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Analysis of Poul Gernes' painted folding doors at Herlev Hospital

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Abstract

An analytical study of the painted folding doors at Herlev Hospital in Denmark has been performed in connection with the creation of new doors. The hospital which construction was completed in 1976 is one of the first polychrome hospitals in the world. The building has achieved international awareness not only as a piece of architecture but also as an artwork being the largest artistic decoration of a public space in Denmark. Besides the decoration of the walls and interior which colour scheme was designed by the Danish artist Poul Gernes, the hospital foyer includes 65 individual paintings and two painted folding doors, which were executed by Poul Gernes. The folding doors are the original doors from 1976 and have never been restored. The paint used for the decoration of the folding doors were analysed by micro-Raman spectroscopy, scanning electron microscopy–energy dispersive X-ray spectroscopy, micro-Fourier transform infrared spectroscopy, and pyrolysis–gas chromatography–mass spectrometry. The results showed, that the variant colours were created by the use of a limited number of pigments and consist of a mixture of inorganic pigments and synthetic organic pigments. The detected pigments were chrome yellow, chrome orange/chrome red, PY3, PR3, PR122, PB15, and PV23. Titanium white (rutile) was found in all paint and preparatory layers, and it was used as both a whitening agent in mixtures with other pigment and a filler material in the paint. The study also shows how the decorations were created and it hence relates to other studies of wall paintings from that period giving useful information for future restoration issues about the possible pigments and binder used.

Keywords: Poul Gernes, Herlev Hospital, Paintings, Alkyd paint, Pigments, SOPs

Background

The Danish artist Poul Gernes (1925–1996), one of the founders of the so-called Ex-school (the Experimental Art School, 1961–1969), is known for his large and colourful decorations of public spaces in Denmark. His works include the decoration of several schools, a dormitory, a town hall, and not least the provocative colouring of the facade of the Palads Cinema, a landmark building in downtown Copenhagen, and the interior and walls of Herlev Hospital at the outskirts of Copenhagen [1]. The decorations by Poul Gernes are characterised by strong and vivid colours and often with simple clear shapes and geometric patterns. Gernes believed that ornamentation had a social effect and a positive emotional influence, and in 1988 he represented Denmark at the Venice Biennial

where he spread his view on the stimulating effect of colours [1]. Gernes also believed that colours could have a stimulating effect on hospital patients in favour of distraction from their pain and suffering [1].

With its colourful decoration of the walls and interior, Herlev Hospital is considered one of the masterpieces of Poul Gernes and when the construction was completed in 1976 it was one of the first polychrome hospitals in the world.

The building, designed by the Danish modernist architects Gehrdt Hinrich Bornebusch, Max Brüel and Jørgen Selchau, has achieved international awareness not only as a piece of architecture presenting a vision of integration of colour, form and function but also as an artwork being the largest artistic decoration of public space in Denmark [1]. Besides the colour scheme for decoration of the walls and interior designed by Gernes, the hospital foyer includes 65 individual paintings and two painted folding doors executed by Poul Gernes [1]. (Originally,

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there were four folding doors but the two doors at the balcony covering a bank and a hairdressing salon were removed around 2003 and replaced by glass walls, when the shops were closed down). The two remaining folding doors are the original doors from 1976 and have never been restored.

The function of the doors is to cover the two shops, a kiosk and a flower shop, placed in the foyer.

The folding doors are of the type mobile partitioning i.e. a system of sliding door leaves where the individual leaves are suspended in a track mounted on the ceiling. The doors consist of six door leaves measuring 130×250 cm each. On both sides of each door leaf a painted panel made of MDF wood (Medium Density Fibreboard) is attached so that when the doors are closed each of the four different connected decorations of c. 20 m^2 are visible (Fig. 1). The decorations named *front* can be seen in the foyer whereas the decorations named *back* can only be observed from the inside of the shops. During the day, the panels are stacked at the side of the shop entrance.

Since the doors have been handled daily, when opening and closing the shops, the decorations were in a critical condition due to several damages caused by collisions with store fixtures. In addition, the mechanical parts of the folding doors were worn out in such a degree that any conservation treatment would have been unaffordable. It was therefore decided that new doors had to be recreated and that the original doors should be stored at Museum of Art in Public Spaces and the paint used by Gernes should be investigated. Samples representing each colour were therefore taken for pigment analysis.

