LINCOLN
CONSERVATION

Research and conservation of historic decorative schemes in the built environment

Project Name: Huddersfield Open Market

Paint & mortar analysis

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Client: Watts (Suzannah Meade)

Report Author: Paul Croft BA(Hons)

www.lincolnconservation.co.uk
info@lincolnconservation.co.uk
01522 835055 or 5051

Table of Contents

List of figures

1.0: Introduction

i) Lincoln Conservation were commissioned by Watts to carry out an architectural paint research exercise at Huddersfield Open Market, on Brook Street HD1 1RY.

Figure 1: Huddersfield Open Market

ii) The market is listed Grade II* (list entry no. 1313799) with the listing notice describing the building as

1887-9. Architect: R S Drydale, Borough Surveyor. Ironwork by the Whessoe Foundry Company of Darlington. Cast iron. Walls and north lights of each aisle roof glazed all over. 6 aisles, each taken on 4 giant iron columns with elaborate foliate capitals. Decorative patterns pierced in girders. Hipped roofs on segment-shaped iron trusses with decorative patterns pierced in them. Glass canopies on pierced ornamental brackets with similar valences. Continuous round-arched lights above these, in 2 tiers, or 3 as ground slopes away towards the east. Frieze with roundels and heraldic ornament[1]

[1] Historic England listing description, on line https://historicengland.org.uk/listing/the-list/list-entry/1313799

Figure 2: View of a single bay

2.0: Method

i) A number of complete paint samples were removed from key locations on the iron framework and joinery. Care was taken to remove complete samples to include all the historic paint layers, including the substrate where possible (joinery only).

ii) All samples were mounted in clear casting resin and polished to expose the build-up of historic paint layers on the surface and examined in cross section under a high-powered microscope to reveal the stratigraphy of the paint layers applied over time. These paint 'cross sections' were viewed under both reflected white light and ultra-violet[2].

iii) Examination under white light determines the number of layers present, provides an indication of the paint colours

[2] Microscope: Leica DM2400M at magnifications X50 – X200. Long wavelength ultra-violet generator (380 – 580nm).

applied and identifies dirt layers between decorative schemes, helping to distinguish between primers and top coats.

iv) Ultra-violet light causes different types of paints and varnishes to fluoresce in a characteristic manner assisting the identification of varnish layers and the type of paints applied. Traditional oil paints do fluoresce under UV, whilst the modern alkyd paints introduced after World War II do not, assisting the dating of pre and post war layers.

v) This microscopic examination creates a slice of decorative schemes through time, similar to an archaeological record with the earliest layers at the base of the image and subsequent layers stacked above as they were applied over time.

vi) XRF analysis of the historic paints was carried out on site to establish the typical levels on lead in the underlying oil paints and to confirm the constituents of a layer of gold leaf noted on the armorial shields above column capitals.

3.0: Presentation of Results

The architectural paint research findings are presented here in three formats

- Scheme chart
- Annotated photomicrographs
- Discussion

i) Scheme Chart: A chart-based representation of the paint samples as seen in cross section. Each column represents a paint sample, and each row within the column represents a layer of paint in that sample. The far left-hand side column indicates the decorative scheme number that the layer corresponds to. The substrate is simply whatever base the paint is applied to (in this case wood or iron).

A decorative scheme represents each time the market was painted, and represents a snapshot in history. There

are often multiple layers to a scheme, that include primers and top coats.

Sometimes, a scheme chart will have blank cells with no information contained. This signifies that either a scheme has been retained or that information is missing from the record. Here, some evidence is missing from samples removed from the joinery and armorial shield, either because loose paint has been cleaned from the surface or timber replaced. Scheme Charts are included in Section 7.0.

ii) Annotated photomicrographs: A photograph taken at high magnification through a microscope. Selected images are included in section 6.0 of this report. Some of them display a large number of paint layers, starting in the late 19th century, immediately after construction with many others stacked above, up to the present day. Others show fewer layers (not displayed here), indicating areas that have been stripped or replaced. Where possible the timber substrate is included with the image, indicating a complete record has been examined.

iii) Discussion: This summarises the research and provides the concluding remarks, with an option for redecoration that re-introduces the earliest appearance of the Huddersfield Coat of Arms armorial based on the evidence uncovered. There are several options for colour to other areas and it is left to the Project Team to use the evidence presented here to decide on a suitable allocation of colour.

4.0: Summary of Results

i) The decorative appearance of Huddersfield Open Market may be broadly summarised into 3 phases. Note: the dates provided below are approximate and there will doubtless be overlapping between them, with potential for some areas being painted in isolation, typically at times of addition and repair (notably the joinery).

- Phase 1: c1890 – c1930
- Phase 2: c1930 – 1950's
- Phase 3: c1960's/70's – present

ii) A total of 16 schemes of paint have been recorded across the site, which represents a repaint on average once every 8-10 years

iii) Phase 1: Immediately after construction in 1889 the iron columns were painted deep green (lower column shafts) with the upper column shafts and collars in cream/stone colour; the column bases were painted deep red. Ochre coloured oil paints were used on the capitals immediately beneath the Borough Coat of Arms. Evidence for the paints on the windows and other joinery elements from this early period is quite fragmentary, due to repeated cleaning and rubbing down of surfaces prior to re-painting; some joinery has also doubtless been repaired/replaced over the years. However, there is evidence on the window glazing bars to suggest they were painted cream/stone (as the upper column shafts).

At the first repainting (probably c1900), the lower columns were painted entirely in deep red (without green). This appears to be 'Pompeian Red' – frequently used during this period, with a theme of deep red along with paler cream/stone colours, continuing throughout phase 1. Toward the end of this period salmon pink was applied to the column capitals, with the decorative spandrels painted to match the column capitals (initially in yellow ochre and later salmon). The windows continued to be painted in cream/stone colour.

Toward the end of the phase 1 period the iron columns were painted brown with the spandrels, windows and potentially other joinery in pale brown.

iv) Phase 2: During this period all features (iron columns and joinery) were painted uniformly in green oil paints. Five schemes of green oil paint have been applied, so it is very likely this green theme continued well into (and possibly throughout) the 1950's

v) Phase 3: This is the post WW2 phase that sees a gradual move away from the use of traditional lead oil paints and

the introduction of the modern alkyd (plastic) paints in use today. The first paint scheme of this period was a distinct gloss black to the columns with the collars picked out in gold oil paint. Gold paint was also used to accentuate and highlight some features on the column capitals. It was at this time, red was first introduced to the window frames and associated joinery, with the glazing bars picked out in white and later pale cream (as currently extant).

The current blue and turquoise theme we see today has been applied on three occasions, with red and cream to the joinery.

vi) <u>The Huddersfield coat of arms above column capital</u>

The current colour allocation of the Huddersfield coat of arms above the column capitals is presented as a silver shield and helm, picked out in black and silver, set against an ochre background, bounded by a red frame. These colours are anathema to the historic appearance of the armorial and do not represent the historic colour allocation.

Defining the colour allocation of the armorial has been challenging due to the continuous cleaning back of peeling and failing paint from surfaces at times of re-painting, resulting in the loss of paint layers and gaps in the record.

