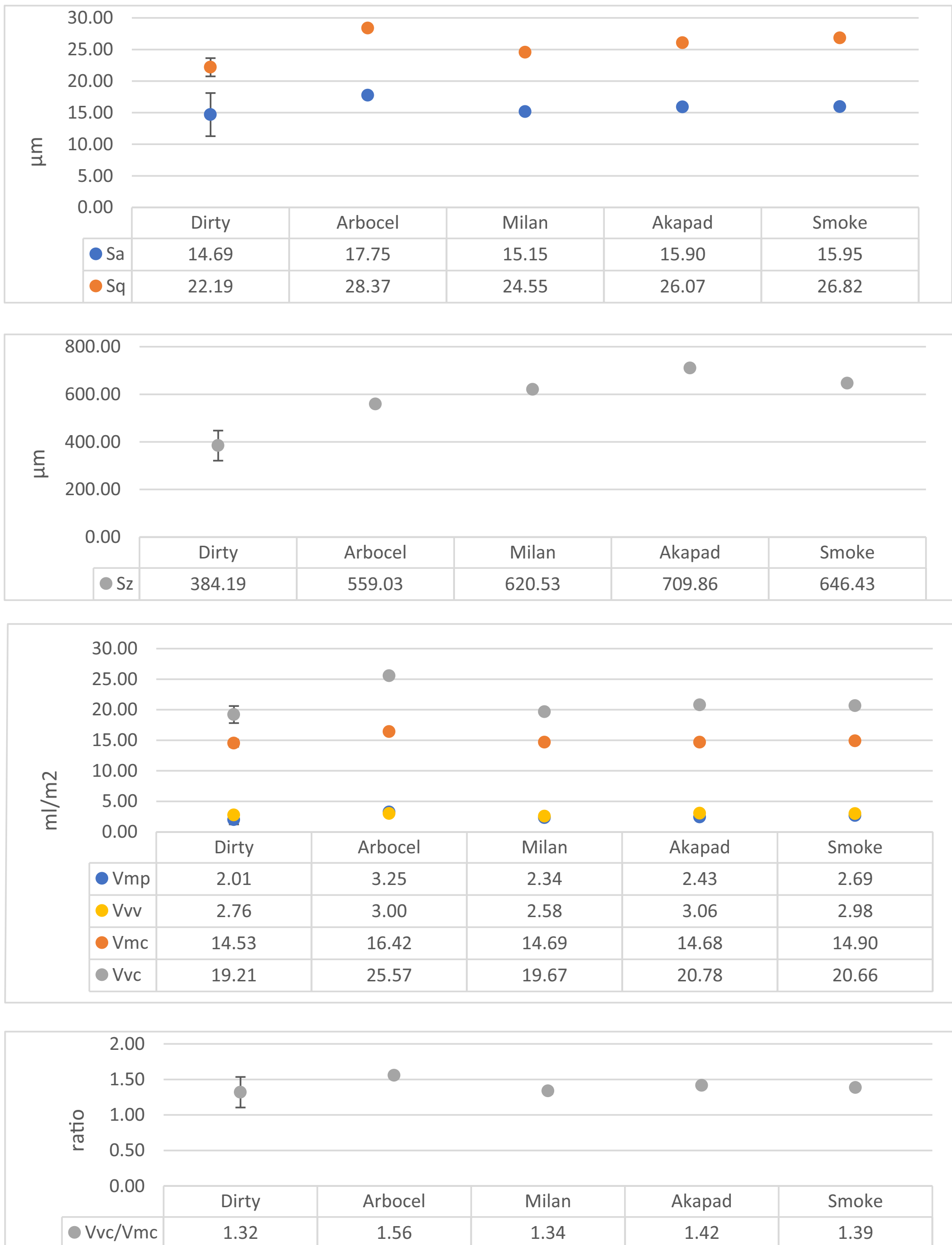


Fig. 3 Results of confocal laser microscopy with surface roughness measurements

whereas large amounts of dirt remain after cleaning with the Milan® eraser and the Akapad®Soft sponge.

