Heritage Science

RESEARCH

Open Access

Saturnino Herrán's portable murals: symbolism, material agency and conservation

Nathael Cano[1], Oscar G. de Lucio[1*], Miguel Pérez[1], Alejandro Mitrani[1], Edgar Casanova[2] and José Luis Ruvalcaba Sil[1]

Abstract

Alegoría de la construcción and Alegoría del trabajo were the first mural paintings commissioned to Saturnino Herrán (1887–1918), and they occupied a significant place in one of the most important schools in Mexico. The non-invasive methodology employed included different documentation phases and in situ multi-technique analyses. Hyperspectral imaging and digital radiography were used for a general characterization of the materials and were complemented with localized analyses by portable microscopy, and XRF and FORS spectroscopies. A complete identification of the original and the restoration palettes was achieved. Results from this work allowed us to understand the production context, painting technique, and conservation state, thus providing insights for the proper conservation of these murals, while also unveiling a new perception of the artist and his historical place among the muralist movement.

Keywords Muralism, Conservation Science, Heritage Science, XRF, FORS, Hyperspectral imaging

Introduction

Saturnino Herrán Guinchard (Aguascalientes, 1887—Mexico City 1918) was a prominent Mexican painter renowned for his "critical art" [1], an original artistic representation of custom and manners of the working class,[1] known for portraying indigenous peoples and depicting religious syncretism and cultural *mestizaje*.[2] Notably, his paintings constitute a precursor of the Mexican muralism movement started in 1922, the major artistic and cultural byproduct that emerged immediately after the Mexican revolution of 1910 [2–5].

In 1910, before the start of the revolution, Saturnino created the portable murals *Alegoría de la construcción* and *Alegoría del trabajo* (Fig. 1) for the National School of Fine Arts and Craftsman (ENAOH),[3] which was the forerunner of what is now known as the National Polytechnic Institute (IPN), a public university of science

[1] Pérez C. Saturnino Herrán: Entre la tradición y la modernidad [Saturnino Herrán: Between tradition and modernism]. Tesis de maestría en Sociología. México: UNAM; 2010. p. 70. (Unpublished dissertation).

[2] Ramírez F. *Saturnino Herrán*. México: UNAM; 1976. p. 40.

[3] Ramírez E. Salón de Actos de esta Escuela. Oficio de la Secretaría de Instrucción Pública en que dispone el Sr. Saturnino Herrán decore los panneaux del referido salón [Auditorium of this School.- Office of Public Instruction Secretary, allowing Mr. Saturnino Herrán's panneaux to decorate the mentioned hall]. Escuela Nacional de Artes y Oficios para Hombres [National School of Fine Arts and Craftsman (ENAOH)]. México: AHESIME-IPN; 1910–1911, Expediente no. 3, C138. (Unpublished report).

*Correspondence:
Oscar G. de Lucio
olucio@ciencias.unam.mx
[1] Laboratorio Nacional de Ciencias Para La Investigación y Conservación del Patrimonio Cultural (LANCIC), Universidad Nacional Autónoma de México (UNAM), Mexico City 04510, México
[2] CONAHCYT-LANCIC, Universidad Nacional Autónoma de México (UNAM), Mexico City 04510, México

Fig. 1 Alegoría del trabajo (left) and Alegoría de la construcción (right), Saturnino Herrán, portable mural paintings, 1910, IPN

and technology in Mexico. In 2021, these murals were selected for the temporary exhibition *Greatness of Mexico* at the National Museum of Anthropology (MNA-INAH). As part of the curatorship, the conservation project required updating the documentation of these works and evaluating their state of preservation. As part of this research, it was found that the catalogs from previous exhibitions were incoherent (different years of production and techniques were assigned in all of them), and that the restoration records were missing. Hence, the creation of an archive was imperative.[4]

The murals were detached by stacco (consisting on protecting the pictorial layer on the front, while roughing on the back to keep the fine plaster and adhering it to a wooden support) in the course of an intervention process in 1976, due to the damages suffered by the building during the 1957 earthquake[5]. At some point afterwards, the paintings were misclassified as easel paintings, in particular oil on canvas. However, their large size, the observation of a wooden panel reinforced by bars used as a support on the back, and the research on their cultural biography between the production process and their restoration[5], suggests a different technology, other than oil on canvas [6]. This points towards an early development of a complex technique by the painter.

Saturnino Herrán had a limited production due to his early death. His work has been seldomly studied, with only a few approaches focused on his history and a noticeable absence of technical studies on his artworks. This opens a discussion on the material agency, understood as the innovation process, the use and incorporation of new materials and the development of techniques, [7] as well as the conservation of his limited works, constituted by murals, easel paintings, drawings and engravings. As he has been considered a precursor of the Mexican muralist movement, the answer to these questions may provide further insights into his influence on the development of this movement.

In this work we present the results of a non-invasive, in situ study carried out on the two previously mentioned artworks, which was developed as an inter-institutional collaboration made possible by the support of the curators and museum designers of the temporary exhibition. The methodology applied was based on previous works on historic murals, as well as modern and contemporary wall paintings from Europe, Asia, US and Latin America [8–19]. It encompasses archival research, followed by a

[4] Cano N. Informe del comisariado de las obras portátiles de Saturnino Herrán 2021–2022. [Curator report of Saturnino Herrán's portable murals]. Departamento de Difusión Cultural del Instituto Politécnico Nacional DDC-IPN. México: UNAM; 2022. p. 7. (Unpublished report).

[5] Servín J, Desprendimiento de los murales al óleo del pintor Saturnino Herrán [Saturnino Herrán oil murals detachment]. Cuadernos de arquitectura y conservación del patrimonio artístico. 1981; 3: 54–59.

material and painting-technique analyses (including a first approximation using imaging techniques and point analyses with atomic and molecular spectroscopies) and, finally, the diagnosis of their conservation state, alterations and restoration works. Each section discusses the results from the perspective of heritage sciences [20], following a cross-disciplinary and synergistic approach focused on the description of physical aspects by using non-invasive techniques and encompassing areas such as technical art history [21] and conservation [22].

Research aims

Our research was focused on understanding the value, context and history of these mural paintings, the materials used in its creation, the artist tradition shared in with other modern artists between 19th and early twentieth centuries and on identifying later restoration processes. In all, this will lead to a reclassification of the paintings and a complete conservation diagnosis.

Materials and methodology

Archive research

The documentary analysis of archives was focused on a collection of primary sources, most of them unpublished. It involved analyzing and interpreting them as to explore meanings, context, temporality and changes of the objects [23, 24]. This survey of historic sources [25] required the creation of worksheets and interpretation of the gathered information [26] by data units or keywords: authors, dates, institutions, and visual characteristics of historical archives, images, drawings, restoration records, and art exhibition catalogs relative to the mural paintings and the former convent of San Lorenzo. The sources for this work were from the Historic Archive of the High School of Engineering, Mechanics and Electronics (AHESIME-IPN), the Historic Archive of National Polytechnic Institute (AHI-IPN), the documentation record of Saturnino Herran's mural paintings from the Cultural Department of this institution (DDC-IPN); the General Archive of the Nation (AGN), the conservation record from National Center for Registration and Conservation of Fine Arts (CENCROPAM-INBAL); and an interview with the conservators Javier Servín and Tomás Zurián, who worked with the artworks since the 1950s, and were in charge of their detachment from the walls in 1976.

Visible Imaging techniques (Vis-I)

The use of Visible Imaging provides information regarding the technique of the paintings. In this study, they were recorded with a camera CANON Rebel i7, EF-S 18–55 mm, f/3.5–5.6 IS STM. Illumination of the artworks was done with two 500 W tungsten halogen lamps, placed at about 3 m from the paintings surface and in a geometry that could help to reduce specular reflectance. Details on the recorded images from the front and the back of the paintings allowed to infer that their classification was incorrect.

X-ray Imaging

X-rays were generated by a PXM-40BT POSKOM system (TOSHIBA D124 X-ray tube) and images were registered by means of a VIDISCO Flash X PRO system. Irradiation parameters were fixed during the acquisition as follows: Distance from the irradiator to the object was 3 m, and from the paintings' surface to the detector was 25 cm; nominal voltage was set at 45 kV and the intensity at 50 mAs. Since the dimensions of the painting are considerably larger than that of the detector, the complete radiographic image was created from the overlap of 66 images, divided in 6 rows and 11 columns, by using the Adobe Photoshop software (Adobe Inc., USA).

Hyperspectral (HS) Imaging

This analysis was performed with a Surface Optics 710VP system, with a 400 nm to 1000 nm acquisition range, and 4.5 nm spectral resolution. Standard illuminant D65 was employed in a 45° geometry, to record diffuse reflectance. Calibration with a Spectral on certified reflectance standard (model SRT-99–050 AA-00821–000) was performed to rule out detector efficiency and illuminant contributions.

HS cube calibration and pigment mapping algorithms were applied by using Harris Geospatial Software ENVI 5.5 routines. Analysis of HS images allowed the generation of pseudo color infrared images (PC-IR), and after a multivariate analysis pseudo color principal components (PC) images. HSI generates useful information by assigning different bands to corresponding RGB channels, thus producing images in PC-IR. This method produces in a direct way insights about the presence and spatial distribution of pigments on the studied artworks, as the conversion of visible to IR hues are known to be linked with specific materials [27–29]. Additionally, principal component analysis (PCA) was performed, providing a basic pixel classification by considering the spectral variance, noticeably enhancing the information displayed with respect to that contained in each one of the single-band images. PC images reduce significantly the dimension of the hypercube, condensing valuable information for a better description of material, spectral, and painting techniques. Further details on the scope and limitations of this analytical tool can be found in [28].

Digital Microscopy

Microscopic imaging of the surface was performed with a AF4915ZT Dino Lite microscope. The device has an adjustable LED Light Source, a polarizer and a magnification power ranging from 5×to 100 x. These images provided information about the painting technique and alterations present on the surface.

Fiber optic reflectance spectroscopy (FORS)

In order to gather molecular information, FORS spectra were recorded by a FieldSpect-4 ASD system, with spectra in the visible, near infrared (NIR) and shortwave infrared (SWIR) wavelengths. Spectral resolution is 3 nm for the UV–visible-NIR regions (300—1000 nm), and 10 nm for the remaining region of the spectra (1000—2500 nm). The analysis area is about 1 cm^2 and requires for the probe to be in contact with the studied object. The system is continuously calibrated by an ASD Inc. certified reflectance standard (AS-02035-000CSTM-SRM-990–362). Additionally, colorimetry information was extracted from the acquired FORS spectra [30, 31], with results presented in the CIE Lab 1964 10º color standard.

X-ray Fluorescence Spectroscopy (XRF)

Elemental information was acquired with a Tracer-III SD (Bruker) handheld spectrometer equipped with a rhodium X-ray tube. Acquisition conditions were 40 kV, 11 μA and 30 s integration time. The acquired spectra were processed with the software Spectra Artax v.7.4.6.1 (Bruker) to measure the X-ray intensities from the specific elements. The analyzed surface is an ellipse with major and minor axes of approximately 9 and 7 mm, respectively.