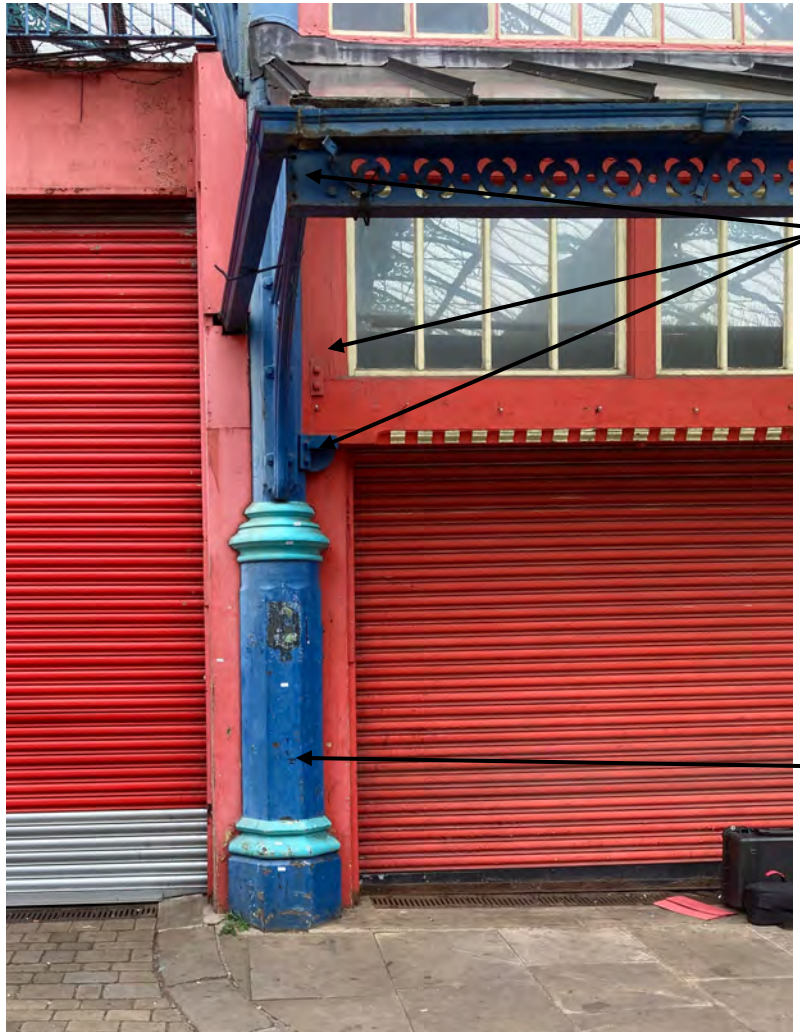
However, most samples have retained evidence for the earliest paints applied, allowing a reasonably accurate reconstruction of the armorial's initial appearance. A suggested colour allocation that reflects this, is provided in section 9.0.

5.0: Sample locations

5.1: List of locations

1. Column base
2. Column lower collar
3. Column shaft lower section
4. Column shaft mid collar A
5. Column shaft mid collar B
6. Red painted timber roller door frame
7. Blue painted frame supporting iron spandrel
8. Red painted timber beam above roller door
9. Cream painted dentils decorating the timber beam above roller door
10. Blue painted decorative iron spandrel
11. Turquoise painted flower set into iron spandrel
12. Blue painted iron fixing bracket
13. Cream painted window above roller door
14. Blue painted lower iron frame above roller door
15. Blue painted upper timber frame above roller door
16. Blue painted pierced girder supporting glass canopy
17. Blue painted iron gutter glass canopy
18. Column shaft upper section
19. Blue painted higher spandrel
20. Turquoise painted flower set into higher spandrel
21. Red painted drip moulding beneath window frame
22. Red painted window frame
23. Cream painted window glazing bars
24. Blue painted collar (capital)
25. Turquoise painted volute (capital)
26. Turquoise central flower (capital)
27. Turquoise painted column capital
28. Red painted arches window frame at high level
29. Turquoise painted flower set into high level window frame
30. Red painted window frame at high level
31. Blue painted heraldic frame above capital
32. not taken
33. Cream painted fascia above the frieze
34. Blue painted gutter above armorial
35. not taken
36. not taken
37. White painted ram above helm (armorial)
38. silver painted helm
39. Silver painted leaf (armorial)
40. Black painted ram (armorial)
41. Silver painted background to the shield (armorial)
42. Silver painted ‘castles’ inside chevron (armorial)
43. not taken
44. Black painted chevron (armorial)
45. Red painted border surrounding armorial
46. Ochre background behind armorial
47. Blue painted frame on rosette frieze
48. Turquoise background to rosette frieze
49. Silver painted relief (armorial side panel)
50. Ochre background (armorial side panel)
51. Red painted border (armorial side panel)
52. Silver painted rosette (corner of armorial panel)
53. Blue painted rosette on frieze

5.2: Images of Locations



Samples 6 – 17:

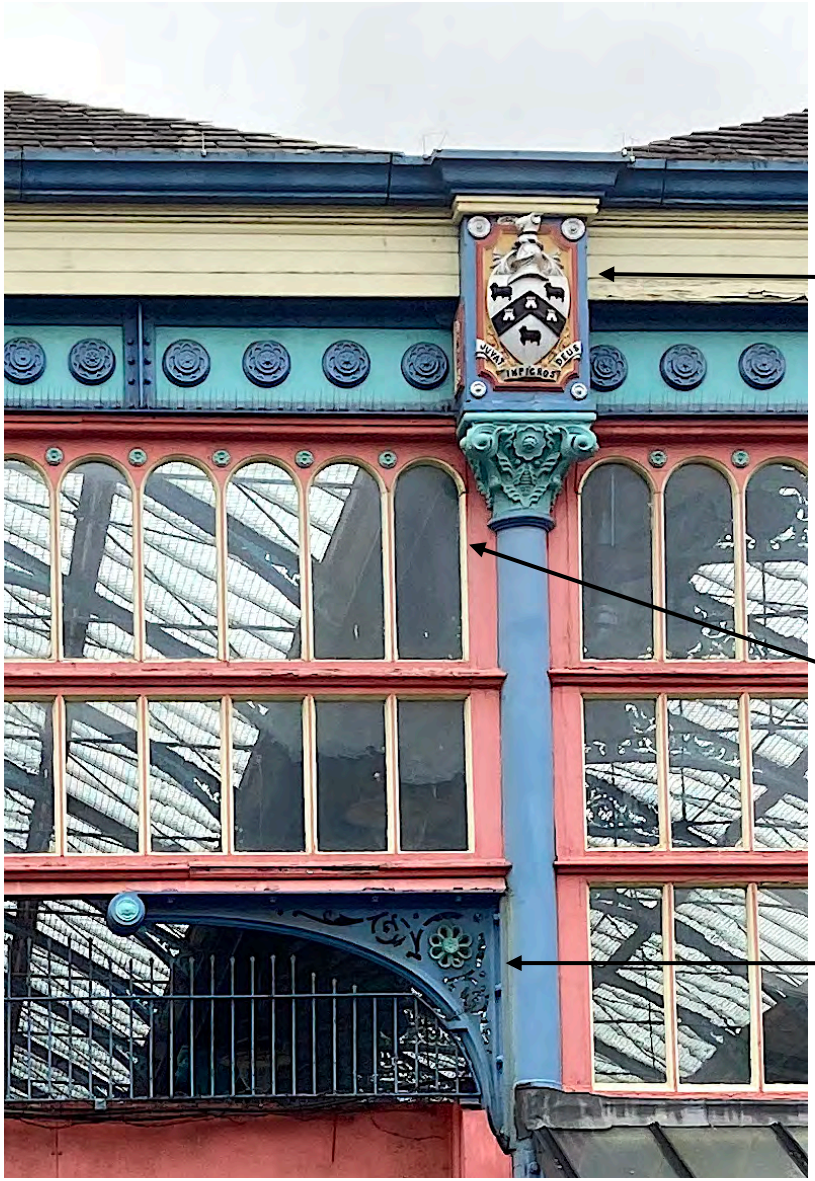
- red painted door frame & window frames.
- Cream glazing bars and dentils.
- Blue painted fixing bracket, guttering & pierced girder

Samples 1 – 5:

- column base and turquoise painted collars

Samples 10 & 11

- Decorative iron spandrel and inset turquoise flower



Samples 31– 53:
- Cream fascia
- Blue gutter
- Frieze & roundels
- Column capital
- Armorial & frame

Samples 21 – 30:
- Red window joinery
- Cream glazing bars
- Turquoise flowers

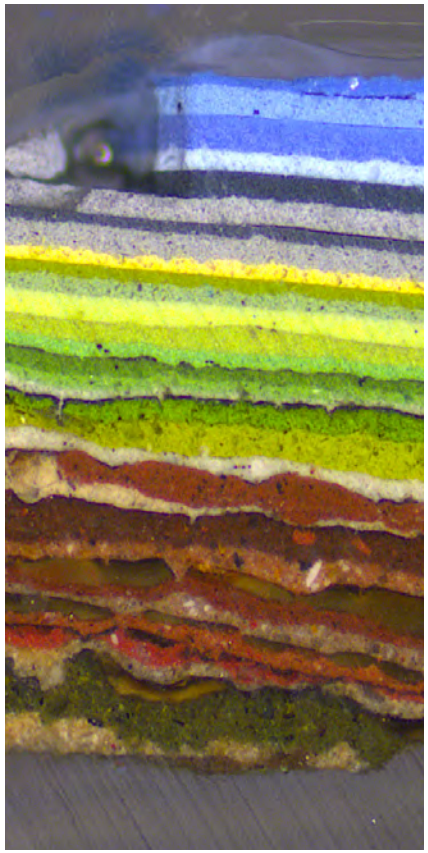
Samples 18 – 20:
- Upper column shaft
- Spandrel

Samples 48 – 53:
Image of the armorial side panel and adjacent frieze with blue painted roundels.