It is known that Poul Gernes until the mid-1970s had a close collaboration with the Danish paint factory Beck & Jørgensen, and afterwards with the paint factory Flügger and their colour engineer Willum Thomsen (personal information from Poul Gernes' daughter Ulrikka Gernes). It is therefore possible that one or both of these companies produced the house paints used for the decorations at Herlev Hospital. However, no records of the actual paints and their composition have been available, and to our knowledge this is the first analysis of the paints used by Poul Gernes.

Experimental

Cross sections

Paint samples were taken from the folding doors and prepared as cross sections by embedding them in Technovit 2000 LC light curing resin placed in EasySections. The resin was cured for 10 min with blue light under a flow of nitrogen gas in a light-curing oven (Egger EL 1 plus N_2). The cross sections were polished wet with silicon carbide and then dry with Micro-Mesh® (granularity 2400–12,000).

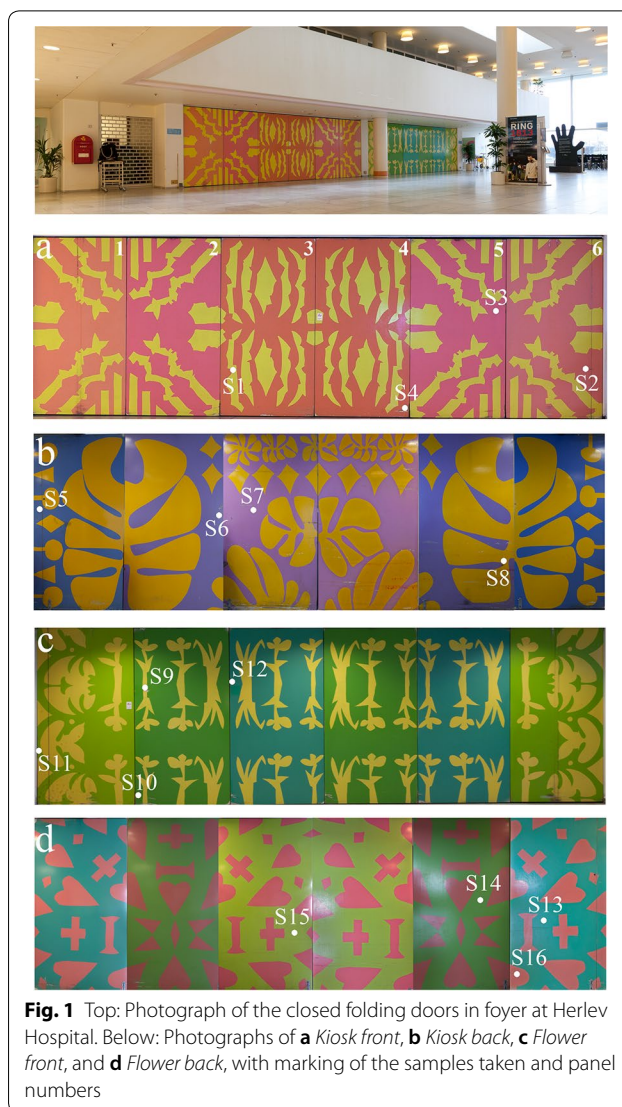


Fig. 1 Top: Photograph of the closed folding doors in foyer at Herlev Hospital. Below: Photographs of **a** Kiosk front, **b** Kiosk back, **c** Flower front, and **d** Flower back, with marking of the samples taken and panel numbers

Optical microscopy (OM)

Cross sections were studied with an optical microscope Axio Imager M1 (Carl Zeiss) under polarised white light and ultraviolet radiation with magnifications between 100 and $500\times$.

Raman

Micro-Raman spectrometer analyses were performed on cross sections at IRPA/KIK with a Renishaw inVia dispersive micro-Raman spectrometer equipped with a 785 nm laser. The laser power was kept between 0.1 and 1 mW by neutral density filters to avoid thermal degradation. A detailed description can be found in Ref. [2].

SEM-EDS

Scanning electron microscopy–energy dispersive X-ray spectroscopy (SEM–EDS) analyses were carried out on

cross sections using a Hitachi S-3400N scanning electron microscope with an energy dispersive X-ray spectrometer (SEM–EDS) operating at an acceleration voltage of 20 kV and low vacuum mode at 25 Pa. The EDS system, QUANTAX 200, was equipped with two 30 mm² SDD X-ray detectors (XFlash[®] 6 | 30 Silicon Drift Detector) from Bruker instruments.