Results

Archive research results: historical context and paintings commission

The studied paintings were part of a monumental and technical work commissioned for the commemoration of the Centennial of Mexican Independence in 1910, a turbulent time when defining a Mexican identity was of paramount importance. The beginning of the Mexican revolution coincides with a search for a new aesthetic and educational paradigm in which the National School of Fine Arts (ENBA), the National University (today known as UNAM) and the ENAOH[6] were the main driving forces.

ENAOH was established in the second half of the nineteenth century seeking to improve the quality of artisan production through technical and scientific knowledge responding to the needs of the country. The school had workshops on different crafts, as well as sporting and recreational facilities and courses on different languages. A complex renovation plan started in 1907, where the figure of the craftsman was replaced by the worker, created by the State with the aim of enhancing the nation. This renovation concluded in 1910 with a reinauguration ceremony.

In this context, the diptych was painted in the former convent of San Lorenzo, in a large and illuminated assembly hall conceived for academic events and decorated by a neoclassical style (see Fig. 2) with the traditional use of the formal presentation of an altarpiece, by conditioning a colonial architecture space to produce two mural paintings supported by brown benches and the enunciated words of construction, work and effort. These in turn were framed by plaster, whose cartouches in the center present the symbols of work. The relevance of this hall is evidenced by the reinauguration ceremony held in 1910 during the Centennial celebrations of the Mexican Independence on September 23rd. Images of the event (Fig. 2) show Justo Sierra – the General Supervisor of Public Instruction in Mexico, who was responsible for the commissioning of the artworks – enthroned under a velvet canopy and the national coat of arms in the background.

Documents in the AHESIME-IPN historical archive with an official letter dated to May 11th, 1910, mention the commission and the production swiftness of these masterpieces which were finished on August 12th, 1910:

> *The Undersecretary of the Office of Public Instruction and Fine Arts, Ezequiel Chavez, communicated to the director of the National School of Arts and Craftsman, Engineer Gonzalo Garita, about the commission to Saturnino to paint the murals of ENAO's auditorium [...]*
> *Letter dated August 12th, 1910, the ENAO's director, informed Justo Sierra the conclusion of the oil mural paintings in accordance with the approved sketches and the speed with which they were completed.*[7]

[6] Sánchez M. Escuela Nacional de Artes y Oficios para Hombres: Discurso y vida cotidiana (1867-1915) [ENAOH: narrative and costumbrism (1867-1915)]. (Unpublished dissertation]. Tesis de maestría en Ciencias en Metodología de la Ciencia. México: IPN; 2003. p. 46, 71, 91-94.

[7] Ramírez E. Salón de Actos de esta Escuela.- Oficio de la Secretaría de Instrucción Pública en que dispone el Sr. Saturnino Herrán decore los panneaux del referido salón [Auditorium of this School.- Office of Public Instruction Secretary, allowing Mr. Saturnino Herrán's panneaux to decorate the mentioned hall]. Escuela Nacional de Artes y Oficios para Hombres [National School of Fine Arts and Craftsman (ENAOH)]. México: AHESIME-IPN; 1910–1911, Expediente no. 3, C80, 428, 516, 598, 80. (Unpublished report).

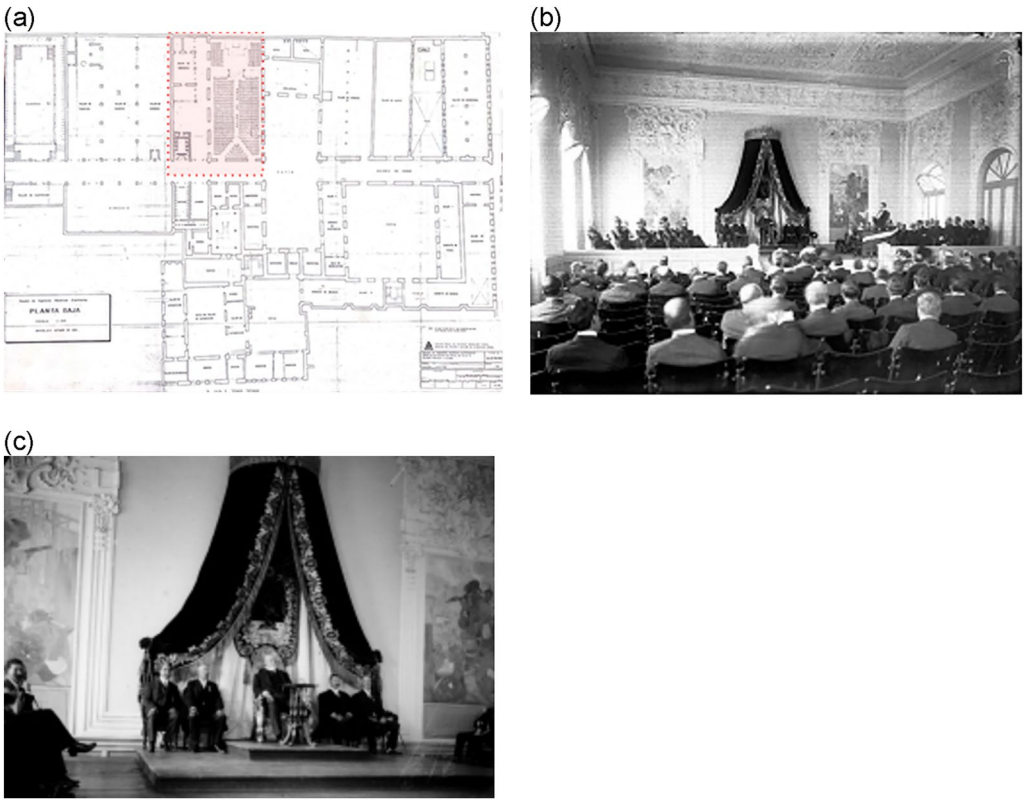

Fig. 2 **a** Architectural floor plan of ENAOH, EIME, 1924, AHESIME-IPN. The assembly hall remark in red color, damaged by the 1957 earthquake and currently destroyed. **b** Unknown author, September 23rd, 1910, AHESIME-IPN. Inauguration of ENAOH by Justo Sierra during the Centennial of Mexican Independence 1910; **c** detail of mural paintings at the ceremony of inauguration led by Justo Sierra

The mural technique strategy

Formal composition

This diptych anticipated a developing national aesthetic and symbolism narrative of a modern working class, with the craftsman, family, and buildings of an emerging city. Before their painting, small easel format sketches were created and exhibited in the southeast hallway of ENBA's first floor, and dated to February 19, 1910. This temporary exhibition was promoted by Gerardo Murillo "Dr. Atl" (1875–1964) [32], whose project was to manage the execution of mural paintings in the amphitheater of the National Preparatory School (now the San Ildefonso Museum), a plan frustrated by the outbreak of the Revolution, and which would be continued in 1922 by Diego Rivera [33].

The murals are much larger than Saturnino Herran´s previous paintings. They stand out for the human form traced with a large charcoal underdrawing, which can be noticed in plain sight and is even more evident in the hyperspectral images, and the palette can be described as luminous with evening hues, recorded by visible photography and microscopy.

The murals also have a symbolic function. At its central plane, *La Alegoría de la Construcción* presents half-naked bodies of the potters and workers performing their activities: a craftsman painting pottery, or carrying ashlars, beams and mortar that will cover the façades of modern buildings. The intensity of the physical effort, the diversity of the exposed skin tones, the idealized *mestizo race* features represented in classical postures [34], as well as the westernized clothing of the worker, evident in the blue navy overalls, suggest a new model of masculinity away from the hegemonic representation of the man [35]. And in them, you can appreciate their role in the construction of the city that rises above the horizon of the upper left plane, dominated by the scaffolding that fades into the violet, bluish and grayish vespertine background, perhaps as a projection of an uncertain future.

In the painting to its right, *Alegoría del trabajo*, the family is represented in a triangular composition in the foreground, the face of a man leaning out in half profile meets with his wife and children; and in the background between planes, other groups of workers from different craftscan be distinguished. Both paintings deal with an interiorized and symbolism lecture, the time and

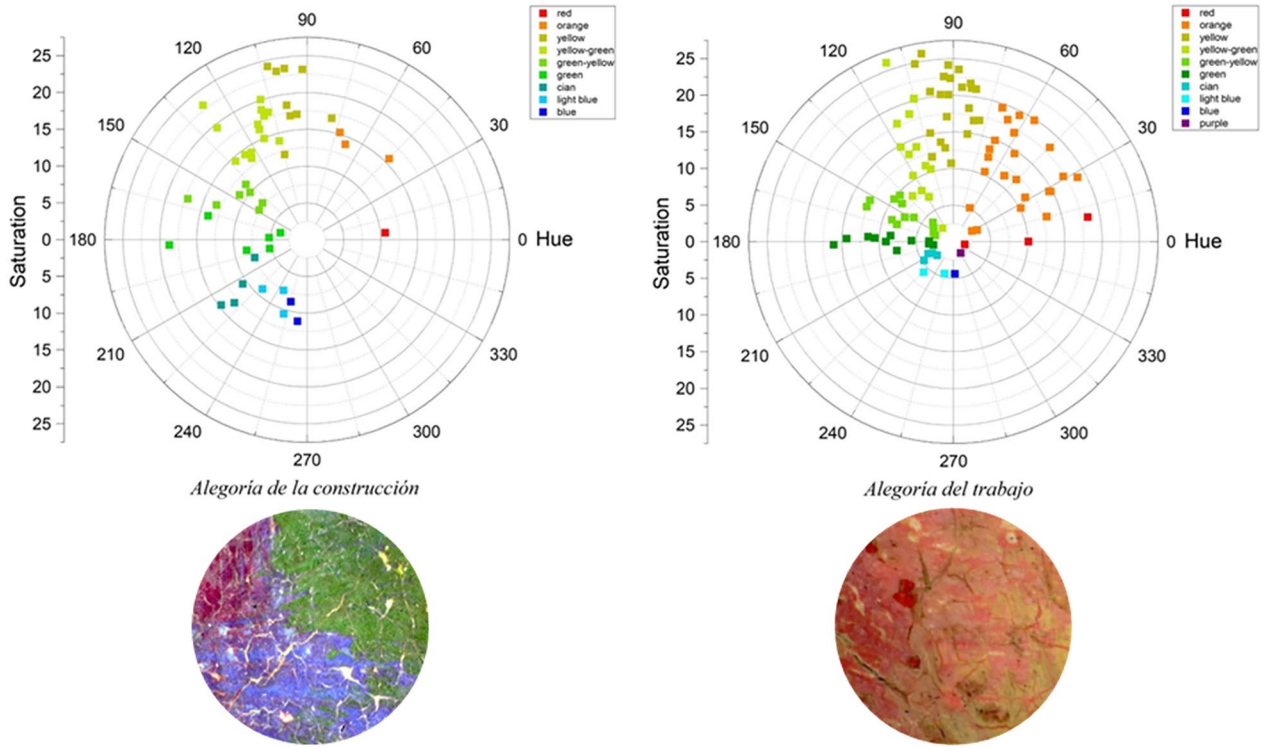

Fig. 3 (Top) Colorimetry analysis of Alegoría de la construcción and Alegoría del trabajo mural paintings and (bottom) corresponding representative microscopic images of pigment application at 55x

industrial change in the Mexican capital, a transformation of the urban working classes and their environments, a reconfiguration of the classical models by other bodies in tension with physical effort.

