Colour shifts

On methodologies in research on the polychromy of Greek and Roman sculpture

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This article offers a partial overview of methodologies of research on the polychromy of Greek and Roman sculpture. The character of the evidence requires an interdisciplinary approach. This evidence is briefly presented, after which aspects of the actual investigation are considered, the section on analytical methods dealing only cursorily with invasive techniques. Attention is drawn to the importance of research-based experimental reconstruction of polychrome sculptures. Finally, some interdisciplinary research scenarios are described. The article is based on work done within the framework of the 'Tracking Colour' project of the Ny Carlsberg Glyptotek and the Copenhagen Polychromy Network, 2009-13, with the support of the Carlsberg Foundation.

Key words: Sculpture, Greek Sculpture, Roman Sculpture, Polychromy, Colour, Research Methodology, Experimental Reconstructions, Tracking Colour, Ny Carlsberg Glyptotek

The term 'colour shift' means 'a change in colour quality'. This concept is particularly, and dramatically, applicable to the case of colour on Greek and Roman sculptures as it originally appeared and as it is seen today: in fact, rather than having undergone a shift, their colours have in most cases almost entirely disappeared. In the title of this article, the 'shift' becomes a plural, in an attempt to indicate the complex character of the change which the polychromy of ancient sculpture has undergone. But, at the same time, the word also becomes a verb with the meaning 'to change position', reflecting the fact that the re-emergence of colour must fundamentally shift our approach to classical sculpture. That kind of shift is not the subject of this contribution; it deals rather with the means by which the shift may be brought about.

Interdisciplinary collaboration lies at the root of the present phase of research on polychromy, one which has been characterized as a "break-through phase".[2] Disciplines within the humanities, objects conservation, conservation science and the natural sciences have joined forces to become a *sine qua non* for future discoveries.

Writing about methodology with the ambition of reaching readers from the several disciplines involved is correspondingly challenging.[3] It is a particularly daunting task to write about the decisive contribution made by conservation science and the natural sciences in a way which is accessible to scholars from the humanities. Similarly – but requiring perhaps relatively less of an effort of 'translation' – the methodologies employed by the humanities must be described with due consideration of readers from the sciences. Promoting mutual understanding is perhaps the most important aim of this contribution.

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2 Østergaard 2010a, 86 – 7.

3 Briefly on methodology: Abbe 2015, 173-4.

We turn first to the factor which determines the need for an interdisciplinary approach, namely the character of the evidence.

The character of the evidence

Evidence of the polychromy of Greek and Roman sculpture is found in two fundamentally different classes of ancient sources: the written and the material.

Written evidence

The ancient written evidence is predominantly literary, and to a lesser extent epigraphical, i.e. provided by inscriptions. The literary evidence has survived thanks to the transmission of manuscripts; the earliest preserved manuscripts are from Antiquity, while the great majority are much later, dating mainly from the medieval period. Epigraphical evidence, on the other hand, has by its very nature come down to us from Classical Antiquity itself.

The survival of epigraphical sources has been determined mostly by chance, but to a certain extent also by strategies of archaeological exploration with their tendency to focus on famous historical sites. Ancient literature has come down to us by a process in which chance has also played a decisive part; to a certain degree, value judgements and other filters of reception (i.e. Christianity) have determined the transmission of texts as well. The study of both categories of written evidence is the province of classical philology, epigraphy and ancient history, with classical archaeology being involved more closely in epigraphy.[4] The common feature of the two categories of written evidence is that the quantity that has survived to the present day represents a minute percentage of what was originally produced. The little that remains is, however, uniquely valuable in throwing light on aspects of ancient sculpture which the works themselves cannot communicate.

The literary evidence[5]

The literary evidence for polychromy in Greek and Roman sculpture was first extensively collected and used by Antoine-Chrysostôme Quatremère de Quincy in his seminal work *n* (1814).[6] Recently this evidence has for the first time been the subject of a comprehensive study, by Felix Henke, dealing with several hundred ancient texts.[7] Henke's work was inspired and guided by earlier contributions by Oliver Primavesi on Greek sources.[8] From a perspective that includes sculpture, Latin texts have been studied in recent years by Mark Bradley,[9] Ursula Mandel[10] and Fabio Barry.[11]

Chronologically, these texts cover almost the complete span of the history of Greek and Roman polychrome sculpture. Geographically, they are less representative, having a decided emphasis on the great centres of Classical civilization. The texts are found in all ancient literary genres, poetry, philosophy, history and encyclopaedic works; and they deal with sculpture in a wide range of materials and contexts, as well as with technical aspects such as gilding and maintenance.

What, then, is the specific importance of the literary evidence; on what aspects of sculptural polychromy does it shed a light not provided by other sources? Henke deals in some detail with the question of how the evidence has been used hitherto and what its particular value is today. In a situation where investigation of the archaeological evidence is providing a mass of detailed knowledge on the 'how' of sculptural polychromy, Henke rightly concludes that the literary evidence is particularly impor-

4 An example is the pioneering publication of Greek and Latin inscriptions from Aphrodisias, cf. *IAph2007* at http://insaph.kcl.ac.uk/iaph2007/. See also Roueché, Holdenried & Scholz 2014.

5 It should be noted that, in principle, the evidence of ancient papyri belongs in this category. However, the papyrological evidence has not been systematically investigated. Cf. Henke 2014, 12. Evidence may possibly also be found in post-antique sources, cf. for example Baroni et al. 2014.

6 Quatremère de Quincy 1814. The 1814 edition published by Firmin Didot was followed in 1815 by an edition published by De Bure frères.

7 Henke 2014. This PhD dissertation is being prepared for publication.

8 Primavesi 2010; Primavesi 2014. See also Mandel 2010, 306 n. 21.

9 Bradley 2009.

10 Mandel 2010. Her contribution is not limited to literary evidence.

11 Barry 2011.

tant in two respects.[12] First, the texts provide access to levels of interpretation not to be found in the material evidence – namely, beyond the 'how', also the 'why', and furthermore, access to information on the reaction of ancient viewers to the sculptures.[13] Secondly, the texts help close some of the multitude of gaps existing in the material, archaeological record.

Against this background, close collaboration with classical philologists and ancient historians is an obvious necessity in polychromy research, keeping alive the synergy of investigation of the monuments and interpretation of the texts. In this respect, one may recall the fact that only as late as 1969 was the word "ágalma" in the famous passage in Euripides' tragedy *Helena* finally translated as "statue", not just "image".[14]

The epigraphical evidence

A comprehensive study of the evidence for polychromy provided by Greek and Latin inscriptions is yet to be carried out.[15] How necessary and promising such a study would be is demonstrated by the work of a more limited scope done so far, not least the in-depth research published on one period in particular, namely the Hellenistic.[16] Unlike the literary evidence, the inscriptions are not only themselves ancient but often also have an archaeological context. The inscriptions from Delos are the most prominent example of this.

The information on polychromy offered so far by inscriptions covers a narrow field in comparison to that provided by the literary evidence. Their context is almost exclusively that of sanctuaries – above all that of Apollo on Delos –[17] and their content limited to circumstances concerning the upkeep of statues: accounts and regulations specifying which statues to take care of, when, how, by whom and at what cost. The importance of this evidence lies above all in the fact that it is of a kind not provided by the literary sources. Epigraphy is therefore a discipline with which polychromy studies must be in close contact.

Fig. 1. *A statue of Heracles being painted in the encaustic technique. Apulian red-figure column krater, c. 360-350 BCE, H: 51.5 cm. New York, Metropolitan Museum of Art, inv. no. 50.11.4. Rogers Fund, 1950. (Credit New York MMA).*

The material evidence

The term 'material', rather than 'monumental' or 'archaeological', has been chosen in order to reflect the breadth of this category of evidence, encompassing as it does not only the sculptures themselves, but also other classes of objects not easily subsumed under the heading 'monumental', as well as objects which have no archaeological context but nonetheless provide important evidence. The material evidence may be grouped under two headings, as follows.

12 Henke 2014, 7-8. Cf. also Leka 2014, 61 on the words and expressions used for the protection, maintenance and repair of sculpture as reflections of the value ascribed to the works.

13 On ancient viewers: Zanker 2000; Elsner 2007 (not limited to the Roman world); Marconi 2011, 145.

14 Eur. Hel. 260-66. Kannicht 1969.

15 Publication of corpora of inscriptions in digital form opens new possibilities. Cf. the Greek and Latin inscriptions from Aphrodisias, *IAph2007* at http://insaph.kcl.ac.uk/iaph2007/.

16 Leka 2014, dealing with literary and epigraphical sources; Bourgeois 2014; Blume 2015, 127-31, with a heavy emphasis on Delos.