μ-FTIR

Micro-Fourier transform infrared spectroscopy (μ-FTIR) spectra of the preparation layers were performed in ATR mode on cross sections in the range of 4000–600 cm⁻¹ with a resolution of 4 cm⁻¹ acquired over 64 scans using a Hyperion 3000 spectrometer equipped with a Mercury Cadmium Telluride (MCT) detector cooled with liquid nitrogen. (μ-FTIR analyses were performed at IRPA/KIK).

Py–GC–MS

Pyrolysis–gas chromatography–mass spectrometry (Py–GC–MS) analyses were performed at IRPA/KIK. Prior to the Py–GC–MS analysis, the solid sample was placed in a glass vial and put into suspension with 15 μL of a 2.5% solution of tetramethylammonium hydroxide (TMAH) in methanol, and 4 μL of the suspension was placed in a stainless steel Eco-cup containing an Auto-Rx disc. 1 μL of C17 internal standard was added into the Eco-cup and the Eco-cup was placed in the Frontier lab AS-1020ET auto sampler. The pyrolysis interface was purged with helium and the sample was pyrolysed at 550 °C for 12 s. The pyrolysis unit was a multi-shot pyrolyser EGA/PY-3030D attached to a Trace GC 2000 chromatograph coupled to a Finnigan PolarisQ ion trap MS detector. Pyrolysis interface to the column was kept at 250 °C. Separations were accomplished on a SLB-5 ms capillary column. Helium was used as carrier gas at a constant flow of 0.9 mL min⁻¹. The temperature program adopted was an initial temperature of 35 °C maintained for 1 min during split injection (split ratio 20). Then a 10 °C min⁻¹ gradient was applied until 320 °C and this temperature was maintained for 5 min. The MS transfer line was maintained at 290 °C during the whole procedure. Ionization was carried out in the ion volume of the ion trap mass spectrometer under the standard EI positive mode at 70 eV. The mass spectrometer was scanned from *m/z* 35 to 500 with a cycle time of 0.5 s. The data was processed with Xcalibur 1.4 software.

Results and discussion

Preparatory layers

Before the background colour and the design pattern were painted, two preparatory layers were applied on the MDF panels. The two distinctive layers can be seen