Insights of materials

First results from the initial approach, which included the registration of the visible imaging, hyperspectral imaging, along the microscopic observation and the global colorimetry, indicate that each panel is biased towards a specific hue. In *Alegoría de la construcción* the palette tends to bluish, while in *Alegoría del trabajo* the tendency leans towards a reddish tone (Fig. 3).

The color palette of the original painting technique -and restoration process for both paintings- is abundant in blue, red and yellow hues, observed in the priming, as well as the skin tones of the characters and other complementary colors for the objects such as orange, pink, green or violet. Elemental features determined with XRF displayed a constant Ca and S signal all over the murals, which along with FORS information (Table 1 and Fig. 4g) allowed us to identify the use of gypsum ($CaSO_4{\cdot}2H_2O$) presumably for the fine plaster.

Reflectance spectra from the blue regions (Fig. 4a) present a maximum between 490—520 nm, an inflection point around 720 nm and a characteristic absorption band at 600 nm, which along with an associated XRF signal of Al and Si which was clearly observed in dark blue areas – particularly in the worker's pants –, indicate the use of ultramarine blue (approximate formula $Na_7Al_6Si_6O_{24}S_3$) [36, 37]. Some particular spectra for reddish tones (Fig. 4b) exhibit features such as absorption bands around 520 nm and 570 nm, and an inflection point between 600 nm–610 nm, which indicate the use of cochineal lake (carminic acid) [38, 39]. These absorptions were analyzed by observing the first derivative in the log(1/R) spectra, in order to precisely find the position of the absorbance maxima.

Yellow areas presented a clear Cd signal on their XRF spectra with the corresponding reflectance spectra (Figs. 4c, 4d) showing an inflection point around 470 nm which could also be related with sigmoid behavior of cadmium yellow (CdS) [40, 41], although the spectra also show features associated to a mixture with a green pigment. Green hues were associated with viridian green ($Cr_2O_3{\cdot}2H_2O$) by considering the Cr line present in the XRF results, together with the information from the reflectance spectra (Fig. 4e), an inflection point at 720 nm and a characteristic shoulder [42, 43]. Finally, lead white ($2PbCO_3{\cdot}Pb(OH)_2$) has been identified by elemental

Table 1 Materials identified on the allegories by spectroscopies FORS and XRF, as well as pigment mixtures observed to produce different hues

Color	*XRF*	*FORS* **spectral features**
Blue hues	Al, Si	Ultramarine 490 nm–520 nm 600 nm, 720 nm
Red hues	–	cochineal lake 522 nm 567 nm
Yellow hues	Cd	cadmium yellow 470 nm
Green hues	Cr	viridian green 625 nm 720 nm
White hues	Pb, Zn	lead white 1208 nm 1448 nm zinc white 384 nm
Fine mortar	Ca, S	Gypsum 1449 nm, 1490 nm, 1535 nm 1943 nm, 1978 nm
Binder	–	1726 nm 1762 nm 2310 nm 2350 nm
Hues	**XRF**	**Pigment mixtures**
Yellowish hues	Cd, Cr, Pb, Zn	cadmium yellow, viridian, lead & zinc white
Orange hues	Cd, Pb	cadmium yellow & lead white
Pink hues	Pb, Zn	cochineal lake, lead & zinc white
Violet hues	Pb, Al, Si	ultramarine, cochineal lake & lead white
Skin tones	Cd, Pb, Cr, Al, Si	lead white, cochineal lake, ultramarine, cadmium yellow & viridian

analysis and infrared absorption features (Fig. 4f) present in 1208 nm and 1448 nm [44]. The ratio between the M and L X-ray emission lines of a given element is a direct indication of the attenuation these photons underwent from their point of origin to the detector and provides a way to test the depth in which the photon originated. In consequence, this ratio allows us to infer if this white pigment was applied closer to the painting's surface when compared to the restored areas (Fig. 5).

Regarding the medium, the resulting FORS spectra from both paints present the use of lipids related with an oil and a constant signal of wax from the varnish applied in the restoration process (Fig. 4i). In the spectral information associated with the original areas, a broadening of the bands is noticeable in the region from 2300 to 2355 nm, likely to be linked to the superposition of the original oil binder and the upper layer of varnish (whose application is described in the restoration documentation). In contrast, such broadening is not present in spectra from restored regions where we would expect to find a different pigment application. There are also significant contributions from Co, Fe and Ti in many areas, which could be related to the pigments used for its restoration.

PC-IR and PC images resulting from hyperspectral imaging analysis (shown in Fig. 6) provided a tool for accounting the distribution of the pigments on the artworks [36]. Ultramarine [37] used in the potter's overalls transforms into a red hue in the PC-IR image [38], while viridian green transforms into an intense red. Enhancement of carmine red lake for the skin tones is also noticed in the form of a bright orange, it is particularly noticeable the application of this material in the hands of the workers and craftsmen. Complementary, PC images (in particular PC5) indicates zones of retouching lacunas that can be correlated with the radiographic information, and by combining different PC's into an RGB image it is possible to also correlate similar pigment zones between both artworks (Fig. 6) and to provide further information on the painting technique, such as enhancement of the underdrawings (as in the bodies of the characters and in the architecture), and a distinction of the pigment application in different campaigns (see the body and face of the craftsman in the AC painting).

Remarks on the application technique

Documentation (see Sect. "Archive research results: historical context and paintings commission"), microscopy and spectroscopic results indicate that these paintings were murals flattened on a stone wall. The existence of this wall and a mortar was evidenced by a historic photograph from the detachment process (Fig. 7). Microscopic information shows a white plaster under the priming (Fig. 7), which along with spectroscopic results (see Table 1)indicating the presence of S and Ca over all the paintings and the vibrational signals in the NIR corresponding with calcium sulfate (see Fig. 5 and Sect. "Insights of materials"), suggest the presence of a thin gypsum plaster.

A pink priming layer was identified by optical microscopy (Fig. 7, bottom center), with spectroscopic data of this pink region showing the presence of white lead, cochineal lake and ultramarine in different amounts. This layer provides a uniform chromatic aspect from the upper and translucent layers in contrast with opaque layers with high covering power and volume.

Microscopic information allowed to determine that the pigments and dyes identified in the previous section were mixed in a palette and had a superposition of complementary hues to present diverse effects for skin tones, clothing of the workers, pottery, the light and the backgrounds. Each of these pigments has a symbolic

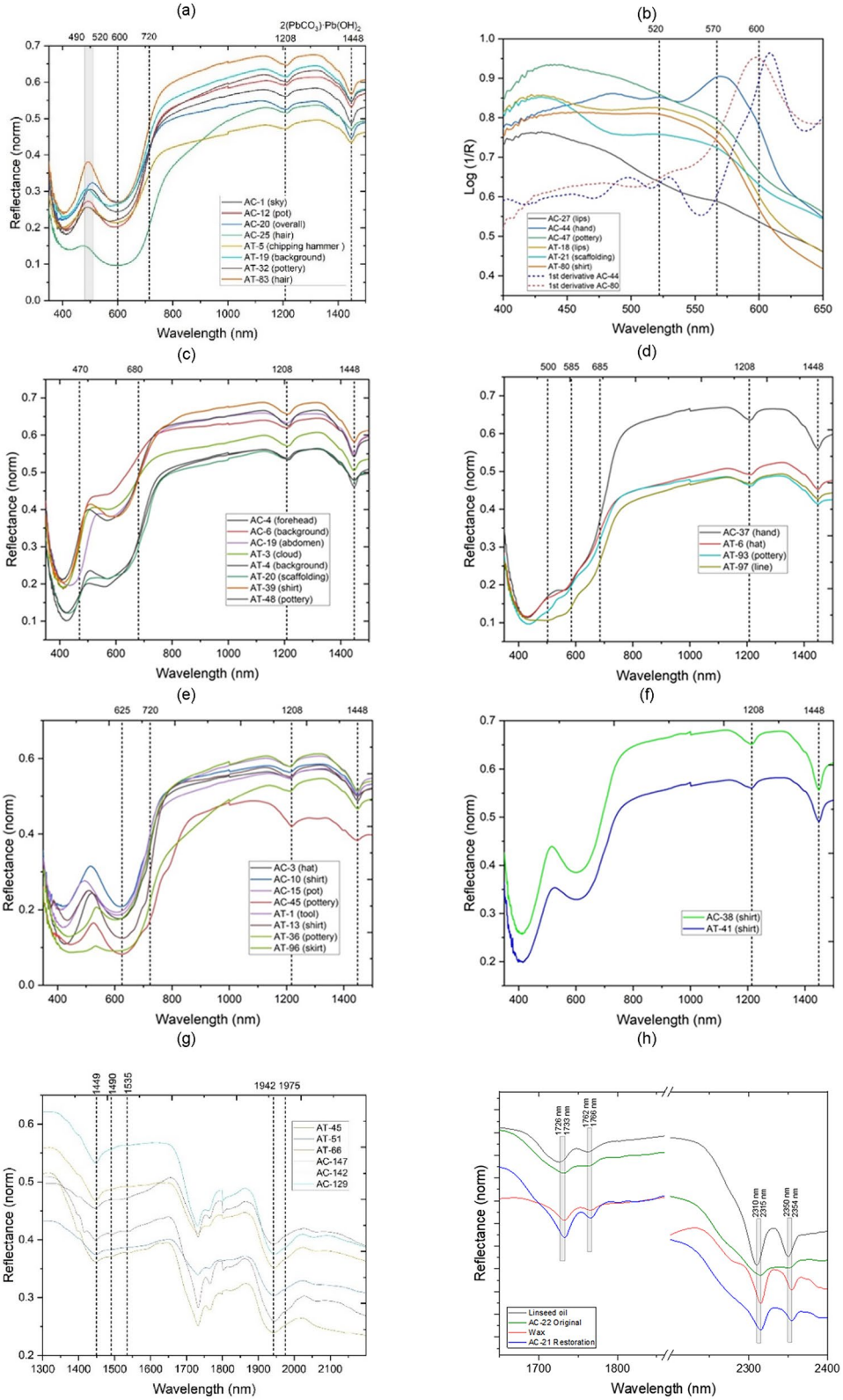

Fig. 4 Representative FORS spectra from **a** bluish; **b** reddish; **c** yellowish; **d** orange; **e** green; **f** white zones; general IR **g** plaster and **h** binder associated features of "Alegoría de la construcción" (AC) and "Alegoría del trabajo" (AT) paintings

