Reconstructions of Oil Painting Materials and Techniques: The HART Model for Approaching Historical Accuracy

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Introduction to the HART Model

In the fields of art and of conservation-restoration, the term 'reconstruction' can have many meanings. A reproduction, or copy, can be made in order to understand how a specific painting was created and has a long and distinguished history in the classical training and education of artists.[1] In conservation training courses, undertaking a reproduction or copy is a successful strategy to help students understand and interpret an artist's technique prior to carrying out a conservation-restoration treatment on the original (see Stols-Witlox in this volume).

The term 'Historically Accurate Reconstruction Techniques' (HART) was coined in the early 2000s to describe a specific approach to the investigation of artists' material choices, including their preparation (using recipes) and application in the act of creating an oil painting. This research model, which was developed during the HART Project,[2] is a significant departure from the aims involved in making oil painting reproductions or facsimiles. It relies on the use of materials appropriate to the time of the recipe(s) with the aim of producing historical models at the material level, not only in terms of surface appearances.

What is meant by historical accuracy?

As will be seen, the search for historically appropriate materials for replicating or reconstructing recipes leads directly into a practical cul-de-sac. It is obviously not possible to recreate the past. However, attempting to is in itself a highly edifying goal. Not only do we learn unexpected things by aspiring to historical accuracy, we also ask new questions of what has already been discovered.

For example, chemical analyses of historical paintings frequently identify the presence of calcite, commonly in the form of chalk, in the preparation layers (or grounds) used to coat canvases and panels prior to painting.[3] Reconstructions using unprocessed chalk, rather than modern cleaned and treated chalk, show that the unprocessed material mixed in oil is not the pure creamy-white we get with modern chalk, but is in fact dark beige (Plates 1a & b).[4] In this case the new questions posed of an old discovery (the presence of chalk) are: What colour was it when it was used? Were early oil-based chalk grounds dark beige? Does that explain artists' descriptions of grounds that were tan or leather coloured?[5] When did chalk begin to be processed in such a way that it maintained its white colour in oil?[6]

In order to pursue this work, to experience the outcome of following old recipes (a form of re-enactment), and to create reference materials for future analysis and study, it is necessary to adopt a concept of historical accuracy which is entirely relative. As outlined elsewhere[7] and briefly summarised here, the scientific term for accuracy as defined in ISO Standard 5725-1, is useful for illustrating what 'accuracy' can mean for reconstructions using historical materials.[8] ISO 5725-1 illustrates accuracy in a bullseye diagram where it is shown as a measure of the relative distance from a goal, or in ISO terms, trueness. Plate 2 shows how aspirations for historical accuracy, such as choosing representative recipes from large collections of documentary sources, or sourcing materials at least somewhat appropriate to the time, takes researchers closer to the ISO bullseye of trueness than if we blindly reconstruct so-called historical oil paint using commercially available oil and modern pigments and fillers, most of which bear only a passing resemblance to those available in the past.

The HART Model components

The HART Model evolved from research into historical documentary sources covering recipes and instructions for painting in oil. The intention was to understand what material choices artists were making and why, and how they proceeded to construct their paintings.[9] This work naturally led to the question of what written instructions actually meant in practice. Reconstructions were made to explore how the materials might behave during preparation and application, and to investigate whether they could be compared with what is found in paintings contemporary to the recipes.

From the beginning, when undertaking reconstructions, an effort was made to find historically appropriate materials and methods. This step proved to be central; the very act of asking whether a given material was appropriate for a reconstruction uncovered an area of research that previously had not been systematically explored within a comprehensive research model. In addition, in reconstructing an instruction or recipe there were inevitably decisions to adopt one interpretation over another, with consequent compromises.

The assembly of materials and the physical samples from recipe reconstructions (varnishes, oil paints, preparation layers and composites) results in a unique reference collection for comparative visual and chemical analyses in the study of historical oil paintings. The thorough documentation of all aspects of the reconstruction and of the individual components employed results in 'highly characterised reconstructions' (HCRs). As will be seen, this greatly enhances their value as reference materials. What follows is a detailed look at the three interconnected parts of the HART research model.