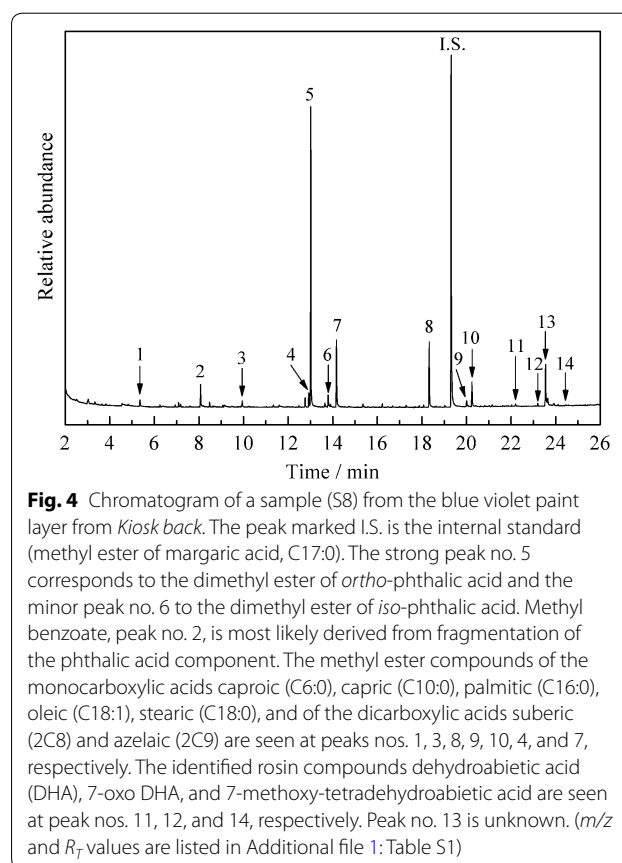
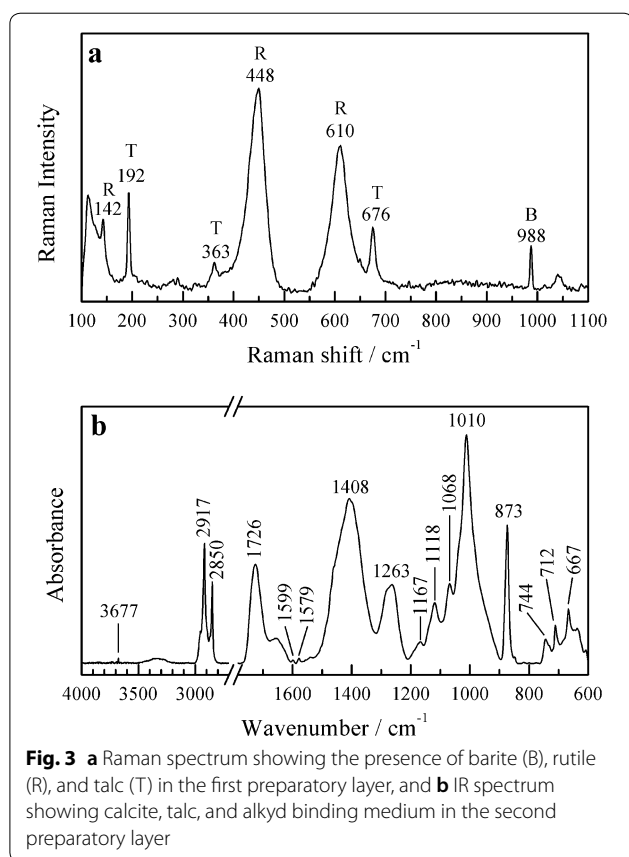
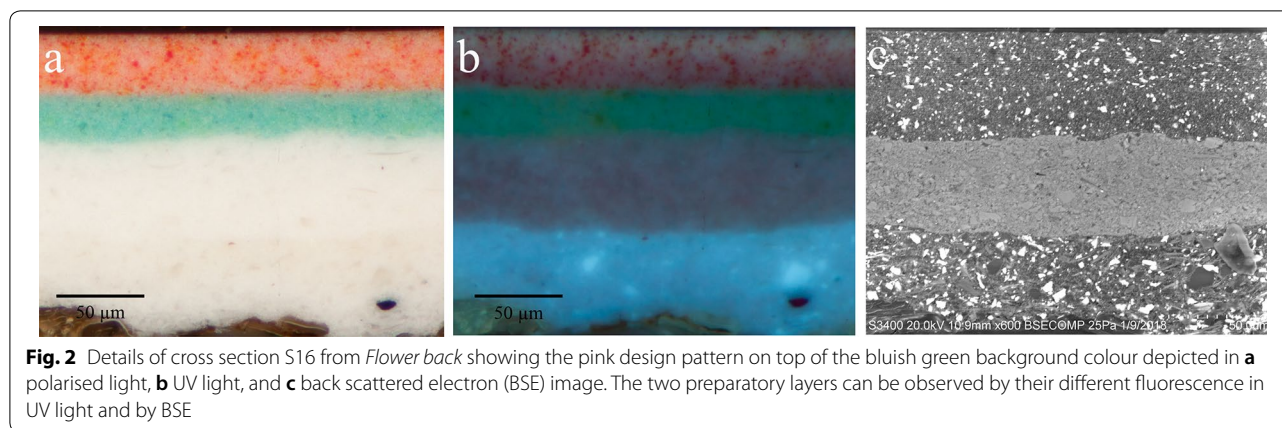
under UV-light in OM due to the different fluorescence of the layers and in backscattered electron images (BSE) (Fig. 2c, d). Raman and SEM–EDS analyses showed that the first layer mainly consisted of large crystals of barite (BaSO₄), fibrous crystals of talc (Mg₃Si₄O₁₀(OH)₂), and small particles of titanium white (TiO₂) of the rutile type. In the Raman spectrum seen in Fig. 3a rutile is identified by its two characteristic broad bands at 610 and 448 cm⁻¹ [2–4], barite by the sharp symmetrical S–O stretching at 988 cm⁻¹ [4, 5], and talc by the Si–O–Si stretching and bending modes at 676 and 363 cm⁻¹, and the lattice vibration at 192 cm⁻¹ [6, 7]. SEM–EDS analysis indicated the presence of a minor amount of magnesium oxide (MgO), and potassium–iron containing aluminium silicate which could be of a mica type (K₂(Al₆Si₆O₂₀)(OH)₄) present in the first preparatory layer.