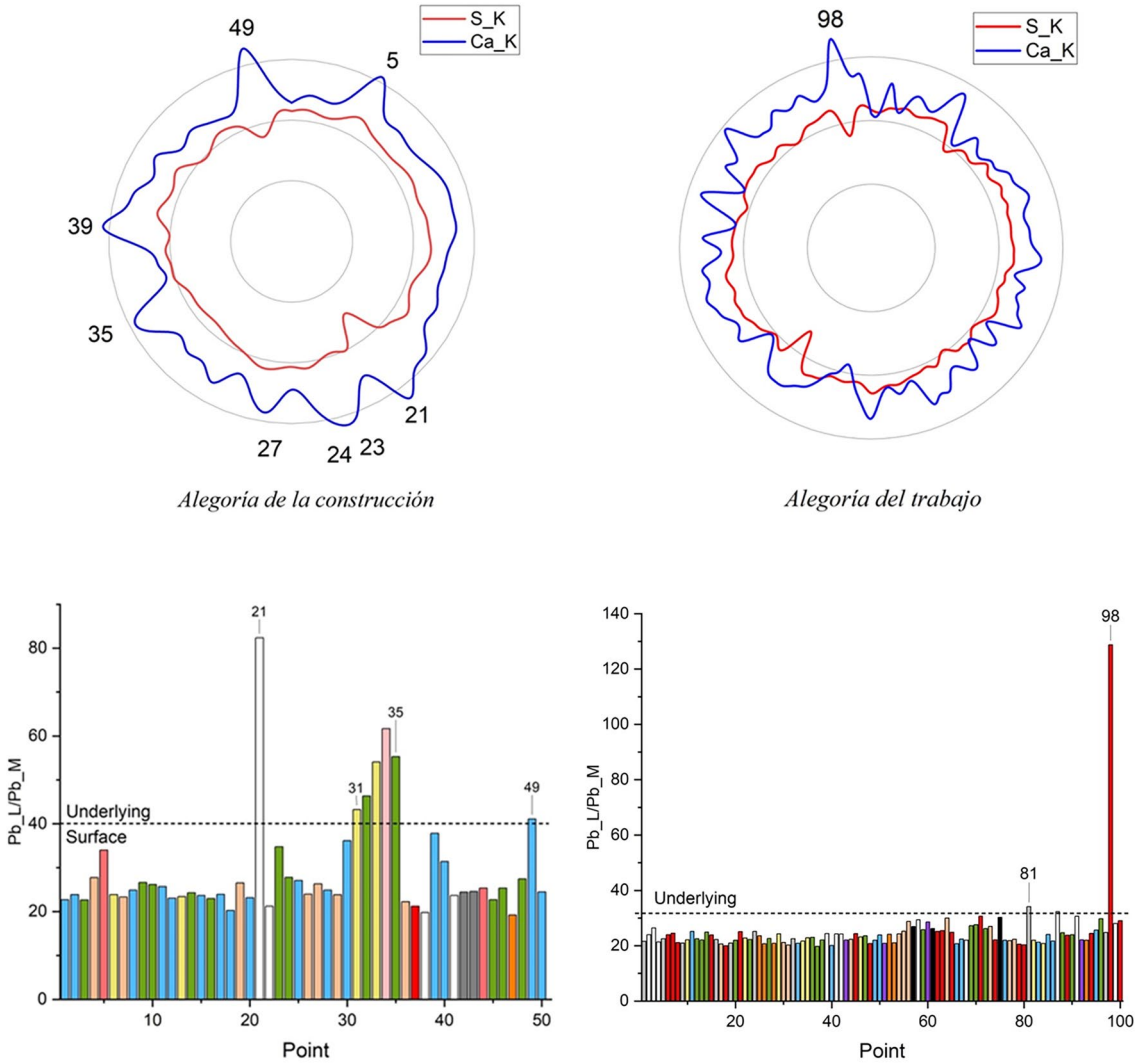

Fig. 5 (Top) Intensities of S-Kα (red line) and Ca-Kα (blue line) signals of all the data acquisition points in Alegoría de la construcción and Alegoría del trabajo mural paintings; (bottom) corresponding ratio of Lα / M lines of Pb calculated for all the analysis data points

aspect linked to their intentional use for representing specific materials and cultural concepts.

It is also a response to the new conditions for the interpretation of theory and chromatic values developed in the nineteenth century [45], with saturated and brilliant shades [46]. In mexican paintings from Eugenio Landesio (1810–1879), José María Velasco (1840–1912) and Hermenegildo Bustos (1832–1907) XRF allowed to identify the use of this kind of materials [24]. Our results indicate a continued tradition in the work of Saturnino. In short, Saturnino used different pigment mixtures to generate specific skin tones in accordance with the character's age, sex or social status.

Diversity for the skin tones

In these paintings it was noted that the physical representation of the mestizo worker reflects a diversity of mixed ethnic members in the urban environment. It's noticed that there are three types of skin tones represented: light, brown and yellow, a most singular aspect due to their composition and symbolic dimension, because of an unusual and novel use in modern Mexican mural painting of cochineal lake, [47] a scarlet-colored tone like the blood, which gives an opaque characteristic to these paintings.

From microscopic (Fig. 7, second to last row) and spectral information (Fig. 4b) it is inferred that Herrán used different amounts of this red material, together with other pigments. For example, the child in Alegoría del

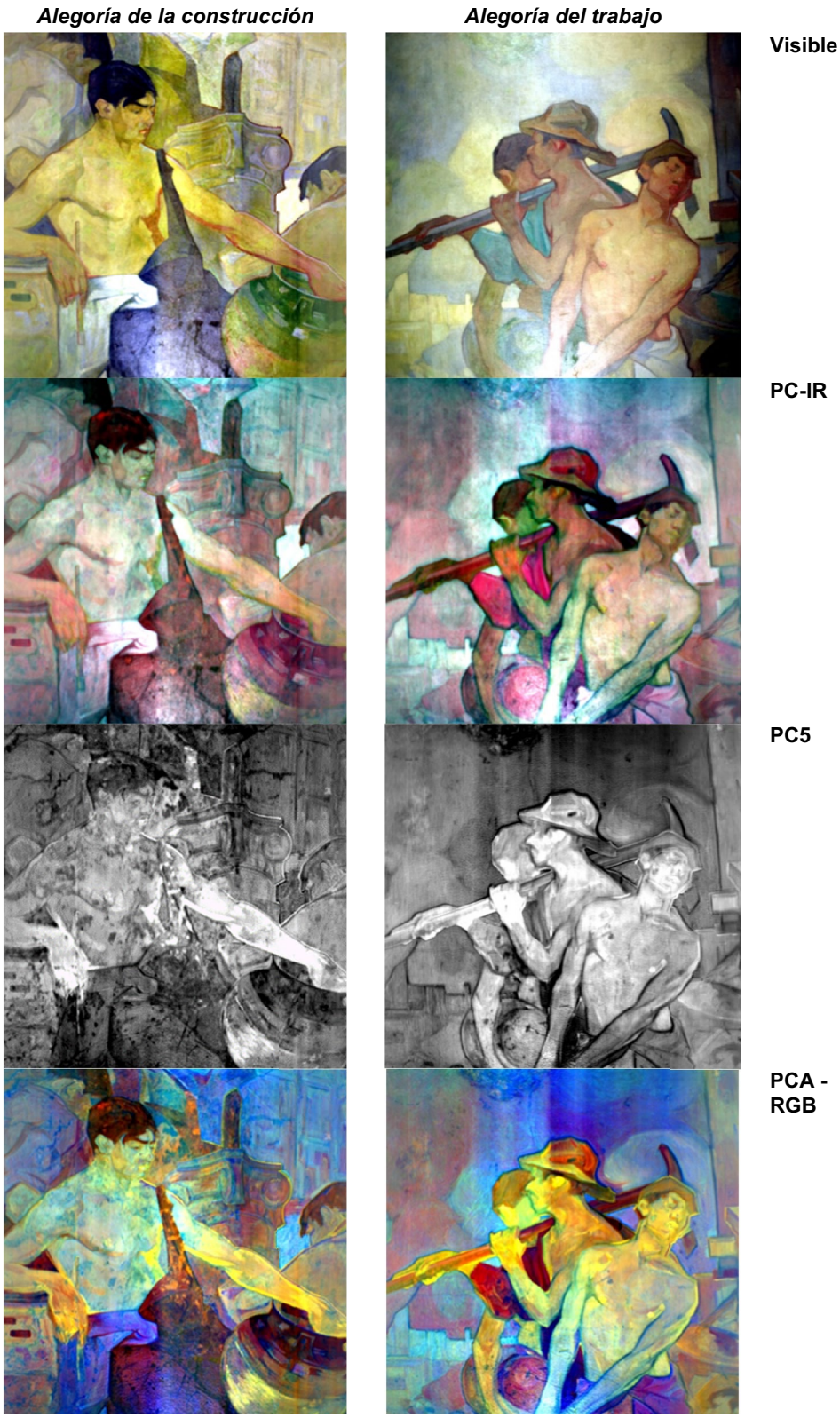

Fig. 6 Comparison between visible and hyperspectral images of *Alegoría del trabajo and Alegoría de la construcción* mural paintings. PC-IR image is composed as R: 1030 nm, G: 650 nm, B:535 nm. PCA-RGB image is composed as R: PC-5, G:PC-4, B:PC-2

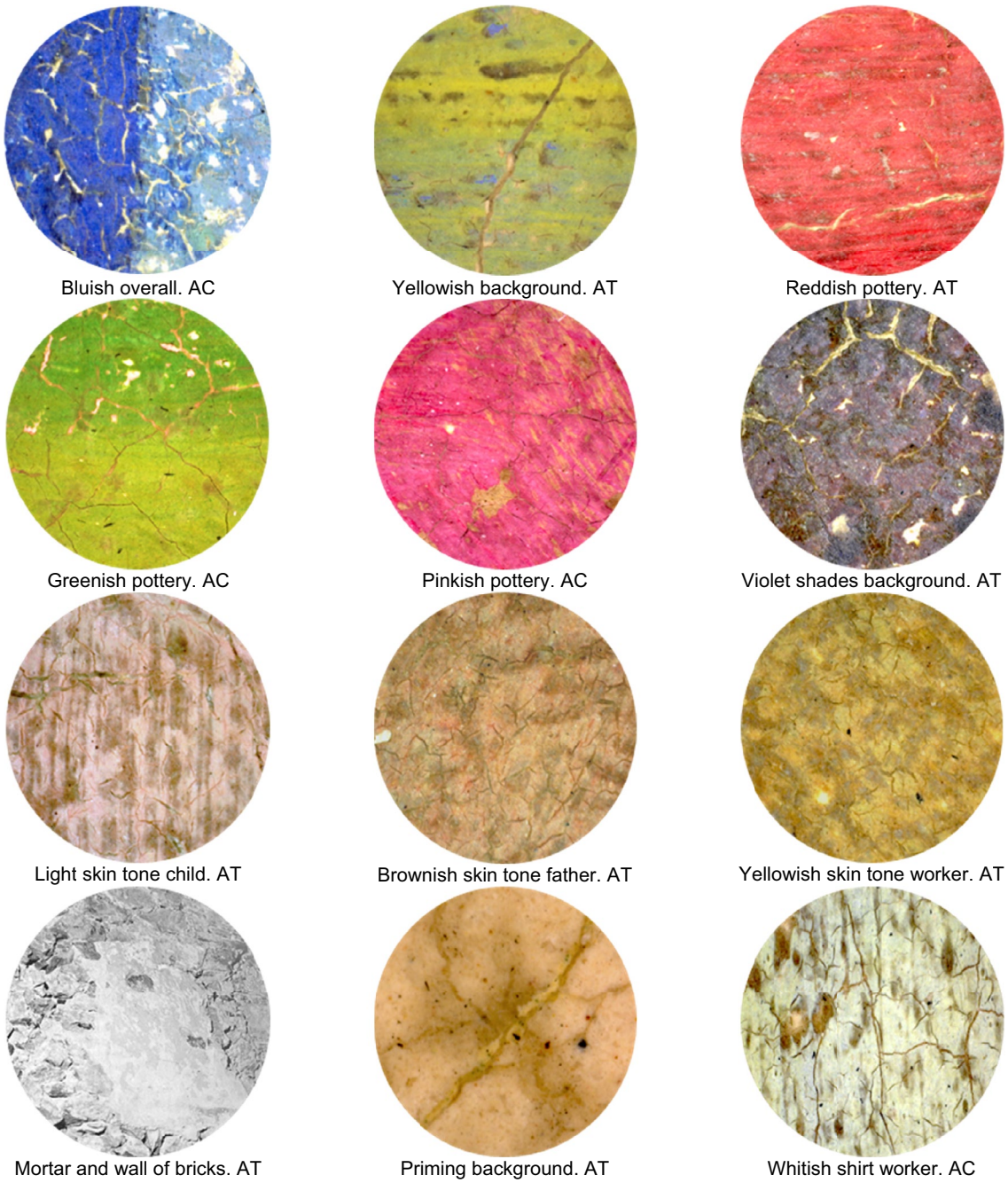

Fig. 7 Microscopic photographs showing representative details of the color palette, priming, mortar and wall identified in Alegoría del trabajo (AT) and Alegoría de la construcción (AC), all images are microscopic photographs at 55x, except bottom left image, corresponding to Miguel Rivera Estrada, Detachment process, ca. 1976, AHCENCROPAM-INBAL