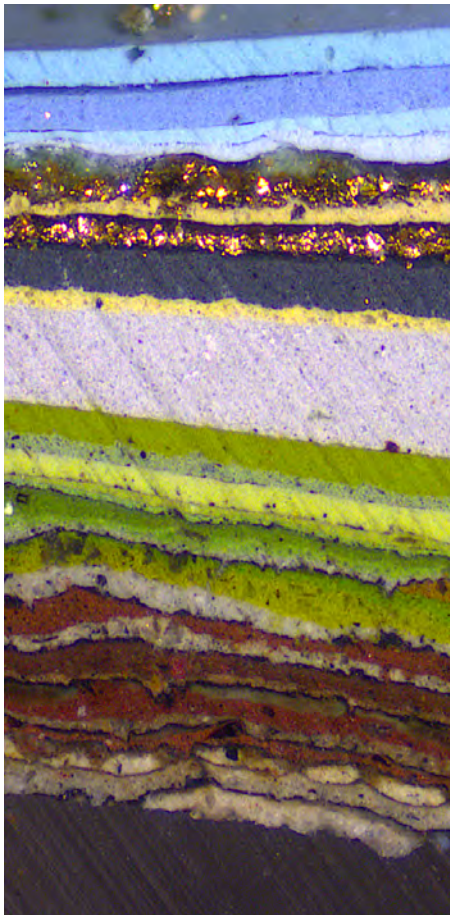
6.0: Microscope cross section images

6.1: Iron columns (shaft & collars)

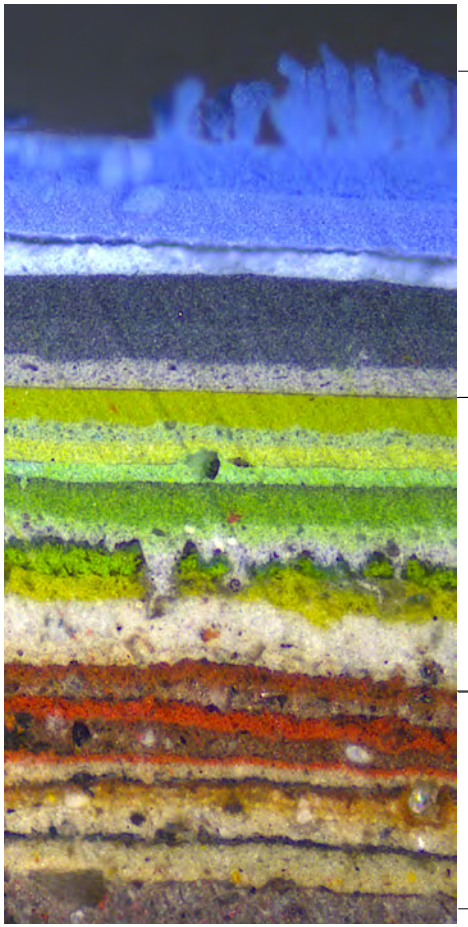
Sample 3 (lower shaft)



Sample 5 (collar)



Sample 18 (upper shaft)



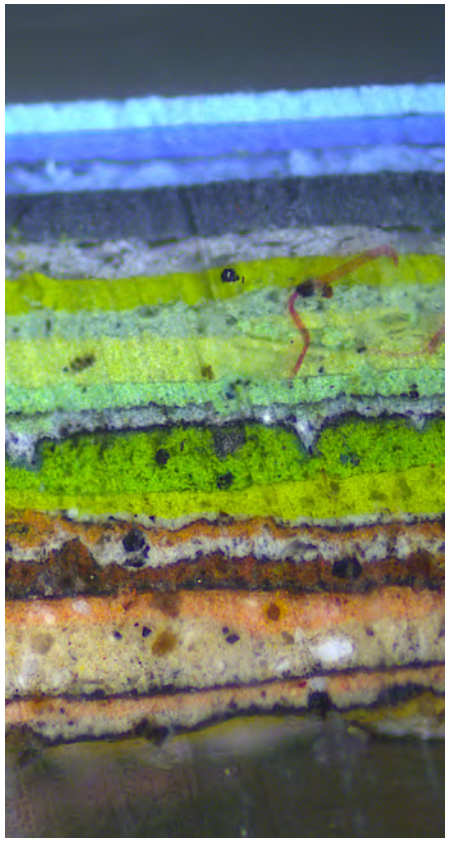
Phase 3 (post-war): initially in black oil paint with collars picked out in gold. Latterly blues (current appearance)

Phase 2: several schemes of green oil paint applied uniformly to shafts and collars

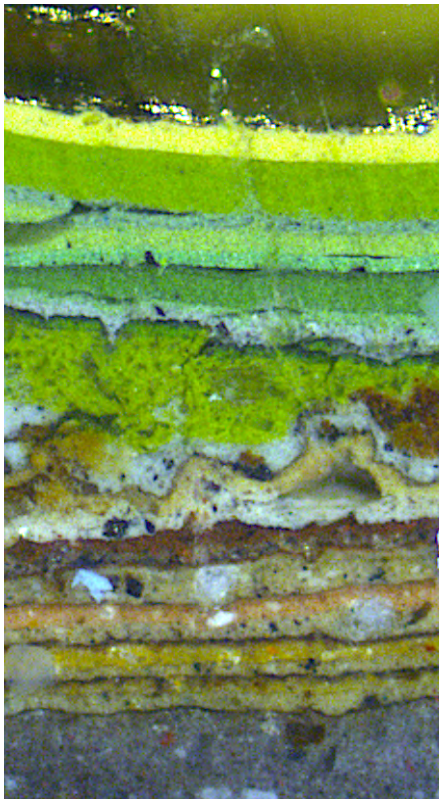
Phase 1 (earliest): lower shaft in green oil paint with the upper shaft & collars in stone. Red and brown oil paints applied later

6.2: Column Capital

Sample 27 (capital)



Sample 26 (flower)



Sample 25 (volute)

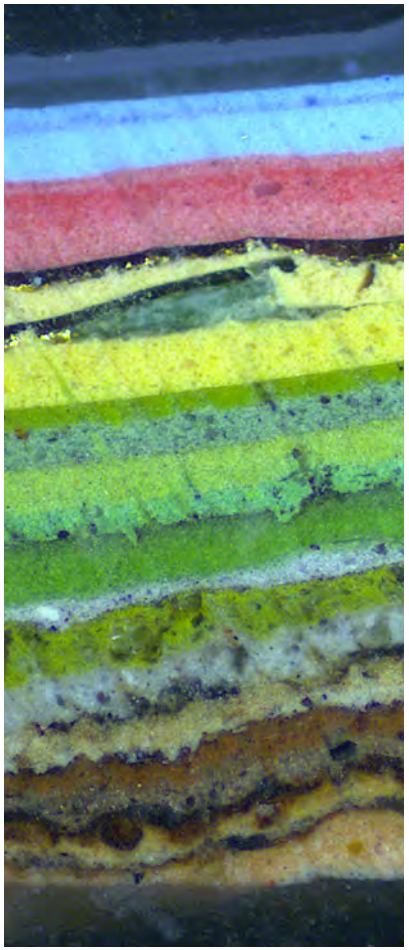
Phase 3 (post-war): initially in black oil paint with details picked out in gold paint. Latterly blues (current appearance)

Phase 2: several schemes of green oil paint.