The second preparatory layer consisted mainly of calcite (CaCO₃) mixed with rutile together and a smaller amount of fibrous talc and potassium–iron containing aluminium silicate. Calcite particles appeared sub-rounded and semi-transparent and were identified by IR from the characteristic broad asymmetric C–O stretching around 1400 cm⁻¹, the sharp out of plane bending vibration at 873 cm⁻¹, and the asymmetric C–O bending at 712 cm⁻¹ [8] as shown in Fig. 3b. Talc was identified by the O–H stretch at 3677 cm⁻¹, the Si–O–Si stretch at 1010 cm⁻¹, and the bending vibration at 667 cm⁻¹ [7]. The binding medium was identified as an alkyd by the C=O stretching vibration at 1726 cm⁻¹, the C–O stretches at 1263, and 1118 cm⁻¹, the aromatic C=C in-plane deformation at 1068 cm⁻¹, and the weak aromatic C=C stretching vibrations at 1599 and 1579 cm⁻¹ which proposed an *ortho*-phthalate alkyd [9–13]. The relative intense C–H stretching absorption at 2917 and 2850 cm⁻¹ suggested an oil modified alkyd formulation [2, 14].

Binding medium

Pyrolysis–gas chromatography–mass spectrometry analyses were carried out on a sample from *Kiosk back* (S8). The sample was separated into the yellow design pattern layer, the blue violet background layer, and the calcite containing preparatory layer. All analyses resulted in chromatograms similar to the one shown in Fig. 4, confirming an oil modified alkyd binding medium based on *ortho*-phthalic acid. Minor amounts of *iso*-phthalic resin and rosin compounds were also found. (*m/z* and *R_T* values are listed in Additional file 1: Table S1).

The monocarboxylic acids are related to the oil modification and suberic and azealic acid are common oxidation products of a siccative oil [11, 15]. Based on the relative peak heights of *ortho*-phthalic acid and of the fatty acids the oil length of the alkyd resin is likely to be a



medium type [16]. The rosin compounds identified were dehydroabietic acid (DHA), 7-oxo DHA, and 7-methoxy-tetrahydroabietic acid which are oxidation products of abietic acid and markers for resin of the Pine tree family (*Pinaceae*) [17–20]. The presence rosin may indicate that oil modification was performed with tall oil fatty acids (TOFA), a by-product from the paper industry which finds major use in alkyds [2, 15]. However, a direct addition of rosin to the oil modified alkyd or pigment modification can not be excluded.

The compound represented in peak no. 13 was not identified. The mass spectrum showed the characteristic homologous series of ions for a long chain carbon backbone ($\Delta m/z = 14$), but whether this compound originates from the oil modification or a paint additive is unknown.

The polyfunctional alcohol was not detected by the Py-GC-MS method, perhaps due to the instrumentation. However, by extraction of a paint sample with 50:50 chloroform/methanol mixture followed by evaporation a

small amount of the binder was isolated. ATR-FTIR analysis of the binder showed a spectrum typical of *ortho*-alkyd and with a broad C–H bending frequency from 1460 to 1440 cm^{-1} indicating that both pentaerythritol and glycerol were used as polyfunctional alcohols [2, 10].

Background colour and design pattern

The painting technique was indicated from the visual inspection of the doors, and is in accordance with the description of the technique given by Poul Gernes' daughter Ulrikka Gernes [1]. Due to the structure of the paint film that has a texture similar to an orange peel, the use of a paint roller for both the background colour and design pattern was possible. In addition to this, the application of a simple stencilling technique was also observed since “woolly edges” were seen where the paint had been flowing under the stencil. In Fig. 5 photographs of the paint surface with this characteristic texture, and damages in the paint layer are shown.

As seen in Fig. 1 each side of a door consists of four colours: The colour of the design pattern which is the same for each side of a door (painted stencilling technique), and the background colour which consists of three different colour nuances. For three of the folding doors, *Kiosk front*, *Kiosk back*, and *Flower back*, the six door panels are symmetrical in their background colouration with 1 and 6, 2 and 5, and two middle panels 3 and 4 having the same colour. For the *Flower front* the panels 1 and 6, 2 and 4, and 3 and 5 have the same background colour. Samples representing the 16 different colours were taken as indicated in Fig. 1, and an overview of the pigments identified is given in Table 1.

Among the inorganic materials, titanium white was present in all samples and most likely used as both a filler material and a whitening agent. A minor amount of barite was found in approximately half of the samples; however, it might have been used as a filler in all the paint.

For simplicity, both rutile and barite are omitted from Table 1.