Part I: Reconstructions using representative recipes and historically appropriate ingredients

One of the cornerstones of the HART Model is that the practical instructions and recipes selected for reconstructions are representative. That is, they represent instructions which exist in a particular context since they were chosen from a substantial body of information[10] (see Part III describing documentary source research).[11]

Historically appropriate materials and historical accuracy

One of the first findings in the HART Project concerned the difference in morphology and behaviour in oil paint, of traditional stack-process lead white and twentieth-century, or modern lead whites (Figures 5.1a, b & c). Scanning Electron Microscope images (SEM-EDX backscatter) of cross-sections from traditional paintings consistently revealed a range of particle sizes, from significant lumps to finely divided particles. This behaviour in oil could only be achieved with historical reconstructions of stack-process lead white; modern sources of lead white exhibited small, uniform and finely dispersed pigments.[12] Similarly, commercial sources of modern processed chalk did not display the clumping behaviour visible in the cross-section from the historical painting (Figure 5.1b). As Figure 5.1c illustrates, clumping could only be achieved by using unprocessed chalk since the product prepared for industry has undergone various treatments such as the addition of anti-clogging agents. As noted above (Plate 1), the differences in colour in oil between the raw material and the commercial product were also very significant.

There are many more examples of modern materials that do not reflect what was in use in the past. While individual pigments may be very similar to historical pigments in their chemical formulae, modern industrial manufacture means that they may exhibit significantly finer particle sizes as well as having received a range of surface treatments and coatings.[13] Pigment surface treatments (intended, for example, to stabilise, aid dispersion in the binder, or improve flow properties of coatings) may interrupt or inhibit pigment/binder interactions that would have occurred in historical oil paints.

Modern sources of artists' linseed oil are also unlikely to be representative of oil available in the past. The oil source itself is a good example for exposing the complexity of sourcing appropriate material and for demonstrating the compromises involved. The oil yield and ratio of components in linseed oil is influenced by many factors, such as growing conditions (e.g. geographic location, temperature) and the plant cultivar.[14] Commercially available artists' linseed oil is reported to be a blend of linseed sources and has been pre-processed before it reaches the market (i.e. to remove the water-soluble component present in freshly extracted oil). Since it was not possible in the HART Project to establish a single linseed cultivar that would have been available for a particular time or place, or even to establish the level of purity that historical sources of linseed oil possessed,[15] linseeds were procured from a single biological grower and used consistently throughout. Because oil pressing on an industrial scale introduces other variables (i.e. heat, pressure, and contamination with other oils), a custom-made stainless-steel oil press was used to control these variables. In the case of the oil source, the ideal of historical accuracy gave way to the compromise of producing reconstructions with a single consistent oil source, making them directly comparable chemically as well as being highly characterised.

Similar issues with historical accuracy involve problems of scale, both in amounts and in time; for example production records from the nineteenth century colourman Winsor & Newton (W&N) reveal that from twenty to seventy gallons (91 to 318 litres) of oil would be maintained at 212°F (100°C) for up to eight days in the preparation of drying oils for paint making, whereas laboratory reconstructions of drying oil typically involve much smaller amounts over a significantly shorter period. This presumably influences the chemical nature of the final product.[16]

Representative recipe use: literal recipe reconstructions and model recipes

In some cases, a recipe from a single source can be shown to be representative in the context of an overall recipe collection. In such cases the recipe is then followed as closely as possible. In other cases, where recipes are complex and/or proportions are not reported, the reconstruction may be made using a simplified model recipe to reduce variables and for consistency throughout a project. In that case the proportion of ingredients can be established by comparing a significant number of records (see below) and determining the proportions which appear most frequently. This working recipe is an editorial synthesis based on a number of documentary sources.

An illustration of a reconstruction which can be followed literally from a single historical recipe is the step-by-step instructions from Winsor & Newton's nineteenth century archive for an oil painting preparation layer (ground) dated 1871. To date, W&N's archive is the only source found which offers detailed information for nineteenth century commercially prepared grounds. The 1871 recipe, like the other production records from their archive, reveals that their commercial practices were far more complex in terms of materials and preparation steps than have been found in recipes published in artists' instruction manuals.[17]

An example of choosing the proportion to use for a representative recipe is the artists' paint addition (or Medium) 'Megilp', which was a popular nineteenth century product used to adjust oil paint flow characteristics and transparency. It consists of a mixture of lead treated linseed oil with concentrated mastic varnish. To determine the proportions to use in reconstructions, a large recipe collection was consulted. Analysis of 26 recipes or descriptions revealed that the most common proportion was 1:1 (fifteen of 26 recipes), with 2:1 being the second most frequently mentioned (eight of 26 recipes). After 1849, recipes were consistent in calling for the 1:1 ratio, making this proportion 'representative' for post 1849.[18]

An example of the creation of a model recipe is the choice of ingredients and production process for a standardised drying oil. After evaluating the many nineteenth century recipes for treating linseed oil prior to use, which frequently called for multiple drying agents, a model drying oil was produced based on recipes with only two ingredients (oil and lead (II) oxide). Fixed proportions and amounts were heated together to a consistent temperature (150°C), to limit experimental variables.[19]