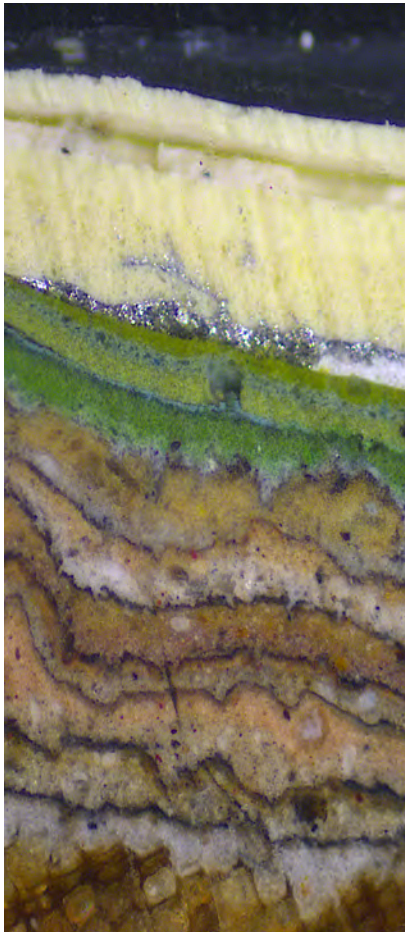
Phase 1 (earliest): initially in yellow ochre, then salmon pink and finally shades of brown

6.3: Window joinery

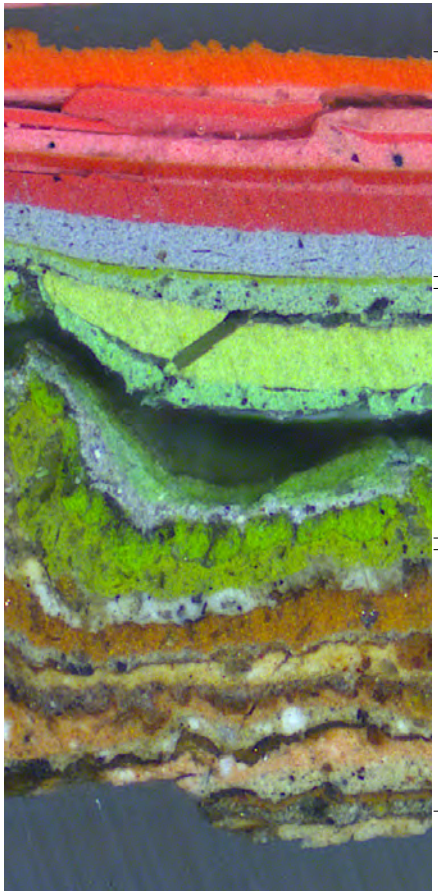
Sample 29 (flower)



Sample 23 (glazing bars)



Sample 30 (window frames)



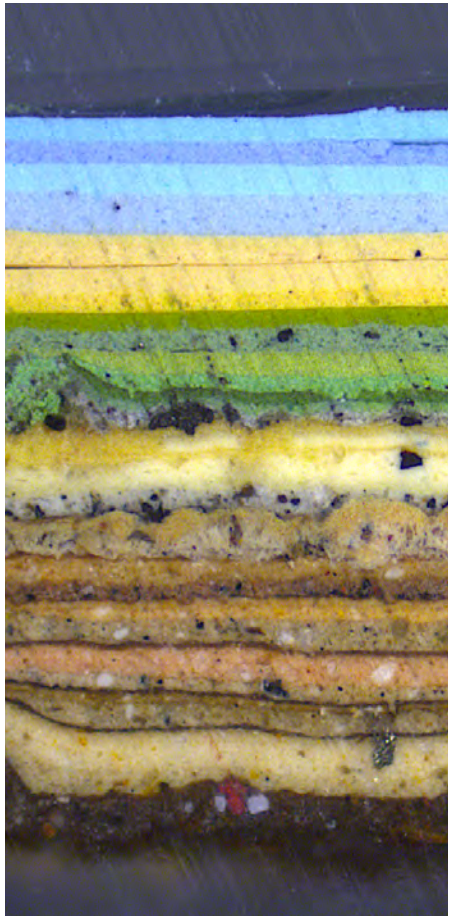
Phase 3 (post-war): predominantly in red with cream glazing bars

Phase 2: several schemes of green oil paint

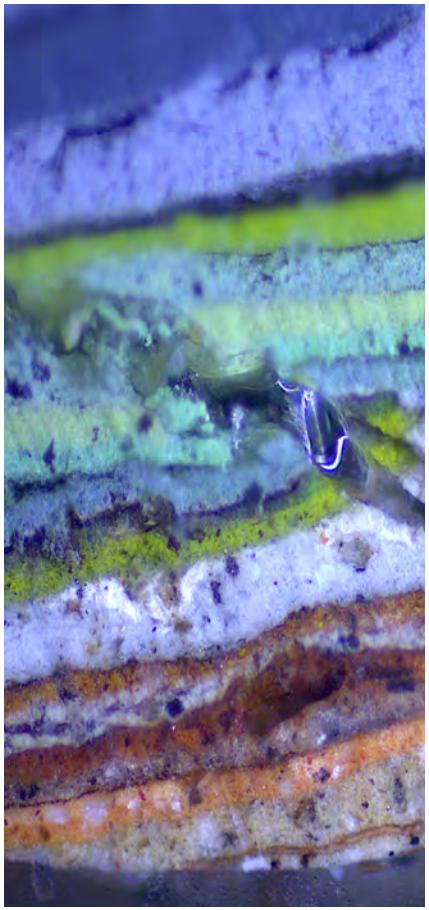
Phase 1 (earliest): initially in pale stone with white glazing bars, then salmon pink. Later pale brown with flower ornament picked iut in dark brown

6.4: High level frieze & roundels

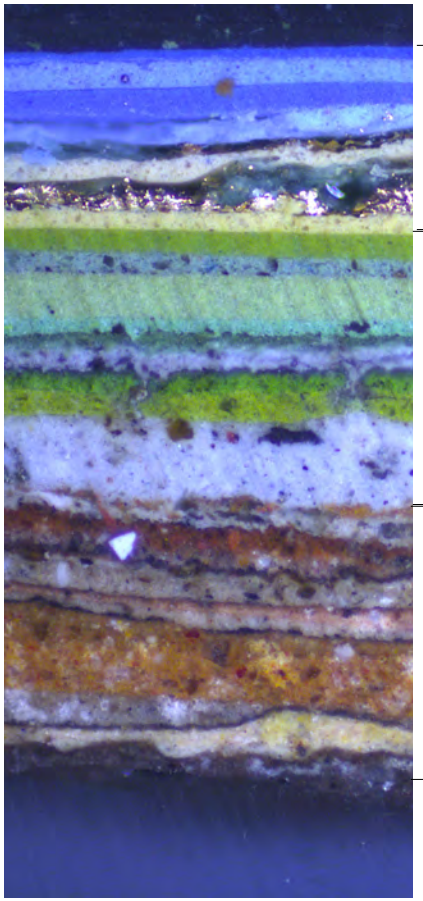
Sample 48 (frieze)



Sample 47 (frieze frame)



Sample 53 (frieze rosettes)



Phase 3: blue & turquoise

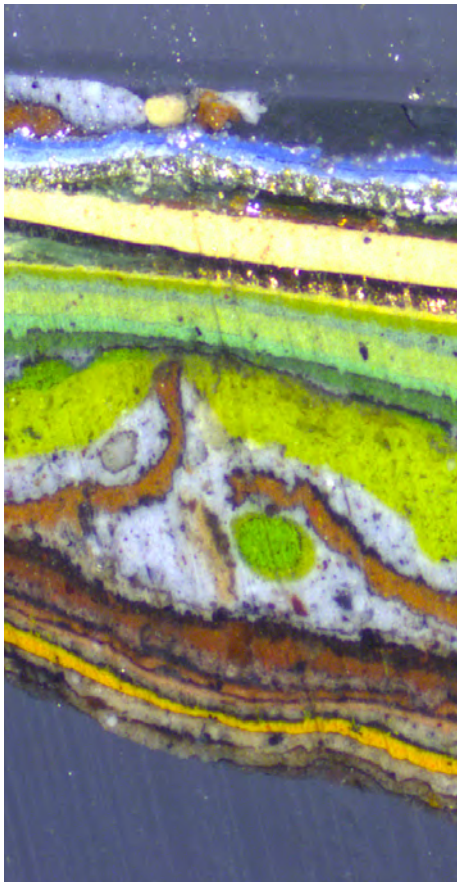
Phase 2: greens

Phase 1 (earliest): frieze background in cream with rosettes picked out in paler cream. Frieze frame painted orange/cream. Later browns and salmon colour.

