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DISSERTATION

The Colour Palette of Toasted Cellulose Powders and Its Many Uses

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ABSTRACT
This study investigates the colour changes achieved by toasting cellulose powder Arbocel B00 at different temperatures and durations of thermal exposure, aiming to establish a reliable palette of brown tones adaptable to diverse conservation needs. To evaluate the applicability of this method, two case studies were conducted, each addressing specific conservation challenges. The first case study, conducted as part of Lilian Samland´s master´s thesis, involved a Berât issued under Sultan Mustafa III, an Ottoman manuscript historically used to confer prestigious positions and privileges. A manual infilling technique with cellulose powder was adapted for water-sensitive documents: toasted cellulose powder was mixed with Tylose MH50 (2%), sprayed with an airbrush onto plastic foils and dried to form colour-matched infill sheets. These sheets were glued with hydroxypropycellulose Klucel G in ethanol, following stabilization of losses with remoistenable tissues. Additionally, a suspension made of cellulose powder and Klucel G in ethanol was used for colour reintegration with a brush. The second case study, undertaken in Mairid Schleinschock's bachelor's thesis, addressed visual stain reduction on a contemporary painting by Mimmo Paladino. Toasted Arbocel B00 was mixed with Klucel G in n-butanol (1%) and applied directly onto the object with an airbrush. Comparative testing demonstrated that n-butanol yielded the most aesthetically integrated result while maintaining the artwork´s material integrity.

KEYWORDS
Cellulose powder; fibre retouching; paper infilling; toasting

ZUSAMMENFASSUNG
Die Studie untersucht die durch Rösten von Zellulosepulver Arbocel B00 bei unterschiedlichen Temperaturen und Einwirkungszeiten erzielbaren Farbveränderungen, um eine reproduzierbare Palette brauner Farbtöne für unterschiedliche konservatorische Anwendungen zu schaffen. Zwei Fallstudien verdeutlichen die Einsatzmöglichkeiten dieser Methode. Die erste, im Rahmen der Masterarbeit von Lilian Samland, betraf einen unter Sultan Mustafa III ausgestellten Berât – ein osmanisches Manuskript zur Verleihung hoher Ämter und Privilegien. Hier wurde eine manuelle Ergänzungstechnik für feuchtigkeits-sensible Dokumente entwickelt: geröstetes Zellulosepulver, mit Tylose MH50 (2 %) versetzt, wurde mittels Airbrush auf Kunststofffolien aufgetragen, getrocknet und zu farblich angepassten Ergänzungsblättern verarbeitet. Diese wurden nach Stabilisierung der Fehlstellen mit befeuchtbaren Papieren mit Hydroxypropylcellulose Klucel G in Ethanol verklebt. Eine Suspension aus Zellulosepulver und Klucel G in Ethanol diente zudem der farblichen Retusche. Die zweite Fallstudie (Bachelorarbeit Mairid Schleinschock) behandelte die optische Reduktion von Flecken auf einem zeitgenössischen Gemälde von Mimmo Paladino. Geröstetes Arbocel B00 wurde mit Klucel G in n-Butanol (1 %) gemischt und per Airbrush direkt aufgetragen. Vergleichstests zeigten, dass n-Butanol das ästhetisch überzeugendste und zugleich materialschonendste Ergebnis lieferte.

SCHLÜSSELWÖRTER
Zellulosepulver; Faserretusche; Papierergänzung; Rösten

Introduction

Toasted cellulose powders offer a novel approach in paper conservation, enabling precise colour reintegration and efficient infilling of losses. Their adaptability arises from their ability to customize colour by toasting cellulose powders at controlled temperatures and specific durations of thermal exposure, resulting in a reproducible colour palette of brown hues.

Previous research by Udina and Escolano (2017) assessed the suitability of toasted cellulose powder for paper conservation purposes. Their study employed artificial ageing through heat and light, following ASTM standards, and found no significant long-term alterations that would hinder its use in conservation. Building on their research, this work explores the practical application of toasted cellulose powder through two case studies, both conducted at the Cologne Institute of Conservation Sciences (CICS) as part of master's and bachelor's theses.

The first case study addresses the conservation of a Berât, an Ottoman-era manuscript dating from the reign of Sultan Mustafa III. These documents were of great importance in the Ottoman Empire, as they conferred esteemed positions and privileges. Due to

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its fragility and high sensitivity to moisture, a non-aqueous infilling method using pre-formed toasted cellulose powder sheets was employed. For colour reintegration, toasted cellulose powder suspensions with minimal binding media were manually applied using a stippling technique.

The second case study focuses on the conservation of a large-scale painting by Mimmo Paladino in the field of contemporary art. The artwork, mounted on canvas, exhibited brown discolouration that could not be removed. To address this, colour-matched cellulose powder suspensions were developed and applied using an airbrush technique.

These case studies illustrate the adaptability of toasted cellulose powders in conservation, demonstrating their seamless integration into both historical and contemporary artworks. By further investigating the material's application potential, this study aims to expand the range of available conservation.

Toasting procedure and the colour palette

To facilitate the colour matching, cellulose powders are toasted at different temperatures and for varying durations of thermal exposure. By controlling these parameters, a range of brownish tones can be produced, forming the basis of a colour palette that enables conservators to select the most appropriate shades for their specific project. This chapter outlines the selection of materials, the toasting process, and the production of fibre sheets, followed by a discussion of the resulting colour palette and its application.

Selection of powdered cellulose

The raw material consists of pure cellulose, a plant-derived functional filler that is chemically inert and mechanically processed to maintain its fibrous structure. This high-grade material has low moisture absorption properties, a pH value ranging from 5 to 7.5, and a cellulose purity of 99.5%. The white, short-fibred substance is characterized by an average fibre length of 120 µm and a thickness of 25 µm. For the development of the colour palette, Arbocel B00 was chosen due to its favourable properties for conservation applications. As an alternative, SolkaFloc 300® can be used, but the specific characteristics of the material should be considered when making a selection. Depending on the requirements of the conservation project, different cellulose fibres can also be mixed, allowing for the manipulation of surface characteristics and the stability of the infilling material. This adaptability ensures compatibility with various aqueous and non-aqueous binders, facilitating a wide range of application techniques.