Reconstructions and samples from oil paintings, comparative analyses

The Evaluation of the visual and analytical evidence in paint micro-samples from historical oil paintings can be greatly improved by comparison with reconstructions (Plates 5.3a-e). This was taken to a new level in the HART Project as a consequence of the need to produce viable reconstructions of Van Gogh's preparation layers (or grounds) as a first step in investigating his paint and how it behaved upon application. While it had been customary to simply report on the presence of different materials, for example, that a given ground in a Van Gogh painting contained both lead white and barium sulphate, the desire to reconstruct that ground led to questioning the proportion of lead white and barium sulphate actually present.

In parallel to this question was another regarding the role of the barium sulphate. A popular additive to lead white in the nineteenth century, the influence of barium sulphate in terms of its behaviour in oil paint and its appearance was not clear. A series of white lead oil paints were therefore prepared with stepped proportions from five percent to 75 percent by weight barium sulphate. Cross-sections of the reconstructions were viewed by Scanning Electron Microscopy backscatter imaging (SEM) and Energy Dispersive X-ray analyses (EDX) software was used to confirm the proportions present. This revealed that the software was reporting percentages that were significantly inaccurate. The need to calibrate the instrument with known mixtures had not been previously appreciated. This was also the case with chalk/lead white ratios.[20]

Issues with detection limits and the ability of a given analytical instrument to identify the presence of a relatively minor ingredient, which could nevertheless have a profound influence on the behaviour of oil paint during and after application, have been explored using HART HCRs. For example, finding analytical evidence of copal oil varnish reported by artists to have been mixed into their oil paint (e.g. as a Medium to modify paint flow) has been challenging, even using state of the art analytical instruments.[21] Recently, a set of HCRs of hand-ground oil paint with stepped proportions of a reconstructed copal oil varnish[22] were used to test the capacity of different analytical protocols and instruments to successfully detect this material in the oil paint matrix.[23] An improved understanding of the composition of copal oil varnish through its preparation according to historical recipes, and of the detection limits for characteristic marker compounds, facilitates the study of this material in historical paintings.

Re-enactment: experiential and visual evidence of oil paint flow properties

The way that oil paint behaves under the brush or palette knife during application (its rheological properties), was rarely described in any detail in the British nineteenth century handbooks and manuals studied. However, an interest in paint flow qualities was implicit in the many recipes provided for artists' Mediums since their addition to the paint influenced flow and transparency. Given how crucial the flow properties of the paint are to the final image, whether fluid or paste-like or somewhere in between, it is surprising that this feature did not receive marked and consistent attention.

When a series of recipes for processing the oil prior to use in paint were explored using a single linseed oil source, the influence of oil processing was found to be surprisingly profound.[24] Untreated freshly expressed linseed oil, hand-ground with stack-process lead white, resulted in a paste-like paint, whereas the traditional oil processing method of washing the oil in water produced a lead white paint that was quite fluid. Similar effects were seen when the oil was heated either to 150°C or 300°C (see Plates 5.4a & b). Why this range of behaviours was not described in late eighteenth-century and nineteenth century British sources is likely explained by the wide availability of pre-processed oil from the artists' colourmen. Even when hand-grinding their own oil paint with powdered pigments, artists would have been selecting from a limited range of oil products which would in turn produce a limited range of behaviours (e.g. nineteenth century colourmen catalogues generally listed only the following: Purified Linseed Oil, Poppy Oil, Nut Oil, Pale Drying Oil, Strong Drying Oil and Fat Oil).[25]

Since the responsiveness of the lead white oil paint was so distinct, depending not only on the oil processing, but also on the effect of extenders such as chalk, barium sulphate, magnesium carbonate, beeswax, and aluminium stearate, it was necessary to define a vocabulary for describing how the oil paint handled during application. Interestingly, it was also found that the paint's behaviour was radically affected by the use of a brush versus a palette knife, and the use of the paint industry's tool: the fixed-distance draw-down bar. Some of the paints prepared could easily be brushed but would not form uniform draw-downs, whereas others which worked well with the palette knife were too stiff to brush out easily. The HART team members, preparing and painting out various lead white oil paint formulations in an effort to recreate the visual evidence of paint flow found in Van Gogh's paintings, worked together to describe the 'feel' of the different paints in an attempt to develop a common vocabulary. Words such as 'flexible', 'springy', 'dead', 'unresponsive', and descriptions like 'has strong/weak cohesive strength' were chosen.[26]

An unexpected outcome of this work was that this close and exacting attention to the paints' flow and appearance after application led to a heightened awareness of paint surfaces on historical paintings and a new visual literacy. The way the paint appeared on a Rembrandt versus a Van Gogh or one of his contemporaries could be 'read' in the now frozen features of a brush stroke; what the fresh paint must have been like in order to produce a fluid line or a thick impasto, its fundamental characteristics, became visible. The reconstructions demonstrated that the paint composition itself dictated the way the paint appeared in application; the material combinations gave results that were largely predictable and characteristic of that particular formulation (Plate 5.5).