Finally, samples cleaned with cellulose are the ones that show the greatest increases in lightness (L* D65), thus confirming its effectiveness as a cleaning agent.

In conclusion, diverse optical techniques, spectrophotometry and area roughness analysis show that, in comparison with the other traditional dry-cleaning agents included in this study, Arbocel® microblasting is the most effective for cleaning, and also minimizes surface alteration.

Based on this initial result, further research is now underway to broaden our knowledge of this technique and its practice for cleaning the canvas of paintings.

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Author contributions
IB-M contributed to the global approach, carried out the cleaning samples and the SEM–EDX analysis, and wrote the main manuscript text. CR-R contributed to the global approach, carried out the spectrophotometry analysis and prepared the manuscript for final publication. MI-C contributed to the global approach, carried out the cleaning samples and the confocal microscopy analysis, and prepared the manuscript for final publication. MO-F participated in the discussion of the results and the writing process. All authors reviewed the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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References

1. Tarnowski A, McNamara C, Bearce K, Mitchell R. Sticky microbes and dust on objects in historic houses. In: American Institute for the Conservation of historic and artistic works (AIC) 32nd annual meeting, Portland, OR. 2004:11–28. http://resources.culturalheritage.org/wp-content/uploads/sites/8/2015/02/osg011-02.pdf.
2. Hackney S. On canvas. Preserving the structure of paintings. Los Angeles: Getty Conservation Institute; 2020. p. 103.
3. Chevalier A, Guillaume-Chavannes G. Compte rendu sur Modern Paints Uncovered, Colloque International, Londres, Tate Modern 16–18 mai 2006. nº 25, 2006:63–5.
4. Murgui A, Prieto MJ. Comparativa de métodos acuosos gelificados en limpieza de soporte textil en pintura sobre lienzo. In: XVII international meeting on heritage conservation, Castelló. 2008.
5. Calvo A. Conservación y restauración de pintura sobre lienzo. Barcelona: Ediciones del Serbal; 2002. p. 189–92.
6. Górecka K, Skłodowski M, Pawłowski P, Szpor J. New materials and methods used in the conservation of the XVIIIth century curvilinear canvas painting "Adoration of the Magi" from the Saint Aubain Cathedral Church in Namur (Belgium). Eur J Sci Theol. 2015;11(2):45–53.
7. Martin RS, Romana MF. Mechanical strength parameters on polyester fabrics. Treatment applied in support of large canvas painting: "the expulsion of the merchants from the temple" by artist Saverio Lillo (1734–1796). Arché. 2010;4–5:139–46.
8. Learner, Thomas JS, Smithen P, Krueger JW, Schilling MR, editors. Modern paints uncovered. In: Proceedings from the Modern Paints Uncovered Symposium, Los Angeles: Getty Conservation Institute; 2007:169.
9. Eipper PB, editor. Comparative examinations of cleaned paint surfaces. Appendix 2. Cambridge: Cambridge Scholars Publishing; 2018. p. 179–80.
10. Sánchez A. Restauración de obras de arte: pintura de caballete. Madrid: Akal, cop; 2012. p. 76–80.
11. Van den Burg JM, Seymour K. Dirt and dirt removal (dry and aqueous cleaning). Paintings conservation part 1. In: van den Berg KJ, Gorter L, editors. Amersfoort: Cultural Heritage Agency of the Netherlands (RCE); 2022:19.
12. Lithgow K, Lloyd H, Brimblecombe P, Yoon YH, Thickett D. Managing dust in historic houses–a visitor/conservator interface. Our cultural past-your future. 2005:662–9. https://www.researchgate.net/publication/267851256_Managing_dust_in_historic_houses_-_a_visitorconservator_interface.
13. Lloyd H, Bendix C, Brimblecombe P, Thickett D. Dust in historic libraries. Museum Microclimates 2007:135–44. https://www.english-heritage.org.uk/siteassets/home/learn/conservation/collections-advice--guidance/musmicdustpaper.pdf.