17 The sanctuary of Apollo at Ptoion in Boeotia being another, cf. Leka 2014, 62.

Fig. 2. *Wall painting from the House of the Golden Bracelet, Pompeii (VI 17, 42): garden scene (detail) with fully polychrome satyr's heads carrying more discretely coloured reliefs. Mid 1st century CE, c. 200 x 375 cm. Pompeii, Antiquarium, inv. no. SAP 40690. (Credit SAP).*

Evidence from categories of material other than sculptures

This type of evidence falls into two groups, one showing the actual act of painting sculpture, the other with representations of polychrome sculptures. The classes of material concerned are – with a few notable exceptions – vase-painting and wall-painting.

Representations of the act of painting

Only four representations of sculptures being painted have come down to us from Antiquity.[18] Two are red-figure vase-paintings of the 4th century BCE (Fig. 1), one a wall-painting and one a ring-stone – the latter two being of Roman Early Imperial date. This is a very small number when one considers the fact that Greek and Roman sculpture in (monochrome) stone material seems throughout its history of a thousand years always to have had some element of applied colour. This extreme paucity of visual evidence of something which must have been an everyday occurrence for centuries all over the ancient world is probably due to the very banality of the act; similarly, representations of sculptors at work are just as rare.

Representations of polychrome sculpture

Depictions of polychrome statuary are mostly, but not exclusively, from the Roman Imperial period – though the sculptures depicted do not necessarily have to be Roman, but may in principle be earlier, i.e. Greek. The great majority of them are to be seen in wall paintings,

18 Østergaard & Nielsen 2014, 319 cat. nos 3-6 (checklist text only).

19 Statues on Greek vases: Reuterswärd 1960, 88-102; De Cesare 1997; Marconi 2011 with bibliography, 145 n. 1 (add Bourgeois 2014c, 71 n. 7). Roman wall paintings: Moorman 1988; Moorman 2008; Moorman 2015, 638, 649. Cf. also Mandel 2010, 306 for possible interpretations. In principle, sculptures depicted on (monumental) reliefs, as for example those on set on the triumphal arch figuring in the Spoils Relief on the Arch of Titus, might, if properly examined, also provide information on polychromy.

Fig. 3. *Head of a youth with inlaid eyes. Marble and diorite. Roman, 2nd century BCE, H: 23 cm. Copenhagen, Ny Carlsberg Glyptotek, inv. no. IN 455.*

Fig. 4. *Visible remains of Egyptian blue on a lid head fragment of an anthropoid sarcophagus from Sidon. Marble. Mid 5th century BCE, H: 43 cm. Copenhagen, Ny Carlsberg Glyptotek, inv. no. IN 471.*

and far fewer in mosaics.[19] Interestingly, a study focusing on depictions of polychrome sculptures has not yet been carried out. This is probably mainly due to the absence of publications illustrated in colour.[20]

The types of sculptures shown in the two-dimensional media involved are in the main free- standing; they appear in a variety of figural contexts, or as part of an architectural setting (Fig. 2). Interpretation of these representations, with Eric Moorman as a leading exponent, seems largely unaffected by developments in research on the polychromy of Greek and Roman sculpture: here, there is work to be done.

The evidence from the sculptures themselves

A very simple distinction may be made between direct evidence on the one hand, and indirect on the other.[21] In both cases, the evidence is found on the surface of the sculpture, a surface which is the end product of the sculpture's life history. Dealing with, and understanding, such a surface may be described as an "archaeology of the history of the surface".[22]

Direct evidence

The term 'direct evidence of polychromy' indicates the physical presence of a polychrome element on the sculpture, in whatever form and however minute. Besides remains of pigments this may also have to do with inlays – such as for the eyes (Fig. 3)[23] – leaf metals and preserved

20 Moorman 1988, the most complete publication of statuary in Roman wall-painting, has a great number of (small) illustrations, but all in b/w. Illustrations in Moorman 2008 are also in b/w. An online edition of Moorman 1988 with high resolution colour illustrations would be a valuable contribution; an example of obvious interest is constituted by the three depictions of the Hermes of Olympia (Moorman 2008, 207).

21 A brief introduction: Brinkmann 2003, 27-8 ('Die materiellen Spuren').

22 Bourgeois 2014b, 3.

23 Hoft 2014. A dissertation on the subject is under preparation by Verena Hoft.

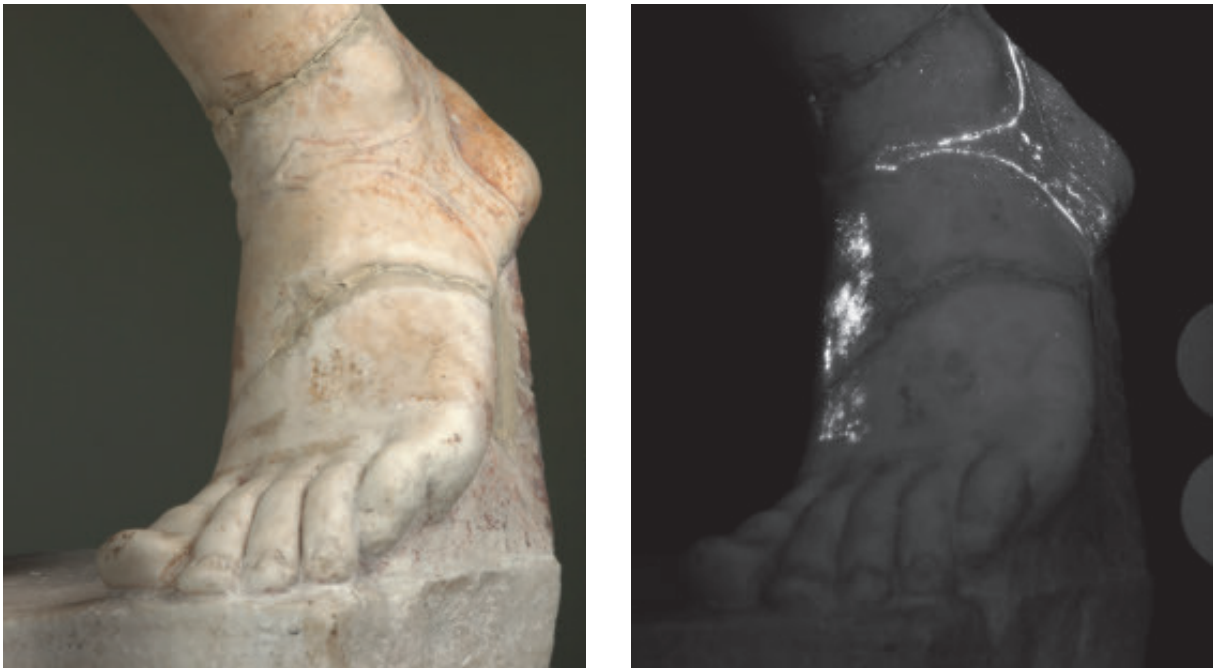

Fig. 5 a–b. *Left foot of the statue of a wounded Amazon ('Sciarra Amazon') in tungsten light (a) and in VIL image (b). The VIL image reveals the Egyptian blue used for a painted-on sandal strap. Marble. Roman, mid 2nd century BCE, H of statue: 197 cm. Copenhagen, Ny Carlsberg Glyptotek, inv. no. IN 1568.*

additions in the form of accessories or attributes, for example earrings or diadems. In the case of pigments, the evidence may at one end of the scale be so well preserved as to be immediately visible to the naked eye (Fig. 4), and at the other be of submicroscopic size and hence quite invisible (Fig. 5a–b). Tracking down and documenting this evidence is one of the main aims of the visual examination protocol dealt with below.

Indirect evidence

Even when no polychrome element is preserved, indirect evidence may be found which proves with absolute certainty that colour was once present on a sculpture – in many cases also just how and where the polychromy was once applied. This kind of evidence may usefully be divided into the following six categories:

Incision of very fine lines was used in the Archaic period to guide the subsequent painting of the sculpture. Both figurative and ornamental motifs were indicated in outline, often quite detailed. The best means of finding and documenting such incisions is by means of extreme raking light for visual examination and photography conducted under darkened conditions (Fig. 6). The development and refinement of raking light photography since the 1980s is due to the pioneering work of Vinzenz Brinkmann.[24]

Weathering relief is another surface feature for which raking light photography is the ideal method of investigation. The term describes the results of the use of pigments of varying durability. Less durable pigments will wear away the quickest and consequently expose the stone surface underneath to weathering for a longer period of time than surfaces covered by relatively durable pigments. This will result in a more or less pronounced relief effect (Fig. 7), revealing the motif of the originally applied polychromy.

'Colour shadows' is an expression used to describe a surface phenomenon closely related to weathering re-

24 Brinkmann 2010, 23. See Brinkmann 2003 for a wide selection of raking light images of incisions and weathering reliefs (as Fig. 7).