The importance of the substrate for oil paint studies

A further interesting development emerging from the HART experiments were the observations resulting from the way the oil paint behaved when applied to a variety of different substrates, ranging from reconstructions of painter's grounds on canvas, to modern artists' boards, ceramic tiles, and polyester film. That the paint is significantly influenced by the substrate was the subject of a great deal of commentary in the British eighteenth- and nineteenth century handbooks and manuals and was later identified as an area of focus in the much broader and deeper study of grounds carried out by Stols-Witlox.[27]

To achieve uniform thicknesses for study and analysis of the oil paints, draw-downs (paint applied with a metal fixed-distance applicator) were applied to transparent polyester film. This film was also used for brushing out any paint left over. While thin paint films on such a non-absorbent surface dry as expected, the same paint brushed out in thick applications behaves very differently, exhibiting defects such as wrinkling, shrinkage and oil separation (forming exudates of oil at the surface) (Plate 5.6a). Some of these effects are not visually apparent for decades. The same paint applied thickly to artists' boards (with commercially prepared grounds over a canvas-like texture) or over ground reconstructions do not exhibit such problems (Plate 5.6b).

The importance of storage conditions for oil paint reconstructions

As the reconstructions undergo decades of natural aging, the importance of keeping oil paint surfaces apart (not stacked together) and allowing surfaces to be exposed to the air becomes more and more evident. After sixteen years, thin polyester films used as dust covers over fully dried paint samples began to stick to the surfaces of some, necessitating horizontal storage with dust covers elevated above their surfaces. Some examples of oil paint applied in 2004 to glass slides, with polyester film dust covers applied after they had fully dried, were completely liquified by 2017.

Part II: Highly characterised reconstructions as reference materials

Documentation

What makes the reconstructions 'highly characterised' and therefore important as reference materials and for future research is that in the HART Model each material used, their combination and the results are all carefully documented. The individual materials used are labelled with the date of acquisition and the supplier and stored alongside the reconstructions.

The materials in any given reconstruction can be identified using its unique and detailed code. An example of the exacting information for a given HART oil paint reconstruction is provided in Carlyle, 'Practical Considerations' p. 109. The sample label includes the date made, the project number, sample number and substrate and the combination of materials used. The materials' code then leads back to precise information on that ingredient. For example, in the code SWAB1-08-05: 'SWA' refers to reconstructed stack-process lead white pigment (S) Batch 2.6 produced by supplier Jeff Seynaeve during the summer of 2003. This was washed in water (WA) and dried prior to use. To this was added B1, an unprocessed barium sulphate from the Sachtleben Company (in this sample present at five percent by dry weight (05) with 95 percent SWA lead white). The code includes the oil used, (08): oil extracted from Electra Linseeds in 1999 and water washed in 2003.

A strip of the metallic lead (roofer's lead) used by Jeff Seynaeve[28] to reconstruct traditional stack process lead white pigment has been kept, as have the original flakes of untreated lead white pigment which are stored according to the batches received and their date. Samples of the original linseeds purchased in 1999 are kept along with the linseed oil extracted, including the date of extraction. Oils which were further processed (water washing, heating with lead (II) oxide, etc.) are also part of the MOLART and HART materials collection. All dry pigments and chemical compounds are preserved as well.

This level of detail in the documentation as well as the preservation of the starting materials has proved essential for recent work on radiocarbon (^{14}C) dating of lead white pigment alone and in oil paint. Dated reconstructions of stack-process lead white pigment and the same pigment then made into oil paint have been invaluable for confirming the accuracy and reliability of this new method for ^{14}C dating of micro-samples.[29]

Part III: Historical technical documents: a database research methodology

This section details a research methodology developed over several different recipe database projects which have designed-in options for data extraction such that the database itself becomes an interactive research tool. Examples are described here as illustrations of the requirements for future online databases if they are to become viable as research tools for a variety of users and not just repositories of searchable information.

While collecting large amounts of data, for example in the form of descriptions of painters' materials and how to use them, has been made easier with the advent of the Web, the sheer volume of information is formidable.[30] A method to investigate the contents of these technical treatises is essential, since repetitions and variations are impossible to evaluate and understand without a system to track editions and query the data.