The toasting process and rinsing

The aim was to develop a low-tech toasting technique that can be carried out without the need for specialized equipment. The cellulose powder was toasted in a pre-heated thick-walled glass container placed on a cordierite stone, at temperatures of 190°C, 200°C, and 210°C in a hot air oven. The cordierite stone was used due to its low thermal conductivity, helping to maintain a stable temperature even when the oven was occasionally opened to check the browning process.

To ensure reproducibility, each toasting recipe was repeated three times under identical conditions. After establishing the optimal recipes, frequent oven opening became unnecessary. Best results were achieved at temperatures of 190 °C and higher, with cellulose powder samples removed at ten-minute intervals to monitor colour changes.

The toasting process simulated an artificial ageing process, inducing browning in the cellulose fibres. However, this process also generated water-soluble byproducts. To eliminate these compounds, which could otherwise cause discolouration or compromise the long-term chemical stability of the material, the toasted cellulose pulp was rinsed thoroughly with distilled water (Udina & Escolano, 2017: 6).

It is important to note that the toasting process is influenced by several variables that cannot be standardized, such as oven heating variations, fibre rinsing procedures, fibre ageing, and the source of the cellulose fibres. As a result, slight differences in the final colour palette may occur when different laboratories replicate the process. However, when the same parameters are followed, a high degree of reproducibility can be achieved.

Production of fibre sheets

The production of fibre sheets from toasted cellulose powders was based on the airbrush application technique mentioned by Reinwater (2014). This method involves forming sheets using SolkaFloc®, a purified powdered cellulose, on Mylar® substrates. To ensure uniform film formation, methylcellulose A4M (viscosity 4.000 mPas) is used as a binder. However, for this adaption Tylose (methylhydroxyethylcellulose, viscosity 50 mPas) MH50 (2%) was selected due to its lower viscosity, facilitating improved fibre dispersion (Horie 2010).

The fibre suspension was prepared by soaking 1 g of toasted cellulose powder in 25 ml of Tylose MH50 (2%) for at least 24 h (see Figure 1). This soaking process promoted fibre swelling, which increased the surface area and improved the potential for inter-fibre bonding (Petherbridge, 1987: 156).

For application a Sparmax DH 810 airbrush gun was used, spraying the suspension evenly onto a fixed Mylar® sheet from a 20 cm distance. Alternative

Figure 1. The fibre suspensions of the cellulose powder toasted at 200°C with increasing duration of thermal exposure (from left to right) (Photos: Lilian Samland).

plastic sheets may be used depending on the desired surface texture, as rougher substrates transfer their structure on the resulting fibre sheet (Pataki, 2007). During practical tests, three successive layers of cellulose suspension were applied. This choice balanced time and material economy with sufficient film strength. Three layers ensured both stability and uniform colour distribution. To achieve a uniform surface, intermediate drying periods of several hours were required. Approximately 12 ml of fibre suspension was needed to cover a 10 × 10 cm area with three layers. To prevent curling, the plastic sheet was secured using magnets on metal plates (see Figure 2). Regular cleaning of the airbrush was essential to prevent clogging.

The colour palette

Following an empirical toasting process, a comprehensive colour palette was created (see Table 1). The palette includes 30 toasting stages at three distinct temperatures (190°C, 200°C, 210°C), with durations of thermal exposure ranging from 20 to 110 min as well as a reference for untoasted cellulose. The shades are classified according to their brown hues.

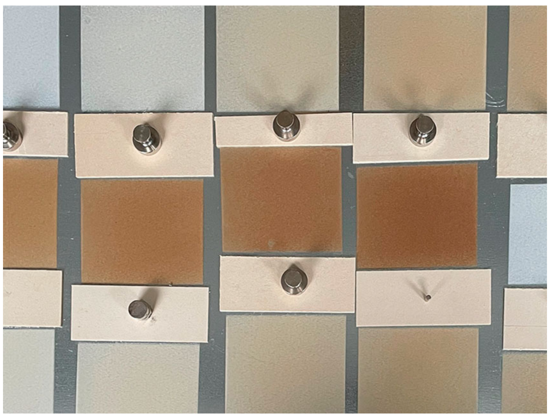

Figure 2. The fibre sheets at different toasting levels fixed on a metal plate with magnets. Bright brown, narrow blotter paper strips are placed beneath the magnets to ensure the films remain flat while drying on the metal plates (Photo: Lilian Samland).

Table 1. The palette of all toasting levels of cellulose powder Arbocel B00 with mean values (M) of L*, a* and b*. The first row is the untoasted reference.

Palette	Level	Temperature	Time	M L*	M a*	M b*
		–	–	94,06	−0,11	1,92
	1	190°C	20 min	93,30	−0,40	4,97
	2	190°C	30 min	92,26	−0,22	7,80
	3	200°C	20 min	91,52	−0,09	8,76
	4	190°C	40 min	90,89	0,11	10,69
	5	210°C	20 min	89,70	0,42	12,54
	6	200°C	30 min	89,09	0,81	13,86
	7	190°C	50 min	89,08	0,83	14,03
	8	190°C	60 min	87,55	1,41	16,11
	9	190°C	70 min	85,80	2,05	17,57
	10	200°C	40 min	84,40	2,68	18,79
	11	210°C	30 min	84,26	2,59	18,96
	12	190°C	80 min	84,02	2,70	18,99
	13	190°C	90 min	82,73	3,13	20,19
	14	190°C	100 min	81,22	3,83	21,63
	15	200°C	50 min	80,06	4,27	21,89
	16	190°C	110 min	80,08	4,25	22,32
	17	210°C	40 min	76,88	5,31	23,57
	18	200°C	60 min	75,67	5,64	23,92
	19	200°C	70 min	71,53	6,76	25,28
	20	210°C	50 min	70,39	7,09	25,62
	21	200°C	80 min	69,47	7,48	26,16
	22	200°C	90 min	65,39	8,35	26,81
	23	210°C	60 min	63,48	8,77	26,94
	24	200°C	100 min	62,40	9,00	27,25
	25	200°C	110 min	60,58	9,53	27,49
	26	210°C	70 min	59,84	9,44	27,04
	27	210°C	80 min	55,97	10,22	27,05
	28	210°C	90 min	53,73	10,64	26,88
	29	210°C	100 min	49,69	11,12	26,12
	30	210°C	110 min	46,95	11,24	25,16

To quantify colour changes, a datacolor UV-Vis spectrophotometer was used. This optical analysis instrument measures reflectance values within a defined area, providing data on CIELAB colour space parameters (CIE, 2004). Colour measurements were taken at four points per sheet, using untoasted cellulose as the standard reference.