Trabajo is represented with a clear and pink incarnation, in which white was mixed with ultramarine, cadmium yellow and a small amount of this reddish hue. In comparison, their parents, as well as the workers and craftsmen in Alegoría de la Construcción, present brownish and/or yellowish hues, achieved by an increase in the use of cochineal mixed with ultramarine, cadmium yellow and lead white. Meanwhile, other workers at the back of the composition showed a skin tone where the amount of cadmium yellow and zinc white increases (see Table 1).

Hyperspectral images were useful to observe the distribution of the cochineal lake on the surface. As can be

observed, the final drawing for the half naked bodies of these workers and children, ends with a red line composed by carmine lake (Fig. 6).

Skin color is a physical characteristic without neutral meaning that influences the perception of social groups throughout history of art [48]. For the artist this representation of identity suggests an open and wide discussion of an ideological State discourse by the government of Porfirio Diaz, which, later on, was thoroughly developed after the Mexican Revolution[8] [49]

The workers clothing

Denim was a highly resistant cotton textile used in the manufacture of trousers, overalls and shirts. For these industrial fabrics of navy-blue tones, their dyeing with indigo, an organic dye, was common, and has its symbolism to a certain social status of the working class [50]. The use of indigo as lake-pigment [51] has an extensive tradition in Mexican paintings [52, 53]. Nevertheless, Saturnino employed ultramarine blue [54] to represent the dark blue color of denim garments, contrasting as a symbolic material, since in the history of Western paintings its use has been reserved to define royalty or a divine being [55]. Additionally, the few material studies on nineteenth century Mexican paintings have identified the use of enamel, Prussian and cerulean blue [56], and there are no published studies on paintings from the early twentieth century, making his use of ultramarine noteworthy. Saturnino Herrán preferred the application of this material, complemented with the vibrant white cloths of lead and zinc white, which contrast with the brownish skin tones of cochineal(Fig. 4a).

The pottery color palette

The practice of pottery at the ENAOH can be traced back to the beginning of the school at the nineteenth century. Herrán represented the craftsmen that produced and decorated it, the same system of the clay oven from which the complementary violet, green, reddish and brown hues stand out, and are linked to the palette of these same objects. It is worth mentioning that the ceramic represented in Saturnino's artwork corresponds with objects produced over the nineteenth and twentieth centuries in Tlaquepaque and Tonalá, Jalisco, Michoacán, Puebla and Oaxaca [57].

Also, the green pigment associated with this pottery is composed of viridian [43] (see Fig. 4e). This is a synthetic pigment, used as a pigment in all types of binding media [58].

Lastly, the use of cadmium pigments was detected by XRF (see Table 1) in the brown layers, while the color layers associated with the slips are related to those of cadmium yellows and chrome green (Figs. 4c and 4e).

Ultramarine and cochineal, a dual light from the background

Saturnino started from luminous pink backgrounds; it is apparently a priming whose function was to give a homogeneous chromatic hue to the works. From the spectroscopic results, this colored background is a fine layer mixed with white lead, ultramarine (see Fig. 4a) and cochineal lake [59] (see Fig. 4b). This last material of pre-Hispanic tradition [60], and with a continuous use between the sixteenth and eighteenth centuries in New Spain [61], al well as in artworks from Italy, Spain, France, the Netherlands, Perú and Chile [62–65], was gradually replaced by synthetic formulations, such as aniline-based pigments or cadmium reds, in the nineteenth century [66, 67]. As mentioned before the use of cochineal is novel in Mexican modern mural paintings. However, its use has been identified in nineteenth century brushes such as Vincent van Gogh (1853–1890), who obtained "pale lilacs" by applying it for primings and backgrounds [68].

A vespertine light of new materials: zinc and cadmium

Zinc oxide is, since the nineteenth century, another of the white pigments most used in paintings [68, 69]. Its use has been described as thin layers in which the saturation and brightness of the hue will stand out [70, 71]. Its presence in Saturnino's murals was inferred by the recorded microscopic information and by XRF.

Cadmium yellow, commonly used in twentieth century [72–74], was inferred by XRF (see Table 1 and Figs. 4c and 4d) in the representation of the light of the sunset. With a meticulous observation and study of the exterior, the impression of the lighting on the bodies and the horizon was a demonstration of mastery, experience and the effort to represent the clear evening with a cadmium yellow and other complementary tones such as violet or green for the shadows.

A lead dryer

Lead white has a tradition in painting as a mixed material that provides hiding power to the paint layer, volume or impasto and accelerated drying when using a binder such as linseed oil [75]. Studies of Mexican painting have shown its use since colonial times in the sixteenth century; in the nineteenth century, based on the mural paintings of Juan Cordero (1824–1884) for

[8] Pérez C. Saturnino Herrán: Entre la tradición y la modernidad [Saturnino Herrán: Between tradition and modernism]. (Unpublished dissertation) Tesis de maestría en Sociología. México: UNAM; 2010.p.64.

the Santa Teresa temple in 1857, or the easel paintings of Hermenegildo Bustos and José María Velasco, where it was commonly used [76]. It was also employed in the first half of the twentieth century [77], and its incorporation into painting was defined by artists such as Saturnino Herrán as a covering material and mixed on the palette for tones (Fig. 5). The pigment has been identified with XRF by the presence of Pb and with FORS (Fig. 4f) by recognizing its spectral signature (see Table 1), its presence can be distinguished on the painting surface and in the underlying layers by the relative attenuation of the lines L/M. Despite its toxicity, the use of this pigment continued in this century, and up to now it has been identified in mural paintings by Federico Silva (1922–2022) in 1952 [78].

Condition report

Over time, appreciation and use of these murals in the trade school took an unexpected turn due to the 7.7 magnitude earthquake of July 28th of 1957 which caused several human and patrimonial losses in Mexico City. The center and north of the city were affected, and the former convent of San Lorenzo was severely damaged.[9]

The instability of the adapted installations in the novohispanic monument led to the migration of this unit to Zacatenco campus, while the reluctance to demolish the former convent led to a long discussion in the Association of Engineers and Architects for the Conservation of Historic Buildings, damaged by the earthquake of 1957. As for the murals, the participation of artists and the conservators of the National Center for Art Conservation from the National Institute of Fine Arts (CNCOA-INBAL) promoted an emergency project for their preservation.

The newly created CNCOA-INBAL (1955) faced a complex situation with murals located in historic spaces like ENAOH and Public Education Secretary (SEP), where Diego Rivera frescos (1923 – 1928) were affected by humidity and by the 1957 earthquake. At that time the valuation of this modern heritage and the actions for its conservation began, followed by the establishment of the work criteria for the following decades in that institution, who learned from Italian conservators that came to Mexico to provide training on new treatments [79].

While the preservation project was developed by the CNCOA-INBAL in the late 1950s, the availability of funding and the sum of wills did not take effect until the 1970s. The department led by Tomás Zurián, Javier Servín, Eliseo Mijangos, among others, defined the conservation campaign for the murals [80]. The definitive solution to the risk of collapse of the building and the preservation of the works, determined the process of detachment of the murals by stacco, a treatment which occurred in 1976 with complex planning and execution processes and stages consisting of the protection of the pictorial layer on the front (Fig. 8), the roughing on the back to keep the fine plaster and its eventual adhesion to a firm wooden support [81]. The list of materials for the restoration process in 1977 includes: beeswax and dammar resin for the varnish; cedar and pine tree for

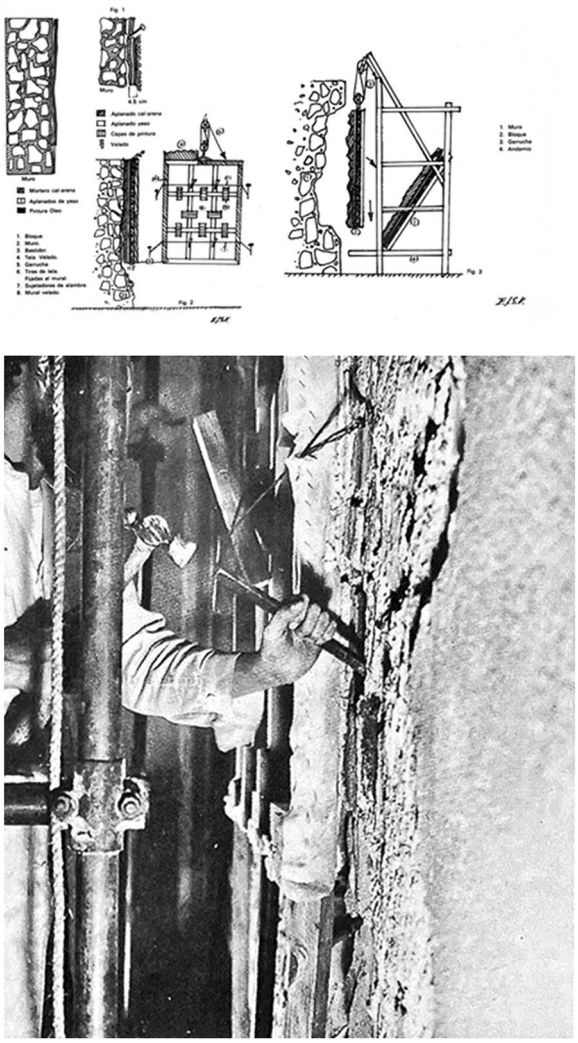

Fig. 8 (Top) Sketching of the detachment process. Javier Servín, Esquema de desprendimiento de pintura mural, ca. 1960, Archivo técnico CENCROPAM-INBAL. (Bottom) Detail of the detachment process. Miguel Rivera Estrada, Detalle de desprendimiento de pintura mural, ca. 1976, Archivo técnico CENCROPAM-INBAL

[9] Saldívar P. Documentos relacionados con la intervención de la Escuela Superior de Ingeniería Mecánica y Eléctrica en suspender la demolición del antiguo edificio de ESIME Allende #38 [Documentation related to the intervention of Higher School of Mechanical and Electrical Engineering to suspend the demolition of the historic building ESIME, Allende #38]. México: AHIPN; 1973. Exp. 1, Folio 1. (unpublished report).