Database design

The investigation of technical historical sources is not by its nature a linear process which simply follows the chronology of the records. Designing and populating a database and unearthing new documents proceed as parallel activities. At the simplest level, records and books are often found out-of-order in terms of their dates and editions with data entry completed on a second or third edition before the first is located. At another, more sophisticated level, the records themselves require repeated evaluation not only because of the acquisition of new sources, but also because of new interpretations. This means that the system of posing and even identifying queries is essentially recursive: a constant process of circling around and back to records entered previously.[31]

Tagging/linking records
Interpretation involves grouping records through a system of 'tagging (annotating)' or 'linking'. For example, in recipes for 'Bitumen Tube Paint' in the Winsor & Newton Nineteenth Century Archive Database (W&N Database), one of the ingredients was 'Bitumen C'.[32] Initially we pictured a large bag or crate of raw bitumen labelled C'. This made sense in view of the company's habit of recording the source of the materials called for in a given recipe: e.g. Egyptian Asphaltum bought off 'S D Aug 1857' (Plate 5.7).[33] However, after collecting and reading through all their records on this topic, we discovered that Bitumen C, is in fact another heat-processed material made by the company with a complex list of ingredients of its own; it is not a simple raw material at all. A fixed database would not allow users to correct assumptions nor to annotate and link records, leaving future researchers to potentially repeat the misinterpretation of Bitumen C ad infinitum.

The authority field and the field for interpreted terms
Regarding the interpretation of terminology, while in many cases researchers can resort to commonly available dictionaries of historical terms, this is not always possible. As the W&N Database revealed, the company used general terms, such as 'Spar' very specifically; in their case 'Spar' consistently refers to magnesium carbonate. Other terms appear to be idiosyncratic: 'White Earth' as produced by W&N consisted of aluminate.[34] The need to track the reasoning for the interpretation of the company's terms and to cite both internal and external references led to the introduction of the 'Authority Field'.[35]

To provide a controlled consistent vocabulary with normalised spelling, and to identify arcane and obsolete terminology (e.g. 'Sacrum' and 'Sugar of Lead', both of which were synonymous with lead acetate), the W&N database includes fields for 'Interpreted terms' which appear in the recipe summary page alongside the company's original names. The explanation for interpreted terms is held in the Authority Field. As new insight and expertise is developed, both the 'authority field' and 'interpreted terms' need to be capable of revision.

Information extraction through recursive refinements
Current work to extract information from a collection of over 900 records relating to historical methods for the cleaning of oil paintings (see endnote 30) offers a good example for describing the procedure of successive topic 'refining'. This is such an important aspect of carrying out a critical analysis of historical records that it deserves explanation. After all bibliographic details were placed in appropriate fields (author, title, date of publication, location of publication etc.), records were sorted into broad categories: e.g. recipes which identify materials and amounts; general instructions; and comments/observations. General categories were then subdivided by introducing yes/no fields. For example, to investigate liquid cleaning, further refinements were introduced, e.g. aqueous based versus solvents (Plate 5.8). Then, new subdivisions were introduced to break down aqueous ingredients into alkaline or acidic, and in the case of cleaning with solvents, to track their identity (e.g. alcohols or hydrocarbons).

At this point it was possible to show that of the aqueous-based cleaning records, over fifty percent involved cleaning with alkalis (Plate 5.9) and that a frequent source of the alkali was wood-ash lye. Damaged and abraded paint on historical oil paintings was thought to have resulted from the use of lye, but only based on anecdotal evidence. For the first time rigorously investigated evidence demonstrated that this type of cleaning has been described over an extended period of time and in a variety of locations.[36]

To identify a representative recipe to reconstruct lye with historically appropriate materials and methods, new fields were introduced to effect the extraction of information in more and more detail: was the wood type for making the lye identified? If so, was any particular wood mentioned more frequently than others? Each query then involved going back through previous records to tag them accordingly. Finally, a drop-down search field listing all wood or plant matter described in the sources for lye making could be built. The evidence was compiled through successive, increasingly refined queries of large sets of text-based data. The database ensured that meaningful reconstructions of historically appropriate cleaning agents could be accomplished within a reasonable time frame.

The 'End Use' field

Another refinement to extract information from recipes is a keyword field entitled 'End Use'. It revealed that a single ingredient, such as 'mastic resin', most often associated with a final picture varnish, was not restricted in use to the top varnish layer of a painting. The collection of keywords showed that this material could be present in-between layers of paint (as an isolating varnish), on top of the preparation layer or ground (to seal the ground) or in the paint itself, as part of a painter's Medium meant to modify the paint's flow properties.[37] Similar multi-functions were revealed for Copal Oil Varnish which, along with Mastic Varnish, was sold throughout the nineteenth century by artists' suppliers.