The results indicate a correlation between the duration of thermal exposure and the overall colour change (ΔE^*). The ΔE^* values, which express the total colour difference based on ΔL^* (lightness), Δa^* (red-green axis) and Δb^* (yellow–blue axis) (CIE, 2004), increase with longer durations of thermal exposure. The measurements show a generally linear trend in colour change for the three toasting temperatures (190°C, 200°C, 210°C). After 110 min, the ΔE^* values range between 25 and 53.

While the overall trend of colour change correlates with increasing duration of thermal exposure and temperature, some deviations from strict linearity are observed. These variations may be influenced by factors such as differential thermal conductivity, or slight inconsistency in fibre moisture content prior to toasting.

Despite exposure to temperatures exceeding 200°C for up to two hours, no charring occurred, and the fibres remained structurally intact. However, as previously discussed (see 'The toasting process and

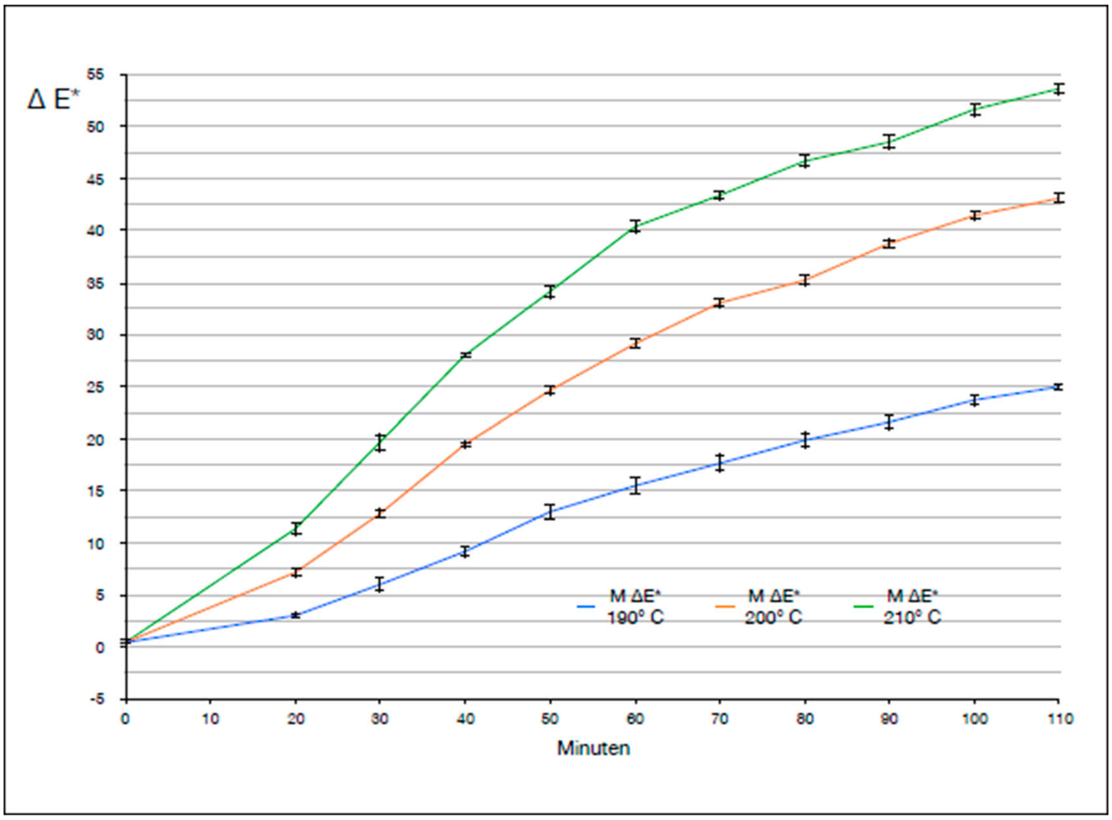

Figure 3. An overview of the overall colour change Δ*E** is given in correlation with the duration of thermal exposure for three temperatures. In this table only the mean values are given.

rinsing'), rinsing the sheets is necessary to remove soluble degradation products (Figure 3).

The established colour palette provides a systematic basis for selecting suitable tones for conservation treatments. By relying on defined recipes, conservators can achieve consistent and reproducible results. The following case studies explore the application of toasted cellulose powders in both historical and contemporary conservation projects, highlighting their adaptability to different material challenges.

Ottoman Berât of Sultan Mustafa III

This section introduces the Berât of Sultan Mustafa III by outlining its cultural and historical significance, documenting the damages it has sustained, and the alterations it has undergone. The conservation treatment, with a focus on infilling losses using colour-matched cellulose powder, is subsequently described.

Description and relevance of the object

The Berât is part of the Max Freiherr von Oppenheim collection, housed at the University of Cologne (Röllig, 2001: 253–254). It is a significant historical document from the mid-eighteenth century Ottoman Empire, specifically dating from the reign of Sultan Mustafa III. Berâts were formal imperial documents issued by the Sultan to confer distinguished positions and privileges (see Figure 4). These written records not only provide information about significant historical events but also offer valuable insights into artistic and stylistic preferences of Ottoman culture. The

Figure 4. The Berât of Sultan Mustafa III. Recto before conservation (Photo: Lilian Samland).

intricate design often found on these documents reflects the skill of Ottoman calligraphers and illuminators. They contain information about the complex administrative system that laid the foundation for the rapid cultural and political development of the Ottoman Empire, shedding light on diplomatic connections, as well as the legal and economic structure of the empire.

The Berât measures approximately 82 × 52 cm. At the top, the tughra – an ornate monogram of the reigning Sultan – serves as a symbol of imperial authority (Kutlukan, 1986: 11). The date of the document is determined through an analysis of the tughra and other inscriptions, placing it between the 14th Rabi‘ al-Awwal 1182 (24 November 1768) and the 14th Rabi‘ al-Awwal 1186 (11 October 1772).