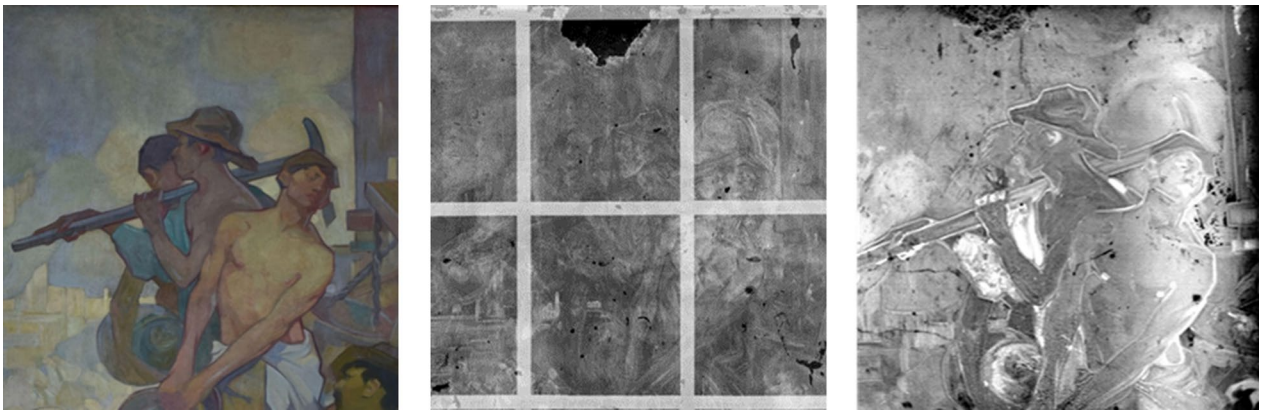

Fig. 9 Comparison of (left) visible; (center) radiography and (right) PC3 images of Alegoría del trabajo by Saturnino Herrán

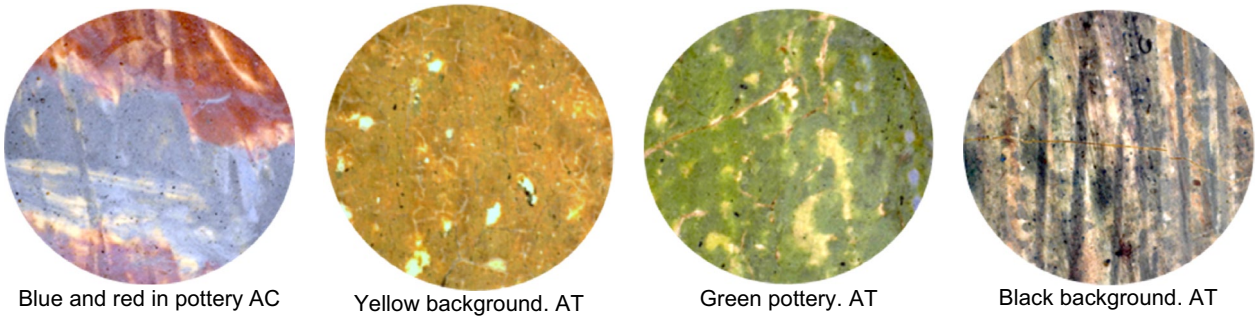

Fig. 10 Microscopic image details of the color palette for restored areas, from Alegoría de la construcción (AC) and Alegoría del trabajo (AT), at 55x

the wooden support, for the plaster lacunas, but doesn't enlist the brand and the composition of the pigments [81].

In our work the diagnosis of the structure and conservation of the panel was determined by a study based on imaging techniques. The record of the artworks in a digital radiography mosaic presents a contrast of white, gray and dark tones, associated with the density or composition of the materials that make up these panels, also showing the construction of the wooden support reinforced by a system of bars joined by metal elements. This fixed system allows the work to remain stable, resistant and in the same plane; likewise, the union with the frame is made by small metallic nails.

Analysis of the radiographies (Fig. 9)showed that these works present two linen canvases with medium density, joined in the middle with a reinforced seam and in vertical direction. This canvas was intended to ease manipulation during the adhesion of the detached pictorial layers to the new support. The radiographic record focused on the distribution of the cracks and fissures to define their depth and the possibility of a structural risk during their manipulation, the assembly, and the planning of a possible restoration treatment.

It was also noted that in some frontal areas, especially in the lower region, these paintings show the imprint of the gauze fabric, adhered as a veil conceived to protect the painting during its detachment; however, they were never painted on canvas.

Likewise, results from the statistical analysis of the hyperspectral images by principal components (Fig. 9), provide information on the state of preservation, and even allows to distinguish the campaigns of volume and color restoration, which suggest more than one participation of criteria and material solutions between the first restoration in 1976–77 and the subsequent in the twenty-first century [82].

A palette from restoration

Tracing the materials used in the Mexican conservation treatments is novel and useful for different purposes. The stability and permanence of its application are relevant for the conservation diagnosis and the possibility of exhibition and retreatment. The X-ray fluorescence results

Table 2 Materials related to restoration treatments identified in allegories by spectroscopies

Color	*FORS* **Spectral features**	*XRF*
Blue hue	Cobalt blue 550 nm, 650 nm	Co
Red hue	–	Fe
Yellow hue	–	Fe
Black hue	–	Fe
White hue	Titanium white 401 nm zinc white 384 nm	Ti, Zn, Ca
Fine mortar	Gypsum 1943 nm, 1978 nm	Ca, S
Binder	Wax 1732 nm, 1764 nm, 2313 nm, 2350 nm	-

(Fig. 10) indicate the use of titanium white and iron earths for the retouching process of lacunas (Table 2).

Titanium dioxide white pigments are products of twentieth century industrial development [83]. Because of their elevated hiding power, nontoxic nature, they substituted other traditional white pigments in the second half of the twentieth century. Brands as Maimeri® and Winsor & Newton® produced this pigment and is commonly used in restoration since 1970, when its formulation was changed [84].

In general, iron-based pigments [85] used in the last few decades for art and conservation are versatile materials developed by the industry, replacing the traditional extraction and preparation of iron based natural pigments. Because of their properties and ease of access they are very common for red, yellow, blue and black hues [86] The results by XRF and FORS indicate the use of cobalt blue, a pigment recently studied in Pablo Picasso's paintings from 1917 [87]. Beside the other iron pigments, it should be noted the compatibility, stability and permanence of this bluish pigment, when mixed with white pigments, in this case, zinc white, because it reduces its durability, while increasing the sensibility to oil absorption and the light-induced, cracks and discoloration process [88].

Discussion

Research on the painting technique and diagnosis in conservation of the studied artworks required a methodology developed from heritage sciences, encompassing conservation, physics, archive research and technical art history. The sum of these perspectives enriches the strength of the non-invasive in situ studies, and the work of processing, interpreting and presenting these results with an interdisciplinary dialogue.

Regarding the absence of records of the exhibition, mounting and, of course, conservation of the paintings, the documentary compilation carried was essential for addressing the research questions. In terms of the painting technique of these artworks, our study evidenced that they are mural paintings, with a partial loss in the lower area and other architectural elements designed and intended for a historical space and subject to a visual perspective from within.

Results from this work, involving both archive documentation and analysis techniques, show that the production of these paintings generates a necessity to further study this artist over his entire artistic creation. In particular, the layer sequences observed with microscopy and the materials interpreted from these works, exhibit that these masterpieces result from a mixed tradition between the construction of pictorial layers commonly used in oil paintings and the new conception of mural production. Thus, anticipating the narrative of the muralism movement in 1922.

The novelty regarding the color palette and its agency for the early twentieth century relies on the incorporation of industrial and organic materials that are used for the first time in Mexican modernism. Results from this study indicate that Saturnino developed a novel painting technique similar to that of contemporary painters in Europe, and prior to other Mexican muralists. The growing interest in studying similar masterworks and artists from this period will eventually provide a global insight on practices and knowing of techniques.

Innovation and a symbolic use of materials and their appreciation is shown by the artist through a complex material relationship and skill in handling the mixtures with the oil binder. As examples, this is shown by his unprecedented intention in which ultramarine blue was used in the overalls, symbol of the worker, cochineal lake in the skin tones of the characters, and the expansion of its application in priming in this era, suggests innovation and a symbolic use for the local materials and its appreciation.

Meanwhile, the use of two types of white, lead and zinc, suggest experience, maturity and knowledge of quality materials in the early era, contrary to what was considered in the collected documentation. The rest of the materials used in the complementary shades suggests a study of plastic development; and situates the temporality and tradition of the artists' materials in the twentieth century, because of the understanding of light, the complementary hues like green, orange, and violet for the shadows.

Finally, following up on the preservation of modern works in Mexico opens a broad panorama of discussion on the attribution of cultural and symbolic values, which, despite the temporal distance, invites us to consider other

perspectives of what we consider heritage, the vicissitudes through which work groups positioned themselves to preserve it, the way in which we made this diagnosis in conservation and, of course, our passage through them.

Conclusions

The combined methodology of documentation and spectroscopic analyses allowed us to characterize the painting materials employed in the creation of both master pieces, as well as providing evidence that the artworks were created as mural paintings. Results also display an interesting use of materials to produce complex creations.

Results from this study will provide further insights into his influence on the Mexican muralist movement, Mexican art and encourage the development of further studies into his artistic production.

This study clearly exhibits how the materials and techniques were used in the conservation of modern paintings in Mexico,

Abbreviations

ENAOH	National School of Fine Arts and Craftsman
FORS	Fiber Optic Reflectance Spectroscopy
XRF	X-ray fluorescence spectroscopy
AHESIME-IPN	Historic Archive of the High School of Engineering, Mechanics and Electronics
AHI-IPN	Historic Archive of National Polytechnic Institute
DDC-IPN	Cultural Department of this institution
AGN	General Archive of the Nation
CENCROPAM-INBAL	National Center for Registration and Conservation of Fine Arts
PC	Principal Components
PCIR	Pseudo Color Infrared images
ENBA	National School of Fine Arts
CNCOA-INBAL	National Center for Art Conservation from the National Institute of Fine Arts

Acknowledgements

The authors acknowledge the following people for granting access to historical archives and commission to the study and conservation of the murals: Omar Matamoros-Hernández, Arturo Figueroa y Victoria Ruiz, DDC-IPN; Juana Hernández, AHIPN/; Gabriela Uribe Aragón, AHESIME-IPN; Mauro Alberto Enciso Aguilar Dir. ESIME Zacatenco IPN; Museographers MNA-INAH; Frida Montes de Oca, Patricia Gutiérrez, Carla Zurián de la Fuente, CNMyE-INAH; Soledad Ortiz Ruiz and Nathael Cano for providing the binder materials.