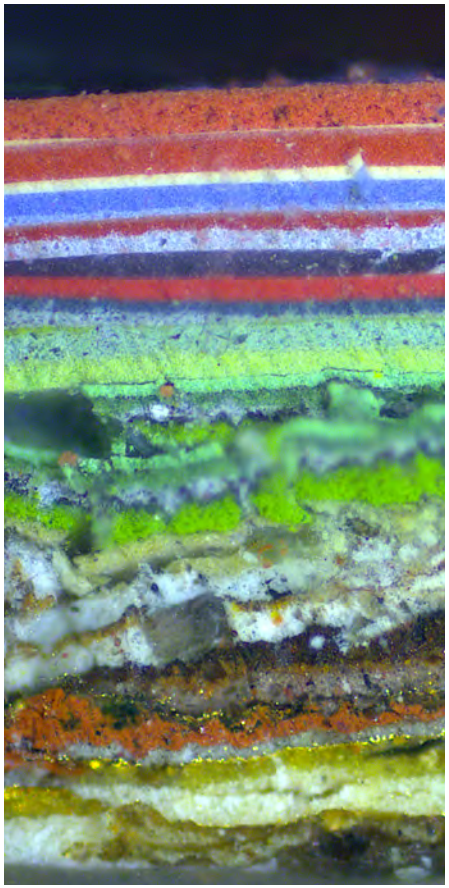
6.5: The armorial & frame

6.5.1: Frame surrounding armorial

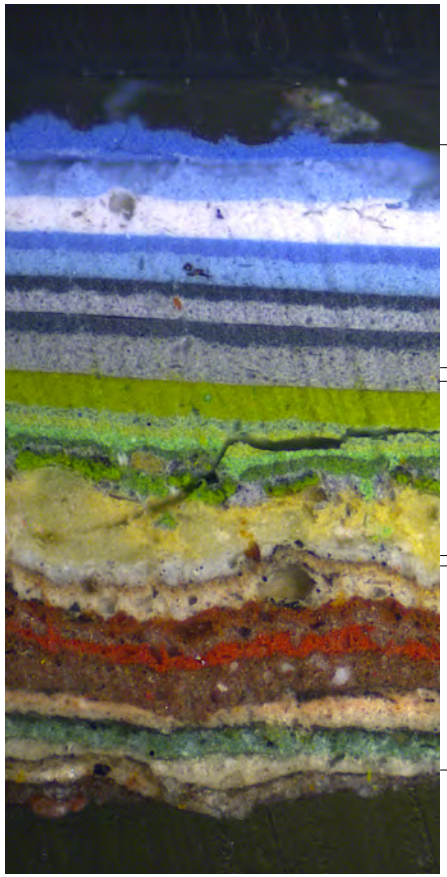
Sample 52 (rosette)



Sample 45 (frame)



Sample 31 (background)



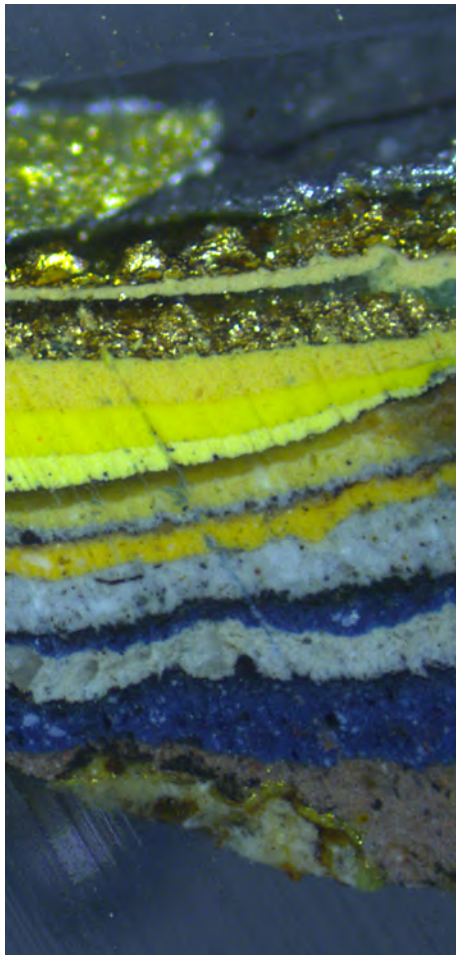
Phase 3: current appearance, red frame, silver rosettes & blue background

Phase 2: greens

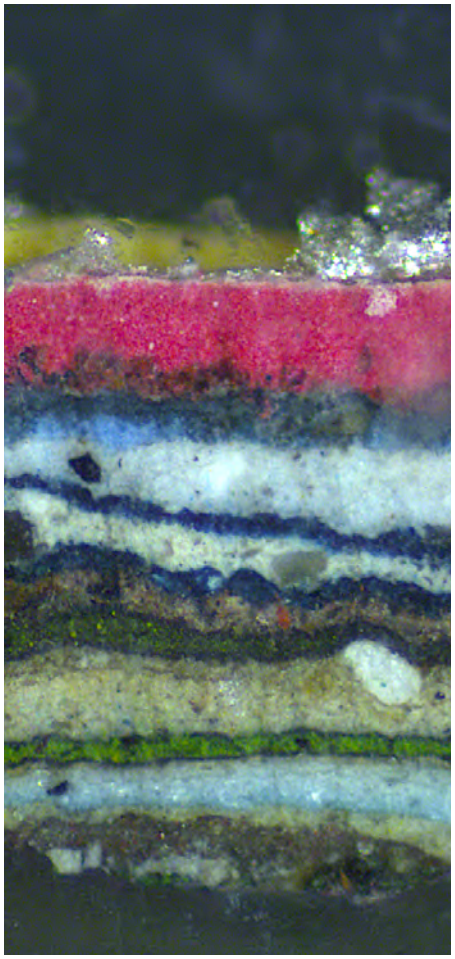
Phase 1: initially grey background and rosettes in a gilded frame. Later a bluish green background with yellow rosette. Gilded frame retained.

6.5.2: The armorial shield

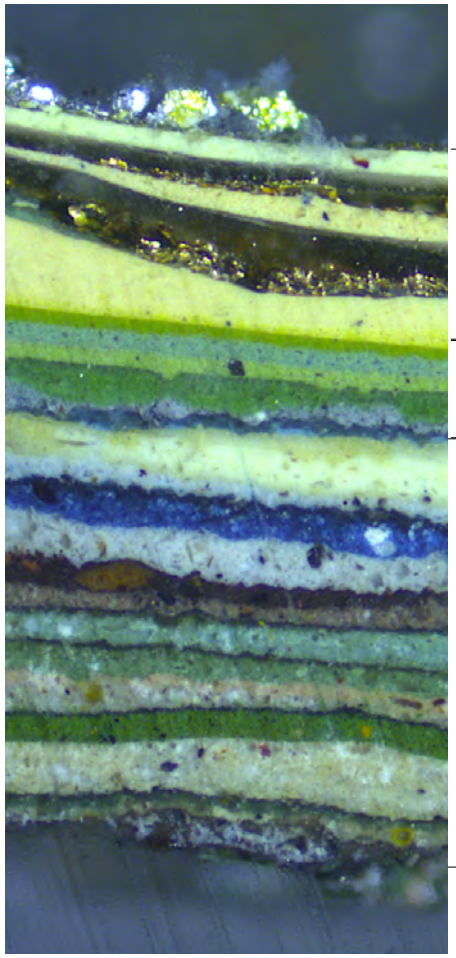
Sample 41 (background)



Sample 38 (helm)



Sample 39 (foliage)



Phase 3: features currently picked out in silver; previously gold oil paint

Phase 2: greens

Phase 1: initially gilded shield background, green foliage and pale steel blue helm.