Beneath the tughra are seven script bands, speckled with gold and varying in hues of red, green, and dark brown. The text is written in the dîvânî script, which was commonly used for official correspondence within the Ottoman Empire (Osborn, 2017: 60). The content of the text refers to the firâschet, a prestigious position held in the Prophet‘s Mosque in Medina. These highly respected officials, along with a group of eunuchs, were responsible for the upkeep and cleaning of the mosque, particularly the illumination between the pulpit and the tomb of Mohammed (Caskel, 1933: 138–141).

The object is adorned with various arrangements of golden dots, which are part of the intricate decoration. The floral ornamentation at the bottom, known as mahall-i tahrîr, indicates the place of issuance. The final text of the Berât was expertly crafted by a skilled calligrapher. His work was further formalized by the addition of the tughra, applied by the nişancı (the royal scribe) or their assistants. Sometimes, additional embellishments were made by an illuminator (Kutlukan, 1986).

On the reverse side, multiple inscriptions are present (see Figure 5). A substantial portion of these inscriptions is found on previous paper repairs and

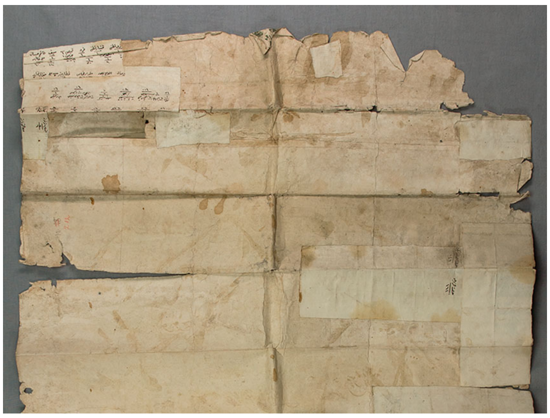

Figure 5. The inscriptions on the verso on the previous paper repairs (Photo: Lilian Samland).

relates to inheritance matters of an individual from Aleppo, which are not directly related to the content of the Berât.

Various art-technological examination methods were employed to analyse the Berât, aiming to gain insight into the paper's origin, fibre materials, writing media, binders, and the alterations it has undergone over time. These methods included light microscopy, transmitted light examination, microscopic analysis of fibres and binding media, Fourier-transform infrared spectroscopy, visible colour spectroscopy, infrared reflectography, X-ray fluorescence analysis, and scanning electron microscopy.

The manuscript is written on polished, smooth and glossy Arabic paper typical of that period. The writing media do not penetrate the paper substrate and are therefore highly sensitive to mechanical and aqueous treatment (Karabacek, 1887). The calligrapher employed a variety of traditional Islamic writing fluids. The tughra and the green script areas were executed using a mixture of indigo, orpiment, and lead white. Vermilion and lac were used for red script areas. The brown hue of the script is difficult to identify definitively, but it likely represents a blend of iron gall ink and carbon ink, with the brown tone resulting from the ageing process. Initially the script was likely a deep black, which would have been appropriate for a document of such significance. The gold illuminations were likely produced with a small amount of silver mixed into the gold. Gum Arabic served as a binder for these materials.

By capturing both transmitted and reflected light images of the Berât, concealed inscriptions could be revealed without removal (see Figure 6).

Further information about the art technology of the Berât can be viewed in the master's thesis (Samland, 2022).

Damages and alterations to the original

As the following discussion focuses on the use of toasted cellulose powder, the description will initially concentrate on the mechanical damages. However, the object also shows other types of damage and signs of ageing, including soiling, discolouration, stains, mould infestation, and areas in the paint layer of the tughra that are potentially vulnerable. The mechanical damages include folds, creases, tears, and losses. The previous paper repairs, which were likely applied to stabilize the object, are now negatively affecting its preservation. The repairs are thicker and more rigid than the original paper, creating tension at the edges and causing the Berât to tear. Significant losses have occurred at the edges, particularly at the top and bottom. The floral ornamentation of the mahall-i tahrîr at the bottom, which once indicated the place of issuance, is mostly absent, as is the