As the W&N database revealed, the company incorporated residues from a variety of products in multiple ways, e.g. oil varnish 'bottoms' or residues in their varnish-making pots were used in their preparation of artists' grounds,[38] and more recently it has become evident that the Purple Lake colour used in their Bitumen Oil Tube paints, was produced from residues of other lake manufacture.[39] An 'End Use' field would quickly capture W&N's incorporation of manufacturing residues in their other products, and 'links/annotations' between records would make the original passages from the manuscript (MS) containing this information immediately accessible.

Manual transcription versus digital page-imaging

With the W&N Database the necessity of a full typed text transcription was eliminated by providing a high-resolution image of each MS page from the 85 MS books available (e.g. see Plate 5.7). Researchers can find individual page images through a series of summary and keyword fields, such as recipe title, topic (pigment or varnish manufacture, etc.) and by individual ingredients. Once a given page is accessed, the user can then page through the MS forwards or backwards as one would with a real book, such that the information on the page of interest can be seen in the context of the MS as a whole.[40] The incorporation of page images avoids transcription errors and allows abbreviations, line breaks, corrections, cross-outs and annotations to be easily viewed, enhancing interpretations. The Authority Field can be used to explain interpretations of abbreviations and conventions in the handwritten texts.

Report function

An essential feature for using a text-based database as a research tool is the 'Report' function. This can entail customised print-outs of fields containing for example, varnish and Medium recipes, to reveal patterns and commonalities as well as chronological developments. Report options should include the ability to show content from selected fields in a variety of chosen orders and layouts (e.g. in tables by column or in a paragraph format). While summary tables can be produced by exporting information to spreadsheets or word documents, this is unnecessarily time consuming when a database can be designed to produce tables and reports directly.[41]

Historical sources databases for multi-topic research

The W&N Database was designed primarily for materials historians, conservation scientists and oil painting researchers, to identify how pigments, binders and paints were manufactured by a colourman in the nineteenth century, and what range and type of materials were used. Records describing pigment manufacture have been thoroughly investigated, analysed, and reconstructed in work carried out for Masters and PhD theses, for example, on W&N's lead chromate pigments[42] and their cochineal lake pigments.[43] An evaluation of binders and additives used in W&N paints was crucial to various projects for reconstructing nineteenth century oil paints[44] and as seen, their production of Bitumen paint is under investigation in the work of Marques (see endnote 32).

During the construction of the database, it was evident that the W&N manuscripts also contain details of the labour involved ('man's time') and other aspects of the company's operation, including the cost of producing their products as well as diagrams of specific manufacturing equipment. The original W&N Database was designed with a number of 'open fields' in anticipation of queries for this information and on other topics which were not the focus of the initial database designers. Open fields were intended to allow future researchers to populate their own fields and create their own tags and links to other records.

At the time this was a novel concept, that once all data had been entered, the ability to search and identify topics in the digital information was not restricted to a particular focus or unconscious bias built in by the original designers. There was also the intention that the database could receive updates and new expert information based on the findings of users. [45]

Conclusion

The central role of performative research within the HART model has been highlighted by recounting discoveries that can only be found through the physical act of making. The need for intellectual rigour in choosing the route and developing the means to explore past practices has been expressed in the details provided which explain how large collections of historical information can be mined with interactive databases, and how historically appropriate materials can be identified and sourced.

The HART model rests on the aspiration to achieve some degree of historical accuracy, but as argued here, it is recognised that 'accuracy' can only ever be judged in relative terms: from wildly inappropriate material choices (e.g. modern silica coated pigments to represent historical materials) to the more appropriate option of using pigment reconstructions based on historical recipes. The need for thorough documentation of each reconstruction was argued with examples of how these products of re-enactment can be used in both visual and chemical analyses in comparison with historical oil paintings.

One aspect of the investment involved in the HART Model, which was not discussed directly, is the problem of sustaining the collection of the HCRs produced in terms of institutional commitments to providing long-term storage and accessibility. The value of the physical samples produced only increases as they age naturally and undergo the 'slow chemistry' that their historical counterparts in actual painted objects have already experienced.

A similar challenge awaits with regard to the sustainability and development of text-based databases, not only to make them widely available online, but also to build into their design methodologies for users to extract and interrogate the data beyond the expectations of the original designers. The HART three-part model for investigating historical oil painting methods and materials has proven successful thus far, but its future success rests on the improvements and refinements that will be accrued as new researchers explore and extend its potential.