Fig. 6. *Raking light image of the incised outline of a lion's head on the cuirass shoulder clasp of Aristion. Stele of Aristion. From Athens. Marble. Late 6th century BCE, H (of stele): 204 cm. National Archaeological Museum, Athens, inv. 29. (Credit Städelstiftung).*

Fig. 7. *Raking light image of differential weathering of a meander border on a palmette anthemion of Classical Cypriote grave stele. Limestone. 5th century BCE, H (of anthemion): 46.0 cm. Copenhagen, Ny Carlsberg Glyptotek, inv. no. IN 431.*

liefs, being due also to the differences in durability of the pigments employed. The two types of indirect evidence may therefore be observed together on one and the same monument; and they may be subsumed under the common heading of 'differential weathering'.

In the case of 'colour shadows', the difference in pigment durability is evident from the tone of the stone surface: the better protected surfaces are less weathered and consequently lighter in tone than areas once covered by pigment of lower durability.

Iconographic evidence lies in the absence of something which must once have been present in colour. It is the logic of the scene or object represented which reveals what is now no longer there, but was once shown in colour. The most commonly occurring instance of this type of evidence is undoubtedly that of sandals being shown without straps; similar finicky details are missing on a Late Classical Attic relief fragment in the Ny Carlsberg Glyptotek (Fig. 9) where the sculptor left the rein and bridle to be painted in.

Inlays and other additions form a wide-ranging category of indirect evidence of polychromy. Whether inlaid eyes, jewelry (Fig. 10), divine attributes or the equipment and weapons of mortals, the sure indirect evidence of their erstwhile presence is in the form of a preparation for their insertion in the stone surface. The signs of the former presence of inlays and/or other additions are of course evidence of the presence of the colour of the material they were made of; but they are also evidence of polychromy of other parts of the sculpture: would the skin surfaces of the marble head of a youth with inlaid eyes (Fig. 3) have been left white?

The character of the surface finish and the choice of marble must be viewed as potentially determined by the intended polychrome finish and therefore indirect evidence of it. The surface is the interface between the craftsmanship, the *technè*, of the sculptor and the painter; or it may be thought of as the result of a dialogue between the two.[25] We may take the case of the rendering of dress

25 As Bourgeois 2012, 37; Heilmeyer & Maasmann 2014, 121; Skovmøller 2016.

Fig. 8. *UV image enhancing the polychromy of the Late Classical Attic grave lekythos of Paramythion. Marble. C. 370 BCE. W. of stele 33,4 cm. Munich, Staatliche Antikensammlung und Glyptothek inv. no. Gl 483. (Courtesy Städelstiftung).*

Fig. 9. *Stable boy with horse. The reins were painted in. Fragment of the side panel (parastasis) of a Late Classical Attic funerary monument. Marble. Mid to late 4th century BCE, H: 88 cm. Copenhagen, Ny Carlsberg Glyptotek, inv. no. IN 2807.*

in the widest sense, where we find the sculptor providing the painter with a surface texture in accordance with the material to be represented, be it a leather belt or the texture of a toga.[26]

Seeing the finished surface of the marble as a canvas for subsequent application of paint implies that the material itself was, or may have been, chosen in the light of what polychromy was to be applied and the chromatic value of the marble. An investigation of the potential value of the marble itself as indirect evidence of polychromy requires an effort to describe, identify and locate the stone. Petrographic and isotopic analysis is therefore to be integrated whenever possible in the investigation protocol, just as the interdisciplinary network should include the competences needed.[27]

Investigating polychromy

When investigating an ancient sculpture for remains of its polychromy, autopsy is of course a basic prerequisite.[28] What meets the eye is the surface in its three-dimensionality; it is the interface between the sculpture and the physical

26 The picked surface of the leather belt of the wounded Amazon ('Sciarra Amazon') NCG IN 1568, Østergaard, Sargent & Therkildsen 2014, 55, fig. 5; the toga of Fundilius NCG IN 707, Skovmøller 2014, 289. This aspect has led to collaboration with research on ancient textiles such as that conducted by the Centre for Textile Research at the University of Copenhagen, http://ctr.hum.ku.dk/. For related work, see Drinkler 2009.

27 Therkildsen 2012, 3.

28 See Bourgeois 2012, 38 for a precise formulation of what investigating polychromy is about.

Fig. 10. *Female funerary relief portrait. From the Qasr Abjad tomb, Palmyra. Limestone. C. 200 BCE, H: 55 cm. Copenhagen, Ny Carlsberg Glyptotek, inv. no. IN2795.*

environments it has passed through since it left the ancient workshop. As Brigitte Bourgeois has recently written, we are faced with "an archaeology of the surface" whose physical and historical depth must be probed and scientifically documented – keeping in mind the multiplicity of mostly anonymous hands which have handled and treated the surfaces over centuries, from Antiquity until today.[29] Included in this aspect is the biography of the possible maintenance and repainting of the sculpture in Antiquity.[30]

The importance of conducting such investigations with the highest possible degree of precision can hardly be exaggerated: the extent of ongoing deterioration of the remains of polychromy on ancient sculpture[31] means that the results we obtain today may one day be the only documentation available.

Archaeological context and the post-antique 'biography' of the sculpture

The study of Greek and Roman sculpture is the province of classical archaeologists. Consequently, the decision to investigate a given sculpture is taken because it fits a set of criteria set up within the framework of a project primarily devised by the archaeological curatorial staff responsible for it. The individual decisions will, however, in the best of worlds be the result of an informed dialogue between archaeology and conservation: win-win initiatives will always take the day. On this view, the methodology of research in our field requires that all available archaeological information on the sculpture is assembled and made accessible. It will also be a curatorial contribution to write up a 'biography' of the work, from the time of its discovery until its present position. Without this information, the state of preservation of the sculpture cannot be understood, and the 'excavation' – non-invasive and/or invasive – cannot be allowed.

Organization of work and data

In the course of the last 40 years or so, research on Greek and Roman sculptural polychromy has increasingly acquired an international character. It is still a relatively small field, but activity has increased considerably over this period, resulting in a growing quantity of primary data. To allow the essential, comparative studies of data acquired and of their interpretation, methods of data acquisition, data presentation and data organization/storage specific to polychromy should ideally conform to some agreed protocols and standards within the larger framework of established methodologies of the disciplines involved. Immediately related to these points is

29 Bourgeois 2014b, 3-5; cf. Romualdi et al. 2005; Bourgeois 2012 with an excellent bibliography for post-antique restoration of Greek sculpture, applicable in many respects also to Roman sculpture.

30 Bourgeois 2014c.

31 The factors chiefly responsible for the degradation of polychromy – humidity, temperature and light – are rarely controlled in galleries of ancient sculpture.

the matter of access to data, data sharing and intellectual property rights. In the present context, these complex issues cannot be dealt with in any detail. I shall confine myself to some general observations.

Protocols and standards

Contributing to the development of protocols and standards has from the outset been one of the principal aims of the work done by the Copenhagen Polychromy Network (CPN) and the Tracking Colour project.[32] A pilot study published in 2009 laid the foundations of the CPN protocol.[33] It noted the relatively limited literature on the technical examination of the polychromy of Greek and Roman sculpture and at the same time the apparent similarities between ancient and later European practices. The examination techniques chosen were therefore based on an existing tradition of studying polychromy on European medieval wooden polychrome sculpture and panel paintings.[34]

Within the framework of the Tracking Colour project, it was soon realized that two protocols were needed: a survey protocol and an in-depth protocol for qualitative research in the form of case studies, characterized by the application of a broader suite of analytical, non-invasive and invasive methods. [35]

Fortunately quite a number of publications with results from investigations following well-described protocols and standards are now available.[36] What is rarely made clear in these publications is the fundamentally iterative character of working according to such protocols; observations made at a certain stage of the investigation will frequently make it necessary to return to a procedure already carried out.[37]

Data management: organization of data; data access; data sharing

Arguably the most important objective at the present time in this field of research is well-considered (rather than random) acquisition of primary data conducted according to the protocols and standards now available, and their rapid publication – including archaeological comment connecting the data with the status of our knowledge.

The data thus acquired are entirely digital in form, whether written, graphic or visual. These data must therefore be organized, stored and made accessible on digital platforms. The challenges this presents are of considerable proportions; meeting them is an ongoing, multifaceted process further complicated by the interdisciplinary character of the field.[38] The Tracking Colour project decided to set up a low-budget project website as a front-end outlet for a back-end 'keep-it-simple' database to which project members and professional users had access.[39] To my knowledge, this example has not yet been followed by other polychromy research websites.[40]

Both on its website and in preliminary reports for free download, the Tracking Colour project gave access to and shared primary data before publication in peer review

32 Østergaard 2009b, 69; Østergaard 2010a, 11; Sargent & Therkildsen 2010, 11-3.

33 Scharff et al. 2009; Therkildsen 2011, 31-2.

34 Scharff et al. 2009, 14-5; Scharff 2013, 80. For an overview of techniques in medieval sculptural polychromy see Theiss 2010.