Author contributions

NC: strategic planning study in situ, conception, design, acquisition, analysis and interpretation of data, drafted and revised work. OGL: design, acquisition, analysis and interpretation of data, visualization, drafted and revised work. MP: acquisition, analysis and interpretation of data, drafted work. AM: acquisition, analysis, interpretation data, drafted and revised work. ECG: acquisition, analysis, revised work. JLRS: strategic planning study in situ, interpretation data, revised work. All authors approved the submitted version.

Funding

This research was partially funded by CONAHCYT, grants numbers LN315853, LN299076, LN314846. N. Cano acknowledged the PNPC scholarship and M. Pérez acknowledged the postdoctoral fellow, both granted by CONAHCYT.

Availability of data and materials

Spectral data will be available on request. Historical archive data and information is subject to access permits.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 15 August 2023 Accepted: 25 February 2024
Published online: 02 April 2024

References

1. Birbragher-Rozencwaig F. Essays on 20th century Latin American art. New York: Routledge; 2022. p. 1.
2. Coffey M. How a revolutionary art became official culture. Murals, museums, and the Mexican State. Durham: Duke University Press; 2012. p. 1.
3. González-Mello R. Propaganda and muralism. In: Cantú R, editor. Mexican mural art. Critical essays on a belligerent aesthetic. UK: Cambridge Scholars Publishing; 2021. p. 56.
4. Between GR. Between official propaganda and street art. CAP Public Art J. 2023;3(2):42–59.
5. Haskell B. Vida Americana: Mexican muralist remake American Art, 1925–1945. New Haven: Yale University Press; 2020. p. 208.
6. Lopez L. El patrimonio artístico y las voluntades de la conservación: CENCROPAM [CENCROPAM: Artistic Heritage and wills for its conservation]. In: Gil G, editor. CENCROPAM. 50 años de conservación y registro del patrimonio artístico mueble: inicios, retos y desafíos. México: CENCROPAM-INBAL; 2014. p. 104–19.
7. Gell A. The technology of enchantment and the enchantment of technology. In: Gell A, editor. The art of anthropology essays and diagrams. NY: Routledge; 1999. p. 43.
8. Asscher Y, Halevi S. Characterizing the pigments in wall paintings: comparing portable and stationary multiband remote sensing imaging systems. In: Osman A, Moropoulou A, editors. Advanced nondestructive and structural techniques for diagnosis, redesign and health monitoring for the preservation of cultural heritage. Springer: Cham; 2016. p. 71–82.
9. Kriznar A. Material and technical analysis as a support for art-historical characterization of selected mural paintings in Austria around 1400. Colorants. 2023;2(3):471–86. https://doi.org/10.3390/colorants2030022.
10. Arjonilla P, Domínguez-Vidal A, Rubio Domene R, Correa Gómez E, de la Torre-López MJ, Ayora-Cañada MJ. Characterization of wall paintings of the Harem court in the Alhambra monumental ensemble: advantages and limitations of in situ analysis. Molecules. 2022;27(5):1490. https://doi.org/10.3390/molecules27051490.
11. Hu K, Bai C, Ma L, et al. A study on the painting techniques and materials of the murals in the five Northern Provinces' assembly hall, Ziyang. China Herit Sci. 2013;1:18. https://doi.org/10.1186/2050-7445-1-18.
12. Kriznar A, Želinská J. Materials and techniques of selected mural paintings on the "Gothic Road" around 1400 (Slovakia). Heritage. 2021;4:105–4125. https://doi.org/10.3390/heritage4040226.
13. Pagán E. Alba, et al. Coloring materials and technical recipes in the mural paintings of the Hermitage of "Mas de Tous"(La Pobla de Vallbona, Valencia). Physicochemical and cultural study. In: Calderón PO, Puerto FP, editors. Science and digital technology for cultural heritage-interdisciplinary approach to diagnosis, vulnerability, risk assessment and graphic information models. Boca Raton: CRC Press; 2019. p. 215.
14. Giorgi L, et al. In-situ technical study of modern paintings part 1: The evolution of artistic materials and painting techniques in ten paintings from 1889 to 1940 by Alessandro Milesi (1856–1945). Spectrochim Acta Part A Mol Biomol Spectrosc. 2019;219:530–8.
15. El-Rifai I, Mahgoub H, Ide-Ektessabi A. Multi-spectral imaging system (IWN) for the digitization and investigation of cultural heritage. In:

Ioannides M, editor. Digital heritage progress in cultural heritage: documentation, preservation, and protection. Springer; 2016. p. 232–40.
16. Ágredos Pascual V, de M Luisa, et al. In-situ technical study of contemporary painting from the heritage collection of the Universitat de València, Spain Canvases and colorful landscapes by Manuel Moreno Gimeno. Color Res Appl. 2023. https://doi.org/10.1002/col.22860.
17. Pugh E. Graffiti and the critical power of urban space: Gordon Matta-Clark's Made in America and Keith Haring's Berlin wall mural. Space Cult. 2015;18(4):421–35. https://doi.org/10.1177/1206331215616094.
18. Wang Y, Wu X. Current progress on murals: distribution, conservation and utilization. Herit Sci. 2023;11(61):1–14. https://doi.org/10.1186/s40494-023-00904-9.
19. Strlič M. Heritage science: a future-oriented cross-disciplinary field. Angew Chem Int Ed. 2018;57:7260–1. https://doi.org/10.1002/anie.201804246.
20. Hermens E. Technical art history: the synergy of art, conservation and science. In: Rampley M, Lenain T, Locher H, Pinotti A, Schoell-Glass C, Zijlmans K, editors. Art history and visual studies in Europe transnational discourses and national frameworks. Boston: Leiden; 2012.
21. Iazurlo P, Piqué F, Moretti P. Gino Severini in Switzerland: a technical study of the wall paintings of Saint Nicolas de Myre in Semsales. Stud Conserv. 2023;68(2):171–92. https://doi.org/10.1080/00393630.2021.1975612.
22. Gavrilov D, Maev R, Almond DP. A review of imaging methods in analysis of works of art thermographic imaging method in art analysis. Can J Phys. 2014;92(4):341–64. https://doi.org/10.1139/cjp-2013-0128.
23. Nadolny J. Recipes for deceit documentary sources for the production of paintings forgeries from 1300 to 1900. In: Eyb-Green S, Townsend J, Pilz K, Kroustallis S, van Leeuwen I, editors. Sources on art technology, back to basics. London: Archetype Publications; 2016.
24. Dupré S. Materials and techniques between the humanities and science: introduction. Hist Human. 2017;2(1):174–7. https://doi.org/10.1086/690577.
25. Stanley L. Archival methodology inside the black box. In: Moore N, Salter A, Stanley L, Tamboukou M, editors. The archive project. Archival research in the social sciences. New York: Routledge; 2017. p. 36–8.
26. Greeley R. Witnessing Revolution, Forging a Nation. In Affron M, Castro M, Cruz D, y González R. (eds.) *Paint the Revolution: Mexican Modernism 1910–1950*. México: INBAL-Philadelphia Museum of Art; 2016. p. 263–269.
27. Pérez M, Cano N, Ruvalcaba-Sil JL, Mitrani A, de Lucio O. Technical non-invasive study of an 18th century novo-hispanic panel painting. Heritage. 2021;4(4):3676–96. https://doi.org/10.3390/heritage4040202.
28. Pérez M, Arroyo-Lemus E, Ruvalcaba-Sil J, Mitrani A, Maynez-Rojas M, de Lucio O. Technical non-invasive study of the novo-hispanic painting the Pentecost by Baltasar de Echave Orio by spectroscopic techniques and hyperspectral imaging In quest for the painter's hand. Spectrochim Acta Part A Mol Biomol Spectrosc. 2021;250:119225. https://doi.org/10.3390/heritage4040202.
29. Hayem-Ghez A, Ravaud E, Boust C, Bastian G, Menu M, Brodie-Linder N. Characterizing pigments with hyperspectral imaging variable false-color composites. Appl Phys A Mater Sci Process. 2015;121:939–47. https://doi.org/10.1007/s00339-015-9458-8.
30. Reinhard E, Khan EA, Akyuz AO, Johnson G. Color imaging fundamentals and applications. Massachusetts: A K Peters, Ltd; 2008.
31. Ohta N, Robertson AR. Colorimetry. Fundamentals and Applications. Annual Review of Materials Science. Chichester: Wiley; 2005.
32. Moyssén X. El Dr. Atl y los antecedentes de la pintura mural contemporánea [Dr. Atl and the background of contemporary mural painting]. Boletín de Monumentos Históricos. 1980;4:71.
33. García P. Exposición de los artistas mexicanos de 1910. In: García P, editor. 1910: El arte en un año decisivo: La exposición de artistas mexicanos [1910: art in a decisive year: the exhibition of Mexican artists]. México: MUNAL; 1991. p. 84.
34. Lear J. Picturing the proletariat. Artists and labor in revolutionary Mexico. Austin: University of Texas Press; 2017. p. 25–34.
35. Macías-González V, Rubenstein A, editors. Masculinity and sexuality in modern Mexico. US: University of New Mexico Press; 2012. p. 5–7.
36. Aceto M, Agostino A, Fenoglio G, Picollo M. Non-invasive differentiation between natural and synthetic ultramarine blue pigments by means of 250–900 nm FORS analysis. Anal Methods. 2013;5:4184–9. https://doi.org/10.1039/C3AY40583D.
37. Aceto M, Agostino A, Fenoglio G, Idone A, Gulmini M, Picollo M, Ricciardi P, Delaney JK. Characterisation of colourants on illuminated manuscripts by portable fibre optic UV-Visible-NIR reflectance spectrophotometry. Anal Methods. 2014;6:1488–500. https://doi.org/10.1039/c3ay41904e.
38. Maynez-Rojas MA, Casanova-González E, Ruvalcaba-Sil JL. Identification of natural red and purple dyes on textiles by fiber-optics reflectance spectroscopy. Spectrochim Acta A Mol Biomol Spectrosc. 2017;178:239–50. https://doi.org/10.1016/j.saa.2017.02.019.
39. Gulmini M, Idone A, Diana E, Gastaldi D, Vaudan D, Aceto M. Identification of dyestuffs in historical textiles: strong and weak points of a non-invasive approach. Dyes Pigm. 2013;98:136–45. https://doi.org/10.1016/j.dyepig.2013.02.010.
40. McCrone WC, Fitzhugh EW. Artists' Pigments: A Handbook of Their History and Characteristics. J Am Instit Conserv. 1999. https://doi.org/10.2307/3180006.
41. Cosentino A. Transmittance Spectroscopy and Transmitted Multispectral Imaging to Map Covered Paints. Conservar Património. 2016;24:37–45. https://doi.org/10.14568/cp2015021.
42. Delaney JK, Conover DM, Dooley KA, Glinsman L, Janssens K, Loew M. Integrated x-ray fluorescence and diffuse visible-to-near-infrared reflectance scanner for standoff elemental and molecular spectroscopic imaging of paints and works on paper. Herit Sci. 2018;6:1–12. https://doi.org/10.1186/s40494-018-0197-y.
43. Newman R. Chromium Oxide Greens. In: West E, editor. Artists' pigments. A handbook of their history and characteristics. London: National Gallery of Art Washington-Editorial Archetype; 2012. p. 273–94.
44. Bacci M, Picollo M, Trumpy G, Tsukada M, Kunzelman D. Non-invasive identification of white Pigments on 20th-century oil paintings by using fiber optic reflectance spectroscopy. J Am Instit Conserv. 2007;46:27–37.
45. Ball P. Bright Earth. Art and the invention of colour. London: Vintage Random House; 2008. p. 189.
46. Ruvalcaba-Sil JL. La pintura de caballete vista desde la fluorescencia de rayos X. In: Perujo J, editor. La materia del arte José María Velasco y Hermenegildo Bustos. México: MUNAL-INBAL; 2004. p. 81–90.
47. Schweppe H, Roosen-Runge H. Carmine-cochineal, carmine and kermes carmine. In: Feller R, editor. Artists' pigments A handbook of their history and Characteristics. London: National Gallery of Art Washington-Editorial Archetype; 2012. p. 261–71.
48. Jablonski N. Skin color and race. Am J Phys Anthropol. 2021;175:437–47. https://doi.org/10.1002/ajpa.24200.
49. Dalton D. Mestizo modernity: race, technology, and the body in post-revolutionary Mexico. USA: University Press of Florida; 2018.
50. Blue PM. History of a color. New Jersey: Princeton University Press; 2018. p. 166–9.
51. Cesaratto A, Leona M, Pozzi F. Recent advances on the analysis of polychrome works of Art: SERS of synthetic colorants and their mixtures with natural dyes. Front Chem. 2019;7:105. https://doi.org/10.3389/fchem.2019.00105.
52. Casanova-González E, García-Bucio A, Ruvalcaba-Sil JL, Santos-Vazquez V, Esquivel B, Falcón T, Arroyo E, et al. Surface-enhanced Raman spectroscopy spectra of Mexican dyestuffs. J Raman Spectrosc. 2012;43:1551–9. https://doi.org/10.1002/jrs.4086.
53. Cano N, Quintanar-Isaías A, Ruvalcaba-Sil JL, Casanova-González E, Espinosa-Pesqueira M, Jaramillo A, et al. Testigo material de un retablo deparecido: Conjunto tabular del exconvento de San Francisco Tepeyanco, Tlaxcala, México. Intervención. 2019;20:13–22. https://doi.org/10.3076/Intervencion.2019.20.217.
54. Plesters J. Ultramarine Blue, Natural and Artificial. In: Roy A, editor. Artists' pigments. A handbook of their history and Characteristics. London: National Gallery of Art Washington-Editorial Archetype; 2012. p. 55–7.
55. Delamare F. Blue pigments 5000 years of Art and Industry. London: Archetype; 2013. p. 113.
56. Cato E, Borca C, Huthwelker T, Ferreira ESB. Aluminium X-ray absorption near-edge spectroscopy analysis of discoloured ultramarine blue in 20th century oil paintings. Microchem J. 2016;126:18–24. https://doi.org/10.1016/j.microc.2015.11.021.
57. Dorotinsky D. El Elogio de las ollas [An eulogy for pots]. Nineteen Twenty. 2015;2:15–20.
58. Wiesinger R, Pagnin L, Anghelone M, Moretto M, Orsega E, Schreiner M. Pigment and binder concentrations in modern paint samples