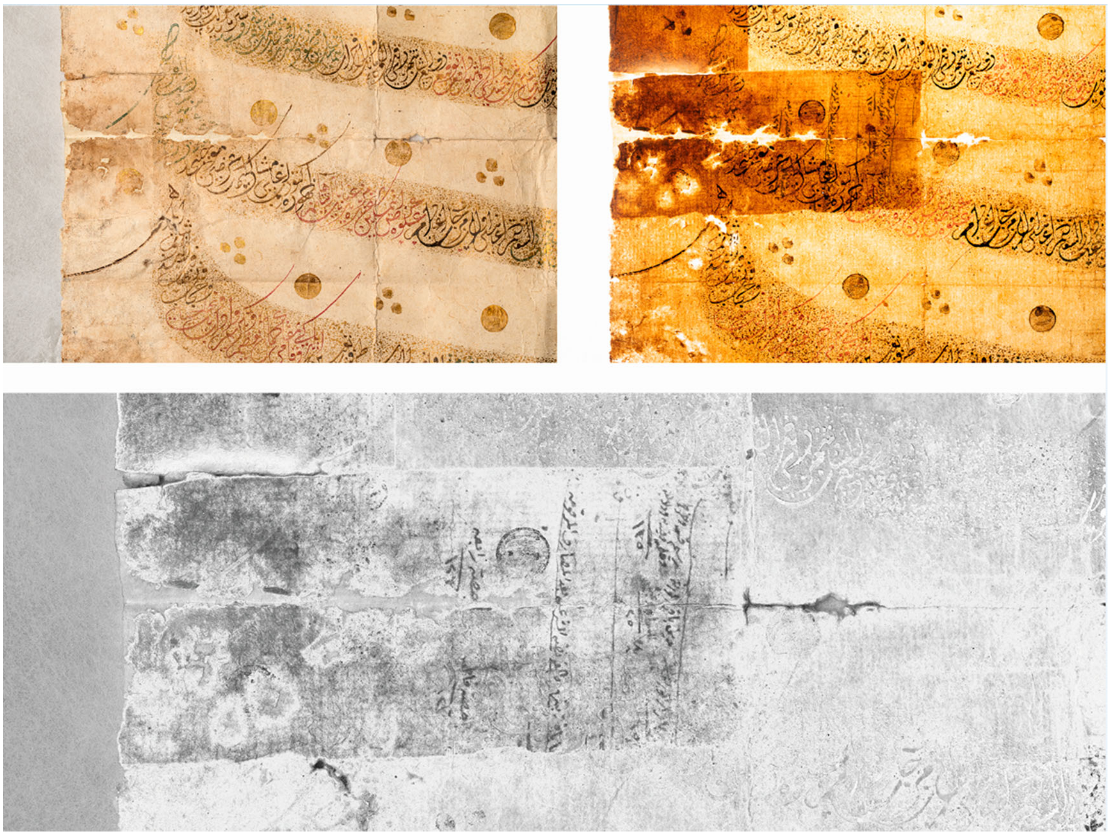

Figure 6. Close-up capture in the area of a loss with previous paper repairs in reflected light (top left), transmitted light (top right) and the differential image of the two upper figures (bottom) (Photos: Lilian Samland).

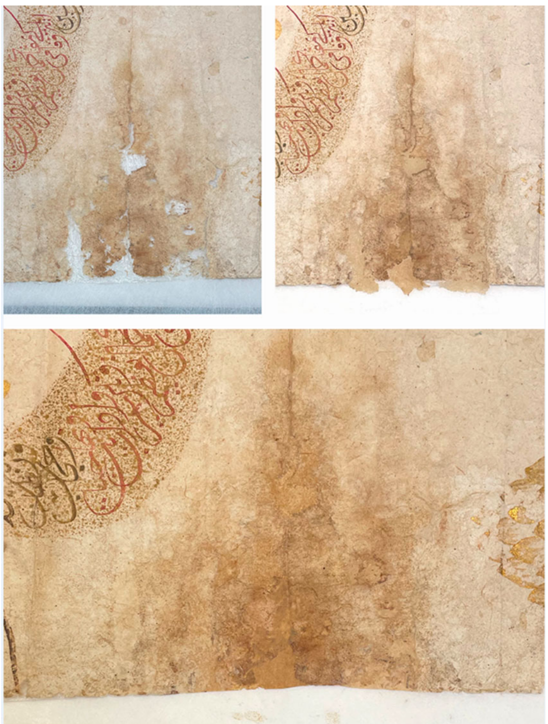

Figure 7. Close-up images during the process of infilling losses with cellulose powder. The loss was secured with a remoistenable tissue (top left). Subsequently, the infilling with toasted cellulose powder sheet was performed (top right). Finally, the transitions and lighter areas were treated with suspensions of toasted cellulose powder and Klucel G in ethanol using a brush (bottom) (Photos: Lilian Samland).

invocation at the top (see Figure 4). The paper has suffered significant abrasion, which resulted in the loss of the characteristic sheen typically found on Arabic papers. This is particularly evident at the edges and corners, areas that have experienced the most mechanical stress over time.

Conservation treatment

Only minimal interventions were carried out to ensure proper handling, storage, and maintain the object's integrity. The primary aim was to stabilize the vulnerable areas of both the paper and the paint layer, thereby ensuring its long-term preservation and suitability for future exhibition. Due to the document's pronounced water sensitivity, particularly concerning writing fluids and surface finishes, an exclusively non-aqueous treatment strategy was adopted.

The object was dry-cleaned with a soft brush. Further cleaning was not feasible due to the fragility of the paper surface. Small tears were closed and supported by using remoistenable tissues (RK00; 1,6 g/m^2; coated with Klucel G in Ethanol) (Pataki-Hundt, 2009).

Colour adjustment of the infilling material was carried out through toasting in accordance with the colour palette of toasted cellulose powders previously described. The selection of appropriate toasting levels for the infillings was based on multiple colour measurements in the vicinity of the losses. An average of the brightest values was used. The fibre sheets were sprayed in three layers, allowing for the material´s thickness to be adjusted to match the original. For another object it might require more or fewer layers.

Initially, the loss area was stabilized by a remoistenable tissue on the verso side, which had been coated with Klucel G in ethanol (2.5%) (see Figure 7 top left). This remoistenable tissue provided the necessary stability between the original material and the infill, as well as to the infill itself. On the recto side, the fibre sheet was adhered using the same adhesive and levelled up to match the original (see Figure 7 top right).

Due to the irregular colour of the original paper, a small amount of fibre suspension was applied with a fine brush to visually integrate the infill and conceal the transition, while also stabilizing particularly fragile areas (see Figure 7 bottom). For the fibre suspensions used in direct infilling on the object, the cellulose powder was mixed with Klucel G in ethanol (2.5%).

Assessment of the infilling technique

The infilling technique with cellulose powder allows for smooth transitions between the infill and the original material. Applying the infill in multiple layers allows adjusting the thickness to match the original paper seamlessly.

In addition to these aesthetic advantages, this technique enhances the strength of the original paper, particularly in brittle areas surrounding the losses. Under mechanical stress, the cellulose powder infill yields before the original paper, ensuring that the Berât remains unharmed.

Toasting the cellulose powder results in a reproducible technique for infilling that can be applied to a variety of objects. The existing colour palette can be expanded by mixing different powders, allowing for more precise colour matching.

The cellulose fibre sheets can be adhered using both aqueous or non-aqueous systems. This makes it well suited for water-sensitive objects that are not expected to undergo future aqueous treatments. The use of Klucel G in ethanol is a proven alternative, primarily owing to its solubility in alcohol (Pataki-Hundt et al., 2021).

The process of infilling with toasted cellulose powders is relatively time consuming, especially in the preparation phase. However, once the fibre sheets are ready, they can be stored on Mylar® for future use, making subsequent applications significantly more efficient. Once the fibre sheets are available, the infilling process itself can be executed efficiently as needed. The non-aqueous infilling technique with cellulose powder does not require expensive or complex equipment setup. It allows for precise colour-matching, making it a valuable alternative depending on the conservation needs and the condition of the objects. It can serve as a viable alternative to the traditional Japanese paper infilling, particularly for paper that has already undergone significant deterioration and may require consolidation (see Figure 8).