35 Therkildsen 2011.

36 A selection: Sargent et al. 2009; Verri, Opper & Deviese 2010; Sargent & Therkildsen 2010; Sargent 2011a; Abbe, Borromeo & Pike 2012; Sargent 2012; Bourgeois 2014c; Santamaria et al. 2014; Donati 2014 (more programmatical); Verri, Opper & Lazzarini 2014; Verri et al. 2014; Brecoulaki et al. 2014; Iannaccone et al. 2015. Bottini & Setari 2007, 120-66 deals with two-dimensional painting on stone, not sculptural polychromy, but is exemplary. Kakoulli 2009 is equally rewarding, including a technical study of the painting on the marble throne from the tomb of Eurydice at Vergina on 87-92; the book increases awareness of the interface between techniques in marble polychromy and wall paintings.

37 This adds to the difficulty of assessing the man hours needed for investigations.

38 For the complexity of the matter, cf. for example the Getty Conservation Institute Expert's Meeting September 10-2, 2013: "Integrating Imaging and Analytical Technologies for Conservation Practice". A report is available at http://www.getty.edu/conservation/our_projects/integrating_imaging.html; on p. 16, this aspect of Graham 2012a is summarized.

39 Skovmøller2011.

40 For example: Frankfurt am Main, Stiftung Archaölogie (ceased operations in 2016), http://www.stiftung-archaeologie.de/; Firenze, Dipartimento di Antichità Classica, Galleria degli Uffizi http://www.goldunveiled.it/; Athens, Georgia (US), University of Georgia http://www.ancientpolychromynetwork.com/menu-2/; London, The British Museum http://www.britishmuseum.org/research/research_projects/all_current_projects/ancient_polychromy.aspx.

Fig. 11a–c. *Head of a female deity ('Treu Head'). a) Present state, tungsten light; b) UIL image showing orange red luminescence of organic pigments; c) VIL image with the white luminescence of Egyptian blue. Mid 2nd century CE. London, The British Museum, inv. no. GR 1884, 0617.1. (Credit The British Museum).*

fora. Open access to data and publications related to research funded by public sources has been discussed with increasing intensity in recent years, in close connection with the modalities of intellectual property rights and publisher's copyrights.[41]

Visual investigation, technical imaging and non-invasive analysis

These three phases of the protocol have in common the fact that they are directed at the sculpture itself, either in situ wherever the work is kept, or, preferably, in a work space.[42] If the object is a large sculpture, the procedures which can take place in situ are usually restricted to all-round macroscopy, and, for accessibility reasons, imaging and analysis of only the front of the statue. In cases where the sculpture is still in its original position the situation is obviously difficult, but integrated, multi-methodological approaches are now being developed.[43] In the following, it is assumed that a work space is available.

Tungsten light photography and macroscopy

The initial step in an investigation is photographic documentation and systematic macroscopy under tungsten light.[44] Macroscopy takes place with the naked eye, assisted by magnification glasses and a binocular magnifier and/or a small video microscope. [45] Macroscopy and pho-

41 For access to research data see, for example, the Registry of Research Data Repositories and the thinking behind it: http://service.re3data.org/about; for access to publications see, for example, the plan implemented by the Smithsonian Institution http://interdisciplinary.si.edu/collaboration-highlights/public-access/; see also the 2003 http://openaccess.mpg.de/Berlin-Declaration. For copyright issues (in conservation) the International Institute for Conservation of Historic and Artistic Works (IIC) is developing guidelines to be made available at www.iiconservation.org/resources/guidelines.

42 On the Tracking Colour work space see Østergaard 2009, 70-7, 72, figs 1-4 and 2010, 7, 8 figs 1-3 (early version); Østergaard 2012, 7-8, 9 fig. 1 (later version).

43 Iannaccone et al. 2015 is a pioneering example of this.

44 Scharff et al. 2009, 16-7; Sargent & Therkildsen 2010, 12. On light sources see also Blume 2015, 16. For a wide selection of such documentation see the plates in Brinkmann 2003 and Blume 2015.

45 As an Eschenbach Lupe x3 and a Dino-Lite AM7013MT video microscope with x20/50 to x200 zoom magnifications.

Fig. 12. *Mapping of pigment remains on the short side of a Metropolitan Roman sarcophagus with Dionysus and Ariadne ('Casali Sarcophagus'). Marble. Late 2nd century CE, H (of chest): 68 cm. Copenhagen, Ny Carlsberg Glyptotek, inv. no. IN 843.*

tographic documentation often stand in an iterative relationship. Thus photographic documentation in colour[46] will be carried out at an early stage in the form of total views beginning with the front (Fig. 11a) and subsequently in 90-degree rotations of the sides and back. It is important also to photograph the sculpture from above.[47] A colour reference standard for subsequent colour balancing is included in all images. These images serve as support for mapping features observed in the course of subsequent examination of the surface (Fig. 12), as well as for pinpointing the locations of non-invasive and invasive analysis.[48] As macroscopy proceeds, a need for detail photographic documentation will usually arise. The photographic documentation will therefore consist of two main sections, total views (T) organized by degrees (thus 'T 0' for frontal view) and detail views (D), and be stored accordingly.

The initial phase may reveal features which must be examined and documented under raking light using a mono-directional light source and under total blackout for exposures; if possible or desirable, the Polynomial Texture Mapping (PTM) technique may also prove useful.[49] Raking light will typically be relevant in cases with such indirect evidence of polychromy as outline incisions and differential weathering.[50]

Technical imaging

A variety of digital technical imaging techniques are used to explore features and map the spatial distribution of materials on the surface of ancient sculptures, and in some cases also to provide information on the character of materials. The systematic use of these techniques in polychromy research was pioneered by Vinzenz Brinkmann from the 1980s onwards.[51]

When using such techniques in combination, one speaks of digital multispectral imaging (MSI) to indicate that they move through the ultraviolet (UV), visible (VIS) and infrared (IR) ranges or spectra of light waves. MSI is the quickest, most affordable and technologically most straightforward means of non-invasive, non-contact analytical investigation of the polychromy of an ancient sculpture.[52]

46 In the Tracking Colour project the camera used was a digital Canon EOS 5D Mark II with a Canon Zoom Lens EF 24-105mm and a Canon Compact-Macro Lens EF 50mm for detail photography.

47 The top surfaces can otherwise not be shown on virtual 3D models, cf. for example Graham 2012a, 74, fig. 8 'polar caps'.

48 Mapping of UV-VIS measurements: Brinkmann, Koch-Brinkmann & Piening 2010, 194, fig. 139 (Phrasikleia); mapping of sampling locations: Verri, Opper & Deviese 2010, 45, fig. 4a 'Treu Head'.

49 Earl, Martinez & Malzbender 2010.

50 Above, 6.

51 Brinkmann built on work begun in the 1960s by Volkmar von Graeve, Christof Wolters and Frank Preusser. For a bibliography of their contributions see http://www.stiftung-archaeologie.de/publicationsen.html

52 See Dyer, Verri & Cupitt 2013. A brief introduction and download of the manual is available on the British Museum website as part of the European CHARISMA project (Cultural Heritage Advanced Research Infrastructures: Synergy for a Multidisciplinary Approach to conservation and restoration). http://www.britishmuseum.org/research/research_projects/all_current_projects/charisma/technical_imaging.aspx

MSI falls into two categories, namely reflectance and luminescence imaging.[53] The former registers the radiation which the object reflects from the radiation source (reflectance imaging), the latter the radiation which the object emits in the form of luminescence (luminescence imaging). Luminescence is "the emission of light by a substance, which occurs when an electron returns to the electronic ground state from an excited state and loses its excess energy as a photon".[54] The excited electronic state is a result of the absorption of energy in the form of photons from the radiation source, triggering the transition of electrons from the ground state to the higher (excited) electronic energy state. It should be made clear here that 'luminescence' is a higher-order term encompassing two forms of luminescence, namely fluorescence and phosphorescence. In the literature on sculptural polychromy research, 'luminescence' and 'fluorescence' are used interchangeably. 'Luminescence' is the term preferred by the leading practitioner of MSI, Giovanni Verri, and will be used here.[55] In both categories of imaging, complete black-out conditions have hitherto been required; a new technique provides an alternative that may be used under ambient light conditions.[56]

Of particular value to polychromy research are the following imaging techniques:[57]

– Infrared-Reflected imaging (IRR) may reveal significant pictorial details, as has been demonstrated most recently in the investigation of polychromy on Classical Greek marble vases.[58]

– Ultraviolet-Reflected imaging (UVR) and Ultraviolet-Induced Luminescence imaging (UIL)[59]

UV-reflectography will strengthen the contrast of 'colour shadows' (Fig. 8), while UIL captures the luminescence from certain organic pigments on the surface and may also reveal otherwise invisible features of an original polychromy (Fig. 11b).[60]

– Visible-Induced Luminescence imaging (VIL), which captures the luminescence of Egyptian blue, a synthetic pigment first produced in Egypt in the 3rd millennium BCE and subsequently widely used in Classical Antiquity (Fig. 11c). The radiation source is visible light with a minimum of emission in the infrared spectrum; the pigment re-emits the energy absorbed in the form of luminescence in the infrared range, invisible to the human eye but visible in a digital image taken by a camera with the appropriate filters. Because the luminescence is found on the near-infrared range, the term NIR (Near-InfraRed) luminescence is also used instead of VIL.[61]

The images obtained through the application of the technical imaging methods just described are always to a greater or lesser extent open to interpretation, not least in the case of VIL.[62] Examination by other methods as a cross-check are, as always, to be recommended.