7.0: Scheme Charts

7.1: Columns & Spandrels

	COLUMNS								SPANDREL
	Base (1)	Lower collar (2)	lower shaft (3)	mid collar (5)	Upper shaft (18)	Upper collar (24)	Capital (25/26/27)		Spandrel (19/20)
16	BLUE	TURQUOISE	BLUE	TURQUOISE	BLUE	BLUE	TURQUOISE	16	BLUE WITH TURQUOISE FLOWER
15	BLUE	TURQUOISE	BLUE	TURQUOISE	BLUE	BLUE	TURQUOISE	15	
14	BLUE	TURQUOISE	BLUE	TURQUOISE	BLUE	BLUE	TURQUOISE	14	
13	BLACK	GOLD	BLACK	GOLD	BLACK	GOLD	BLACK WITH GOLD HIGHLIGHTS	13	BLACK WITH GOLD FLOWER
12	BLACK	GOLD	BLACK	GOLD	BLACK	GOLD		12	
11	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	11	MID GREEN
10	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	10	MID GREEN
9	YELLOW/GREEN	YELLOW/GREEN	YELLOW/GREEN	YELLOW/GREEN	YELLOW/GREEN	YELLOW/GREEN	YELLOW/GREEN	9	YELLOW/GREEN
8	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	8	MID GREEN
7	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN	7	MID GREEN
6	BROWN	BROWN	BROWN	BROWN	BROWN	BROWN	BROWN	6	PALE BROWN
5	BROWN	BROWN	BROWN	BROWN	BROWN	BROWN	BROWN	5	PALE BROWN
4	NO EVIDENCE	STONE	DEEP RED	DEEP RED	DEEP RED	STONE	SALMON	4	DEEP RED
3	DEEP RED	STONE	DEEP RED	STONE	DEEP RED		SALMON	3	SALMON
2	DEEP RED	DEEP RED	DEEP RED	STONE	STONE	NO EVIDENCE	YELLOW OCHRE	2	YELLOW OCHRE
1	DEEP RED	STONE	DEEP GREEN	STONE	STONE		YELLOW OCHRE	1	YELLOW OCHRE
	Foundry Finish		Foundry Finish		Foundry Finish		Foundry Finish		Foundry Finish
	Substrate	Substrate	Substrate	Substrate	Substrate	Substrate	Substrate		Substrate

7.2: Window joinery

	WINDOWS & ASSOCIATED JOINERY					
	Roller Door frame (6)	**Window frames (30)**	**Dentils beneath window (9)**	**Iron fixing bracket (12)**	**window glazing bars (23)**	**flower ornament (29)**
16	RED	RED	PALE CREAM	BLUE	PALE CREAM	BLUE
15	RED	RED	PALE CREAM	BLUE	PALE CREAM	BLUE
14	RED	RED	PALE CREAM	BLUE	PALE CREAM	RED
13	**Substrate**		BLACK WITH GOLD DENTILS	BLACK	White	GOLD
12		RED		RED	White	GOLD
11		MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN
10		MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN
9		YELLOW/GREEN	YELLOW/GREEN	YELLOW/GREEN	YELLOW/GREEN	YELLOW/GREEN
8		MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN
7		MID GREEN	MID GREEN	MID GREEN	MID GREEN	MID GREEN
6			PALE BROWN	PALE BROWN	PALE BROWN	PALE BROWN
5		PALE BROWN	PALE BROWN	PALE BROWN	PALE BROWN	BROWN
4		SALMON	STONE	STONE	STONE	STONE
3		SALMON	STONE	STONE	SALMON	SALMON
2		STONE	YELLOW OCHRE	NO EVIDENCE	STONE	NO EVIDENCE
1		STONE	YELLOW OCHRE		LEAD WHITE	
		Softwood	**Softwood**		**Softwood**	
				Substrate		**Substrate**

7.3: Frieze, fascia & gutters

	FRIEZE, FASCIA & GUTTERS				
	fascia above frieze (33)	**Gutters (17)**	**Frieze (48)**	**Frieze Rosettes (53)**	**Freize Frame (47)**
16	PALE CREAM	BLUE	TURQUOISE	BLUE	BLUE
15	PALE CREAM	BLUE	TURQUOISE	BLUE	BLUE
14	PALE CREAM	BLUE		BLUE	BLUE
13	White	**Substrate**	CREAM	GOLD	
12	White	The gutters are relatively modern replacements	CREAM	GOLD	
11	MID GREEN		MID GREEN	MID GREEN	MID GREEN
10	MID GREEN				
9	YELLOW/GREEN		YELLOW/GREEN	PALE GREEN	PALE GREEN
8	RED LEAD PRIMER		MID GREEN	MID GREEN	MID GREEN
7	**Softwood**		CREAM		
6	Fascia added at the beginning of the phase 2 period		PALE BROWN	RED/BROWN	RED/BROWN
5			BROWN		BROWN
4			DARK STONE	PALE STONE	
3			SALMON	SALMON	ORANGE/CREAM
2			DARK STONE	RED/BROWN	
1			CREAM	STONE	ORANGE/CREAM
			Foundry Finish		
			Substrate	**Substrate**	**Substrate**

7.4: The Armorial

	ARMORIAL										
	outer backgound (31)	Frame (45)	Corner Rosette (52)	Foliage (39)	Shield (background) (41)	inner background (46)	Chevron inside shield (44)	Rams (40)	Helm (38)	Ram's head (37)	Castles (42)
16	BLUE	RED	SILVER	SILVER	SILVER	OCHRE	BLACK	BLACK	SILVER	White	SILVER
15	BLUE	RED					BLACK	BLACK		White	White
14	BLUE	RED	SILVER	SILVER		OCHRE	BLACK	BLACK	SILVER	White	SILVER
13	BLACK	RED	GOLD PAINT	GOLD PAINT	GOLD PAINT	MISSING	BLACK	GOLD PAINT	MISSING	MISSING	MISSING
12	BLACK	RED	GOLD PAINT	GOLD PAINT	GOLD PAINT		BLACK	GOLD PAINT			
11	MID GREEN	MID GREEN	MID GREEN	MISSING	MISSING	MID GREEN	BLACK	BLACK			
10	MID GREEN	MID GREEN	MID GREEN			MISSING	BLACK				
9	YELLOW/GREEN	YELLOW/GREEN	YELLOW/GREEN	YELLOW/GREEN			BLACK				
8	MID GREEN	MID GREEN	MID GREEN	MID GREEN	YELLOW		BLACK		PALE BLUE	SILVER	SILVER
7		MID GREEN			YELLOW		BLACK				
6	PALE BROWN	PALE BROWN	PALE BROWN	DEEP BLUE	DEEP BLUE	DEEP BLUE	DEEP BLUE	OIL GILDING	DEEP BLUE	OIL GILDING	OIL GILDING
5	BROWN	PALE BROWN	BROWN	DEEP BLUE	DEEP BLUE	MISSING	DEEP BLUE		DEEP BLUE	OIL GILDING	LEAD WHITE
4	DEEP RED	BLACK	BLACK	OIL GILDING	OIL GILDING		BLACK			YELLOW	LEAD WHITE
3	SALMON	OIL GILDING	SALMON	GREEN	OIL GILDING		BLACK		GREEN	YELLOW	LEAD WHITE
2	BLUE/GREEN		YELLOW		OIL GILDING	STONE	BLACK		GREEN	YELLOW	LEAD WHITE
1	MID GREY		MID STONE		OIL GILDING	STONE	BLACK	BLACK	PALE STEEL BLUE		LEAD WHITE
	Foundry Finish	Foundry Finish	Foundry Finish	Foundry Finish			Foundry Finish		Foundry Finish	Foundry Finish	
	Substrate	Substrate	Substrate	Substrate	Substrate	Substrate	Substrate	Substrate	Substrate	Substrate	Substrate

8.0: X-Ray Fluorescence (XRF) analysis

i) Hand held XRF analysis was carried out on site using a Bruker Titan 600 instrument, specifically calibrated for lead in paint and restricted materials[3]. In this instance the XRF has also been used to detect the presence of gold in the early gilding layers uncovered on the armorial shield.

ii) Three key sample sites were chosen. On the iron framework, the joinery and armorial shield

Results

i) Joinery (pre- phase 3 paint layers)

Element		Min [%]	Conc. [%]	Max [%]	Stddev. [%]
Lead	Pb		12.99		0.04
Titanium	Ti		10.67		0.07
Chromium	Cr		1.25		0.02
Zinc	Zn		0.61		0.02
Mercury	Hg		< LOD		0.01
Cadmium	Cd		< LOD		0.01
Arsenic	As		< LOD		0.03

ii) Iron framework (pre-phase 3 paint layers)

Element		Min [%]	Conc. [%]	Max [%]	Stddev. [%]
Lead	Pb		20.07		0.04
Chromium	Cr		1.74		0.03
Zinc	Zn		1.36		0.04
Titanium	Ti		< LOD		0.12
Mercury	Hg		< LOD		0.01
Cadmium	Cd		< LOD		0.01
Arsenic	As		< LOD		0.08

iii) Gilding on armorial shield

Element		Min [%]	Conc. [%]	Max [%]	Stddev. [%]
Copper	Cu		12.61		0.11
Lead	Pb		6.30		0.03
Zinc	Zn		1.87		0.03
Tin	Sn		0.03		0.01
Arsenic	As		< LOD		0.04

iv) There are high concentrations of lead in all painted surfaces beneath the phase 3 layers (typically at levels of 12% - 20%). The necessary precautions will need to be taken when preparing for re-painting. No other toxins were detected.

v) Gold is absent from the early gilded layers on the armorial shield, with copper and zinc present; evidence for the use of Dutch Metal leaf.