14. López A, Narváez J, Tello N, Blanc R, Espejo T. Impact of erasers for dry-cleaning surfaces in graphic documents. Science and Art VII Experimental Sciences and Heritage Conservation. Madrid: Ministerio de Cultura y Deporte. 2018:410–8. https://es.calameo.com/read/0000753354c1fd0863020.
15. Cowan J, Guild S. Dry methods for surface cleaning of paper, Canadian Conservation Institute Technical Bulletin 11. 2005:1–12. https://publications.gc.ca/collections/collection_2016/pch/NM95-55-11-2001-eng.pdf.
16. Brokerhof AW, De Groot S, Perdesoli JL, Van Keulen H, Reissland BY, Ligterink F. Dry-cleaning. The effect of new wishabs Spezialschwamm and Spezialpulver on paper. Papier Restaurierung. 2002;3:13–9.
17. Noehles M. Die Kunst des Radierens: Radiermittel im Überblick. Papier Restaurierung. 2002;3(1):22–8.
18. Nitzberg N, Duhl S. Surface cleaning. Paper conservation catalog. 1988.
19. Córdova KG, Llamas-Pacheco R, Valcarcel-Andres J. Conservation of contemporary painting: a compartative study of the effect of dry-cleaning techniques. In: 4th international multidisciplinary scientific conference on social sciences and arts SGEM2017. 2017:117–24.
20. Van den Berg KJ, Daudin-Schotte M, van Keulen H. Analysis and application of dry-cleaning materials on unvarnished pain surfaces. Villatora: Il Prato publishing house srl; 2016.
21. Daudin-Schotte M, van Keulen H. Dry-cleaning: research and practice. In: van den Berg KJ, Burnstock A, de Keijzer M, Krueger J, Learner T, de Tagle A, Heydenreich G, editors. Issues in contemporary oil paint. Cham: Springer; 2014. p. 363–72.
22. García S, López M, Manuel J, San Andrés M. Evaluación de sistemas de limpieza en seco sobre pinturas mates contemporáneas, Conservaciónde Arte Contemporáneo, 15ªJornadas, Madrid: Museo Nacional Centro de Arte Reina Sofía. 2014:137–51. https://eprints.ucm.es/id/eprint/34922/1/LimpSeco-MNCARS2014.pdf.
23. Daudin-Schotte M, Bisschoff M, Joosten I, van Keulen H, van den Berg KJ. Dry-cleaning approaches for unvarnished paint surfaces. In: Mecklenburg M, Charola AE, Koestler RJ, editors. New insights into the cleaning of paintings: proceedings from the cleaning 2010 conference. Washington, D.C.: Smithsonian Institution;2013:209–19. https://repository.si.edu/handle/10088/20512.
24. Tsang JS, Babo S. Soot removal from acrylic emulsion paint test panels: a study of dry and non-contact cleaning. In: Preprints, ICOM-CC (International Council of Museums-Committee for Conservation) 16th Triennial Conference, Lisbon, Portugal, ICOM-CC. 2011:19–23.
25. Van Den Berg KJ, Daudin M, Joosten I, Wei W, Morrison R, Burnstock A. A comparison of light microscopy techniques with scanning electron microscopy for imaging the surface cleaning of paintings. Proceedings of Art. 2008:25–30.
26. Digney-Peer S, Arslanoglu J. Extended abstract residues on unvarnished surfaces after absorene sponge dry cleaning. In: Mecklenburg MF, Charola AE, Koestler RJ, editors. New insights into the cleaning of paintings: proceedings from the cleaning 2010 international conference, Universidad Politecnica de Valencia and Museum Conservation Institute. Washington DC: Smithsonian Institution. 2013. https://doi.org/10.5479/si.19492359.3.1.
27. López M, Chércoles R, Andrés M. Propuesta metodológica para valorar la eficacia de la limpieza mecánica de tejidos mediante el uso de esponjas. Conservación de Arte Contemporáneo 18ª Jornada. Madrid: Museo Nacional Centro de Arte Reina Sofia; 2017. p. 223–234. https://www.museoreinasofia.es/sites/default/files/18_jornada_conservacion.pdf.