The only coloured inorganic pigment found in the examined cross sections was lead chromate, which was found in all the design patterns and in several of the background colours. Lead chromate was present as either chrome yellow (PbCrO_4) or chrome orange/chrome red ($\text{PbCrO}_4 \cdot \text{PbO}$). Mixtures of the chromate pigments were also used as observed by OM and Raman spectroscopy (sample S8, Fig. 6a). From the Raman spectrum the mixture was identified by the strong symmetric Cr–O vibration at 839 cm^{-1} of chrome yellow overlapped with the characteristic Cr–O bands at 825 and 847 cm^{-1} from chrome orange, and from the two strongest bending modes at 359 and 343 cm^{-1} belonging to chrome yellow and chrome orange, respectively. The bending mode at 402 cm^{-1} is also ascribed to chrome yellow, while the bands at 381 and 325 cm^{-1} are assigned as overlaps from both pigments [4, 21–23].

Beside the use of lead chromates as pure colouring pigments, these were also used together with SOPs like PY3 for shades of yellow or PR3 for pink. The absence of green pigments should be noticeable. The green colours were made by mixing blue and yellow e.g. chrome yellow and PB15, or PY3 and PB15. This is possibly due to financial aspects in fabrication of house paint as low-cost green shades combining PB15 with yellow pigments are cheaper than e.g. the green copper phthalocyanine complex PG7 or chromium oxide greens (Cr_2O_3 or $\text{Cr}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$) [24, 25].

The most abundant SOP used for the decoration of the doors was the copper phthalocyanine blue, PB15. PB15 was also mixed and toned with other SOPs like PV23 and PR122 for shades of blue and violet colours. The pigment PB15 was identified by MRS by its strong scattering and the characteristic and distinct bands at 1529, 1451, 1342,

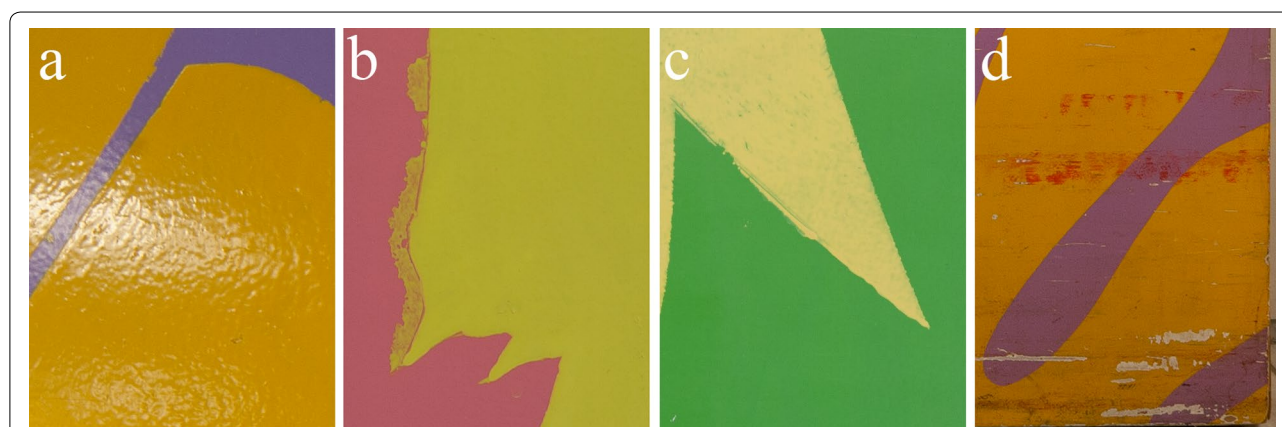


Fig. 5 Photographs of the paint film surface showing **a** the orange peel texture, **b** and **c** the “woolly edges”, and **d** damages to the door decoration

Table 1 Pigments identified by Raman and SEM-EDS in the background colours and design patterns

Paint layer	Background colour			Design pattern
<i>Kiosk front</i> , panel nos.	1, 6	2, 5	3, 4	All, 1–6
Colour	Light orange	Pink	Orange	Yellow
Pigments	Chrome orange Chrome yellow	PR3	Chrome orange	Chrome yellow Chrome orange PY3 PB15
<i>Kiosk back</i> , panel nos.	1, 6	2, 5	3, 4	All, 1–6
Colour	Blue	Blue violet	Violet	Yellow
Pigments	PB15 PV23	PB15 PR122	PB15 PR122	Chrome yellow Chrome orange
<i>Flower front</i> , panel nos.	1, 6	2, 4	3, 5	All, 1–6
Colour	Light green	Green	Blue green	Yellow
Pigments	PB15 Chrome yellow	PB15 Chrome yellow	PB15 Chrome yellow	Chrome yellow
<i>Flower back</i> , panel nos.	1, 6	2, 5	3, 4	All, 1–6
Colour	Bluish green	Green	Light green	Pink
Pigments	PB15 PY3	PB15 Chrome yellow	PB15 Chrome yellow	Chrome orange PR3

Rutile is omitted as present in all colours

1143, 954, 748, 681, and 484 cm^{-1} caused by vibrations of the porphyrin ring [13, 26, 27].