Microscopy

The results of macroscopy, photographic documentation and technical imaging may be followed or accompanied by more focused microscopy of relevant areas of preserved polychromy. In the Tracking Colour project, a high-end video microscope became the main microscope.[63]

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53 Cf. Verri & Saunders 2014, 83.

54 Ganio et al. 2015, 815.

55 For a basic understanding of the terms luminescence, phosphorescence and fluorescence see Verri et al. 2008, 1-2; Verri & Saunders 2014, 83 with references.

56 Verri & Saunders 2014.

57 Infrared and ultraviolet false-colour reflected images (IRRFC; UVRFC) have to my knowledge not been relevant to sculptural polychromy research (yet?). See Dyer, Verri & Cupitt 2013, 4, 5 figs 1-3.

58 Dyer, Verri & Cupitt 2013; Brecoulaki 2014, 161; cf. Brecoulaki, Kavvadias & Verri 2014, 19-24.

59 Or frequently, ultraviolet-fluorescence imaging (UV-FL), cf. the point just made on terminology.

60 Koch-Brinkmann & Posamentir 2010, 180 figs 196-8, 182-3 (UVR and UIL of NCG IN 2564); Sargent & Therkildsen 2010, 20 fig. 10 (UIL of NCG IN 2687 Caligula).

61 Verri 2009; Ganio et al. 2015, 814-5 with references. A paper is under preparation for the Research & Technical Studies Session at the 2016 AIC Annual Meeting, entitled: "Visible-Induced Luminescence Imaging: Past, Current and Future Applications in Conservation Research".

62 On interpretation and analysis see Dyer, Verri & Cupitt 2013, 6, 8-34; Verri et al. 2008.

63 Tracking Colour main microscopes: 1) Leica M651 binocular optical surgical stereo microscope, to X26 magnification at a working distance of 15 cm, using a 150 mm lens; a 130 mm lens allowed working distance of up 30 cm with X13 magnification. Limitations: being designed for surgical functions, the lowest and uppermost parts of a full-size sculpture could not be examined. 2) The more versatile Leica DVM 5000 video microscope, now the preferred instrument. 3) A Leica DM 2500 dark field microscope for cross-section analysis.

The use of video microscopes in research on ancient sculptural polychromy was pioneered in France from 1996 onwards by Brigitte Bourgeois; such instruments became the 'work horse' of the investigations conducted by her and a French–Greek team from 1999 to 2007 on the surface features of marble sculpture from Delos. The instrument now in use by Brigitte Bourgeois is a Hirox KH-8700 with a zoom magnification to 400X and provided with sophisticated software allowing 3D and micro topographical imaging.[64] Using a Keyence VHX-500 video microscope, with a lens giving 20-175X magnification, Mark Abbe has also produced important results.[65] The case for choosing a video microscope for sculptural polychromy research has been well-stated by Bourgeois: maneuverability, rapidity of use and spectrum of magnification –[66] to which one might add the constant development of relevant digital software.

Analytical investigation

The observations made in the course of the investigations outlined above may encourage a closer look at the physical and chemical properties of the pigments discovered.[67] To this end, a suite of geophysical, physico-chemical and biochemical analyses may be applied; the sequence in which they are applied will reflect the two main categories into which they may be divided, namely non-invasive and invasive. Several of these analytical methods are applicable in both categories.[68] In the following, each category is dealt with in turn.

Non-invasive methods

These methods have in common the fact that they allow acquisition of quantitative data without contact with the historical material. It follows that these methods are applied in situ, i.e. on the sculpture itself. The term 'non-destructive' is sometimes, wrongly, used synonymously with 'non-invasive'; 'destructive' and 'non-destructive' describe two categories of invasive methodology as will become apparent below.

The standard protocol for non-invasive analysis includes the following methods:[69]

X-ray Fluorescence spectroscopy (XRF) performed in situ with a portable spectrometer (p-XRF) provides information on elements present in the pigment.[70] An advanced version of the instrument is the portable ARTAX micro-XRF (μ-XRF).[71]

Ultraviolet-Visible Spectroscopy (UV-VIS) (or UV-VIS absorption spectroscopy in diffuse reflection, to indicate the inclusion of near UV 300-400 nanometer and near IR 800-1100 nanometer bandwidths) has been in use for identifying pigments since around 1990 and has in recent years been applied in research on ancient sculptural polychromy. Its leading exponent is Heinrich Piening, working in close collaboration with Vinzenz Brinkmann

64 Bourgeois 2012, 31-3, 34; Bourgeois 2014b, 5-6 with note 18; Bourgeois 2014c, 77, fig. 14; micro topography, ibid. 78 fig. 17; Bourgeois & Jeammet 2014. Cf. C2RMF website report on investigation of the archaic Greek 'Kore of Lyon': http://c2rmf.fr/actualite/les-couleurs-de-la-kore (accessed February 19, 2016).

65 Abbe, Borromeo & Pike 2012.

66 Bourgeois 2012, 34.

67 The subject challenges this archaeologically trained author; when publishing the results of interdisciplinary research more attention needs to be paid by all disciplines involved to guiding the intended, but untrained reader. The instrumentation involved is always very expensive and only experienced professionals should use it. The heading of this section might have been 'Materials analysis', cf. Abbe, Borromeo & Pike 2012, 766. There are several handbooks available on analytical methods in cultural heritage conservation contexts, each with their particular strengths, but none with a focus on ancient artefacts, let alone sculpture. One may mention for example Ciliberto & Spoto 2000, with the introduction Ciliberto 2000. Abbe 2015, 174 has a very brief introduction.

68 Among recent publications demonstrating such full sequences one may mention Bottini & Setari 2007, 132-66; Scharff et al. 2009; Verri, Opper & Deviese 2010; Sargent & Therkildsen 2010a; Abbe, Borromeo & Pike 2012. Though on the subject of Gandharan sculpture, Talarico et al. 2015 is very instructive. In the following, references will be given to several more publications in connection with the individual analytical methods.

69 Bracci et al. 2014 gives a concise overview of methods.

70 Liritzis & Zacharias 2011; Abbe, Borromeo & Pike 2012, 766; Sargent & Therkildsen 2010a, 33, 47; Ganio et al. 2015, 814.

71 https://www.bruker.com/products/x-ray-diffraction-and-elemental-analysis/micro-xrf-and-txrf/artax/overview.html, cf. in situ application Leona 2009, 7, fig. 7.

and Ulrike Koch-Brinkmann.[72] The method involves the combination of UV-VIS measurements with colourmetry using chromaticity coordinates in order to estimate the colour values of the pigment traces found.[73]

Fiber Optics Reflectance Spectroscopy (FORS) is a non-invasive technique closely related to UV-VIS.[74] Its limitations are due to the lack of easily accessible libraries of comparative data.[75]

Raman Spectroscopy was applied non-invasively, using a portable set-up, in the pilot project phase leading to the Glyptotek's Tracking Colour research.[76] It was not successful, due to the interference from the marble substrate. For good results in situ use of the technique requires micro-Raman spectroscopy (μ-Raman; MRM).[77]

Invasive methods

As the term indicates, invasive methods entail physical contact with the historical materials of the original and the removal of a sample for analytical investigation. The methods of investigation used may either be non-destructive or destructive; in the latter case, the sample is destroyed in the analytical process, in the former, the material remains available for future analysis. A decision to apply invasive methods requires an awareness of contemporary conservation ethics, and more specifically, of the criteria by which such a decision may be taken. This is a wide field which cannot be surveyed in the present context. I shall restrict myself to some basic observations.

First of all, the general state of preservation of polychromy on Greek and Roman marble sculptures must be recognized for what it is: so deteriorated as to be completely out of touch with the originally intended visual effect. This stands in contrast to the rare instances of better preserved polychromy on an ancient sculpture – terracotta statuettes above all – and, especially, the almost complete and complex state of many post-antique, European polychrome sculptures. This must enter the equation when discussing whether the application of invasive methods is permissible or not – as a rule this is not a matter dealt with in publications; here, the Tracking Colour project is no exception.