28. Anderson AM. Comparison of dry-cleaning sponges used to remove soot from textiles. University of Rhode Island. 2016. https://doi.org/10.23860/thesis-anderson-allison-2016.
29. Hackett J. Observations on soot removal from textiles. American Institute of Conservation, AIC. Textile Specialty Group Postprints, 9. 1999:63–9. http://www.museumtextiles.com/uploads/7/8/9/0/7890082/observations_on_soot_removal_1998_aic_tsg_postprints.pdf.
30. Moffatt E. Analysis of "Chemical" Sponges used by the commercial fire clean-up industry to remove soot from various surfaces. IIC-CG Bulletin. 1992;17:9–10.
31. Estabrook E. Considerations of the effect of erasers on cotton fabric. J Am Inst Conserv. 1989;28(2):79–96.
32. Silverman S. Irwin Fire and ice revisited: a comparison of two soot removal techniques for book. Int Preserv News. 2009;49:31–5.
33. Jaček B. Das weiche Feinstrahlen. Ein neuer Ansatz zur Trockenreinigung von Papier und Pergament. Restauro. 2013(3):44–7.
34. Iglesias-Campos M, Ruiz-Recasens C, Díaz-Gonzalez E. First experiments for the use of microblasting technique with powdered cellulose as a new tool for dry-cleaning artworks on paper. J Cult Herit. 2014;15:365–72. https://doi.org/10.1016/j.culher.2013.09.001.
35. Iglesias-Campos M, Ruiz-Recasens C. Surface cleaning of intaglio prints with microblasting powdered cellulose and erasing: treatment effects on inks and support texture. J Cult Herit. 2015;16(3):329–37. https://doi.org/10.1016/j.culher.2014.08.001.
36. Stoveland LP, Frøysaker T, Stols-Witlox M, Grøntoft T, Steindal CC, Madden O, Ormsby B. Evaluation of novel cleaning systems on mock-ups of unvarnished oil paint and chalk-glue ground within the Munch Aula Paintings Project. Herit Sci. 2021;9(1):1–32.
37. Lglesias-Campos M, Prada JL, García S. Spot analysis to determine technical parameters of microblasting cleaning for building materials maintenance. Constr Build Mater. 2017;132:21–32. https://doi.org/10.1016/j.conbuildmat.2016.11.115.
38. Villers C. Artist's canvases: a history. In: ICOM-CC 6th Triennial Meeting: Ottawa, 21–25 September 1981, Paris: International Council of Museums, 1981:81/2/1-1–81/2/1-12.
39. Ormsby BA, Soldano A, Keefe MH, Phenix A, Learner T. An empirical evaluation of a range of cleaning agents for removing dirt from artists' acrylic emulsion paints. AIC Paint Spec Group Postprints. 2013;23:77–87.
40. Bartoletti A, Barker R, Chelazzi D, Bonelli N, Baglioni P, Lee J, Angelova LV, Ormsby B. Reviving WHAAM! a comparative evaluation of cleaning systems for the conservation treatment of Roy Lichtenstein's iconic painting. Herit Sci. 2020;8(1):1–30.
41. Arbocel®. https://grupofiltrantes.com.mx/producto/fibra-de-celulosa-jrs-arbocel-b-600/. Accessed 10 Nov 2021.
42. Art Sponge®. https://shop-espana.ctseurope.com/623-esponja-art-sponge. Accessed 10 Nov 2021.
43. Akapad® Soft. https://shop-espana.ctseurope.com/627-esponja-wishab-akapad. Accessed 10 Nov 2021.
44. Milan® https://www.milan.es/en/box-30-soft-synthetic-rubber-erasers-430-squared-white-and-pink-assorted-colours-/. Accessed 24 Dec 2021.
45. Treating the back of a canvas painting. https://heritagepreservationatelier.com/2020/07/18/treating-the-back-of-a-canvas-painting/. Accessed 29 July 2022.