An example of the preparation of green by mixing blue and yellow is seen in sample S10 from *Flower front*. In the Raman spectrum in Fig. 6b bands assigned to PB15 appear together with two bands assigned to chrome yellow (841 and 360 cm^{-1}) marked Cr.

A shading of the blue colour of PB15 is seen in sample S5 taken from the blue door of *Kiosk back* in which Raman analysis revealed the presence of the violet pigment PV23. PV23 is one of the most important dioxazine pigments. It is especially used to shade the colour of blue phthalocyanine pigments [24], and also for violet house paint [28]. The Raman spectrum seen in Fig. 6c shows the combined use of PV23 characterised by its bands at 1431 , 1393 , 1257 , 1208 , 528 and 316 cm^{-1} [26–28] and PB15 (marked PB).

The violet colours present in samples S6 and S7 from *Kiosk back* were made by mixing PB15 with the red quinacridone pigment PR122. This pigment is known for its use as a tinting and shading pigment [24] but is also found in house paint used for mural paintings [28]. PR 122 is characterised by the Raman bands at 1650 , 1594 , 1567 , 1313 , 720 542 and 308 cm^{-1} [26–28] as seen in Fig. 6d where bands assigned to PB15 (marked PB) are also present.

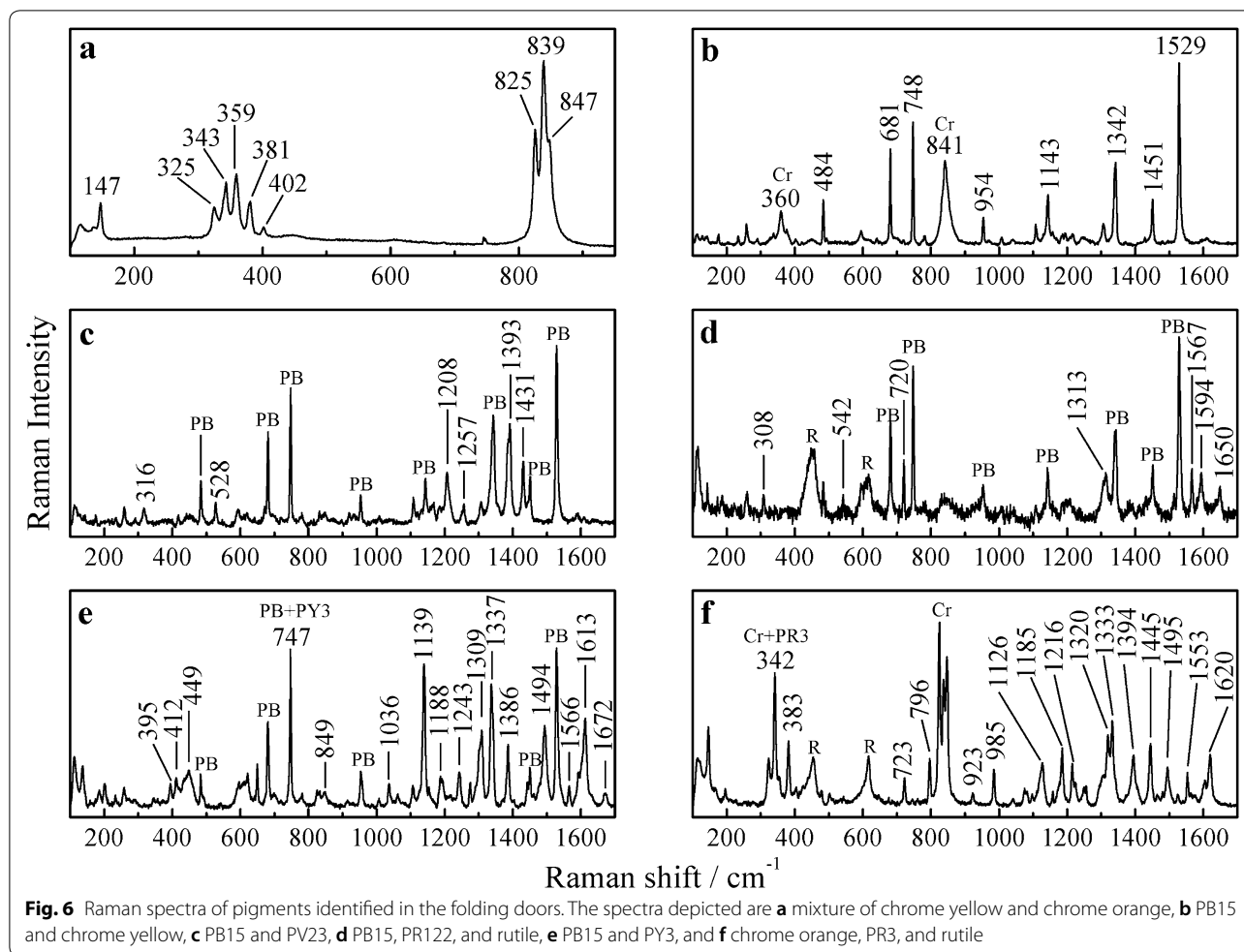
The bluish green colour of *Flower back* (S13) was a mixture of PB15 and yellow acetoacetic arylid azo pigment PY3 also known as Hansa Yellow 10G. PY3, a greenish yellow pigment, is often combined with blue