[3] These are toxic or hazardous materials specified under the *Restriction of Hazardous Substances Directive (RoHS*) and includes the toxic elements found in early paints, typically: lead, mercury and arsenic.

9.0: Concluding remarks and observations

i) The paint evidence suggests most of the original late 19th century structure of the Open Market has survived to the present day, with only minor alterations and additions.

ii) New joinery was fitted to support the red painted roller doors and blue painted timber fillets above, when the doors were installed. The only paint evidence here is for the current red and blue respectively, indicating they are a relatively recent installation. The cream painted fascia boards fitted above the frieze at high level was installed in the

iii) Further repair work has been carried out to the joinery, notably replacement drip mouldings on the upper windows, with stripping of paint and potentially other localised repair at the same time.

iv) The only evidence on the blue painted pierced iron girder fronting the glass canopy and all the cast iron guttering is the blue currently extant today, without any traces of earlier schemes. This suggests the glass canopy fitted above bays around the perimeter of the building and the iron guttering are later additions.

v) The stratigraphy of the paints on the iron frame work has survived well, retaining solid evidence for the historic appearance of this structure. The accompanying scheme charts provide a coloured representation of the iron work throughout the past 130 years or so.

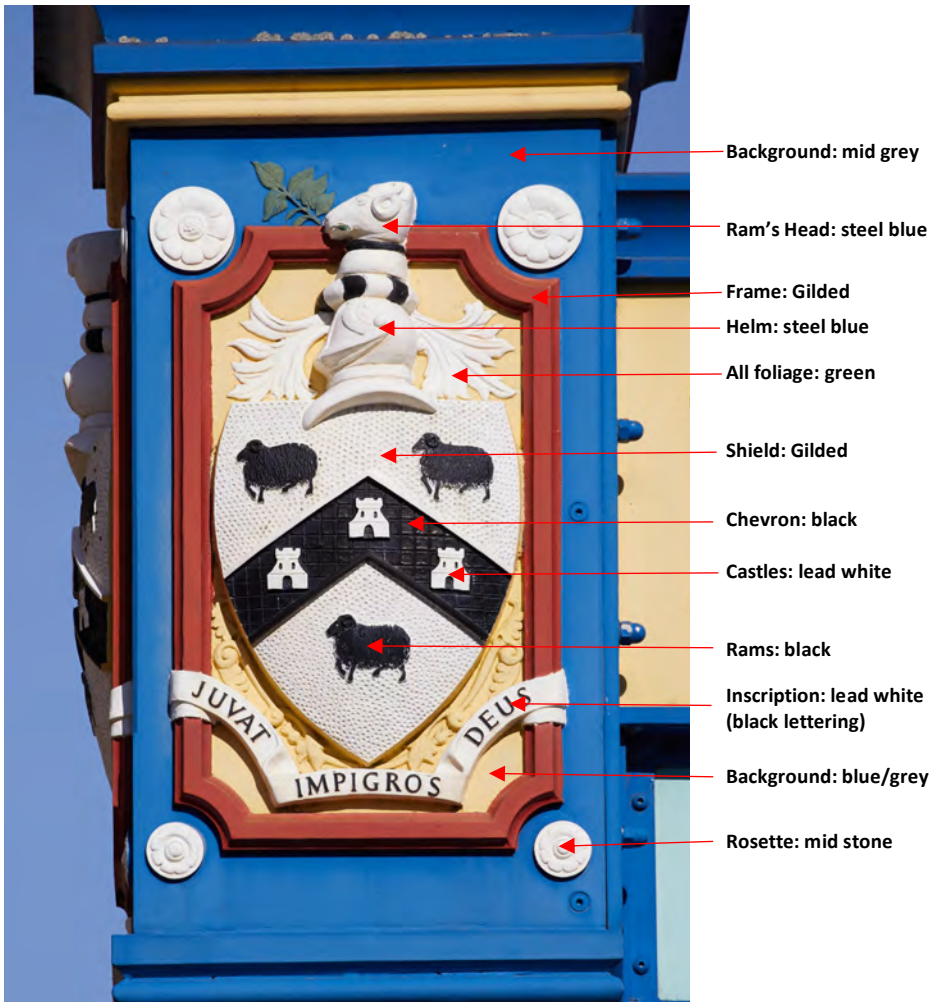
vi) It should be noted that the colours presented in the scheme charts are only representative and intended to provide an overall impression of colour. If there is a need to faithfully reproduce any of the historic colours a further site visit will be required to clean back surfaces, expose the target colours and measure using a

spectrophotometer. Accurate colour references may then be provided, allowing the historic colours to be mixed using a modern safe and durable paint system.

vii) One of the key decorative features here is the Huddersfield Coat of Arms armorial capping each of the supporting columns. The remaining paint evidence on the example sampled was quite fragmentary and a little confused due to the cleaning and preparation of surfaces prior to repainting.

viii) A suggested colour allocation for the armorial is provided in fig.3 that represents the original late 19th century appearance.

Figure 3: Suggested colour allocation for the armorial[4]



[4] Mark Waugh / Alamy Stock Photo (licence purchased)

9.0: Mortar Analysis

Six mortar samples were removed from the masonry inside the market itself and from the external perimeter wall, in order to understand the composition of the mortars. In order to achieve this, aggregate and binder portions were separated followed by analysis by powder X-ray Diffraction (pXRD). The resulting diffraction patterns were cross-referenced against a database of known materials in order to determine the dominant and minor phases present.

9.1: Sample details

Sample Location	Sample no.
Market Hall interior, black re-pointing	1
Market Hall interior, early mortar underlying the black repointing	2
Exterior (toilet block hard ribbon pointing)	3
Exterior (Market café hard ribbon pointing)	4
Exterior (market café early underlying mortar)	5
Exterior (underlying mortar next to red roller door)	6

9.2: Sample locations

9.2.1: Samples 1 & 2

9.2.2: Samples 3 - 6

9.3: Method (light microscopy / powder X-Ray Diffraction

i) The mortar samples were ground by hand to an even powder. A portion of the powder (~5g) was sieved, initially through a 1.7mm sieve to remove any unbroken mortar and then through 0.140 mm and 0.045 mm sieves respectively.

ii) For the purposes of pXRD analysis that fraction of the sample which was retained by the 0.140 mm sieve was designated aggregate whilst that fraction passing through the 0.045 mm sieve was determined to be binder. For the determination of aggregate and binder masses, that fraction which was > 0.045mm was designated aggregate whilst material < 0.045 mm was determined to be binder.

iii) The two fractions were imaged using a stereo microscope at x40 magnification. The sieved aggregate/ binder fractions were then analysed using powder X-Ray diffraction (pXRD) using a Bruker D8 Discover instrument.

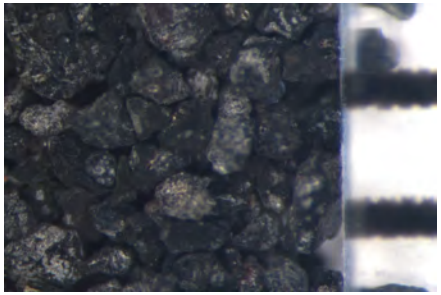
9.4: Results

9.4.1: Aggregate:Binder ratios

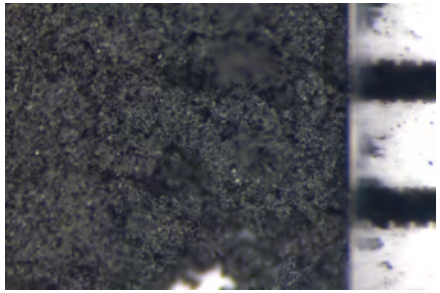
Indicative aggregate:binder ratios by weight and by volume.