Next, one must have a clear idea of the size of samples needed to permit the application of the methods dealt with in this section.[78] The sample size required for analyses has in general steadily decreased to the degree that the refinement of analytical technology has increased. Today, average samples are of a size hardly visible to the naked eye, yet a distinction is still drawn between sampling and micro-sampling, according to the minimum size required for the great variety of analyses relevant to ancient sculptural polychromy.[79] By extension, such practical aspects as methods of extracting and storing, and of safely sending samples when working with external network partners, are all part of the workings of invasive methodology. Furthermore, one must qualify modern concepts of an 'original' material by drawing attention to the 'biography' of a sculptural surface, from discovery onwards – a biography which will include 'invasive' treatment in the field and in museums.[80]

In the Tracking Colour project, guidelines for the use of invasive methods, i.e. the taking of samples, were established verbally on a professionally informed, common sense basis: there must be a sufficient volume of material remaining after sampling to allow future investigation; the reasons why a sample is needed must be closely argued; the methods of investigation must be explained and the necessary collaboration with external partners must be in place. These criteria being met, invasive methodologies were welcomed, as they are by other institutions carrying

72 Brinkmann, Koch-Brinkmann & Piening 2010; Piening 2010a; Piening 2014; Blume 2015, 134-6 (Heinrich Piening, Harald Theiss, Annegret Fuhrmann). The exclusive use of non-invasive methods is regarded as a given by Piening (Piening 2014, 185). UV-VIS-NIR spectrometers covering the 200-1800nm range are available and desirable, but beyond the financial reach of Piening. I thank Heinrich Piening for this information.

73 Piening 2010, 112-3; Brinkmann, Koch-Brinkmann & Piening 2010, 200-2.

74 Leona 2009, 7.

75 I thank Heinrich Piening for this opinion.

76 Berg 2009.

77 Brecoulaki, Kavvadias & Verri 2014, 155. Cf. Smith et al. 2009.

78 On this point misconceptions are frequent. Precise information in publications is the remedy.

79 On sampling generally, see for example Ciliberto 2000, 5. The average size needed for cross-sections is from 0.25 to 1 mm^2; up to 2 mm^2 (the size of the head of a pin) may be needed for other analyses (those for organic materials especially).

80 Cf. Bourgeois 2014c.

out polychromy research.[81] This positive attitude to invasive analysis is determined by what is to be gained from it: a decisive widening of the results of non-invasive analyses, and knowledge on features of polychromy which are (as yet) beyond the reach of non-invasive methods.

The following brief overview points to some relevant invasive analytical methods, divided into three groups, the first group having to do with the identification of inorganic pigment components, the second with colourants, i.e. organic pigments, and the third, intimately related to the first two, with painterly technique, and stratigraphy in particular.[82]

1. Identifying inorganic pigments

XRF; μ-XRF; Raman Spectroscopy and μ-Raman Spectroscopy are iterative methods, repeating non-invasive analyses carried out in situ on the sculpture (see above). The designation μ indicates that method may be applied to very small (micro) samples.

X-ray Diffraction Spectroscopy (XRD)

Scanning Electron Microscopy / Energy Dispersive X-ray spectroscopy (SEM-EDX)

Fourier Transform Infrared Spectroscopy (FTIR)

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is an analytical technique used for elemental determinations. This method has special relevance for polychromy studies because it permits the study of isotopes of lead and subsequently determination of its source.[83]

Electron Micro Probe Analyzer (EMPA) for non-destructive determination of the chemical composition of small volumes of material.[84]

2. Identifying organic pigments (colourants)

Gas Chromatography – Mass Spectrometry (GC-MS) is the most important method of identifying organic components in the form of binding media and colourants in polychromy.[85] The method is destructive.

Chemical Spot tests can be done on small samples to identify a substance.[86] Such tests are also destructive.

3. Painterly technique and stone characterization

Cross-section stratigraphy through analysis of samples by polarization microscopy.[87]

Thin section marble petrography and isotopic analysis for provenancing of the stone used.[88]

Experimental reconstruction as a research tool

To my knowledge, this is an aspect of methodology which has not yet been comprehensively addressed.[89] The earliest attempts to show the polychromy of ancient stone sculptures on copies of the originals date to the middle of the 19th century;[90] still earlier are similar attempts in two-dimensional media.[91] Both techniques have been in use since then, with varying frequency. A third means of 're-introducing' colour is far more recent, namely that of digital, virtual reality techniques.[92] Of these three meth-

81 For example Ny Carlsberg Glyptotek; Paris, Louvre/C2RMF; London, The British Museum; Firenze, The Uffizi; Rome, Musei Vaticani and Museo Nazionale dell'Arte Orientale.

82 Pallecchi et al. 2009 for the full suite of invasive methods, there applied to wall painting, but nevertheless instructive. See also Abbe, Borromeo & Pike 2012, 766-7 and, especially, Verri, Opper & Lazzarini 2014.

83 Rosing & Østergaard 2009; Fink-Jensen 2013.

84 Therkildsen 2011, 33.

85 Andreotti et al. 2014; Santamaria et al. 2014; Verri, Opper & Lazzarini 2014, 160-1. Binding media in Fayum mummy portraits determined by NIR-FT Raman, cf. Reeler et al. 2013.

86 Feigl & Anger 1937/2012; Odegaard, Carroll & Zimmt 2005.

87 See for example Sargent 2012, 35-8.

88 Sargent 2011, 44; Therkildsen 2012, 39-41, 44-8 (NCG IN 821, IN 822, IN 826); Verri, Opper & Lazzarini 2014, 158-60.

89 On reconstructions: Brinkmann 2010, 24-7; Schmaltz 2009; Brinkmann 2010a, 20; Piening 2010; Brinkmann & Koch-Brinkmann 2010; Koch-Brinkmann, Piening & Brinkmann 2014; Verri, Opper & Lazzarini 2014; Skovmøller & Therkildsen 2014; Brinkmann 2015, 95-6; Zimmer 2016. On the pigments: Brinkmann 2010b. Virtual 3-D reconstruction: Frischer 2015; http://vcg.isti.cnr.it/roman-sarcophagi/ulpia-sarcophagus-3d/index.html (E. Siotto & R. Scopigno). On scanning: Graham 2012a; Brinkmann 2015, 97.

90 Plaster casts of slabs of the Parthenon Frieze, in the Crystal Palace as re-erected in Sydenham 1854. Cf. Nichols 2015, 74-7.

91 Quatremère de Quincy 1814, frontispiece (Phidias' chryselephantine cult statue of Zeus at Olympia).

92 See Earl et al. 2009; Graham 2012; Frischer 2015.

ods, this section deals almost exclusively with reconstructions on copies of the originals. A further limitation, as indicated by the section title, is that I shall restrict myself to a research context. What this means is that the polychromy applied to the copy is to the greatest possible extent based on (preferably published) data acquired from the original, that historical pigments are used and that the process involved is as extensively documented as possible.[93]

Practically speaking, this means going back to the early 1990s and the pioneering efforts of Vinzenz Brinkmann and Ulrike Koch-Brinkmann in their investigation of the sculptures in the west pediment of the temple of Athena Aphaia on Aegina.[94] The reconstructions were carried out on copies made of plaster and later synthetic marble. Brinkmann, Koch-Brinkmann and Heinrich Piening have since made up a core polychromy research group with the Stiftung Archäologie as its organizational basis. They have collaborated with various partners, investigating and reconstructing works with particularly well-preserved polychromy, from different collections and spanning from the Greek Archaic to the Roman Imperial period. Besides the materials mentioned earlier, crystalline acrylic glass and marble have been used.[95] In a number of cases, sequences of reconstructions have been produced over some years, reflecting the research-based, experimental archaeological character of the activity.[96] Only a few outside the Stiftung Archäologie group have produced similar work;[97] it is to be hoped that more will follow.[98]

In connection with an ongoing project to produce a research-based reconstruction of a 2nd-century CE female marble head in the British Museum[99] – the so-called 'Treu Head' – Giovanni Verri has introduced a novel method of two-dimensional reconstruction, involving projecting colours found on relevant ancient works on to an image of the head.[100] Two-dimensional reconstruction of a similarly high quality, using coloured crayons, is used by Clarissa Blume in her research on the polychromy of Hellenistic sculpture.[101]

Research-based experimental reconstructions, also described as 'approximations', are important tools in the endeavour to rediscover the lost techniques of painting on stone. It is basically a case of 'learning' by doing. The implicit recognition of our very incomplete understanding of the craftsmanship of the polychromy of Greek and Roman marble sculpture makes it clear that such reconstructions emphatically do not claim to show what a given sculpture looked like when it left the workshop in Antiquity. It would be quite absurd to assert anything of the kind. The fact is that we will *never* know, or see, what an antique polychrome sculpture looked like in its original state. What we can do is to gradually gain an understanding of many important aspects of such a work. The raison d'etre of research-based reconstruction is that it is a tool in a learning-by-doing process.[102]

Another aspect of the reconstruction is almost as important, namely that of communicating some very basic facts to a wider public: above all the fact that ancient marble sculpture *was* polychrome, not white. The research-based reconstruction – despite its limitations – is nearer to a historical reality than any faded original. The impact of this on 'ordinary' viewers cannot be overestimated; for a great majority, it is demonstrably an 'aha' experience, awakening a new interest in the ancient world.