pigments to produce shades of green as in this case [24]. PY3 (commercialised around 1910), has strong and medium Raman bands at 1613 , 1494 , 1386 , 1337 , 1309 , 1139 and 748 cm^{-1} together with several minor characteristic bands [26, 27, 29]. The spectrum of PY3 can be seen in Fig. 6e together with PB15 (marked PB). The band at 748 cm^{-1} marked PB + PY3 is an overlap of both pigments making this band intense.

The pink colour of the design pattern (*Flower back*, S16) was identified as a mixture of the β -naphthol azo pigment PR3 also known as toluidine red and chromium orange. PR3 was launched on the market in 1905 and together with PY3, belongs to the groups of the earliest azo-pigments. It is one of the few β -naphthol pigments still playing a commercial role [24]. PR3 is well known in modern paintings containing SOPs both alone and in mixtures with lead chromates and/or titanium white, as well as in house paint [30–34]. PR3 is characterised by its multiple sharp and distinct Raman bands such as 1620 , 1445 , 1333 , 1320 , 1185 , 1126 , 383 , and 342 cm^{-1} [26, 27, 29]. The spectrum of PR3 is shown in Fig. 6f together with chromium orange and rutile marked Cr and R, respectively. The band at 342 cm^{-1} marked Cr + PR3 is an overlap of the sharp PR3 band and the strongest bending mode of chromium orange making this band very intense.

Conclusions

This paper has investigated the composition of modern paint material and the stratigraphic build-up of Poul Gerne's folding doors at Herlev Hospital completed in 1976.



The study relates to other studies of wall paintings from that period giving useful information for future restoration issues about the possible pigments and binders used. The analyses suggested that the decorations were made with alkyd house paints based mainly on *ortho*-phthalic acid, which is one of the most common dibasic acid used in alkyd house paints, though a smaller amount of *iso*-phthalic acid was also identified. Pentaerythritol and glycerol were both used as the polyfunctional alcohol.

The 16 different colours were created by the use of a limited number of pigments, i.e. chrome yellow, chrome orange/chrome red, and the SOPs PY3, PR3, PR122, PB15, and PV23. Titanium white was present in all paint and preparatory layers in variable amounts as a whitener in the colour shades. The major SOP used was the blue copper phthalocyanine complex PB15 which was mixed with other SOPs to create shades of blue, bluish green, violet blue, and violet, or with chrome yellow for green colours.

Among the colours, the most notable might be the lack of green pigments. A mixture of blue and yellow pigments created all the green colours. This suggests that

the price issue was an important aspect in fabrication of house paint as low-cost green shades combining PB15 with yellow pigments are cheaper than e.g. the green copper phthalocyanine complex PG7 or chromium oxide greens (Cr_2O_3 or $\text{Cr}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$).

The abundant use of lead chromate pigments in the decorations on the doors is probably due to the fact that lead chromates were a part of typical alkyd paint compositions from the 1920s through their wide distribution in the 1950s and until lead chromate was abolished from house paint due to health risks. However, as lead chromates on the doors are tightly bound in the alkyd matrix their potential hazards are minimal. Breathing of paint dust on the other hand must clearly be avoided and care should in general be taken in connection with restoration of surfaces containing lead chromate.

Additional file

Additional file 1: Table S1. Main peaks, retention time and molecular weight of THM-GC-MS of the blue violet paint layer (S8) from *Kiosk back*.

Authors' contributions

All authors contributed to data interpretation and to finalizing the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

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