The conservation of a painting by Mimmo Paladino

As part of a bachelor's thesis, the previously described colour palette of toasted fibres was employed for visual stain reduction on a modern, large-format painting on paper by Mimmo Paladino. The artwork, which was lined on canvas, exhibited significant browning caused by penetration of adhesive during ageing processes. Given that localized solvent treatments and canvas removal were not viable options (Below, 2021: 59–61), an alternative approach was necessary.

The chosen method involved retouching on the paper substrate. However, due to water-sensitive particles in the paper,[1] traditional colour retouching was not feasible. Instead a fibre retouching technique[2] was developed, taking into account various material properties and the artwork's conservation requirements. Key considerations included the selection of a suitable binder, application techniques, fibre types, and potential removal methods to ensure future reworkability. Extensive testing within a bachelor's thesis led to the development of a fibre retouching technique that effectively achieved the desired visual improvement.

The following section presents the artwork, including a description of its external aspect and an analysis of the damage and changes it has experienced over time. An overview of the art technological context of the artwork is provided, followed by a detailed account of the implementation of fibre retouching using colour-matched cellulose powder.

Description and relevance of the object

The artwork 'Untitled,' created by Mimmo Paladino in 1981, exemplifies his distinctive artistic approach, characterized by mixed media techniques and a diverse array of materials. The work consists of gouache painting combined with plaster elements on paper. This was subsequently mounted onto canvas and tightly stretched over a frame. The composition is a triptych (see Figure 9), with an additional appendix featuring a separate plaster composition on paperboard.

The artist Mimmo Paladino, born Domenico Paladino on December 18, 1948, in Paduli(Italy), is renowned for his vibrant colours, material combinations, and large-scale formats in his art (Di Martino, 2001: 3–16). Notably, Paladino's works often lack titles, allowing viewers an unfiltered and

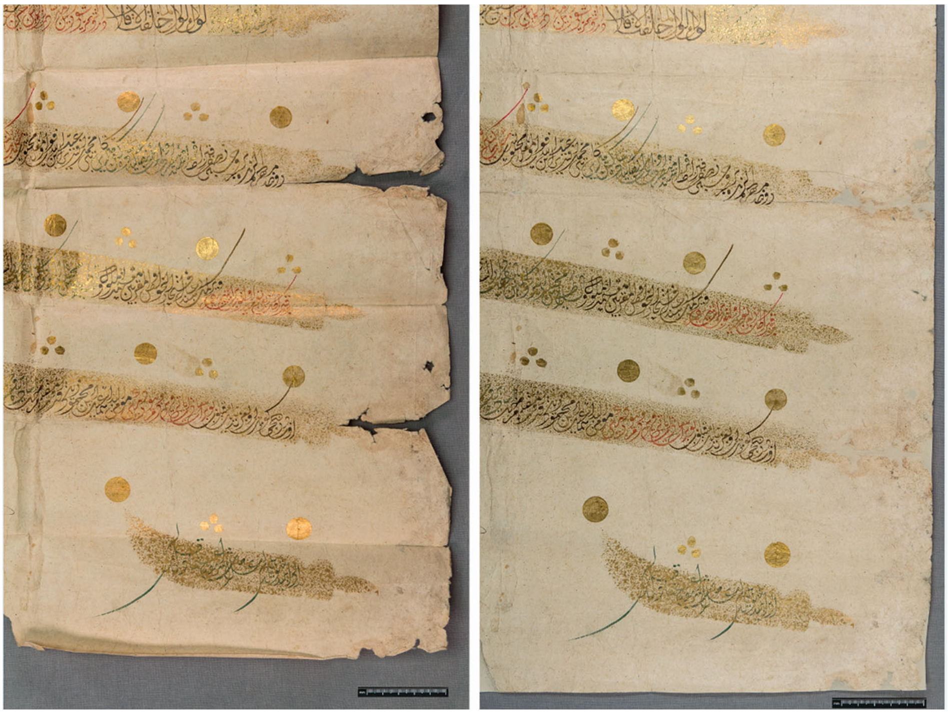

Figure 8. The Berât before (left) and after (right) conservation treatment (Photos: Lilian Samland).

personal connection to the art (Lepschi, 2009: 45). This particular artwork is part of the Henkel corporate collection, reflecting Gabriele Henkel's vision of integrating art into the workplace. Henkel has curated and exhibited artworks since the 1970s. Mimmo Paladino's piece had been displayed in multiple locations within the company based in Nord Rhine Westfalia near Düsseldorf, until it was placed in storage in 2018 due to staining (Henkel & Heymer, 2009: 7; Below, 2021: 40).

The triptych's striking materiality is matched by its impressive dimensions. When fully assembled, the work measures 152 cm in height, 1111 cm in width, and 4 cm in depth. The individual components are as follows:

Paladino I: 152 × 402 × 4 cm
Paladino II: 152 × 420 × 4 cm
Paladino III: 152 × 289 × 4 cm
Appendix: 42 × 85 × 12 cm

Structural analysis of the triptych revealed variations in the thickness of the adhesive layer, with the first two parts of the triptych requiring the most attention. A schematic representation of the artwork's layered structure is provided (see Figure 10).

The artwork's construction involves the doubling of brown, unbleached, machine-made paper onto the canvas. This paper exhibits minimal to no sizing, allowing water to penetrate freely into its structure, leading to fibre swelling and dimensional instability. Microscopic examination revealed the presence of black and grey particles embedded within the fibres, though their exact origin remains unknown. Nevertheless, it is reasonable to assume that they were introduced during the paper's production process. The surrounding areas of the particles show discolouration, indicating sensitivity to solvents.

Damages and alterations to the original

The examined object presents various types of damages, including dust accumulations, abrasion, deformations, tears, scratches, punctures and minor losses along the edges. However, the most visually disruptive issue is the extensive staining on the paper surface. These dark stains appear on both painted and unpainted areas but are less visible where paint is present. Interestingly, the number and prominence of

Figure 9. The entire triptych (untitled) by Mimmo Paladino (Photo: Paladino I by S. Gaisbauer, L. Altschmied, A. Nowack; Paladino II by R. Bermeo Tosi, L. Gras; Paladino III by R. Blasczyk, L. Paetzold).