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93 The interesting reconstructions ('Nachbildungen') of the Kasseler Apollo and the Athena Lemnia are therefore not included: Gercke 2009.

94 The most recent overview with extensive bibliography is Haag, Brinkmann & Koch-Brinkmann 2013, 60-2.

95 For a complete inventory of the reconstructions produced within the framework of the Stiftung Archäologie, see http://www.stiftung-archaeologie.de/reconstructionsen.html. The Stiftung closed down in 2016 and its work will be carried on under the auspices of the Städelstiftung, Frankfurt am Main.

96 For example the so-called 'Peplos Kore': Haag, Brinkmann & Koch-Brinkmann 2013, 55. The portrait of Caligula in Copenhagen: Haag, Brinkmann & Koch-Brinkmann 2013, 69; Østergaard & Nielsen 2014, 270-1. Variant A of Caligula: Brinkmann & Scholl 2010, 218-25 (J. S. Østergaard).

97 The Augustus of Prima Porta: Liverani 2004a; Spada 2004. The Lateran portrait of Ariadne: Liverani 2009, 17-9; Østergaard & Nielsen 2014, 282-3 (Paolo Liverani). The Acropolis Kore 682: Schmaltz 2009. The reconstruction on a marble copy of the polychromy of an early 3rd-century CE Roman portrait of a youth, NCG IN 821: Graham 2012; Skovmøller & Therkildsen 2014; Skovmøller 2016, 150-1.

98 In this connection, the announced publication by Ulrike Koch-Brinkmann of her procedures and vast experience will be of great importance. It is encouraging that she has for some time been teaching on the subject at the University of Göttingen.

99 Verri, Opper & Lazzarini 2014; Koch-Brinkmann, Piening & Brinkmann 2014, 146-8, 151.

100 Verri, Opper, & Lazzarini 2014, 171-2. 174-5, figs 17-20.

101 As for example Blume 2015, Pls. 77, 22.29; Østergaard & Nielsen 2014, 185, fig. 25 (Blume).

102 Quatremère de Quincy also found it necessary to stress this: Quatremère de Quincy 1814, xviii.

The experimental reconstructions/approximations have therefore made up the core of the highly successful 'Bunte Götter' exhibition series and have been shown in others as well.[103] And in some museums, they have found a place as permanent exhibits, in the galleries, next to the originals – as in the Ny Carlsberg Glyptotek in Copenhagen and the Acropolis Museum in Athens.[104]

In this communicative function, as exhibition objects, the reconstructions have met with especially strong critical reactions from colleagues in classical archaeology and art history. Quite heated verbal discussions have taken place in professional fora, but seldom in print;[105] for such discussions to be constructive and bear fruit they must find a written form, and the sooner the better.

Only by reaching a common understanding of, and agreement on, the ways and means of our research will we move forward with success.

Research must be organized accordingly. This is the subject of the final section of this article.

Organization of research

The complexity of sculptural polychromy, as described in this article, requires an interdisciplinary research approach. Recognizing this is a first step which may be taken by any individual wanting to contribute to the field.[106] Mobilizing and organizing the necessary interdisciplinary resources is a different matter. This section offers some thoughts on organizational practice, or 'research scenarios'. They will seem self-evident to those who have long worked in the professions involved, but as short-term project employment is becoming an unfortunate fact of life in all types of research it becomes necessary to ensure continuity in, and transmission of, experience by other means than those afforded in better times by long tenures.

Research scenarios

Though sculptures kept in museums are at the heart of sculptural polychromy research, [107] the initiative to organize it and the responsibility for carrying it out may lie with a variety of institutional players.[108] Museums must of course be involved by giving access to the sculptures, but also by being the prime movers, as in the case of the research at the Ny Carlsberg Glyptotek on which this contribution is based.[109] It is most encouraging to note that research activity on sculptural polychromy in museum collections is now also being directed at ancient statues from other geographical areas.[110]

Museum collections

In the present context, museums with collections of ancient sculpture may be divided into three categories, established according to criteria that are decisive for the way in which research may best be organized: the large 'world' museums, the medium-sized museums, and the smaller museums. The latter category is the most numerous one, including such important museums as the archaeological museum in Sperlonga, Italy, or the Musée Saint-Raymond in Toulouse, France. This category will

103 As 'Transformations: Classical Sculpture in Colour', Ny Carlsberg Glyptotek, Copenhagen 2014, cf. Østergaard & Nielsen 2014.

104 The Acropolis Museum's initiative on Archaic Colors (2012) was accompanied by an instructive booklet (Pandermalis 2012).

105 As Schmaltz 2008.

106 Working on their own, scholars can (still) make important contributions. See for example Hoft 2013 on inlaid eyes.

107 Investigation of sculpture still in situ is as important, cf. Iannaccone et al. 2015, on a sarcophagus in the catacombs of St. Mark, Marcellian and Damasus Rome.

108 As for example Università degli Studi di Firenze; Université de Sorbonne Paris IV; the Consiglio Nazionale delle Ricerche (CNR) and the Istituto Superiore per la Conservazione ed il Restauro in Italy; in France the Centre nationale de la recherche scientifique (CNRS) and the Centre de recherche et de restauration des musées de France (C2RMF; http://c2rmf.fr/actualite/les-couleurs-de-la-kore); the National Hellenic Research Foundation/Institute of Historical Research (NHRF/IHR)/Section of Greek and Roman Antiquity (SGRA) http://www.eie.gr/nhrf/institutes/igra/index-en.html.

109 Especially the project 'Tracking Colour. The polychromy of Greek and Roman sculpture in the Ny Carlsberg Glyptotek', 2009-14, with the Copenhagen Polychromy Network (CPN). The contribution made by project conservators Maria Louise Therkildsen, BA and MSc, and Rikke H. Therkildsen, BA and MSc, was vital; the generous support offered by external partners in the Copenhagen Polychromy Network is gratefully recognized. Annual preliminary reports 2009-13 are available for download at www.trackingcolour.com. See also Østergaard 2010b. The final report is expected in 2018.

110 See Pannuzi 2015. From the point of view of interdisciplinary research organization, this publication is most instructive.

not be dealt with in the brief survey below because sculptures there have only rarely been investigated for their polychromy.[111]

The large, encyclopaedic 'world' museums

These museums are situated in major cities: they include famous institutions, like the Musei Vaticani, the Louvre, the Hermitage, the Staatliche Museen zu Berlin (Antikensammlung – Altes Museum/Pergamon Museum), the British Museum, the Metropolitan Museum of Art, the Museum of Fine Arts in Boston and the J. Paul Getty Museum. The core resources required for interdisciplinary research are found in-house, namely curatorial departments and departments of scientific research and objects conservation, with spaces allowing visual examination and imaging of sculpture.[112] Other competences needed usually exist close at hand in university institutes, other categories of museums and private companies.[113] The large museums usually also have their own means of publication. Large museums therefore provide ideal conditions for establishing interdisciplinary research networks.

Institutional support and commitment from museum management is of course a prerequisite for any research in museums. The sheer size of the largest museums implies a complex decision-making process between the museum management's lower and higher echelons, and, understandably, intense competition for the often meagre resources available.

As public funding of museums is cut back, the importance of support from external sources increases. In large museums, fundraising and the concomitant coordination of research strategy becomes another filter through which projects must pass to become a reality. Things become even more difficult when research is in a formative phase, like that of ancient sculptural (and architectural) polychromy. To be successful, a sculptural polychromy research project in a world museum must, therefore, be based on common interest established between upper-level museum management and its strategic priorities, the core curatorial, conservation and science departments and above all, the individuals on the staffs concerned. Win–win in aims and means will carry the day, and a lot of preparatory reconnoitering and sounding out is clearly required.

In every phase, on every level, a main strength of argument is the fact that the polychromy of ancient sculpture and architecture is of equal fascination to a wide museum audience on the one hand, and to a scholarly, scientific community on the other.