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Endnotes

[1] *European Paintings*, ed. by Hermens.
[2] The HART Project (Historically Accurate Reconstructions Techniques) 2002-2005, hosted by the Netherlands Institute for Cultural Heritage (ICN) in Amsterdam, was part of The De Mayerne Programme, funded by the Netherlands Organisation for Scientific Research (NWO), see Carlyle, 'Historically Accurate Reconstructions'; Carlyle, 'HART Report'; Carlyle, 'Representing Authentic Surfaces'.
[3] Stols-Witlox, 'Historical Recipes'; Stols-Witlox, *A Perfect Ground*.
[4] Carlyle, 'HART Report', pp.101-106.
[5] Carlyle, *'The Artist's Assistant'*, p. 177.
[6] The role of ground colour in Netherlandish paintings from the sixteenth- and seventeenth century is the topic of the research project *Down to the Ground, a Historical, Visual and Technical Analysis of Coloured Grounds in Netherlandish Painting, 1550-1650,* (University of Amsterdam/TU Delft). This five-year project connects art historical, art technological and scientific research to the question of the role of ground colour, using both material and digital reconstructions. https://www.nwo.nl/onderzoek-en-resultaten/onderzoeksprojecten/i/57/31757.html.
[7] Carlyle, 'Towards Historical Accuracy'.
[8] For a detailed discussion of scientific measurements and the ISO standards, see Heinicke and Heering, 'Discovering Randomness'.
[9] Carlyle, 'A Critical Analysis'; Carlyle, *'The Artist's Assistant'*.
[10] One of the goals in founding the ICOM-CC working group, Art Technology Source Research (ATSR), was to draw attention to a significant body of historical technical literature beyond popularised examples such as the fourteenth century manuscript by Cenino Cennini. See ATSR Conference post-prints by Archetype Publishers Ltd, London, and for medieval technical manuscripts see Mark Clarke (e.g. Clarke, *Tricks of the Medieval Trades*).
[11] Although technically the first step, discussion of the use of a database as a research tool to identify and understand historical materials and representative recipes is reserved until Part III, as its value and importance become clearer after the discussions in Parts I & II.
[12] Carlyle et al., 'Historically Accurate Ground Reconstructions'.
[13] Salis Gomes et al, 'Pigment Surface Treatments'.
[14] Oomah and Kenaschuk, 'Cultivars'.
[15] Carlyle, *'The Artist's Assistant'*, pp. 24-25.
[16] Carlyle et al., 'A Question of Scale'.
[17] Carlyle et al., 'Historically Accurate Ground Reconstructions'; Carlyle et al, 'A Question of Scale'.
[18] Carlyle, *'The Artist's Assistant'*, p. 103.
[19] Carlyle, 'MOLART Fellowship', p. 39.
[20] Haswell et al., 'Van Gogh's Painting Grounds'; Haswell et al., 'Qualitative Determination'; Haswell et al., 'The Examination'; Carlyle et al., 'Historically Accurate Ground Reconstructions'.