determined by IR and raman spectroscopy. Chem Int Ed. 2018;57:7401–7. https://doi.org/10.1002/anie.201713413.
59. Piqué F, Verri G. Organic Materials in Wall Paintings. Getty Conservation Institute: Los Angeles; 2015.
60. Maynez M, Arroyo E, Casanova E, Falcón T, Ruvalcaba JL. Estudio de colorantes y pigmentos laca de cochinilla en colecciones mexicanas. In: Casanova M, Sánchez L, editors. Rojo mexicano La grana cochinilla en el arte. INBAL: México; 2017. p. 350.
61. Casanova-González E, Maynez-Rojas MÁ, Mitrani A, et al. An imaging and spectroscopic methodology for in situ analysis of ceiling and wall decorations in Colonial missions in Northern Mexico from XVII to XVIII centuries. Herit Sci. 2020. https://doi.org/10.1186/s40494-020-00434-8.
62. Carole D, Wicky E, Bensalah-Ledoux A, Paccoud S, Le Luyer C, Pillonnet A, et al. The pigments of the painter Fleury Richard (1777–1852) A Model for Multidisciplinary Study. Heritage. 2022;5(2):1276–94. https://doi.org/10.3390/heritage5020066.
63. Dooley K, Chieli A, Romani A, Legrand S, Miliani C, Janssens K, Delaney J. Molecular fluorescence imaging spectroscopy for mapping low concentrations of red lake pigments: Van Gogh's painting the Olive Orchard. Angew Chem. 2020;59(15):6046–53. https://doi.org/10.1002/anie.201915490.
64. Alviz-Meza A, Iglesias L, Castillo D, De Leo A, Torres-Salazar E, Orozco-Agamez J. Study of pigments of peruvian colonial mural painting through chemical analysis and under simulated conditions for aiming cultural heritage care. Chem Eng Trans. 2023;98:261–6.
65. Tomasini E, et al. Characterization of pigments and binders in a mural painting from the Andean church of San Andrés de Pachama (northernmost of Chile). Herit Sci. 2018;6(61):7. https://doi.org/10.1186/s40494-018-0226-x.
66. Vittorino T, Otero V, Carlyle L, Melo M, Parola A, Picollo M. Nineteenth-century cochineal lake pigments from Winsor & Newton: Insight into their methodology through reconstructions. 2017. Paper presented at International Council on Museums—Conservation Committee, ICOM-CC 18th Triennal Conference, Copenhagen, Denmark.
67. Ghirardello M, Otero V, Comelli D, Toniolo L, Dellasega D, Nessi L, et al. An investigation into the synthesis of cadmium sulfide pigments for a better understanding of their reactivity in artworks. Dyes Pigm. 2021. https://doi.org/10.1016/j.dyepig.2020.108998.
68. Hendriks E, Heldof M, van Bommel M, Pilz K. Carmín es el rojo del vino. La cochinilla en la pintura de Vincent van Gogh. In: Casanova M, Sánchez L, editors. Rojo mexicano. La grana cochinilla en el arte. INBAL: México; 2017. p. 275.
69. Giorgi L, et al. In-situ technical study of modern paintings-Part 2: Imaging and spectroscopic analysis of zinc white in paintings from 1889 to 1940 by Alessandro Milesi (1856–1945). Spectrochim Acta Part A Mol Biomol Spectrosc. 2019;219:504–8.
70. Moretti P, Zumbühl S, Piqué F. Traditional and modern pigments in Gino Severini's Swiss murals. Color Res Appl. 2023. https://doi.org/10.1002/col.22870.
71. Kühn H. Zinc White. In: Feller R, editor. Artists' pigments. A handbook of their history and characteristics. Washington-London: National Gallery of Art Washington-Editorial Archetype; 2012. p. 169–86.
72. Mass Jr, et al. Portable X-ray Fluorescence and Infrared Fluorescence Imaging Studies of Cadmium Yellow Alteration in Paintings by Edward Munch and Henri matisse in Oslo, Copenhagen, and San Francisco. Smithsonian Contrib Mus Conserv. 2016;5:53–64.
73. Fiedler I, Bayard M. Cadmium Yellows, Oranges and Red. In: Feller R, editor. Artists' pigments. A handbook of their history and characteristics. Washington: National Gallery of Art Washington-Editorial Archetype; 2012. p. 65–108.
74. Gil M, Costa M, Cardoso A, Valadas S, Helvaci Y, Bhattacharya S, Moita P, Candeias A. On the Two Working palettes of Almada Negreiros at DN building in Lisbon (1939–1940): first analytical approach and insight on the use of Cd based pigments. Heritage. 2021;4(4):4578–95. https://doi.org/10.3390/heritage4040252.
75. Gettens R, Kühn H, Chase W. Lead White. In: Roy A, editor. Artists' pigments. A handbook of their history and characteristics. London: National Gallery of Art Washington-Editorial Archetype; 2012. p. 67–72.
76. Ruvalcaba-Sil JL. La pintura de caballete vista desde la fluorescencia de rayos X. In: Perujo J, editor. La materia del arte. José María Velasco y Hermenegildo Bustos. MUNAL-INBAL: México; 2014. p. 89.
77. Hecker S, Bottinelli S. Lead in modern and contemporary art. New York: Bloomsbury Publishing; 2021. p. 33.
78. Cano N, de Lucio O, Pérez M, Mitrani A, Nagaya A, Ruvalcaba-Sil JL, Medina R. Acrylic colors for peace. Non-invasive study of an outdoor mural painting. Color Res Appl. 2023;48(4):10. https://doi.org/10.1002/col.22861.
79. El LL. patrimonio artístico y las voluntades de la conservación: CENCROPAM [CENCROPAM: artistic heritage and wills for its convervation]. In: Gil G, editor. CENCROPAM 50 años de conservación y registro del patrimonio artístico mueble: inicios, retos y desafíos. México: CENCROPAM-INBAL; 2014. p. 118.
80. Servín J. Desprendimiento de los murales al óleo del pintor Saturnino Herrán [Saturnino Herrán oil murals detachment]. Cuadernos de Arquitectura y Conservación del patrimonio artístico. 1981;13:56–8.
81. Bremer J. Estimación 1 de trabajos efectuados durante los meses de enero a julio del año de 1976 referentes al desprendimiento, transporte sobre nuevo soporte y restauración general de dos murales de Saturnino Herrán. México: Expediente Saturnino Herrán; 1976.
82. Mezzadri P. Contemporary murals in the street and urban art field: critical reflections between preventive conservation and restoration of public art. Heritage. 2021;4(3):2515–25. https://doi.org/10.3390/heritage4030142.
83. Laver M. Titanium Dioxide Whites. In: West E, editor. Artists' pigments. A handbook of their history and characteristics. London: National Gallery of Art Washington-Editorial Archetype; 2012. p. 295–355.
84. Morozova E, Kadikova I, Pisareva S. Titanium dioxide whites in XX century works of art: occurrences and composition study. IJCS. 2022;13(1):1553–66.
85. Volpi F, et al. Non-invasive identification of red and yellow oxide and sulfide pigments in wall-paintings with portable ER-FTIR spectroscopy. J CultHeritag. 2023;63:158–68.
86. Helwig K. Iron oxide pigments: natural and synthetic. In: Berrie B, editor. Artists' pigments. A handbook of their history and characteristics. London: National Gallery of Art Washington-Editorial Archetype; 2007. p. 51.
87. Fuster-López L, Izzo F, Andersen C, Murray A, Vila A. Picasso's 1917 paint materials and their influence on the condition of four paintings. Springer Nat Switserland. 2020;2:2159. https://doi.org/10.1007/s42452-020-03803-x.
88. Fuster-López L, Caterina F, Damato V, Yusà-Marco D, Zendri E. An insight into the mechanical properties of selected commercial oil and alkyd paint films containing cobalt blue. J Cult Herit. 2019;35:225–34. https://doi.org/10.1016/j.culher.2018.12.007.

Publisher's Note