Sample	*Aggregate:Binder*		*Aggregate Grain Size*
	By weight	*By volume*	*(mm)*
1	2.1:1	2.1:1	≤0.5
2	2.1:1	2.2:1	*0.1-1*
3	3.6:1	3.4:1	0.5-1
4	3.5:1	3.6:1	0.5-1
5	3.7:1	3.7:1	0.5-1
6	3.9:1	3.8:1	0.5-1

9.4.2: Photomicrographs (X40) of the ground samples (1mm scale)

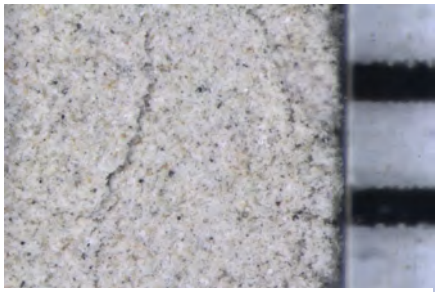


Sample 1: aggregate

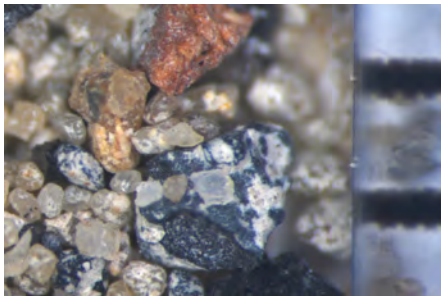


Sample 1: binder

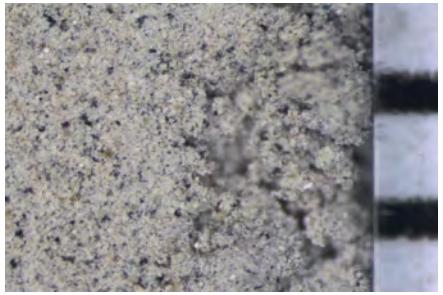
Sample 4: aggregate



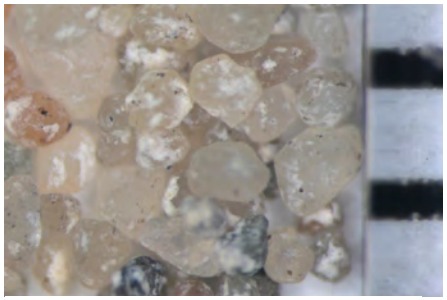
Sample 4: binder



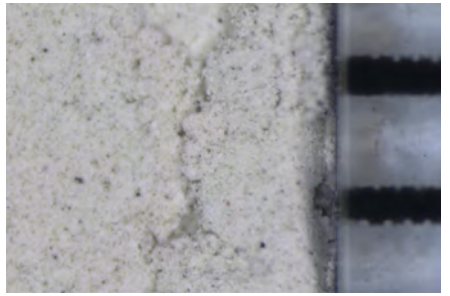
Sample 2: aggregate



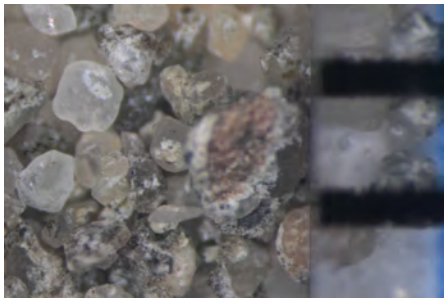
Sample 2: binder



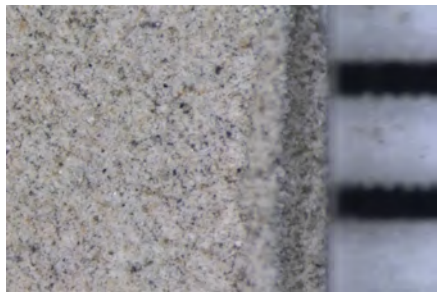
Sample 5: aggregate



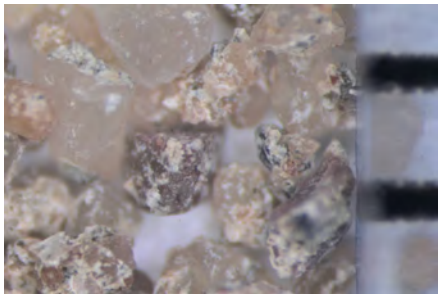
Sample 5: binder



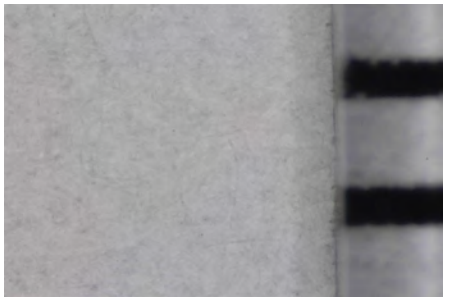
Sample 3: aggregate



Sample 3: binder



Sample 6: aggregate



Sample 6: binder

9.4.3: pXRD Analysis

9.4.3.1: Sample 1

The aggregate was comprised primarily of gypsum, calcite (limestone) and quartz (sand). Also present were the pyroxene (silicate) minerals enstatite and ferrosilite which are common in the earth's crust co-existing with other igneous and metamorphic rocks and presumably present as mineralogical impurities. These minerals were only present at appreciable levels in this sample and may be responsible for the dark appearance of the sample compared to the other mortars. Alternatively, a dye or colourant may have been added, that is not detectable using this type of analysis. The only difference between the aggregate and binder fractions was the presence of Muscovite (mica) in the binder fraction. This is an aluminosilicate mineral which was again presumably only present as an impurity. The sample mineralogy was consistent with a **non-hydraulic lime mortar**, possibly with a limestone aggregate used together with sand.

9.4.3.2: Sample 2

The sample was compositionally similar to sample 1 with the additional presence of anorthite observed. This is a rare aluminosilicate mineral and its detection is unusual in these types of samples. In addition, chlorite, another aluminosilicate, was observed in the binder fraction only. Overall, the sample mineralogy was consistent with a **non-hydraulic lime mortar**, possibly with a limestone aggregate used together with sand.

9.4.3.3: Samples 3 & 4

The aggregate fraction was comprised primarily of quartz and calcite with the additional presence of gypsum and muscovite. The binder was compositionally similar suggesting poor separation of the fractions but did contain brownmillerite and trace amounts of portlandite. This is evidence of **Ordinary Portland Cement (OPC)**.

9.4.3.3: Sample 5

The aggregate fraction was dominated by the presence of calcite and quartz with some aluminosilicate minerals also present. The binder fraction was similar except that gypsum and an iron/ magnesium silicate mineral (Enstatite) was also present. Orthoclase, typical of clay type minerals was also present in both fractions. The presence of belite together with calcite suggest the sample is a **hydraulic lime mortar**, possibly with a limestone aggregate used together with sand.

9.4.3.4: Sample 6

The aggregate fraction was again dominated by the presence of calcite and quartz. Muscovite and Biotite were also present, presumably as mineralogical impurities. The binder fraction was compositionally similar to the aggregate fraction with the additional presence of silicate minerals, indicative of clay-type minerals. The sample mineralogy was consistent with a **non-hydraulic lime mortar**, possibly with a limestone aggregate used together with sand.

9.5: Summary

i) The original non-hydraulic lime mortar underlies a later dark re-pointing on the interior wall inside the market (samples 1 and 2). Both are non-hydraulic lime, with similar strong mix ratios (approx. 2 parts aggregate to 1-part binder). The later re-pointing has a high compressive strength and is very dark (almost black) in colour, rendering it inappropriate in this location and should be removed prior to re-pointing.

A non-hydraulic repair mortar (NHL 2.0) of a neutral limestone colour using a 2:1 mix ratio with an average aggregate grain size is suggested for this location.

ii) Samples 3 and 4 were removed from the hard 'ribbon' re-pointing applied relatively recently (possibly during the 1980 restoration or even later). This is a hard and inflexible Ordinary Portland Cement (OPC) overlying the original lime mortars defined here as samples 5 and 6.

iii) Samples 5 & 6 are early mortars that lie beneath the later OPC ribbon pointing. Both are lime based, with sample 5 defined as a hydraulic lime and sample 6 as non-hydraulic. Presumably both samples were applied at different periods and may represent an example of earlier repair or repointing. In both cases a mix ratio of approx. 4 parts aggregate to one part binder was used with an average aggregate grain size of 0.5 – 1.0mm.

HISTORIC MATERIALS ANALYSIS

HISTORIC INTERIORS

ARCHITECTURAL CERAMICS AND TILES

OBJECT CONSERVATION

DIGITAL HERITAGE

LINCOLN
CONSERVATION

www.lincolnconservation.co.uk
info@lincolnconservation.co.uk
01522 835055 or 5051

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