46. Carlisle M. The Conservation of Poedua—Part 3. https://blog.tepapa.govt.nz/2011/04/13/the-conservation-of-poedua-part-3/. Accessed 29 July 2022.
47. Coy A. Contents corner: cleaning and deodorizing artwork. 2013. https://www.randrmagonline.com/articles/86587-contents-corner-cleaning-and-deodorizing-artwork. Accessed 29 July 2022.
48. Alberston C. Conservation of floor cake (Part 7). 2010. https://www.moma.org/explore/inside_out/2010/09/09/conservation-of-floor-cake-part-7/. Accessed 29 July 2022.
49. Kraft NE. Assessment and cleaning. 2013. https://blog.lib.uiowa.edu/conservation/2013/02/11/assessment-and-cleaning/. Accessed 29 July 2022.
50. Cardaba-López I, Marugueri Olabarria I. Estudio de limpiezas aplicadas a pinturas de emulsión acrílica sobre soporte poroso y no poroso. Estudio previo y aplicación sobre la obra de Iñaki Imaz. In: Conservación de arte contemporáneo: 17ª jornada. Madrid: Museo Nacional Centro de Arte Reina Sofía. 2016:107–18.
51. Wada M, Uriarte Padró V. La restauración de un plano del s. XIX, del edificio de la Universidad Central. http://webs.ucm.es/BUCM/foa/pecia/num7/Articulos/0703.htm. Accessed 29 July 2022.
52. Klein L. Rapport de stage de quatrième année. centre de restauration de la ville de Düsseldorf en Allemagne. France: Institut national du patrimoine. 2016; p. 13.
53. Reche Martínez S. Estudio y propuesta de restauración de una pintura al óleo sobre lienzo de la Iglesia Nuestra Señora de la Asunción (Ayora), Final Degree Project (TFG) at the UPV, Valencia. 2019. http://hdl.handle.net/10251/126029.
54. Barabant G, Bajon-Bouzid T, Fierle C. Une technique de restauration des textiles appliquée aux peintures modernes et contemporaines: le nettoyage d'un ensemble décoratif de Paul Vera (vers 1924) par compresses d'argile montmorillonite. In: Technè. La science au service de l'histoire de l'art et de la préservation des biens culturels, Centre de recherche et de restauration des musées de France. 2015(41):118–26. https://doi.org/10.4000/techne.4972.
55. Sansano Palazon, M. Estudio técnico y propuesta de conservación-restauración de una pintura sobre lienzo del Museo de Pusol de Elche. 2020. http://hdl.handle.net/10251/149886.
56. Bejarano Quintero-Tacoronte ÁM, Pérez Sánchez MJ, de la Rosa Vilar DM. La Virgen del Carmen sobre el Purgatorio de la Iglesia de Santo Domingo de Guzmán. Estudio analítico, Conservación y Restauración. Trabajo fin de Grado. Universidad de La Laguna. 2016. http://riull.ull.es/xmlui/handle/915/3542.
57. García Abad C, Barros García JM. Estudio técnico y propuesta de intervención del óleo sobre lienzo San José con el niño Jesús (ermita de La Consolación, Llutxent). Trabajo final de Grado. Universitat Politècnica de València. 2021. http://hdl.handle.net/10251/172493.
58. Vangindertael Z. Restauration d'un peinture de paysage du Musée Faure par imprégnation de cire-résine. Étude du élange cire-résine et recherche d'une alternative à la cire d'abelille. Memoire de Fin d'Etudes. Conservation Restauration des Peintures. Ecoles de Conde. Formation Restaurateur du Patrimoine. 2013. https://issuu.com/ecolesconde/docs/z.v._m__moire_2013/78. Accessed 29 July 2022.
59. Restauración del lienzo san Joaquin, santa Ana y la virgen Niña. 2012. http://obrasrestauradasgaia.blogspot.com/2012/11/restauracion-del-lienzo-san-joaquin.html. Accessed 29 July 2022.