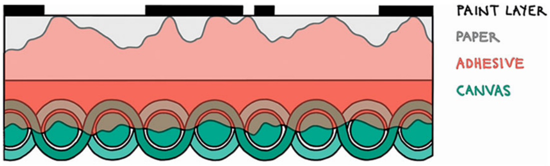

Figure 10. Schematic structure of the triptych without stretcher (Graphic: Lena Below and Lilian Samland).

these discolourations progressively diminish from the first to the third part of the triptych. It was determined that these stains originated from the adhesive used during lining process. Over time, this adhesive penetrated the paper, darkening as it aged (see Figure 11).

Microchemical analysis of the adhesive revealed that the brown discolourations were induced by a starchy component, a conclusion substantiated by positive starch detection through iodine potassium iodide (here and below: Below, 2021: 21). FTIR analysis further revealed that the adhesive, which shows a decreasing presence from Paladino I to Paladino III, have been artistically modified to mitigate its deteriorative effects. It contained a natural resin, which had migrated to the paper's surface due to its low molecular weight.

Solubility tests following Zumbühl's methodology (Zumbühl, 2017: 258–272) indicated that the stains responded to a broad range of solvents. However, certain solvents were excluded due to their potential to dissolve the particles within the paper. The most effective solvents for stain reduction included water, acetone:n-hexane, D-limonene, and various non-polar solvents like boiling limit petrol and Toluol (Banik & Brückle, 2015: 43; Below, 2021: 25, 28–30).

These findings underscore the multifactorial origins of the stains on the artwork, emphasizing the need for targeted stain reduction to restore the work's aesthetic integrity. Insights into the adhesive composition are pivotal in guiding the selection of appropriate solvents and techniques for the conservation of the artwork.

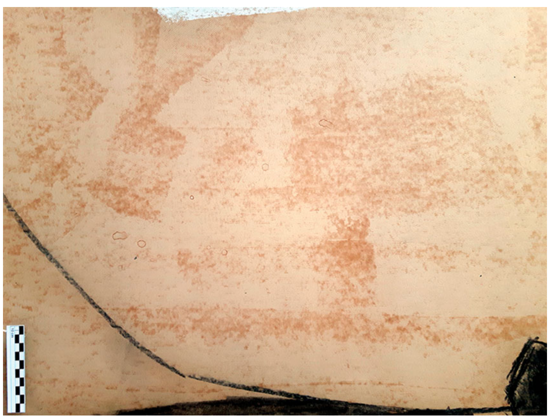

Figure 11. Exemplary adhesive stain on Paladino I (Photo: Lena Below).

Previous treatment approaches

A prior Master's thesis by Lena Below explored various stain reduction methods including aqueous treatments, bleaching, and solvent-based techniques (here and below: Below, 2021: 65–71, 79–81, 86–87, 89–91). However, many of these were unsuitable for large-scale works. The study focused on localized solvent-based stain reduction, but identifying an appropriate solvent was challenging due to the sensitivity of the paper containing the colour particles.

A mixture of toluene and xylene (1:1) was selected as the most viable solvent. While these solvents may not have ranked as the most effective in the Zumbühl test, this drawback could be compensated for by extending the exposure time, up to one hour. The treatment was applied using a mobile suction plate on the reverse side of the material. Due to the volatile and hazardous properties of the solvent, appropriate ventilation and personal protective equipment were required.

Although this method was successfully applied, the technique was deemed impractical for large-scale applications due to health risks and logistical constraints. Further research into safer, more efficient stain reduction methods remained necessary.

Conservation treatment

Fibre retouching was selected as a conservation approach to visually reduce staining while preserving the artwork's integrity. The objective is to visually diminish the damage caused by staining, employing cellulose fibres to conceal the stains. The treatment of the individual triptych components must be executed with precision, ensuring that the collective appearance remains as homogenous as possible. Given the paper's sensitivity, conventional colour retouching was unsuitable, reinforcing the necessity of fibre retouching (Below, 2021: 62).

It relies primarily on the adhesive strength of fibres in a binder system, forming a layer of the desired thickness on the paper's surface, effectively concealing discolouration. This not only supports the preservation of the artwork but also provides additional paper stabilization, especially in areas where the paper has deteriorated.

The fibre retouching criteria for Mimmo Paladino's work encompassed the following key aspects: it must match the original paper type, be subtle in texture, shade, and sheen. The fibre retouching should also offer sufficient flexibility and adaptability to address the varying intensity of the stains. Minimizing moisture was essential to prevent bleeding of any particles. Furthermore, it should be removable or at least reducible, allowing for future reworking if necessary.

Extensive testing was conducted to determine the most effective approach to fibre retouching, examining parameters such as binder, solvent, and application method. Klucel G in n–butanol (1%) and MH300 (1%) proved to be the most suitable binders based on optical criteria. Alcohol-based suspensions were preferred for their removability, while water-based suspensions proved more difficult to reduce.

A smear test following DIN EN ISO 4628-6:2011-12 was conducted to assess adhesion (Wetten, 2021: 39–41). Results indicated that n-butanol-based suspensions allowed for reduction with minimal impact on the underlying paper.

The previously developed colour palette proved invaluable in guiding the selection of fibres for retouching. The colour palette was first compared to the triptych to determine the most appropriate shade, along with slightly lighter and darker variations for subtle blending. This selection led to the identification of six toasting levels (level 12, 16, 17, 18, 20, 21) (see Figure 12). Additional toasting levels (23 and 27) were subsequently incorporated.

Accurately reproducing the colour palette posed challenges due to variables such as oven heating fluctuations and the number of fibre washes required to remove degradation products from toasting. In this case, the fibres were rinsed until the water remained clear, which required approximately five to seven wash cycles using a decanting method. The rinsed fibres were then filtered with a Whatman filter and laid out to dry (see Figure 12).

The fibre suspension for spraying was prepared according to Reinwater's (2014: 107) recipe, specifying 1 g of cellulose fibres per 25 ml of binder. Extensive testing determined that a 1% n-butanol solution with Klucel G yielded the best results. The preparation steps included soaking the fibres for 24 h, sieving the fibres through a filter paper following the previously described method and incorporating the fibres into the preprepared binder. Vigorous mixing facilitated fibre dispersion, resulting in a uniform suspension suitable for spraying.

Before application it was essential to protect the artwork by using cut-out masks around the treatment areas (see Figure 13). Blotting paper or foil were both effective as masking material. In this case blotting paper was primarily used due to its ease of quick preparation and adaptability to the individual edges. Surface texture could be adjusted using polyurethane (PU) sponges.