[21] Van den Berg et al., 'Recognition of Copals'.
[22] Carlyle, 'Representing Authentic Surfaces'.
[23] Langley et al., 'Scenes from the Life'.
[24] Carlyle, 'MOLART Fellowship'
[25] Carlyle, *'The Artist's Assistant'*, pp. 337-340.
[26] Carlyle, 'HART Report', Chapter 4, Appendix IV, pp. 290-296.
[27] Stols-Witlox, 'Historical Recipes'; Stols-Witlox, *A Perfect Ground*.
[28] Jeff Seynaeve, a Belgian artist and picture restorer with a strong interest in historical painting techniques, reconstructed stack-process lead white for the HART Project using the traditional method (Carlyle, 'HART Report'). We visited him to take notes and photograph the process he was using so that we could fully understand the conditions. The images are in the 'HART Report'.
[29] Hendriks et al., 'Selective Dating'.
[30] Examples include the Winsor & Newton Nineteenth-century Archive Database (Clarke and Carlyle, 'Page-Image Recipe Databases' (2005a&b)) which contains over 15,000 records, and a database currently under construction by Joana Devesa as part of her doctoral studies at Universidade NOVA de Lisboa on historical recipes for cleaning oil paintings. It contains information from 130 sources published between 1600-1900, and currently holds over 900 records (Devesa et al., 'Early Cleaning'). See also the Cologne Database for painting materials and reconstructions http://db.cics.th-koeln.de/start.fau?& (and Oltrogge, 'The Cologne Database'), as well as the Artechne Database: https://artechne.wp.hum.uu.nl/artechne-database/ developed under the direction of Sven Dupré.
[31] In her doctoral work on the preservation of Performance Art, Hélia Marçal describes the process of documenting these works as 'recursive' in the same sense that it is being used here: the research must revisit what appears to be the same information over and over, bringing new insights and views each time, informed by what has been learned since the information was initially encountered (Marçal, 'From Intangibility to Materiality').
[32] The ingredients in W&N's 'Bitumen for Tube Paint' are of particular interest since a significant number of nineteenth century oil paintings suffer from severe paint defects commonly referred to as 'Bitumen Cracking' or 'Alligatoring' (due to the resemblance to alligator skin of the distorted dark surfaces they exhibit). Raquel Marques is currently engaged in doctoral studies of this phenomenon at Universidade NOVA de Lisboa, using the HART Model to combine technical source research, reconstructions and visual/chemical analyses of affected paintings.
[33] 'Weig[h] out 8 Parcels of Asphaltum of 4lbs each composed of 3# of Egyptian bot of S D in Aug 57 and 1# of the brown sort bot of S D in Aug[t] 1852 then let each parcel be broken down roughly to ab[t] the size of hazle nutts' (W&N Researcher's Edition V2P465). The identity of S D was established by other references in the W&N database to S Druke selling asphaltum (e.g. P2P115A), then by cross-referencing S Druke to the Roberson Archive Bought Ledgers where they purchased similar materials from a Sarah Druke on 5 Cloak Lane (Carlyle database, see Carlyle, 'Using a Portable Computer'; Carlyle, 'A Critical Analysis of British Handbooks'). Her identity was fully revealed in Jacob Simon's database on British Artists Materials: https://www.npg.org.uk/research/programmes/directory-of-suppliers.php. Checked on April 4th, 2019.
[34] Vitorino et al., 'Nineteenth-Century Cochineal'; Otero, 'Historically Accurate'
[35] Introduced by Mark Clarke along with his design for allowing forward and backward movement through each of the 85 books in the archive. Another of his many innovations was a programme to automatically convert old British measures to metric equivalents for ease of interpretation and for comparison with similar recipes (Clarke and Carlyle, 'Page-Image Recipe Databases' (2005a&b))
[36] Ashes from oak and beech woods are being characterised in terms of their chemistry and the pH of their lye solutions made with a number of variables, such as the source and age of the ashes, the age of the lye and the exposure of the lye to evaporation. A variety of oil painted surfaces (naturally aged and model reconstructions) will be 'cleaned' with the lye to determine whether there is a visual/chemical correlation between the surface damages seen on old paintings and that caused by wood-ash lye.
[37] Carlyle, 'British Nineteenth-Century Oil Painting'.
[38] Carlyle et al, 'Historically Accurate Ground Reconstructions'.
[39] Vitorino, 'Nineteenth-Century Cochineal'.
[40] Clarke and Carlyle, 'Page-Image Recipe Databases' (2005a&b)
[41] In her research with the HART Project, and later in her PhD on documentary sources covering artists' ground preparations, Maartje Stols-Witlox introduced the use of graphs to illustrate information by topic and chronology (Stols-Witlox, 'Historical Recipes'; Stols-Witlox, *A Perfect Ground*). This has been further refined in the work of Devesa (Devesa et al., 'Early Cleaning').
[42] Otero et al., 'Chrome Yellow'; Otero, 'Historical Accurate Reconstructions'.
[43] Vitorino et al., 'Nineteenth-Century Cochineal'.
[44] Carlyle, 'HART Report'.

[45] Unfortunately, these aspirations were not realised in the final Researcher's Edition since at that time the W&N company chose to impose limited access and restrictions on certain records (detailed in Otero, 'Historically Accurate'). The Winsor & Newton Nineteenth-century Archive Database project was initiated by Leslie Carlyle as part of the De Mayerne Programme funded by The Netherlands Organisation for Scientific Research (NWO). The initial database design was carried out in partnership with Mark Clarke, who then led its continuation and further development in the UK with a Resource Enhancement Grant from the Arts and Humanities Research Council (AHRC). The NWO funded database, known as the Pilot Project, was then supplanted by the AHRC funded Researcher's Edition completed in 2008. Portals for access to the Researcher's Edition are available at RKD Netherlands, Tate Britain (Conservation Department) and at the Department of Conservation and Restoration, Faculty of Sciences and Technology, University NOVA of Lisbon. The Hamilton Kerr Institute, University of Cambridge currently hosts a limited and partial edition of the Researcher's Database which is available online but is not currently fully functional for researchers.