Medium-sized museums: Research networks

This category includes a number of state and regional archaeological museums, often located in major cities or university towns: well-known examples are the Staatliche Antikensammlung und Glyptothek in Munich, the Liebieghaus Skulpturensammlung in Frankfurt am Main, the Ny Carlsberg Glyptotek in Copenhagen and the Antikenmuseum Basel und Sammlung Ludwig. There are many others. They differ from their larger sister institutions in not having the same spectrum of in-house conservation capabilities. More specifically, they are rarely equipped with a conservation science unit, but usually with staff and facilities for objects conservation relevant for their collections. Only if sculpture is a dominant category will they be served by a stone conservation workshop or 'studio', as for example the Glyptotek in Copenhagen. Even then, spaces suitable for visual examination and imaging of large-scale sculpture are often not available and must

111 Calandra et al. 2014. The urns investigated are in the Museo Archeologico Nazionale dell'Umbria, Perugia, and in the Antiquarium comunale, Corciano.

112 This 'in-house' resource may be in the same building as the collections, as in the British Museum or the Metropolitan Museum of Art; see Leona 2009 for the set-up in the latter. In other cases, it is physically and institutionally separated from the museum. Thus, the Rathgen-Forschungslabor in Berlin/Charlottenburg (far from museums) serves the conservation science needs of all the Staatliche Museen Berlin (http://www.smb.museum/en/museums-and-institutions/rathgen-forschungslabor/home.html), while the objects conservation needs of the Antikensammlung are met by a stone workshop in the Archaölogisches Zentrum not far from the Museumsinsel (http://www.smb.museum/en/museums-and-institutions/archaeologisches-zentrum/home.html), and metal and ceramic objects are conserved in the building of the Altes Museum (http://www.smb.museum/museen-und einrichtungen/antikensammlung/restaurierung.html). In Paris, the main objects conservation and scientific research resources serving the Louvre are to be found in a national centre, the Centre de recherche et de restauration des Musées de France (C2RMF; http://c2rmf.fr/).

113 Humanities in particular: ancient history, classical and medieval philology, art history, digital humanities.

be improvised. The challenge in this scenario is to establish a network of external partners. The network must be set up to provide resources in conservation science and natural science on the one hand, and humanities on the other:

Network resources in conservation science and natural science

These resources are a sine qua non, but the relevant external (potential partner) institutions and persons will often belong to a sort of professional terra incognita. Relevant partner institutions are the following:

1. Schools of Conservation. The School of Conservation in Copenhagen has been the key external partner institution in the Copenhagen Polychromy Network, established on the initiative of Ny Carlsberg Glyptotek in connection with the Tracking Colour Project. [114] Some of the reasons for this pivotal role go beyond the specific context: First and foremost, the objects conservator(s) who must necessarily be part of the museum's research team will have received their professional training at such a school. This forms a decisive link to the resources which make a school of conservation such a vital network partner in polychromy research. It can offer highly competent advice and support in matters of both objects conservation and conservation science, and also provide access to analytical instrumentation (i.e. SEM-EDX; XRF) and other equipment not available at the museum. Furthermore, both parties may profit from having students attached as interns to the museum team as part of their training, perhaps leading to a Master's thesis on the work done.[115] For their part, the schools of conservation stand to benefit from gaining access to the international contacts of the museum partner and the data acquired may be relevant to aspects of the research being carried out at the schools themselves, in particular in technical art history and the development of preventative conservation measures in relation to ancient stone sculpture.[116]

2. Museums of natural history. Such museums may be institutionally linked to universities[117] and thus to university institutes/departments. They will always have an academic staff trained in disciplines relevant to polychromy research, most particularly geology, but also zoology and botany.[118] Besides the natural scientific competences, such network partners will also often have access to relevant analytical instrumentation.

3. Archaeometric research units. These units constitute a resource staffed and equipped to serve the humanities by conducting analyses of a variety of artefacts, both archaeological and art historical. Such units are imbedded in university institutes or affiliated to universities and/or other research organizations.[119] An archaeometric unit is attuned in a general way to the mindset of humanities researchers, to their organizational setups and the type of research questions they pose: it is therefore a very valuable network asset.

4. Digital humanities (DH). DH is a field of teaching and research at the intersection of computing and the humanities. It is found in a variety of environments, often at universities as a resource shared by several academic disciplines. Among the aspects useful to polychromy research are 3D digitization and modelling,[120] and virtual reality reconstruction of the polychromy of individual

114 The School of Conservation is an integrated part of The Royal Danish Academy of Fine Arts Schools of Architecture, Design and Conservation https://kadk.dk/en/school-conservation.

115 As for example Sargent 2011; Therkildsen 2012.

116 Scharff 2013.

117 As is the case of the Natural History Museum of Denmark, cf. http://snm.ku.dk/english/.

118 The possible presence of microorganisms in pigments containing marble dust; the identification of species of plants providing madder lake; the identification of plants represented on monuments (as on the Ara Pacis, cf. Caneva 2010).

119 A number of units are directly involved in polychromy research. In the Copenhagen Polychromy Network, the Cultural Heritage Archaeometric Research Team – CHART/University of Southern Denmark, Institute of Chemistry is a partner, cf. http://www.sdu.dk/en/om_sdu/institutter_centre/c_chart/research.

120 Frischer 2015, 82 and *passim.* Cf. also Graham 2012 and 2012a in collaboration with the University of Lund's HumLab and Nicol'Dell'Unto: http://www.ark.lu.se/en/research/research-groups/823); The Visual Computing Lab of Pisa (CNR, ISTI) http://vcg.isti.cnr.it/; Eliana Siotto et al. http://vcg.isti.cnr.it/roman-sarcophagi/ulpia-sarcophagus-3d/index.html and http://vcg.isti.cnr.it/Publications/ with several titles relevant for polychromy research. See also the web page of V-Must, a network of excellence composed by a large number of European infrastructures working with 3D visualization and Museums http://www.v-must.net/.

sculptures and polychrome sculpture in its architectural setting.[121]

5. Commercial partners. Polychromy research requires specialized equipment and materials. It is worthwhile establishing close collaboration with the suppliers; mutual benefit has been shown to accrue from such collaboration, i.e. as regards microscopes, scanning equipment, and, for reconstructions, 3D printing and casting.

Network resources in the humanities

Collaboration with disciplines within the humanities not usually available at the museum will mean moving in more familiar territory, involving competences found at most universities, namely classical philology, epigraphy, ancient history and art history.

Among the benefits of working with universities is the possibility of supporting MA theses in classical archaeology[122] and establishing shared, co-financed PhD fellowships,[123] all connected to the museum's research project and thus aiding all-important recruitment to the field as well as strengthening the institution's research profile. From a strategic point of view this is one of the ways in which independent or private, non-state museums may gain recognition on a par with state museums and with it access to government research funding. New insights into one's own collection may become the spectacular 'acquisitions' of the future and thus the fuel for an exhibition activity less dependent on costly loans than on international research collaboration.

Concluding remarks

Brief and uneven as it is, this attempt at a survey does not do justice to the range and sophistication of methodologies applied in research on the polychromy of Greek and Roman sculpture; nor does it give anything like a full picture of the publications presenting the results of this research. But it does reflect the very positive and accelerating pace of development in this field since the 1980s; the expression 'break-through phase' would seem justified.[124] One might even dare to hope that a point of no return has been passed, assuring polychromy its place in the equation when we try to understand Greek and Roman sculpture – were it not for the fact that obvious dangers lurk.

It seems to me that research on the polychromy of Greek and Roman sculpture is for a number of reasons still in the nature of an imperiled species. Thus, to my knowledge, the subject is not as yet generally offered as a course at universities teaching classical archaeology, affecting the vital issue of recruitment to the field. Far more serious is the lack of an institutional foothold which would ensure continuity and consequent build-up of research experience and data as well as maintenance of specialized instrumentation. As it is, research in this field is project-based, i.e. time limited; the team and networks involved will therefore again and again be broken up and dispersed. This article has made it clear that it is a field of research which requires the expenditure of considerable resources. For the results of such an investment not to have an institutional foothold would be found intolerable in other fields of knowledge.

To me, assuring an institutional foothold in the form of a permanent research unit, preferably as a joint European venture, seems the greatest challenge now facing our field. Such a unit would best reflect the relevance to 'us in the West' of the return of colour to the sculpture of Classical Antiquity.

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121 Cf. work done at the University of Southampton's Archaeological Computing Research Group http://acrg.soton.ac.uk/, http://acrg.soton.ac.uk/projects/amazon/ and Earl *et al*. 2009; Beale & Earl 2011. See also Bernhard Frischer's work on Hadrian's Villa https://www.phf.upenn.edu/events/recovering-polychromy-statues-hadrians-villa

122 As Graham 2012, Siotto 2013, Hoft 2014, Lenzi 2014, Kopczynski 2015, Iannaccone 2015, Blume 2015.

123 As Skovmøller 2016; Verena Hoft in progress (Eberhardt Karls Universität,Tübingen).

124 That a chapter has been devoted to 'Polychromy' in the Oxford Handbook of Roman Sculpture is most encouraging, cf. Abbe 2015.

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Abbreviations specific to this paper:
IN = Ny Carlsberg Glyptotek inventory number
NCG = Ny Carlsberg Glyptotek

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