Figure 12. Selected fibres to evaluate suitable toasting levels (Photo: Mairid Schleinschock).

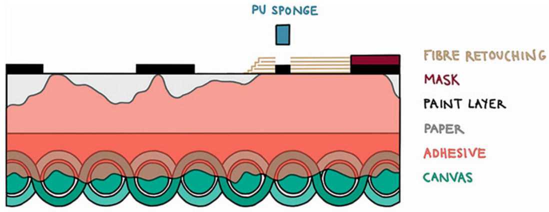

Figure 13. Schematic structure of the fibre application: Individually adaptable fibre layers over the stains. A mask is visible on the right to secure the painting. Fibre layers can also be carefully manipulated with a PU sponge (Graphic: Mairid Schleinschock and Lilian Samland).

The application of fibre retouching involves a multi-step process, applied in several thin layers that are individually adjusted to address each stain, using lighter and darker fibres. This approach enables precise colour matching to capture subtle nuances. For the current artwork, toasting levels 16, 18, 21, and 27 were selected to recreate the historical paper tone (see Figure 14).

Assessment of the retouching technique

The practical phase of the project highlighted the significant value of the colour palette for fibre retouching. This palette enabled precise colour matching, effectively addressing the complexities of reproducing historical tones. Matching the original paper tone proved to be a challenge. To avoid overly dark results, lighter shades were preferred. Achieving sufficient opacity required multiple layers of cellulose powder. Due to long evaporation times, up to 12 h per layer, the final colour match had to be evaluated over time. The spraying process with Klucel G in n-butanol required personal protection equipment and, where possible, a mobile suction system.

Klucel G in n-butanol produced optimal results without forming tide lines. The dried fibre suspension

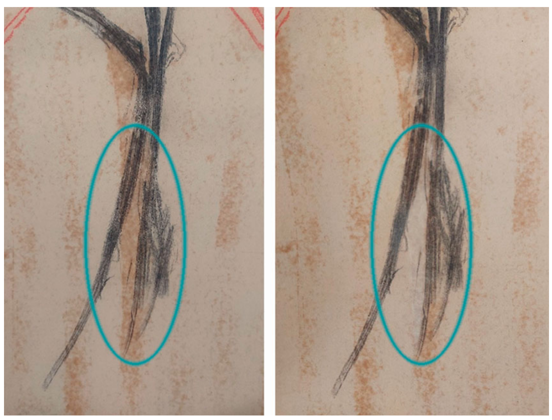

Figure 14. Condition before (left) and after (right) treatment (Photo: Mairid Schleinschock).

blended seamlessly with the original paper, eliminating the need for additional smoothing. PU sponges allowed for easy removal and adjustments where necessary. This case study demonstrates that fibre retouching with toasted cellulose powder is a viable method for visually reintegrating stained paper supports.

Conclusion

The exploration of colour-adaptable cellulose powder has opened up a range of non-aqueous possibilities for loss infilling and retouching in conservation practices. The development of a reliable process for creating this versatile material and a consistent palette of brown shades have been facilitated by the investigation of the colour changes resulting from the toasting of cellulose fibres at various temperatures and durations of thermal exposure.

Furthermore, a manual infilling technique using cellulose powder has been successfully adapted to address the conservation needs of water-sensitive documents, as exemplified by the conservation of a Berât dating from the reign of Sultan Mustafa III. This approach involved the processing of Arbocel B00 cellulose powder with Tylose MH50 (2%), followed by the application of a fibre suspension through airbrushing onto plastic foils. Subsequently, the dried cellulose powder sheets were adhered with Klucel G in ethanol. Notably, this method incorporated the use of remoistenable tissue to stabilize losses before adhering. Additionally, colour reintegration with a brush using a fibre suspension of cellulose powder and Klucel G in ethanol allowed for the stabilization of delicate areas and the seamless blending of colours.

Finally, practical application of colour-matched cellulose powder suspensions was demonstrated for visual stain reduction in the conservation of a contemporary painting by Mimmo Paladino on paper which was lined on a canvas. Arbocel B00 cellulose powder mixed with Klucel G in n-butanol (1%) was employed to achieve optimal results. Despite the challenge of relatively low adhesion associated with n-butanol, the retouching process was successfully completed.

It becomes apparent that the applications described not only expand the range of conservation techniques but also highlight the versatility and effectiveness of colour-adaptable cellulose powder as a valuable material for addressing various conservation challenges concerning historical as well as contemporary objects.

Notes

1. As part of a previous master's thesis by Lena Below (2021), various local stain reductions and colour media were ruled out for the work of Mimmo Paladino due to its characteristics.
2. Fibre Retouching is a retouching technique that deliberately uses cellulose fibres to visually reconstruct damaged areas. The term includes 'retouching', which is well established in technical terminology for aesthetic and structural image interventions. Thus, 'fibre retouching' is used here to precisely define this specific fibre-based retouching method.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Suppliers list

Harder & Steenbeck GmbH & Co. KG, Hans-Böckler-Ring 37, 22851 Norderstedt, Germany, Tel: +49 (40) 87 87 989 30, www.harder-airbrush.de (Airbrush gun Sparmax DH 810 with 0.8 mm nozzle and 125 ml cup)

Carl Roth GmbH & Co KG, Schoemperlenstr. 3-5, 76185 Karlsruhe, Germany, Tel: +49 (0)721/5606,www.carlroth.com (ethanol, n-Butanol)

WMF GmbH, WMF Platz 1, 73312 Geislingen/Steige, Germany, Tel: + 49 (0) 73 31 – 25 1, www.wmf.com (Fresh-keeping and storage glass container 23×15 cm ProfiSelect)

IKEA Deutschland GmbH & Co. KG, Am Wandersmann 2–4, 65719, Hofheim-Wallau, Germany, Tel: 061 92 / 93 99999, www.ikea.com (Convection oven ANRÄTTA)

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Deffner & Johann GmbH, Mühläckerstraße 13, 97520 Röthlein, Germany, Tel: +49 (0) 9723 9350-0, https://deffner-johann.de (Cellulose powder Arbocel B00 (soft abrasive B), Hydroxypropylcellulose Klucel G, Tylose MH300 and MH50)

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