60. Lienzos del antiguo Hospital de San Bernardo. http://www.villasecadelasagra.es/recursos/documentos/Restauracion/lienzos_del_antiguo_Hospital_de_San_Bernardo.pdf. Accessed 29 July 2021.
61. Restauración de lienzos del altar mayor de la colegiata de los Santos Justo y Pastor. 2006. https://www.juntadeandalucia.es/export/drupaljda/CUADROS_BOCANEGRA_SAN_JUSTO_GRANADA_comprimido_1_0.pdf. Accessed 29 July 2022.
62. Restauració de Passeig solitari. Hort del duc de Gor de Santiago Rusiñol. 2013. https://centrederestauracio.gencat.cat/web/.content/crbmc/pdf/arxiu/rusinol.pdf. Accessed 29 July 2022.
63. Rico L, de las Heras V, Martñinez C. Antes y después de un proceso de limpieza y restauración. Fernando Zóbel, Ornitóptero, 1962. Óleo sobre lienzo. 114 x 146 cm. Colección del Museo de Arte Abstracto Español, Cuenca, Fundación Juan March. 2019. https://recursos.march.es/web/arte/cuenca/exposiciones/zobel/pdf/zobel-restaura.pdf. Accessed 29 July 2022.
64. Catàleg d'activitats 2003–2010. CRBMC Centre de Restaruació de Béns Mobles de Catalunya. https://centrederestauracio.gencat.cat/web/.content/crbmc/pdf/arxiu/cataleg_crbmc_2003-2010.pdf. Accessed 29 July 2022.
65. López T. Restauración de la obra de Rafael Baixeras en el Centro Galego de Arte Contemporáneo. https://www.ge-iic.com/wp-content/uploads/2006/06/Lopez_Thais.pdf. Accessed 29 July 2022.
66. Morera E. Els suports primaris minoritaris en pintura sobre tela. 2018. http://diposit.ub.edu/dspace/bitstream/2445/125465/1/treball_final_grau_elena_morera.pdf. Accessed 29 July 2022.
67. Barros JM. Estudio y propuesta de restauración de una pintura al óleo sobre lienzo de la Iglesia Nuestra Señora de la Asunción (Ayora). http://hdl.handle.net/10251/126029. Accessed 29 July 2022.
68. Cortés G. Restauración de pintura en caballete: obras de Hugo Jorquera, René Poblete Urquieta, Francisco Moya. 2018. https://repositorio.uchile.cl/handle/2250/165727 Accessed 29 July 2022.

69. Tott Cárcamo MS, Muñoz Álvarez JM. Restauración y Conservación del Cuadro Virgen Santísima de la Luz. Guatemala: Universidad de San Carlos de Guatemala. https://silo.tips/download/restauracion-y-conservacion-del-cuadro-virgen-santisima-de-la-luz. 2007; p. 45.
70. Cataluña García E. Estudio técnico y propuesta de intervención de la obra 'Mesa de trabajo en rosa' de Francisca Mompó. 2017. http://hdl.handle.net/10251/165335. Accessed 29 July 2022.
71. Alonso Jiménez S, de Blas García M, Sánchez Díaz L. Restauración del Cartel del XI Salón de Otoño de 1931. 2019. https://apintoresyescultores.es/restauracion-del-cartel-del-xi-salon-de-otono-de-1931/. Accessed 29 July 2022.
72. Kornhauser S. The conservation treatment and technical examination of A German Impressionist Painting. Art Conservation Master's Projects, 2. 2018. https://digitalcommons.buffalostate.edu/art_con_projects/2.
73. Iglesias-Campos M, Prada-Pérez JL. Actual laser removal of black soiling crust from siliceous sandstone by high pulse repetition rate equipment: effects on surface morphology. Mater Constr. 2016;66(321):e078. https://doi.org/10.3989/mc.2016.02215.
74. ISO 25178:2012. Geometrical product specification (GPS)—surface texture: areal—part 2: terms, definitions and surface texture parameters.

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